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Waste Feed Delivery Transfer System Analysis

Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management

CH2MHILL
Hanford Group, Inc.
Richland, Washington
Contractor for the U.S. Department of Energy
Office of River Protection under Contract DE-AC06-99RL14047

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Waste Feed Delivery Transfer System Analysis

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Abstract: This document provides a documented basis for the required design pressure rating and pump pressure capacity of the Hanford Site waste-transfer system in support of the waste feed delivery to the privatization contractor for vitrification. The scope of the analysis includes the 200 East Area double-shell tank waste transfer pipeline system and the associated transfer system pumps for all Phase 1B and Phase 2 waste transfers from AN, AP, AW, AY, and AZ Tank Farms.

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Waste Feed Delivery Transfer System Analysis

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SUMMARY

This engineering analysis was prepared to provide a documented basis for the design pressure rating of the waste-transfer system pipeline and a documented basis for the design and operating pressure of the transfer-system pumps. The waste-transfer system will be used to transfer waste from the Hanford Site double-shell and single-shell tanks to the privatization contractor for vitrification. The scope of the analysis includes all Phase 1B and Phase 2 waste transfers from the AN, AP, AW, AY, and AZ Tank Farms. In performing the analysis, no assumptions were made that might restrict how the wastes are processed before transfer to the privatization contractor. The analysis focuses on the hydraulics of the waste-transfer system using available waste-characterization data. The analysis also compares the design pressure rating of the existing transfer system pipeline to the design pressure rating determined by this analysis.

The initial approach of the analysis was to identify waste properties for each tank and then calculate the pressure drop through the planned transfer routes using the tank-specific waste properties. The pressure drop information is used to determine the pipe and pump design pressure ratings. Calculation of the pressure drop requires knowledge of the waste properties in addition to the physical dimensions of the transfer system. Waste properties include the liquid density, liquid viscosity, particle density, particle size distribution, and volume percent solids. After reviewing available waste-property information, it was found that there are insufficient tank-specific data available to perform the pressure drop calculations. Additionally, the waste feed delivery plan for Phase 1B and Phase 2, which identifies individual waste transfers, has not been finalized. Identification of individual waste transfers is required to determine the physical route of the transfer pipeline and to calculate the pressure drop. In the absence of complete tank-specific waste-property data for each tank and a final plan for waste transfers, the pressure drop for each of the Phase 1B and Phase 2 waste transfers could not be calculated.

As an alternative, this analysis calculates the pressure drop through each transfer route using three sets of typical slurry waste properties. Slurry waste properties, rather than supernate waste properties, were chosen to evaluate each transfer route to provide maximum flexibility for planning of the Phase 1B and Phase 2 transfers. If all of the transfer lines are capable of carrying slurry waste, the Phase 1B and Phase 2 transfers can use any of the transfer pipelines to transfer waste to the privatization contractor. The first set of waste properties was chosen to provide a conservative set of values that would encompass all of the tank waste transfers; it included 30 volume percent solids. The second and third sets of waste properties, while still somewhat conservative, were chosen to be more representative of actual slurry waste properties. These sets of properties included 15 and 10 volume percent solids, respectively, and are similar to the design bases used for projects that are currently making modifications to the waste-transfer system. In addition to the evaluation of the three sets of slurry waste properties, the pressure drop through each of the transfer routes was calculated for a total of 52 different combinations of waste properties. These combinations included supernate and slurry waste transfers. The waste combinations provide an indication of the sensitivity of the pressure drop in the pipeline to variations in the waste properties. The waste combinations also provide a tool to quickly evaluate the pressure drop through a particular transfer route with different waste properties. Waste-transfer routes were identified for all Phase 1B transfers using Hanford Tank Waste Operations Simulator (HTWOS) Cases 3S4 and 3S6D. The physical characteristics of each of

these waste-transfer routes were identified and used as the basis for the pressure-drop calculations. Transfer system physical characteristics include pipe size, equivalent lengths of the carbon steel and stainless steel portions of the transfer pipeline, changes in elevation over the transport route, and pipe interior surface roughness. The transfer routes that were evaluated are comprised of the existing transfer-system infrastructure and the modifications that are planned by Projects W-211, W-314 and W-521.

Calculation of the pressure drop through the transfer-system piping requires a determination of the critical velocity of the waste. The critical velocity correlation in "The Critical Velocity in Pipeline Flow of Slurries" (Oroskar and Turian 1980) was used to determine the minimum waste transport velocity required to maintain solids in suspension for slurry transfers. The velocity at the transition from laminar to turbulent flow was used as the critical velocity for supernate transfers. The pressure drop in the system is calculated at 1.3 times the predicted critical velocity to assure an adequate margin. The pressure-drop correlations in "Solid-Liquid Flow Slurry Pipeline Transportation" (Wasp et. al. 1977), with modifications from *Applied Fluid Dynamics Handbook* (Blevins 1984), were used to determine the drop in pressure resulting from friction losses in the transfer pipeline. The calculated pressure drop was then compared to the design pressure rating of the pipeline. Transfer routes that exceeded the pipe design pressure rating at the critical velocity were identified.

The results of this analysis show that supernate transfers will not exceed the design pressure rating of any of the transfer routes that were evaluated. There is sufficient design margin in the waste-transfer system to transfer supernate. The results of the analysis for slurry transfers show that portions of the waste-transfer system may not be adequate. Using the enveloping first set of slurry waste-property data (Appendix D, Case 3b, Group 2 Properties), a majority of the transfer routes would be subject to settling of solids and possibly plugging of the pipeline. The second and third sets of data (Appendix D, Case 4, Groups 1 and 2 Properties), which more closely approximate the actual waste streams, resulted in a slightly smaller percentage of pipelines being susceptible to plugging. The analysis indicates that there is insufficient design margin in the waste-transfer system to support the use of any of the three selected sets of slurry waste properties. An accurate evaluation of the hydraulics of the transfer system requires a more complete determination of the actual properties of the slurry during transfer. The results of the analysis also indicate that the pressure drop in the system is sensitive to changes in waste properties. A reduction in particle size, particle density, or volume percent solids will each reduce the pressure drop in the system. Reductions in more than one of these waste properties has the potential to significantly reduce the pressure drop in the system.

Based on the results of this analysis, alternatives are identified and recommendations are made to improve the ability to accurately evaluate the waste-transfer system. The recommendations are summarized below.

- Consider addition of a lift station or staging transfers through AP tank farm
- Investigate the viability of increasing the design pressure rating of the existing waste-transfer pipeline that is rated at 1.9 MPa (275 lbf/in^2)
- Determine the maximum design pressure rating of the new waste-transfer pipeline being installed by Project W-314 that could be achieved without design modifications

- Establish a test program to determine the maximum design pressure rating of the Plutonium-Uranium Extraction (PUREX) facility jumper connectors
- Review particle-size data to identify methods of reducing the uncertainty associated with particle size and density
- Inspect the inside of existing transfer lines to establish a baseline condition for the pipe to assess the level of corrosion and roughness
- Ensure that future tank samples are analyzed for properties relevant to the determination of critical velocity and pressure drop and validate modeling with Hanford waste or simulant
- Investigate the application of process controls to control or limit the range of waste properties that adversely affect pressure drop in the transfer system.

The results of this analysis should only be used for conceptual design and planning until more accurate waste characterization information is available.

All eight recommendations do not need to be performed. Favorable results from the recommendations related to waste characterization could preclude the necessity for a hardware related fix. Alternatively, some combination of hardware and better waste property characterization could be sufficient to ensure that the transfer system is adequate for the waste feed delivery mission.

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LIST OF ABBREVIATIONS AND UNITS

DST	double-shell tank
EOL	end of life
HLW	high-level waste
HTWOS	Hanford Tank Waste Operation Simulator
LAW	low-activity waste
PUREX	Plutonium-Uranium Extraction (facility)
°C	degrees Celsius
cP	centipoise = 0.001 kg/m-s
°F	degrees Fahrenheit
ft	feet = 0.3048 meters (m)
ID	internal diameter
in.	inch = 2.54 centimeters (cm)
kg	kilogram
kg/L	kilogram per liter
L	liter
lbf/in^2	pounds per square inch = 0.006895 megapascals (MPa)
mil	0.001 inch (in.)
MPa	megapascal
s	second (unit of time)
μm	micrometer or micron

ENGLISH SYMBOLS USED IN EQUATIONS

C_D	coefficient of drag
C_L	liquid phase volume fraction
C_s	particulate solid phase volume fraction
d_p	particulate solid phase median size diameter
D	internal pipe diameter
f	pipe friction factor (Darcy) for slurry
f_d	$= f - f_v$, pipe friction factor for heterogeneous particulate solid phase of slurry
f_v	pipe friction factor for homogeneous "vehicle" liquid phase of slurry
g	gravitational acceleration
h	fluid head
h_L	head loss
L	length of pipe
n	hindered settling velocity exponent
p	pressure
R	flow regime designation
Re_p	particle Reynolds number
Re_{pipe}	pipe flow Reynolds number
v	slurry velocity
v_{cr}	generic term for critical velocity

v_s	settling velocity
v^*	friction velocity
v_∞	characteristic velocity of a settling particulate
$x_{caustic}$	fraction of dissolved solids composed of sodium hydroxide
x_{salt}	fraction of dissolved solids composed of sodium salts and other salts

GREEK SYMBOLS USED IN EQUATIONS

γ	ratio of hindered settling velocity to critical velocity
θ	angle of pipeline relative to horizontal (positive for upward slope)
κ_{cv}	percent root mean square deviation from critical velocity experimental data
ρ_L	carrier liquid phase density
ρ_s	particulate solid phase density
ρ_v	homogeneous "vehicle" density
ρ_{water}	density of water
χ	fraction of the turbulent fluid eddies that possess a velocity larger than the particulate settling velocity
Φ_v	total volume percent solids attributed to homogeneous "vehicle" phase of slurry
ϕ_{dj}	ϕ_{sj} - ϕ_{vj}, solid concentration of j^{th} particle size remaining in heterogeneous phase of slurry
ϕ_{sj}	solid concentration at pipe centerline for j^{th} particle size
ϕ_{vj}	solid concentration for j^{th} particle size attributed to homogeneous "vehicle" phase of slurry
β	ratio of mass transport coefficient to momentum transport coefficient (see Equation 9)
κ	von Karman boundary-layer constant (see Equation 9)
ε	roughness of pipe
μ_L	carrier liquid phase viscosity
μ_v	homogeneous "vehicle" viscosity
μ_{water}	viscosity of water
Δh	head loss per unit length of pipe

1.0 INTRODUCTION

CH2M HILL Hanford Group, Inc. is responsible for delivering waste from tanks on the Hanford Site to the privatization contractor for vitrification, BNFL Inc. As part of the planning process for waste feed delivery, the capability of the waste-transfer system is being evaluated. The waste-transfer system comprises the transfer pumps, transfer pipelines, transfer system valves, and associated structures and instrumentation used to transport waste between storage tanks and from storage tanks to the privatization contractor. Waste will be pumped out of the tanks using new transfer pumps and will be delivered to the privatization contractor through a combination of new and existing transfer pipelines. Double-Shell Tank (DST) Subsystem specifications are being prepared as a basis for the conceptual design of the new and replacement equipment required to provide a safe and reliable system for transferring waste. These specifications will include design criteria for parameters such as pipe size, pipe material, range of flow rates, transfer pump operating conditions, and waste characteristics. The purpose of this analysis is to provide a documented basis for DST subsystem specifications for piping and pumps.

Wastes have been successfully transferred between tanks at the Hanford Site for more than 50 years. Although a number of pipelines have been plugged during that period, the cause of the plugging generally has been attributed to the formation of salts as the waste cooled in the pipeline. Previous slurry transfers in the tank farms typically were maintained above a specified flow velocity to ensure that any solids that might be present in the waste would not settle out during the transfer. For approximately the last 20 years, the minimum flow velocity was specified in terms of a minimum Reynolds number of 20,000. In an 80 mm (3-in.) nominal pipeline, this equates to a flow velocity of approximately 1.8 m/s (6 ft/s). To meet the mission of delivering waste feed to the privatization contractor, the existing transfer system had to be extended to the location of the new vitrification facility. This extension of the transfer system adds approximately 1,220 m (4,000 ft) of equivalent pipe length to connect the existing transfer system to the privatization contractor. Before the preparation of this analysis, several preliminary pressure-drop calculations were performed to evaluate the adequacy of the new waste-transfer routes to the vitrification facility. The results of the calculations indicated that the existing transfer pipelines might not be adequate to meet the needs of the waste feed delivery program.

The initial approach of the analysis was to identify waste properties for each tank and then calculate the pressure drop through the planned transfer routes using the tank-specific waste properties. The pressure drop information is used to determine the pipe and pump design pressure ratings. Calculation of the pressure drop requires knowledge of the waste properties in addition to the physical dimensions of the transfer system. Waste properties include the liquid density, liquid viscosity, particle density, particle size distribution, and volume percent solids. After reviewing available waste-property information, it was found that there are insufficient tank-specific data available to perform the pressure drop calculations. Additionally, the waste feed delivery plan for Phase 1B and Phase 2, which identifies individual waste transfers, has not been finalized. Identification of individual waste transfers is required to determine the physical route of the transfer pipeline and to calculate the pressure drop. In the absence of complete tank-specific waste-property data for each tank and a final plan for waste transfers, the pressure drop for each of the Phase 1B and Phase 2 waste transfers could not be calculated.

As an alternative, this analysis calculates the pressure drop through each transfer route using three sets of typical slurry waste properties. Slurry waste properties, rather than supernate waste properties, were chosen to evaluate each transfer route to provide maximum flexibility for planning of the Phase 1B and Phase 2 transfers. If all of the transfer lines are capable of carrying slurry waste, the Phase 1B and Phase 2 transfers can use any of the transfer pipelines to transfer waste to the privatization contractor. The first set of waste properties was chosen to provide a conservative set of values that would encompass all of the tank waste transfers; it included 30 volume percent solids. The second and third sets of waste properties, while still somewhat conservative, were chosen to be more representative of actual slurry waste properties. These sets of properties included 15 and 10 volume percent solids, respectively, and are similar to the design bases used for projects that are currently making modifications to the waste-transfer system. In addition to the evaluation of the three sets of slurry waste properties, the pressure drop through each of the transfer routes was calculated for a total of 52 different combinations of waste properties. These combinations included supernate and slurry waste transfers. The waste combinations provide an indication of the sensitivity of the pressure drop in the pipeline to variations in the waste properties. The waste combinations also provide a tool to quickly evaluate the pressure drop through a particular transfer route with different waste properties. Waste-transfer routes were identified for all Phase 1B transfers using Hanford Tank Waste Operations Simulator (HTWOS) Cases 3S4 and 3S6D. The physical characteristics of each of these waste-transfer routes were identified and used as the basis for the pressure-drop calculations. Transfer system physical characteristics include pipe size, equivalent lengths of the carbon steel and stainless steel portions of the transfer pipeline, changes in elevation over the transport route, and pipe interior surface roughness. The transfer routes that were evaluated are comprised of the existing transfer-system infrastructure and the modifications that are planned by Projects W-211, W-314 and W-521.

This analysis is concerned with the hydraulics of the waste as it is transported through the transfer system. The waste is considered to be a slurry because it is composed of a mixture of solids and liquid. The Hanford Site tank wastes cover a broad range of chemical compositions with a diversity of physical and rheological properties. Additionally, some of these properties are very sensitive to changes in temperature, pH, and salt concentrations. The analysis that follows is based on slurry properties alone. Although changes in viscosity with temperature are addressed, the effects of changes in temperature, pH, or salt concentrations are in general beyond the scope of this analysis.

Correlations for determining critical velocity and pressure drop resulting from friction losses in the waste-transfer system are discussed in Section 2.0. In Section 3.0, the various sources of information for the waste properties and transfer system characteristics are identified and some of the shortcomings in the data are discussed. An evaluation of the results of the analysis is included in Section 4.0, along with a description of some of the uncertainties associated with the analysis. Conclusions and recommendations are presented in Section 5.0. References cited in the text are listed in Section 6.0.

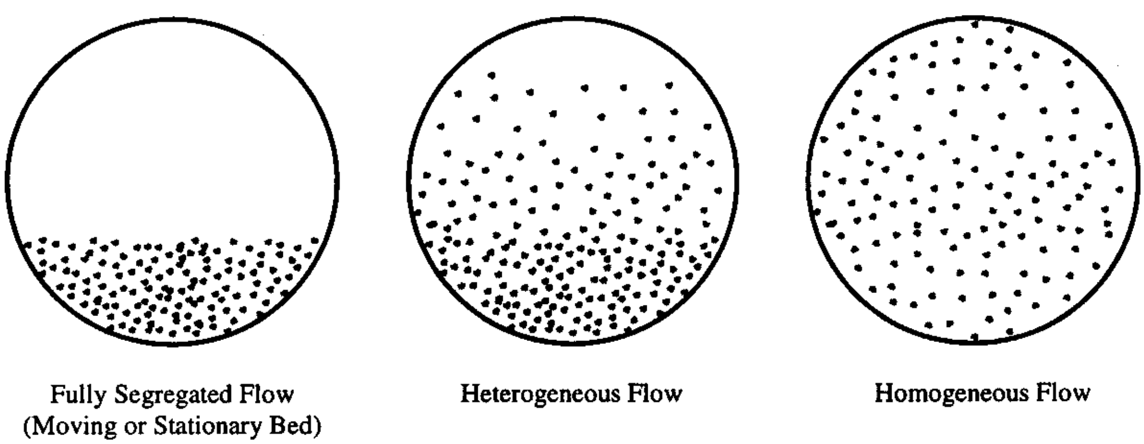
2.0 WASTE FLOW CHARACTERISTICS

Transfer of wastes from the tanks to the privatization contractor will require pumping a mixture of liquids and solids through the waste-transfer system. These mixtures are commonly referred to as suspensions or slurries. Prediction of the flow characteristics of a slurry often is more difficult than for a single-phase fluid because of the large number of variables required to describe the flow and the complexity of the solid-liquid interactions. Before the flow characteristics of the transfer system can be analyzed, the behavior of the slurry must be classified.

2.1 CLASSIFICATION OF SLURRIES

A large number of empirically based correlations have been developed to describe the behavior of slurries as they flow through piping systems. The correlations of interest in this analysis address flows with solids that are fully suspended. These correlations are divided broadly into two categories that treat the slurry as either a homogeneous mixture or a heterogeneous mixture. Within each of these categories, the slurry may be treated as either a single-phase or a multi-phase mixture. Although a slurry may be classified as either homogeneous or heterogeneous, it is far more common for the slurry to exhibit characteristics of both. Figure 2-1 shows a comparison of the distribution of solids for different categories of flow. The proper classification of slurry behavior is essential if the flow characteristics of the transfer system are to be modeled accurately.

Figure 2-1. Flow Regimes.



Homogeneous flow describes the condition where the solid particles are distributed uniformly throughout the cross section of the pipe. An inherently homogeneous flow generally is found in slurries containing high concentrations of solids and small particle sizes (i.e., particle diameter <50 μm). Homogeneous behavior also can be found in slurries with larger particle sizes where the solid-to-liquid density ratio is small or in slurries that flow with sufficient turbulence to distribute the particles evenly. The effect of the small particles in a homogeneous slurry is to increase the viscosity of the mixture as the solids concentration increases. At higher concentrations, the mixture will likely begin to exhibit non-Newtonian behavior. The point at which non-Newtonian behavior begins is difficult to predict because it is a function of the particle size distribution, particle shape, solids concentration, solid-to-liquid density ratio, and particle surface forces. Another characteristic of homogeneous flow is that the viscous or turbulent forces are dominant and the particle inertial forces are small. In the case of inherently homogeneous slurries, this characteristic results in a slurry that can flow at very low velocities without settling and allows the slurry to be treated as a single-phase fluid at all flow velocities. Examples of slurries that are inherently homogeneous include concentrated suspensions of fine limestone, paint, and ink.

Heterogeneous flow occurs when the solid particles are not distributed evenly across the cross section of the pipe although the particles are in suspension. The flow is characterized by a gradient in concentration along the vertical axis of the pipe. Heterogeneous flow generally is found in slurries with low concentrations of solids and larger particle sizes. It also can be found in slurries with smaller particle sizes when the solid-to-liquid density ratio is large. The larger particles found in heterogeneous flow do not have a significant effect on the viscosity of the mixture, and the flow is usually Newtonian in nature. Slurries with a broad distribution of particle sizes may exhibit non-Newtonian behavior as the fine particles change the behavior of the liquid phase and the larger particles are carried along in a heterogeneous suspension. The particle inertial forces are more significant in heterogeneous flow because of the mass of the particles; therefore, the liquid and solid phases of the mixture are considered separately. Examples of slurries that behave heterogeneously include mixtures of sand or coal in water.

Although no single waste characteristic can be used to classify the behavior of a slurry, the particle size and the ratio of particle density to liquid density are important parameters. Documented particle size distributions for the double-shell tanks (DST) cover a wide range of values. Some tanks, such as 241-SY-101, contain particles that range from <1 μm to >1000 μm (*Results of Viscosity Measurements of Tank 241-SY-101 Samples* [O'Rourke 1999]). Similarly, Tank 241-AW-101 covers a range of ~6 μm to >1000 μm (*Results of Dilution Studies with Waste from Tank 241-AW-101* [HNF-4964]. Tank 241-AZ-101 has a range of 5 μm to 225 μm (*Tank Characterization Report for Double-Shell Tank 241-AZ-101* [WHC-SD-WM-ER-410]). Other tanks have narrower distributions, such as 241-AN-104 with a range of <1 μm to 40 μm (*Results of Dilution Studies with Waste from Tank 241-AN-104* [HNF-3352]) and 241-AN-105 with a range of <1 μm to 40 μm (*Results of Dilution Studies with Waste from Tank 241-AN-105* [HNF-SD-WM-DTR-046]). Based on the data available, the range of particle sizes is so broad that the waste slurry that will be transferred cannot be classified as exhibiting either homogeneous or heterogeneous behavior. The waste will exhibit some combination of homogeneous and heterogeneous behavior depending on the mixture velocity, the ratio of particle density to liquid density, and the particle size distribution by volume.

Within the categories of homogeneous and heterogeneous slurries, the rheology of the slurry can be classified as either Newtonian or non-Newtonian. Viscosity is a measure of a fluid's resistance to deformation and is defined as the ratio of shear stress to shear rate. For a Newtonian fluid, the ratio of shear stress to shear rate is constant over a defined range of shear rates. In a Newtonian slurry, the viscosity does not change as the flow velocity in the transfer system pipe changes. Typical non-Newtonian slurries are characterized by viscosities that increase (shear thickening) or decrease (shear thinning) with increasing flow velocity and often have a yield strength that must be overcome before flow will occur. Viscosity measurements are not available for a majority of the tanks, and the data that are available do not necessarily reflect the condition of the waste when it will be pumped through the waste-transfer system. Some tanks will be mixed to homogenize the waste, which will then be pumped to the vitrification plant. For other tanks the supernatant will be pumped off first, the remaining solids will be dissolved, and the remaining waste will be transferred to the privatization contractor. Other tanks will be mixed together, potentially changing the rheology of the waste before it is transferred to the privatization contractor. To properly model the flow characteristics of the waste it is necessary to understand its rheology. In the absence of specific data, and given that it is extremely difficult to accurately predict the viscosity of a mixture based on its individual constituents only, some simplifying assumptions were made.

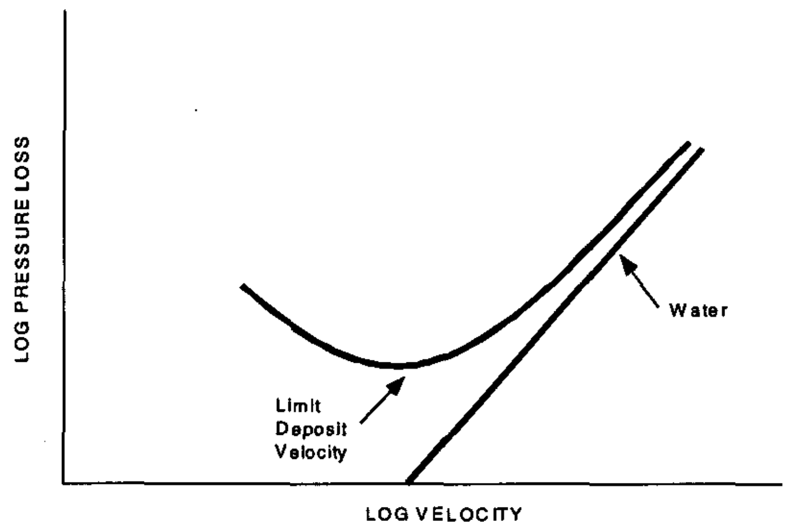
Documented viscosity measurements indicate that the waste samples are predominately Newtonian. However, some samples exhibit non-Newtonian behavior. When reviewing the non-Newtonian test data, it was noted that most of the measurements were performed on tank samples that are not representative of the condition of the waste when it will be pumped. The waste samples typically are representative of in situ tank conditions and do not duplicate the dissolution of salts and mixing of the waste that will occur before being transferred. Dissolution and mixing in the tank has the effect of reducing the solids volume percent below the levels that would be found in a sample taken from a settled, undiluted tank. As the volume percent of solids is reduced, the behavior of the waste will tend toward Newtonian behavior. The non-Newtonian behavior primarily is a result of the presence of the solids in the slurry. It is important to note that there is the possibility that some wastes may be non-Newtonian when they are transferred. As more representative sample data are obtained, it may be possible to predict non-Newtonian behavior. For the purposes of this analysis, based on the data available and the anticipated waste characteristics, the waste that will be pumped through the transfer system will be modeled as Newtonian.

In analyzing the waste-transfer system, it is necessary to determine the critical velocity and the relationship between flow rate and pressure drop. The critical velocity is the minimum velocity that should be maintained to ensure stable and reliable operation of the system. The pressure drop through the waste-transfer system is required to establish the pipe design pressure and pump head requirements. Because the number and range of variables affecting slurry flow are large and the mechanics of the solid-liquid interactions are complex, there are no purely analytical solutions available. Instead, the equations presented in this analysis are correlations based on published data that were developed to predict critical velocity and pressure drop in slurry pipelines. The correlation for critical velocity is described in Section 2.2. The correlation for predicting pressure drop is discussed in Section 2.3. For a more detailed discussion of slurry flow and the derivation of these correlations, see "The Critical Velocity in Pipeline Flow of Slurries" (Oroskar and Turian 1980); *Flow Velocity Analysis For Avoidance of Solids Deposition During Transport of Hanford Tank Waste Slurries* (HNF-2728); and "Solid-Liquid Flow Slurry Pipeline Transportation" (Wasp et al. 1977).

2.2 CRITICAL VELOCITY

In heterogeneous flow, operation of the waste-transfer system below a specified minimum velocity will result in solids settling or sliding along the bottom of the pipe. Continued operation below the critical velocity eventually will lead to plugging of the pipe. The critical velocity for a heterogeneous slurry is the velocity at which the solids begin to settle and is called the limit deposit velocity. The limit deposit or deposition velocity of a heterogeneous slurry is usually in the turbulent flow regime. Figure 2-2 shows the relationship between pressure loss and flow velocity for a heterogeneous slurry.

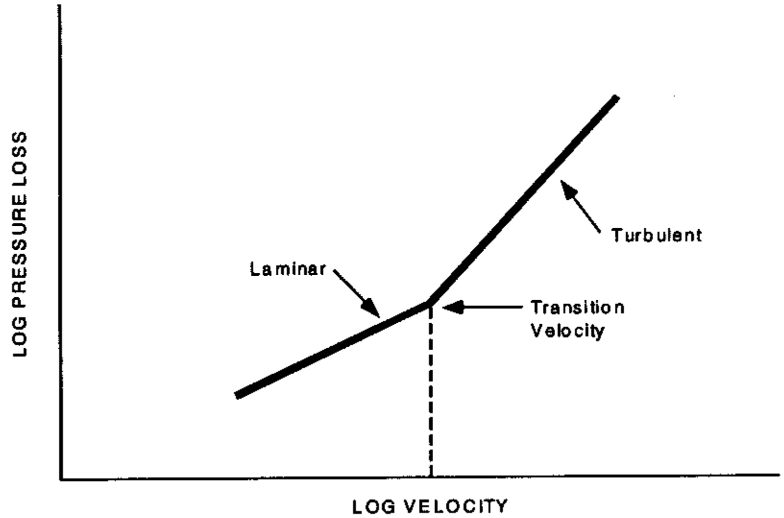
Figure 2-2. Pressure Loss vs. Velocity for a Heterogeneous Slurry.



In homogeneous flow, the critical velocity corresponds to the point at which the flow transitions to a turbulent flow regime. In purely homogeneous flow, deposition of solids does not occur below some minimum velocity. Nevertheless, it is desirable to maintain flow above the laminar-to-turbulent transition region (Reynolds number approximately > 4000) to ensure stable flow. In this analysis, both the limit deposit velocity and the transition velocity are calculated, and the greater of the two values is identified as the critical velocity. Figure 2-3 shows the relationship between pressure loss and flow velocity for an inherently homogeneous slurry.

The concept of critical velocity is very useful in designing slurry transport systems. If the flow rate is less than the critical velocity, buildup of solids will occur and the line will possibly plug. If flow is maintained above the critical velocity, plugging of the transfer line as a result of solids settling out will be avoided. All that remains is to predict the critical velocity accurately. When working with heterogeneous slurries, a large number of correlations are available to predict the limit deposit velocity. Most of the correlations are derived empirically for a specific range of slurry properties. If the correlations are applied to slurries other than those for which they were derived, there generally is poor agreement between the various correlations and actual operating and test data. When designing a transport system for a known slurry composition, it is always preferable to determine the critical velocity by test. In the absence of actual test data, some correlations have been shown to be more accurate than others. An evaluation of seven different correlations documented by HNF-2728 found that the Oroskar and Turian (1980) correlation was

Figure 2-3. Pressure Loss vs. Velocity for a Homogeneous Slurry.



the most sophisticated and yielded the most conservative results over the range of waste characteristics expected at the Hanford Site. Figure F-15 of Appendix F compares a number of correlations in addition to comparisons given in HNF-2728.

The Oroskar and Turian (1980) empirical equation was developed as an extension of their semitheoretical correlation to improve the accuracy of the critical velocity prediction. It is based on extensive slurry flow research and was slightly more accurate than the semitheoretical correlation. The Oroskar and Turian (1980) correlation for limit deposit velocity is given by

$$v_{cr} = \sqrt{g d_p \left(\frac{\rho_s}{\rho_L} - 1 \right)} \, 1.85 C_s^{0.1536} C_L^{0.3564} \left(\frac{d_p}{D} \right)^{-0.378} \left(\frac{D \rho_L \sqrt{g d_p \left(\frac{\rho_s}{\rho_L} - 1 \right)}}{\mu_L} \right)^{0.09} \chi^{0.30} \qquad (1)$$

where

v_{cr} = critical velocity
g = gravitational acceleration
d_p = mean particle diameter
ρ_s = solids density
ρ_L = liquid density
C_s = solids volume fraction
C_L = liquid volume fraction = 1 - C_s
D = pipe inside diameter
μ_L = liquid viscosity
χ = eddy velocity factor.

In formulating their correlation for critical velocity, Oroskar and Turian (1980) developed the concept that the turbulent eddy currents in the slurry flow are responsible for keeping the solids suspended. Because only a fraction of the eddies are effective in lifting the particles, the eddy velocity factor was derived to account for this effect and is given by

$$\chi = \frac{2}{\sqrt{\pi}}\left[\frac{2\gamma}{\sqrt{\pi}}\exp\left(\frac{-4\gamma^2}{\pi}\right)+\frac{\sqrt{\pi}}{2}\left(1-\operatorname{erf}\left(\frac{2\gamma}{\sqrt{\pi}}\right)\right)\right] \tag{2}$$

where

$$\gamma = \frac{v_s}{v_{cr}} \tag{3}$$

v_s = particle hindered settling velocity.

The hindered settling velocity, v_s, is the settling velocity of a particle that takes into account collisions with other particles, and is a function of the concentration of particles in the slurry:

$$v_s = v_\infty (C_L)^n \tag{4}$$

where

$$n = 4.65 - \frac{2.32}{\sqrt{0.5\pi}}\int_{-\infty}^{\infty}\exp\left(\frac{-\log(Re_p)^2}{0.5}\right)d(\log(Re_p)) \tag{5}$$

and the particle Reynolds number is defined as

$$Re_p = \frac{d_p v_\infty \rho_L}{\mu_L} \tag{6}$$

The analytical expression for "n" given in Equation 5 was derived by Estey and Hu (HNF-2728) as an approximation to the graphical relation given by Oroskar and Turian (1980).

For slurry flow, the Reynolds number is approximated assuming that the particles are spheres.

The terminal (free fall) settling velocity, v_∞, of a spherical particle in a stagnant unbounded liquid is given by

$$v_\infty = \sqrt{\frac{\frac{4}{3}d_p\left(\frac{\rho_s}{\rho_L}-1\right)g}{C_D}} \tag{7}$$

The drag coefficient, C_D, for a sphere is given by:

$$C_D = \left[\left(\frac{24}{Re_p}\right)^{1/2} + 0.34035\left(Re_p^{0.06071} + \frac{1}{1.72013 + 0.018Re_p}\right)\right]^2 \tag{8}$$

Note that an iterative procedure is required to obtain v_∞ because it is implicitly defined in Equation 7 through the particle Reynolds number (Equation 6) as used in Equation 8 for the particle drag coefficient.

The above empirical correlation (Equation 1) is one of the better correlations for predicting critical velocity, with an overall 21.8% root mean square deviation compared to experimental data (Oroskar and Turian 1980). Note that the critical velocity, v_{cr}, is implicitly defined in Equation 1 with the introduction of Equations 2 and 3. Hence, an iterative procedure is required to obtain the critical velocity.

2.3 PRESSURE-DROP CORRELATIONS

As with critical velocity, there are a number of correlations that have been proposed for predicting pressure drop in slurry transport systems. The correlations generally fall into the semitheoretical or empirical categories. The weakness with most of the correlations is their inability to predict the pressure drop accurately for slurries with a wide range of slurry properties and flow regimes. Wasp et al. (1977) proposed a correlation for calculating pipeline pressure loss for a slurry with a broad band particle size distribution that accounts for a combination of heterogeneous and homogeneous flow. The correlation employs the concept of a "two-phase vehicle" to describe the homogeneous portion of the flow. It postulates that the concentration and size distribution of the particles that are found at the top of the pipe are equally distributed throughout the pipe. These equally distributed particles and the carrier liquid form the homogeneous "vehicle" portion of the slurry. The method adjusts the density and viscosity of the carrier liquid to account for the effects of the smaller particles in the homogeneous portion of the slurry. The particles that are not equally distributed across the pipe comprise the heterogeneous portion of the slurry. These particles are suspended and carried along by the homogeneous "vehicle" portion of the slurry. Using this concept, the total pressure drop in the system is calculated by summing the pressure-drop contribution from the homogeneous "vehicle" and the additional pressure drop resulting from the remaining heterogeneous suspension.

The Wasp et al. (1977) correlation defines a criterion for determining which portion of the slurry is treated as part of the "vehicle" based on experimental data from "Turbulent Transfer Mechanism and Suspended Sediment in Closed Channels" (Ismail 1952). The correlation considers a slurry to be homogeneous when the ratio of the solid concentration (ϕ) at 0.08D from the top of the pipe to the solid concentration (ϕ_s) at the pipe centerline is at least 0.8. Wasp et al. (1977) provided the following empirical relationship for determining the concentration ratio for each particle size in the particle size distribution that joins the carrier liquid to form the homogeneous "vehicle" phase:

$$\log_{10}\frac{\phi_{vj}}{\phi_{sj}} = -\left(\frac{1.8v_{\infty j}}{\beta\kappa v^*}\right) \tag{9}$$

where

ϕ_{sj} = solid concentration at pipe centerline for j^{th} particle size of the particle size distribution
ϕ_{vj} = solid concentration for j^{th} particle size of the particle size distribution that joins with the carrier liquid to form the homogeneous "vehicle" portion of the slurry
β = constant for a given particle size, varying from 1.0 for fine particles less than approximately 100 μm to 1.3 for coarse particles on the order of 0.1 mm. A value of β = 1.0 was used in this analysis.
κ = von Karman boundary-layer constant, varying from 0.4 for clear liquids to 0.25 for large solids concentrations. A value of κ = 0.4 was used in this analysis.

The terminal settling velocity, $v_{\infty j}$, for the j^{th} particle size in the particle size distribution is calculated from Equation 7 but using the "vehicle" modified carrier liquid density (ρ_v) and viscosity (μ_v) properties as defined below.

The friction velocity, v^*, is defined as

$$v^* = v\sqrt{\frac{f_w}{8}} \tag{10}$$

where

$f_w = f_v + f_d \cos\theta$
f_v = homogeneous "vehicle" contribution to the friction factor
$f_d = f_w - f_v$ = heterogeneous contribution to the friction factor
v = bulk velocity of the slurry.

The cos θ factor accounts for pipe slope from horizontal per *Applied Fluid Dynamics Handbook* (Blevins 1984).

The homogeneous "vehicle" friction factor, f_v, is calculated using an equation developed in "Friction Factor Equation Spans All Fluids Regimes" (Churchill 1977) which is valid for the laminar, transition, and turbulent flow regimes and is given by

$$f_v = 8\left[\left(\frac{8}{Re_{pipe}}\right)^{12} + (A+B)^{-3/2}\right]^{1/12} \tag{11}$$

where

$$A = \left[2.457 \ln \left(\frac{1}{\left(\frac{7}{Re_{pipe}} \right)^{0.9} + 0.27 \left(\frac{\varepsilon}{D} \right)} \right) \right]^{16} \quad (12)$$

ε = *roughness of pipe*

$$B = \left(\frac{37530}{Re_{pipe}} \right)^{16} \quad (13)$$

The pipe Reynolds number, Re, is calculated as follows:

$$Re_{pipe} = \frac{\rho_v v D}{\mu_v} \quad (14)$$

where

ρ_v = density of the homogeneous "vehicle" phase of slurry
μ_v = viscosity of the homogeneous "vehicle" phase of slurry.

The viscosity of the "vehicle", μ_v, is calculated using the correlation given in "Transport Characteristics of Suspensions: Part VIII. A Note on the Viscosity of Newtonian Suspension of Uniform Spherical Particles" (Thomas 1965) as

$$\mu_v = \mu_L \left(1 + 2.5\Phi_v + 10.05\Phi_v^2 + 0.00273 \exp(16.6\Phi_v) \right) \quad (15)$$

where

Φ_v = total "vehicle" solids concentration = $\Sigma\, \phi_{vj}$, summed over each particle size in the particle size distribution.

The viscosity of the carrier liquid, μ_L, is described in Appendix A and is given as

$$\mu_L = \mu_{water} \left[x_{salt} \left(1 + 1.071 \left(\frac{\rho_L}{\rho_{water}} - 1 \right) \right) + x_{caustic} \exp \left(\left(7.143 \left(\frac{\rho_c}{\rho_{water}} - 1 \right) \right)^{1.15} \right) \right] \quad (16)$$

where

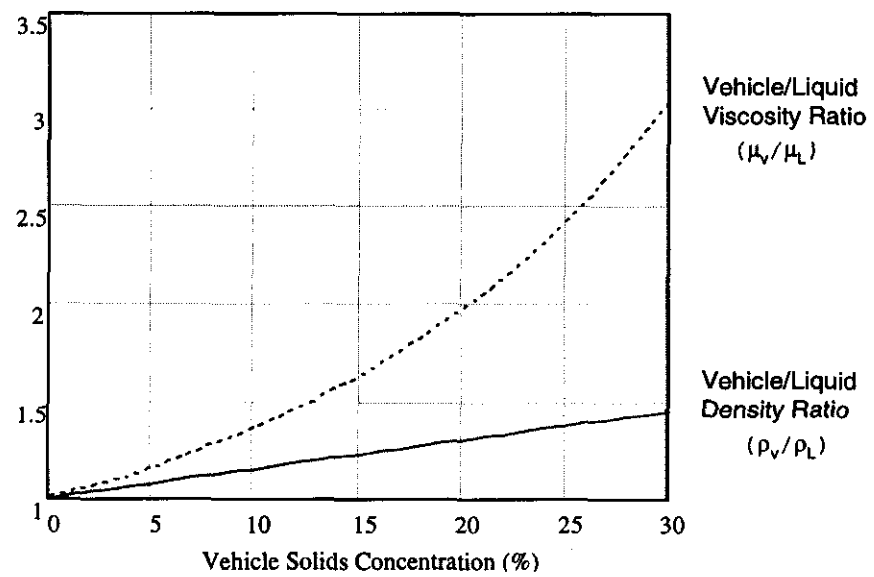
μ_L = viscosity of carrier liquid
μ_{water} = viscosity of water at temperature
ρ_{water} = density of water at temperature
ρ_L = density of carrier liquid
x_{salt} = the fraction of dissolved solids composed of sodium and other salts = 0.9
$x_{caustic}$ = the fraction of dissolved solids composed of sodium hydroxide = 0.1.

The "vehicle" liquid density is given by

$$\rho_v = \rho_s\Phi_v + \rho_L(1 - \Phi_v)$$

A graph of "vehicle" to liquid viscosity and density ratios versus solids content is shown in Figure 2-4.

Figure 2-4. "Vehicle" to Liquid Density and Viscosity Ratios vs. "Vehicle" Solids Concentration.



The determination of pressure loss in a piping system using the Wasp et al. (1977) correlation involves an iterative process. The first iteration assumes that all of the solids form part of the "vehicle." The head loss in the system that is attributable to the "vehicle" is calculated using Darcy's formula

$$\Delta h_v = \frac{h_L}{L} = \frac{f_v v^2}{2gD} \quad (17)$$

where

f_v = pipe friction factor (Darcy) for "vehicle" (Equation 11)
Δh_v = head loss per unit length of pipe attributed to homogeneous "vehicle"
h_L = head loss
L = length of pipeline.

The ratio of ϕ_v/ϕ_s for each size fraction of particles is calculated and multiplied by the volume percent solids of that size fraction to determine the "vehicle" portion of the slurry. The balance of the solids is assumed to be part of the heterogeneous suspension. A second iteration is performed to determine the head loss attributable to the "vehicle." The head loss attributable to the heterogeneous portion of the slurry is calculated for each size fraction of particles using the correlation in "The Hydraulic Transportation of Coal and Other Materials in Pipes" (Durand 1953) as

$$\Delta h_{dj} = 82 \cdot \Delta h_{carrier} \phi_{dj} \left[\frac{gD\left(\frac{\rho_s}{\rho_L} - 1\right)}{v^2 \sqrt{C_{Dj}}} \right]^{1.5} = \frac{f_{dj} v^2}{2gD} \tag{18}$$

where

f_{dj} = heterogeneous contribution to the friction factor for j^{th} particle size in particle size distribution
$\Delta h_{carrier}$ = head loss per unit length attributable to "vehicle" relative to carrier liquid, i.e.,
$= \Delta h_v \frac{\rho_v}{\rho_L}$
ϕ_{dj} = heterogeneous volume percent solids for j^{th} particle size fraction of the particle size distribution
$= \phi_{sj} - \phi_{vj}$
C_{Dj} = drag coefficient of j^{th} particle size using Equation 8 with carrier liquid density (ρ_L) and viscosity (μ_L) properties.

The head losses for each of the size fraction of the particle size distribution are added together to determine the total head loss attributable to the heterogeneous portion of the slurry. This is added to the head loss for the "vehicle" to obtain the total friction head loss. The "vehicle" head loss must be converted to the carrier liquid before adding it to the heterogeneous portion of the slurry to maintain a consistent basis. Additional iterations are performed until the difference in head loss between successive iterations converges within some small tolerances. The described methodology has been modified slightly for this analysis to include the effects of elevation changes along the pipe route. The equation for pressure loss includes a cos θ factor to account for friction losses as the slurry travels through an inclined pipe per Blevins (1984), see Equation 10 above. The resulting total head loss, including the change in elevation, is given by

$$h_L = \frac{Lv^2}{2gD}(f_w) + \left[\left(\frac{\rho_s}{\rho_L} - 1\right)C_s + 1\right]L \sin\theta \qquad (19)$$

where

h_L = head loss
θ = angle of inclination of pipeline from horizontal.

Because some transfer routes contain a combination of carbon steel and stainless steel pipe lengths, the pressure drop is calculated for each respective length with the corresponding pipe roughness for carbon and stainless steel (see Section 3.2.2) to obtain the total head (or pressure) loss.

2.4 EFFECT OF VARIATIONS ON CRITICAL VELOCITY AND PRESSURE DROP

The variables required to determine critical velocity and pressure drop have been identified in Sections 2.2 and 2.3, respectively. While it is evident that the equations are nonlinear, it is not obvious what effect a change in these variables will have on the critical velocity and pipeline pressure drop. Table 2-1 lists the key variables and indicates the general impact that a variation will have on critical velocity and pipeline pressure drop. The impact on differential pressure assumes that the flow velocity is above the critical velocity.

Table 2-1. Key Variables.

Variable	Change	Critical Velocity	Differential Pressure
Liquid density	raise	↓	↑
	lower	↑	↓
Liquid viscosity	raise	↓	↑
	lower	↑	↓
Solids size	raise	↑	↑
	lower	↓	↓
Solids density	raise	↑	↑
	lower	↓	↓
Solids volume fraction	raise	↑	↑
	lower	↓	↓
Pipe inside diameter	raise	↑	↓
	lower	↓	↑
Pipe roughness	raise	n/a	↑
	lower	n/a	↓
Pipe length	raise	n/a	↑
	lower	n/a	↓
Pipe incline to horizontal	raise	n/a	↑
	lower	n/a	↓
Flow velocity	raise	n/a	↑
	lower	n/a	↓

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3.0 WASTE TRANSPORT BEHAVIOR

The rheological and physical properties of the waste and the physical characteristics of the transfer system define the behavior of the waste during transport. The correlations developed for predicting pipeline pressure drop and estimating critical velocity are based on a combination of heterogeneous and homogeneous flow. The correlations predict the waste behavior based on the individual characteristics of the liquid and solid components of the slurry. Waste properties include liquid density, liquid viscosity, solids density, solids size and distribution, and solids volume fraction. A discussion of these properties is provided in Section 3.1. Physical characteristics of the waste-transfer system include pipe inside diameter, length of pipe in the transfer route, elevation changes in the transfer route, and surface roughness of the inside of the pipe. These characteristics are discussed in Section 3.2. The pressure ratings of the existing pipelines are also identified in Section 3.2.

3.1 WASTE PROPERTIES

Accurate measurement of waste properties is essential to the accurate prediction of critical velocity and system pressure losses. The group of waste transfers identified in Phase 1B of the *Tank Waste Remediation System Operation and Utilization Plan to Support Waste Feed Delivery* (HNF-SD-WM-SP-012) focuses on transfers from DSTs in the 200 East Area. An initial review of characterization data for the DSTs was performed to determine if sufficient data were available to support an analysis of waste transfers based on tank specific data. It was found that supernatant density data were available for most of the tanks. Solids volume percent data were available from the Hanford Tank Waste Operating Simulator (HTWOS) for all of the Phase 1B transfers. HTWOS maintains an inventory of the liquid and solid components of the waste as it is transferred between tanks. Solids density data were available for ~40% of the tanks. Data for supernatant viscosity and solids diameter were available for <30% of the DSTs. Based on the lack of necessary input data, Process Engineering was requested to provide an estimate of slurry properties. The estimate, attached in Appendix A, provides a summary of nominal and bounding in situ waste properties to be used as a basis for the analysis of the waste-transfer system. The estimated properties are summarized in Table 3-1.

Table 3-1. In Situ Waste Properties.

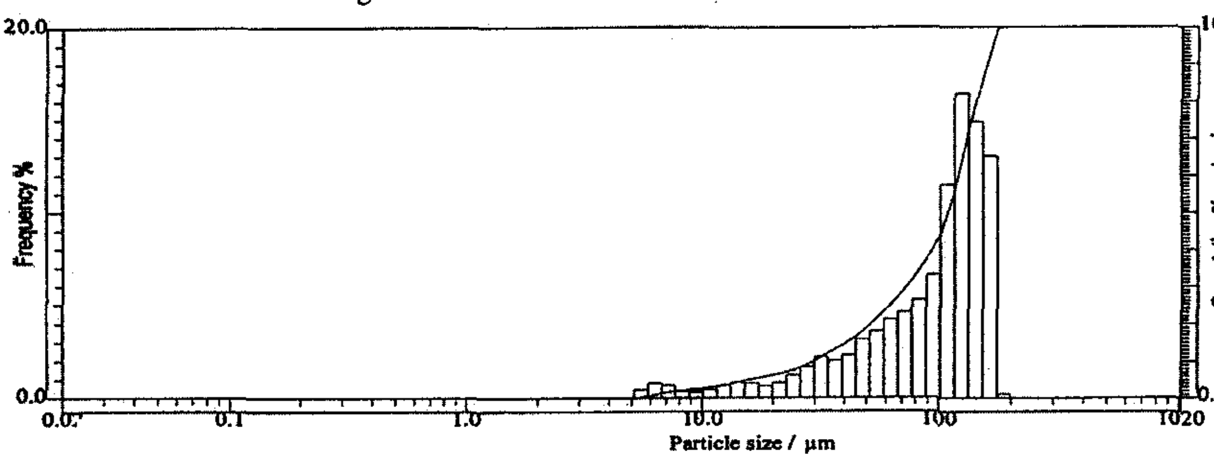
Property	Nominal	Bounding
Median particle size (d_p)	40 μm	400 μm
Volume percent solids (C_s)	15%	30%
Liquid density (ρ_L)	1.21 kg/L	1.46 kg/L
Solids density (ρ_s)	2.50 kg/L	3.00 kg/L
Liquid viscosity (μ_L)	*	*

* The viscosity of the carrier liquid is a function of the density of the carrier liquid, water, and the fraction of dissolved salts and caustic. The equation for viscosity is provided in Appendix A.

Some of the properties listed in Table 3-1 (i.e., particle size and liquid density) are based on actual test data. Other properties (i.e., volume percent solids, solids density, and viscosity) are based on known correlations or engineering judgment. It should be noted that the nominal and bounding cases are not defined quantitatively. Nominal properties are intended to reflect an average tank, not any specific tank. Likewise, the bounding case does not envelop the most extreme values of the individual properties listed.

The specified particle size is the median value from a distribution of particle sizes. The analysis assumes that the distribution of particle sizes approximates a log-normal curve. In performing the pressure-drop analysis, the shape of the particle distribution remains the same. Only the median value of the distribution changes with changing median particle size. A graph of particle size distribution for Tank C-104 is shown in Figure 3-1. The shape of the distribution curve is typical of the distribution used in the analysis.

Figure 3-1. C-104 Particle Size Distribution.



3.2 TRANSFER SYSTEM CHARACTERISTICS

3.2.1 Pipeline Diameter, Length, and Elevation Changes

The HTWOS models for Cases 3S4 and 3S6D were used to identify all waste transfers in Phase 1B. Additionally, a sampling of transfer routes from Case 3S6D, Phase 2 were included in the list of waste transfers. HTWOS identifies the source and receiver tank for each transfer but does not provide information related to the actual route that the waste travels during the transfer. This analysis focused on the transfer routes in the 200 East Area. The transfer routes that were analyzed are identified in Figure B-1 of Appendix B. Pipeline routing, pipe diameter, length of pipe for each transfer route, and elevation changes were identified from the physical piping drawings and from a previous study documented in HNF-2938, *Evaluation of 241-AN Tank Farm Supporting Phase 1 Privatization Waste Feed Delivery.* All pipelines in the transfer routes identified were found to be 80 mm (3-in.) nominal-diameter, schedule-40 pipe. Transfer routes for pipelines that have not been installed were based on preliminary information from the projects. For the purpose of this analysis, it was assumed that all new pipe will be 80 mm (3-in.) nominal-diameter, schedule-40 pipe.

Equivalent pipe lengths for individual transfer routes are shown in Appendix D. Equivalent pipe lengths are used to simplify the analytical model for determining pressure drop while accounting for the friction losses in pipe fittings and valves. Equivalent lengths are based on the number of lineal feet of pipe in each transfer route plus the number of feet of pipe that will provide a pressure drop equivalent to the pressure drop that would be experienced through a pipe fitting or valve. Because the future configuration of fittings and valves in the pump and valve pits is not well defined, a standard configuration of valves and fittings was assumed for these locations. Transfers through valve pits were modeled by assuming that the flow passes through two 3-way valves (run), one 3-way valve (branch), three Plutonium-Uranium Extraction (PUREX) connectors, and five long radius elbows. Transfers through pump pits were modeled by assuming that the flow passes through one 3-way valve (run), two PUREX connectors, and two long radius elbows. If additional in-line components are present, then a greater pressure drop through the system would be expected. Equivalent pipe lengths were determined using the methodology described in *Flow of Fluids Through Valves, Fittings, and Pipes* (Crane 1981). The interface with the privatization contractor requires that the transferred waste move some distance within the vitrification facility. The equivalent lengths identified in the privatization contractor's calculations have been included in the lengths of pipe listed in Appendix D for all transfers to the vitrification facility.

Changes in elevation between end points of the transfer lines were identified from HNF-2938, physical piping drawings, preliminary project drawings, and the privatization contractor's calculations. The elevations of end points of the transfer line were determined from the elevations of the nozzles inside the pump or valve pits. Elevation changes are identified in Appendix D.

3.2.2 Pipeline Roughness

All pipelines in the transfer routes were found to be constructed from either carbon steel (ASTM A106 Grade B or A53 Type S, Grade B) or stainless steel (ASTM A312). Pipeline material for pipes that have not been installed were based on preliminary information from Projects W-314 and W-521. For the purpose of this analysis, it was assumed that all new pipe will be stainless steel.

The surface roughness of the interior of a pipe can be affected by corrosion and scale buildup because of the chemistry of the waste and flush water. The interior surface roughness can also be affected by erosion caused by abrasive solids in the waste and high waste flow rates. As the interior surface of the pipe deteriorates it becomes irregular and rough, and there may be a simultaneous reduction in the thickness of the pipe wall. Although the waste chemistry is controlled to reduce the effects of corrosion and scale buildup, waste-transfer lines have failed in the past. The metallurgical analysis of a failed jumper in the 241-A-B valve pit in 1984 (*Metallurgical Analysis of Leak Failure of 241-A-B Valve Pit Jumper* [WHC-SD-RE-TI-148]) is a good example of the combined effects of erosion/corrosion on the interior of a pipe. The photographs in WHC-SD-RE-TI-148 document the rough surface condition of the pipe even at locations where the pipe did not fail. The effects of this increasing surface roughness can change the flow characteristics of a pipe system significantly. Because there are no data documenting the condition of the interior of the pipelines, surface roughness values were based on an evaluation by Anantamula and Divine (1999), which is contained in Appendix C. For the purpose of this analysis, the values shown in Table 3-2 were used.

Table 3-2. Pipe Surface Roughness Estimates.

Pipe Material	Surface Roughness	
	(μm)	(mil)
Carbon Steel , EOL (50 yr)	3810	150
Stainless Steel, EOL (40 yr)	254	10
Stainless or Carbon Steel, New	51	2

EOL = end of life.

Erosion is expected to increase corrosion near elbows in the pipeline, however, the increase in corrosion is a result of removal of corrosion products. Under these conditions, a significant increase in the friction factor is not expected even though a rough uneven surface is produced. Recent laboratory studies indicated that even at velocities approaching 4.6 m/s (15 ft/s), corrosion products are not removed from the steel surface and, therefore, the friction factors at the elbows are not expected to be significantly different from the straight sections of the pipe. As indicated in Appendix C, the surface roughness values reported are considered conservative for carbon steel since 98% relative humidity and lack of inhibiting effect from nitrite are assumed.

3.2.3 Pipeline Design Pressure

Most of the existing pipelines that will be used for waste retrieval have a design pressure of 2.7 MPa (400 lbf/in^2). Some carbon steel lines in AN and AW tank farms have design pressure ratings of 1.9 MPa (275 lbf/in^2) but have been hydrotested to 3.1 MPa (450 lbf/in^2) (HNF-2938). The pressure rating of the pipe provides an upper bound that limits the flow velocity through the system and the allowable shut-off head of the transfer pump.

4.0 RESULTS

This section presents the results of the critical velocity and pressure-drop calculations. A general discussion of waste parameters investigated is provided in Section 4.1. Results of critical velocity and pressure-drop analyses are given in Sections 4.2 and 4.3, respectively. The sensitivity of the waste and pipe parameters on the pressure drop at critical velocity is presented in Section 4.4. Uncertainties in the waste and pipe parameters are discussed in Section 4.5.

4.1 GENERAL

The critical velocity and transfer line pressure drop were calculated for each of the transfers identified under Cases 3S4 and 3S6D of the HTWOS model for Phase IB waste feed delivery. Case 3S4 was chosen because it is consistent with the latest multi-year work plan. Case 3S6D also was analyzed to evaluate the effects of the changes between the two cases. Approximately 30% of the transfer routes were changed when going from Case 3S4 to 3S6D. The calculations were performed using the length of pipe specific to each transfer route, pipe wall roughness values for new and old pipe at end of life (EOL), and different combinations of waste characterization data. Equivalent pipe lengths were used to account for the various valves and fittings in the transfer routes, and changes in elevation were factored into the calculations. The transfer pipe within the privatization contractor's facility also was included in the pipe routes. A total of 52 different combinations of waste properties and transfer routes were analyzed. These different combinations served to confirm that the analytical model was providing reasonable results and to provide an indication of the sensitivity of the transfer system to variations in waste properties. Of the 52 different combinations, three sets of data were identified for further evaluation. These three sets of data are described below.

Data Set 1

The first set of data is based on the in situ waste properties identified as the bounding case in Table 3-1. This case represents a set of waste properties that would be considered conservative for all of the waste-transfer routes. The intent was to determine whether one set of data could be used as the basis for specifying all new transfer system equipment. If it could be shown that the required critical velocity and associated pressure drop were within the design pressure limits of the pipe, no further evaluation of the pipe would be required. This set of data would then define the design bases for the waste-transfer system. The waste for this case has the following properties (Case 3b, Group 2 Properties – Tables D-11 and D-25 in Appendix D for HTWOS Cases 3S4 and 3S6D, respectively):

- Liquid Density 1.2 kg/L
- Liquid Viscosity 0.01 to 0.1 g/cm-s (1-10 cP)
- Volume Percent Solids 30%
- Solids Density 3.0 kg/L
- Solids Median Size 400 μm
- Temperature 10 °C to 60 °C

Data Set 2

The second set of data is based on the same waste properties identified in the bounding case, with the exception of the liquid density and the volume percent solids. The liquid density was reduced to 1.2 kg/L to reflect the actual waste characteristics more accurately. The volume percent solids was reduced based on values predicted by HTWOS. Cases 3S4 and 3S6D were reviewed to determine the maximum volume percent solids that would be present in a slurry transfer. This value was increased by a factor of two to account for any density gradient that might exist during a transfer because of inadequate mixing or stratification in the tank. The waste for this case has the following properties (Case 4, Group 2 Properties – Tables D-14 and D-28 in Appendix D for HTWOS Cases 3S4 and 3S6D, respectively):

- Liquid Density 1.2 kg/L
- Liquid Viscosity 0.01 to 0.1 g/cm-s (1-10 cP)
- Volume Percent Solids 15%
- Solids Density 3.0 kg/L
- Solids Median Size 400 μm
- Temperature 10 °C to 60 °C

Data Set 3

Low-activity waste (LAW) feed transfers to the privatization contractor are primarily supernatant and have very low solids content. However, as part of the waste-staging process, waste with higher volume percent solids are transferred between tanks that are subsequently used for LAW feed to the privatization contractor. The third set of data is based on the same values used in the second case, with the exception of the volume percent solids. This property was revised to simulate performing a transfer between tanks. This was considered a bounding condition for a tank-to tank transfer. The waste properties for this case are as follows (Case 4, Group 1 Properties – Tables D-14 and D-28 in Appendix D for HTWOS Cases 3S4 and 3S6D, respectively):

- Liquid Density 1.2 kg/L
- Liquid Viscosity 0.01 to 0.1 g/cm-s (1-10 cP)
- Volume Percent Solids 10%
- Solids Density 3.0 kg/L
- Solids Median Size 400 μm
- Temperature 10 °C to 60 °C

The three sets of data were compared to design criteria for ongoing or recently completed projects to determine if there were any inconsistencies. The waste properties for Projects W-058, W-211, and W-314 are shown in Table 4-1. Each of these projects has or is in the process of upgrading the waste-transfer system. The waste properties for the three sets of data in this analysis were found to be similar to the project design criteria, with the exception of the solids density data and the data that Project W-058 used for non-Newtonian flow.

The waste characteristics, transfer line properties, and results of the analyses are tabulated in Appendix D. The first data set is presented in Tables D-11 and D-25 (Case 3b, Group 2 Properties) for HTWOS Cases 3S4 and 3S6D, respectively. The second and third data sets are presented in Tables D-14 (Case 4, Group 2 Properties) and D-28 (Case 4, Group 1 Properties) for HTWOS Cases 3S4 and 3S6D, respectively.

Table 4-1. Waste-Property Comparison.

Property	Project W-058		Project W-211	Project W-314
Specific gravity	1.5	1.25	1.25	1.5
Liquid density, kg/L	--	--	--	--
Liquid viscosity, g/cm-s (cP)	0.3 (30)	0.1 (10)	0.1 (10)	0.3 (30)
Volume percent solids	30%	20%	20%	30%
Solids density, kg/L	--	--	--	--
Solids size, μm	0.5 – 4000	0.5 – 4000	0.5 – 4000	--
Temperature, °C	2 – 93	2 – 93	27 – 93[a]	27 – 116
Friction factor	0.0404[b]	--	--	--

[a]10 °C to 130 °C for aging waste tanks
[b]Non-Newtonian.

4.2 CRITICAL VELOCITY ANALYSIS

Critical velocity is a function of the carrier liquid density and viscosity, solids diameter, density and volume fraction, and pipe diameter. Critical velocity values are tabulated in Appendix D for each set of data. The values of critical velocity are independent of transfer pipeline length. The critical velocity is calculated using Equation 1. A comparison is also performed to ensure that the flow is above the laminar-to-turbulent transition region. The calculated value of critical velocity is adjusted by a factor, κ_{cv}, which is equal to 1.3. This factor accounts for the percent root mean square deviation from experimental data for the critical velocity correlation (Oroskar and Turian 1980) and provides a margin above the calculated value of critical velocity to ensure stable operation.

Table 2-1 shows the general effect that raising or lowering a process variable has on the critical velocity. A review of the calculated values for critical velocity in Appendix D indicates that it is more sensitive to changes in some variables than in others. Appendix F contains a number of graphs that illustrate the effects of adjusting one process variable while holding the others constant. The variable that has the most significant impact on critical velocity is the ratio of carrier liquid density to solids density. Figure F-5b shows the effect on critical velocity for changes in the carrier liquid density, particle density, and temperature for a median particle size of 400 μm with a solids concentration of 10% by volume. Figures F-6a, F-7a, and F-8a of Appendix F show that a moderate percent increase in carrier liquid density will cause a moderate percent decrease in critical velocity. Likewise, Figures F-6b, F-7b, and F-8b of Appendix F demonstrate that a moderate percent decrease in solids density will cause a moderate percent decrease in critical velocity.

The other three process variables (i.e., volume percent solids, solids diameter, and carrier liquid viscosity) require larger percentage changes to have an equivalent effect on critical velocity. Figures F-6a and F-6b of Appendix F show that large percent increases in volume percent solids are necessary to make moderate percent increases in critical velocity. Changes in solids diameter have a small impact on critical velocity. A comparison of Figures F-9a, F-9b, F-9c, and F-9d of Appendix F indicates that a large percent reduction in solids diameter is required to affect a moderate percent decrease in critical velocity. However, the Oroskar and Turian (1980) critical velocity correlation overestimates the critical velocity as the particle size decreases from 400 μm when compared to the Wasp et al. (1977) predicted pressure drop vs. flow velocity curves as shown in Figure E-6c of Appendix E. This is expected because the Oroskar and Turian (1980) correlation was based on large size particle data with a narrow particle size distribution. Note however, as shown in Figure E-6c, that this overestimate on the critical velocity does not significantly affect the pressure drop at the critical velocity. Viscosity also has a small effect on critical velocity. Figures F-6a, F-8a, F-10a, and F-10b of Appendix F show that a significant percent decrease in carrier liquid temperature and corresponding increase in viscosity per Equation 16 is necessary to cause a small percent decrease in critical velocity. The results of the analysis show that it is possible to predict the direction and approximate magnitude of the change in critical velocity when a single variable is raised or lowered, but it is difficult to predict the change when multiple variables are adjusted simultaneously.

As shown in the tables in Appendix D, the calculated values for critical velocity ranged from 0.79 m/s (2.6 ft/s) to 2.26 m/s (7.4 ft/s) for the sets of data that did not use HTWOS data for volume percent solids. The variation in critical velocity for these cases is attributable to the variation in particle size and the change in the ratio of solids density to liquid density. In general, the critical velocity decreased as the solids volume percent and solids diameter decreased.

4.3 PRESSURE-DROP ANALYSIS

The tables in Appendix D show the total equivalent length of pipe for each transfer route, the type of pipe material, and the total pressure drop at the critical velocity using values of surface roughness for old pipe at EOL and new pipe. The value for pipeline pressure drop was calculated using Equations 17, 18, and 19. The tables in Appendix D also show the maximum flow rate at a 2.7 MPa (400 lbf/in^2) pipe design pressure using values of surface roughness for old and new pipe. The values for pressure drop for old and new pipe were included to provide a range of possible values that might be seen during operation. Analysis of the adequacy of the transfer system is based on the old pipe values, which represent the condition of the pipe just before the end of life. The maximum flow rate at design pressure data is based on a pipeline with a design pressure of 2.7 MPa (400 lbf/in^2).

Appendix E, Figures E-1 through E-5 show waste-transfer system curves for the transfer route from Tank 241-AN-107 to the privatization contractor. Each set of curves shows the system pressure drop for a variety of waste properties at three different concentrations and at the beginning and end of the pipe design life. For each set of figures, the particle size is held constant so that the effects of changes in the other variables can be identified. The figures also identify the critical velocity, system operating pressure for the old and new pipe conditions, and the maximum flow rate at the design pressure of the pipe. Figure E-6c shows the system pressure-drop curves at 400, 200, 100, and 40 µm median particle sizes compared to clear liquid system curve for new pipe roughness condition. Also shown is the corresponding best-estimate critical velocity curve based on Oroskar and Turian (1980) and a modified Oroskar and Turian critical velocity based on the "vehicle" concept introduced by Wasp et al. (1977). Both methods appear to overpredict the critical velocity as the median particle size decreases as discussed above. Neither of these predictive results have been verified for this range of smaller particle sizes.

Pressure drop for a slurry is a function of the flow velocity, liquid density and viscosity, solids diameter, density and volume fraction, pipe diameter, pipe length (equivalent length), change in elevation, and pipe roughness. Pressure drop in the system is calculated at the critical velocity. The effects of changing the value of a waste property on the pressure drop in the pipeline can be difficult to predict because the critical velocity also changes. A change in a variable that results in an increase in critical velocity may lead to a decrease in pressure drop. As the viscosity of the carrier liquid is lowered, the critical velocity increases, but the pressure drop in the system decreases. However, as the solids diameter is decreased, both the critical velocity and the pressure drop decrease. Similarly, as the solids density increases, the critical velocity and the pressure drop also increase. When one variable is changed, it is possible to predict the direction of the change in pressure drop if all other variables are held constant. The above effects can be seen through a careful study of the sensitivity analysis given in Appendix E and Figures F-5 through F-10 of Appendix F.

Using the first set of data based on in situ waste properties (Table D-25 in Appendix D), 48 of 63 transfer routes will exceed the rated pressure of at least a portion of the transfer line. The transfer route with the highest pressure drop will be required to operate at a pressure of 7.6 MPa (1,115 lbf/in^2) at a critical velocity of 2.26 m/s (7.4 ft/s). Figure B-2 in Appendix B shows the lines that exceed the rated pressure of the pipeline.

For the second set of data (Table D-28 in Appendix D), 38 of 63 transfer routes will exceed the rated pressure of some portion of the transfer line. The route with the highest pressure drop will be required to operate at a critical velocity of 2.16 m/s (7.1 ft/s) and a pressure of 5.2 MPa (759 lbf/in^2). If all of the old pipe were to be upgraded to a design pressure of 2.7 MPa (400 lbf/in^2), 34 of 63 transfer routes would still exceed the rated pressure of the pipe. Figures B-3 and B-4 in Appendix B show the lines that exceed the pipeline pressure rating.

Using the third set of data (Table D-28 in Appendix D), 37 of 63 routes exceed the rated pressure of at least some portion of the transfer route. The transfer route with the highest pressure drop will be required to operate at a pressure of 4.2 MPa (618 lbf/in^2) and a critical velocity of 2.07 m/s (6.8 ft/s). If all of the old pipe were to be upgraded to a design pressure of 2.7 MPa (400 lbf/in^2), 31 of 63 transfer routes would still exceed the rated pressure of the pipe. Figures B-5 and B-6 in Appendix B show the lines that exceed the pressure rating of the pipeline.

Calculated values for pressure drop in individual transfer routes for the three sets of data range from 338 kPa (49 lbf/in^2) to 7.6 MPa (1,115 lbf/in^2). Using the pipe roughness values for old pipe, Tables D-25 and D-28 in Appendix D show that a majority of transfer routes cannot meet the required critical velocity without exceeding the operating pressure of the system. Using the roughness values for new pipe reduces the number of lines that will exceed their rating, but a majority of the routes still exceed their design pressure.

The pressure drop for supernate transfers was not calculated, but can be evaluated by reviewing the results presented in Appendix D. Cases 1c and 1d of Appendix D provide the calculated pressure drop using median solid particle sizes of 5 and 10 µm, and HTWOS volume percent solids values multiplied by a factor of 1.5 or 2.0. These sets of waste properties bound the pressure drop that would be calculated for supernate waste. The highest pressure drop through any transfer route in Cases 3S4 or 3S6D is 0.8 Mpa (123 lbf/in^2), assuming an end of life pipe roughness value. All of the transfer routes can be used to transfer supernate. It should be noted that the small pressure drops are based on low transfer flow velocities. The maximum calculated flow rate is 5.5 L/s (87 gpm) which is equivalent to velocity of 1.2 m/s (3.8 ft/s) in a 80 mm (3 in.) pipe. However, these values for pressure drop are conservative because they are based on waste with some small particles for an actual supernate transfer, the pressure drop will be lower.

In the preceding discussion, the adequacy of each transfer system route is evaluated by comparison of the design pressure rating of the pipe to the calculated pressure drop. It should be noted that this comparison alone is not sufficient to verify that a particular route is designed adequately. The transfer system pipe also must be designed to withstand the shutoff head of the transfer pump. The transfer pump will be designed with a shutoff head that is ~30% above the pressure drop calculated for each route. This additional design requirement will result in more transfer routes exceeding the rated pressure of the system than identified in the discussion above.

4.4 SENSITIVITY

In reviewing the pressure-drop results in Appendix D for various combinations of waste properties, it was noted that changes in some of the waste properties can have a significant impact on the calculated pressure drop. Figure 4-1 provides a comparison of the effect that changes in waste properties have on pressure drop. Figure 4-1 is based on the longest transfer route (241-AN-107 to BNFL) with a volume percent solid of 15%, 400 µm median size particle distribution, 60 °C, and old pipe. Figure 4-1 shows the magnitude of the change in pressure drop when a single waste parameter is varied from one end of its range to the other. Only one parameter is changed at a time, while the other parameters are held constant. It can be seen that the range of solids volume concentration and particle size have the most impact on the calculated pressure drop.

Figure 4-2 provides a more detailed comparison of the effects of variations in several waste properties and pipe parameters on the required system pressure. Figure 4-2 is based on the same transfer route as Figure 4-1, but also indicates values of pressure drop in the pipe at specific waste properties. The values of pressure drop are calculated by varying one variable while the others are held constant. Figure 4-2 shows that a reduction in solids density, solids size, or volume percent solids will result in a significant reduction in pressure drop. It should also be noted that the variables with the least amount of characterization data have the most significant effect on calculation of pressure drop. A more complete evaluation of the effects of the waste parameters on pressure drop is given in Appendix E for the transfer route from Tank 241-AN-107 to BNFL.

Figure 4-1. Waste-Property Sensitivity (AN-107 to BNFL).

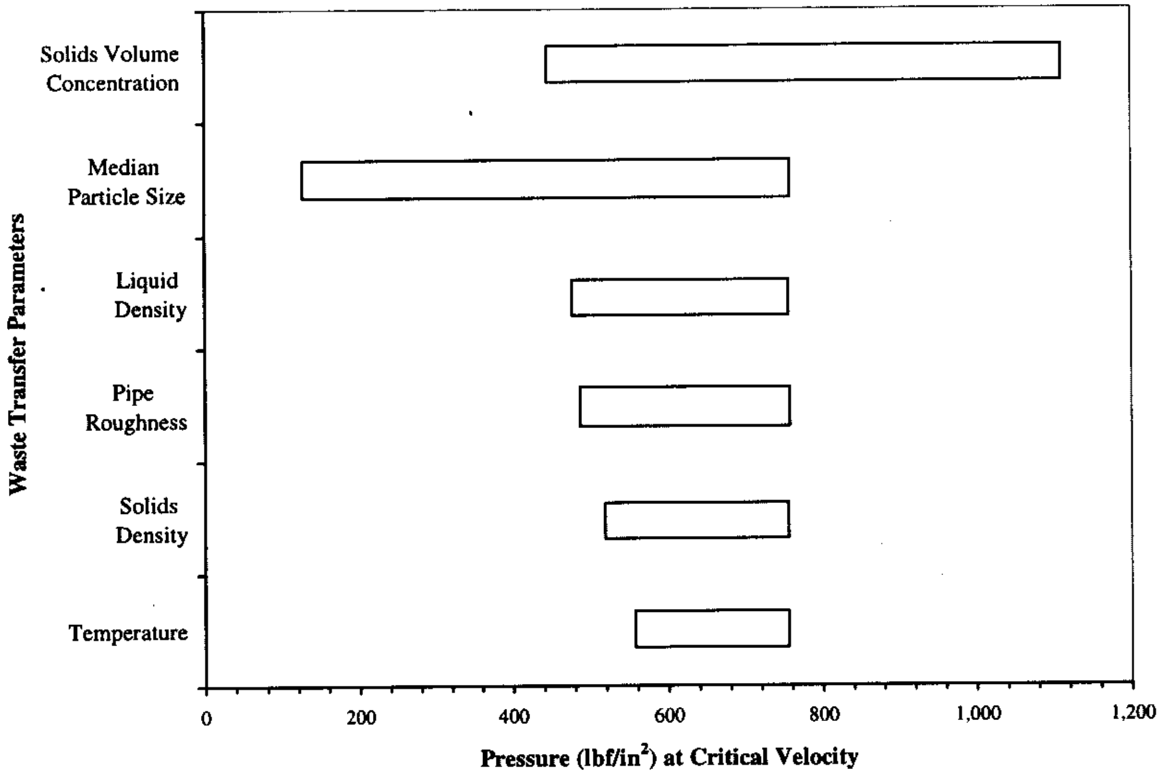
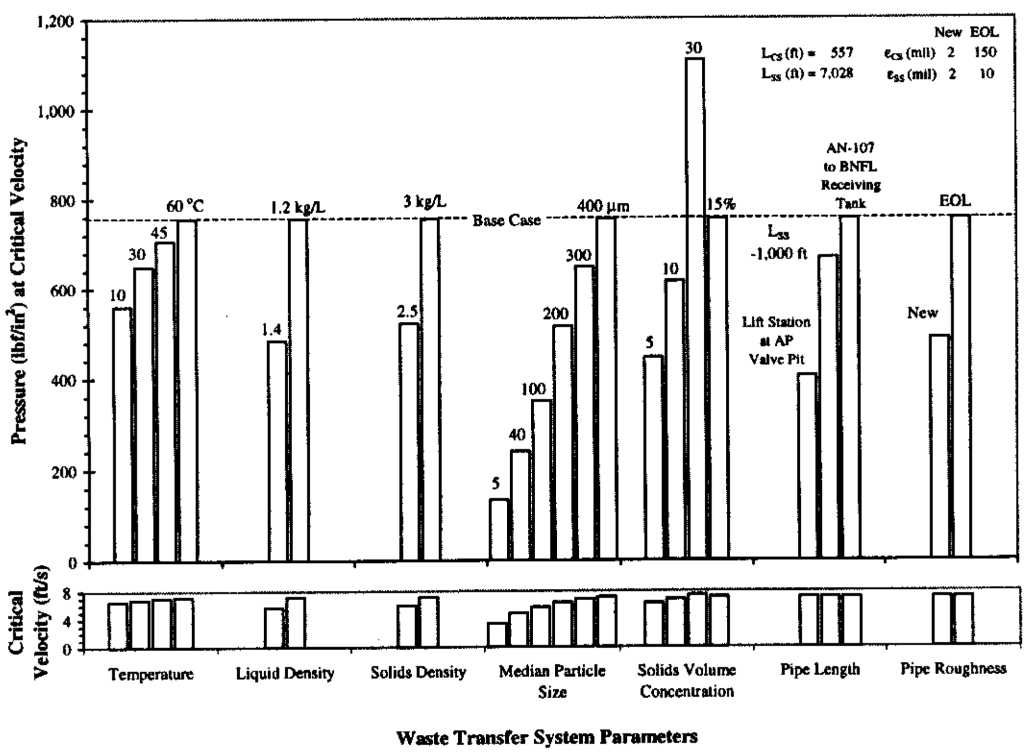


Figure 4-2. Waste-Transfer System Sensitivity (AN-107 to BNFL).



4.5 UNCERTAINTIES

This analysis is based on a number of assumptions that are critical to a proper understanding of the results. The areas of greatest uncertainty are discussed in this section.

4.5.1 Waste Characterization

Waste characteristics from the process flow sheets, the latest revisions of the tank characterization reports, letter reports from the laboratories, and the HTWOS model were reviewed. It was found that liquid viscosity data and solids diameter data for the DSTs generally are not available. Because of the lack of tank-specific data, physical property estimates were provided by Process Engineering. In performing this analysis, some simplifying assumptions had to be made regarding the particle size and particle density. It has been assumed that the density of all solid particles is 3.0 kg/L. This density value is based on densities of dominant chemical constituents in the tanks. The potential effect of this assumption is to overstate the pressure drop in the transfer system significantly if the larger particles are less dense or will be dissolved in the tanks before transfer.

The volume percent solids in the waste for Data Sets 2 and 3 has been estimated by doubling the highest solids content of any transfer identified in HTWOS. This value was then used for all transfers. The rationale for doubling the HTWOS value was to account for density gradients in the tanks during waste transfers. The rationale for using this value for all transfers was to accommodate future changes in the tank retrieval sequence that could affect the volume percent solids for a particular transfer route. In going from Case 3S4 to Case 3S6D, for instance, approximately 30% of the transfer routes were changed.

This analysis was intended to address Phase 1B and Phase 2 transfers from the AN, AP, AW, AY, and AZ tank farms using tank specific waste properties.. Because there is very little tank-specific information describing the Phase 2 transfers at this time, the analysis was performed using estimated slurry properties. HNF-SD-WM-SP-012, Revision 1 contains some assumptions for Phase 2 waste regarding volume percent solids, solids density and supernatant sodium content but does not address waste properties. The waste-transfer system is intended to be used for Phase 1B and Phase 2 transfers. The adequacy of the waste-transfer system for Phase 2 transfers cannot be verified without better data.

4.5.2 Pipe Surface Roughness

The pipe surface roughness was determined by analysis based on assumed waste conditions, a 50-yr life for the carbon steel lines and a 40-yr life for the stainless steel lines. Pipe surface roughness has a large impact on the calculation of pressure drop in the carbon steel transfer pipes. The roughness values provided in Appendix C may be non-conservative, but it is not possible to know without inspecting the inside of the pipe.

4.5.3 Critical Velocity and Pressure-Drop Correlations

Although the critical velocity and pressure-drop correlations have been developed from the analysis of extensive test data, these correlations have not been validated through testing for the Hanford-specific waste characteristics.

The correlation used for determining critical velocity is empirically derived from data that does not include particles <100 μm in diameter. HNF-2728 recommends the use of the Oroskar and Turian (1980) correlation. HNF-2728 compares the correlation to another correlation that is based on flows with smaller particles (< 80 μm) and shows that the Oroskar and Turian (1980) correlation is conservative. It is possible to overstate the critical velocity requirements for slurries with small-size particles without test results using wastes typical of the Hanford Site.

Additionally, the Oroskar and Turian (1980) correlation uses a median particle size to represent the distribution of all particle sizes. This is a reasonable simplification for a slurry with a narrow range of particle sizes. It can lead to underestimation of the velocity required to keep all particles in suspension for a slurry with a wide range of particle sizes.

4.5.4 Waste Rheology

The characterization data that are available indicate that the viscosity of the carrier liquid is very sensitive to temperature. This analysis has made the assumption that the transfers will occur at a temperature that will not cause the waste to begin to gel or cause large changes in the liquid viscosity, which is consistent with current practice. Variations in temperature during a waste transfer resulting from cooling in the pipeline could change the results of this analysis substantially. The effects of non-Newtonian waste also have not been evaluated in this analysis.

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5.0 CONCLUSION

Section 5.1 provides a discussion of the analysis and identifies alternatives to address apparent deficiencies in the waste-transfer system. Section 5.2 provides recommendations to meet program needs and to evaluate the adequacy of the waste-transfer system more accurately.

5.1 DISCUSSION

The intent of this analysis was to provide a documented basis for the design pressure rating of the waste transfer system pipeline and a documented basis for the design and operating pressure of the transfer system pumps. Slurry correlations for heterogeneous and homogeneous flow were identified for estimating the critical velocity and the pressure drop through the waste-transfer pipelines. Transfer system characteristics were reviewed for each of the transfers identified in Phase 1B of Cases 3S4 and 3S6D. These transfer cases were consolidated into distinct transfer routes for evaluation of the transfer system fluid flow characteristics. More than 50 different combinations of waste properties were analyzed for each of the transfer routes in Cases 3S4 and 3S6D. Three different sets of slurry waste properties were identified as being representative for all of the waste transfers. One set of data was evaluated to determine whether a single set of waste properties could envelop all waste combinations and meet the design constraints of the transfer system. The other two sets of data were used to address specific types of waste transfers.

Use of a single waste composition that envelops all waste combinations requires a robust transfer system design. The results of the analysis for the first set of data indicates that approximately 75% of the transfer pipelines would exceed their design pressure at the critical velocity. Use of waste properties that more closely approximate expected waste conditions showed that the waste-transfer system would require fewer pipeline replacements. The results of the analysis for the second set of data found that over 50% of the lines could not meet the critical velocity without exceeding the design pressure of the pipe. The analysis for the third data set found that about 50% of the lines would exceed their design pressure at the critical velocity. Additionally, if some of the conservatism can be removed from the predicted surface roughness values by performing inspections of the pipe, fewer pipelines would have to be replaced in the system. Based on the results of the first three sets of slurry waste data, all of the 1.9 MPa (275 lbf/in^2) rated lines will have to be rated at a higher design pressure or replaced. Supernate transfers will not exceed the design pressure rating of any of the transfer routes that were evaluated.

Several alternatives exist to address the apparent deficiencies in the waste-transfer system and to reduce some of the uncertainty in the waste properties. Some of the alternatives would completely resolve the pressure limitations of the pipe if implemented. Others would contribute to a reduction in the required design pressure of the pipe. These alternatives are addressed below.

Alternative 1

Design the waste-transfer system to the highest calculated pressure, plus a 30% rise to pump shutoff, for the first set of data, 10 MPa (1,450 lbf/in^2). This alternative is not realistic because it assumes that the jumper connectors can be rated for a significantly higher pressure than their present rating. It also requires that the existing pipe be re-rated or replaced.

Alternative 2

Particle size and density have a large impact on the determination of pressure drop in the transfer system. Refinement of the particle size and density data has the potential to provide substantial reductions in the amount of rework that would be required by the present analysis. If it can be shown that the larger particles (>100 μm) are not very dense and will not settle, a significant reduction can be made in the number of lines that exceed their design pressure.

Alternative 3

A large contribution to the overall pressure drop in the system is because of the long transfer routes that are required to pump waste to the privatization contractor. A method of reducing line lengths is to add a lift station adjacent to the new AP valve pit or to stage all transfers through the AP tank farm. A lift station would comprise storage tanks, pumps, instrumentation, power, and ventilation equipment. All transfers to the privatization contractor and between Tank Farms AN, AY, and AZ, and Tank Farms AP and AW would be routed through the lift station or Tank Farm AP. Table D-29 in Appendix D lists the pressure drops through the transfer system assuming that waste is staged through a lift station at the new AP valve pit. With the addition of a lift station, the critical velocity is 2.16 m/s (7.1 ft/s) and the largest pressure-drop estimate for any transfer is 2.8 MPa (409 lbf/in^2). A velocity of 2.16 m/s (7.1 ft/s) corresponds to a volumetric flow rate of 10 L/s (160 gal/min). A discharge pressure of 2.8 MPa (409 lbf/in^2) corresponds to a discharge head of approximately 195 m (640 ft).

To account for wastes of different densities, the pressure at the discharge of the pump must be adjusted. The bulk density of the waste listed above is 1.47 kg/L. If, however, the liquid density were to be 1.46 kg/L (bounding value per Table 1 of Appendix A), the bulk density of the waste would be 1.69 kg/L. A centrifugal pump is rated in meters (or feet) of head. At a specified flow rate, the discharge head will remain constant, but the discharge pressure will vary if the density of the pumped liquid changes. The discharge pressure from a pump is estimated for a new density by the ratio of specific gravities:

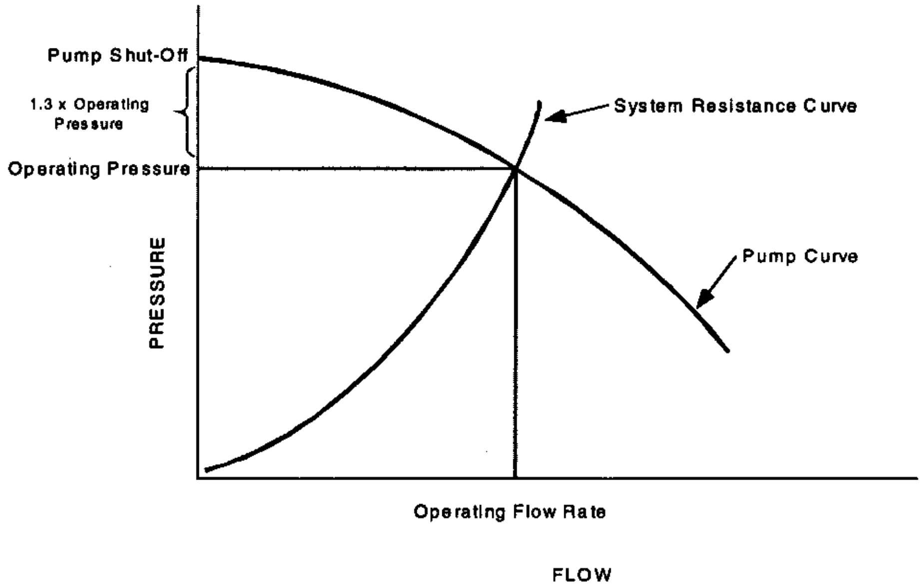
$$2.8 \text{ MPa } (409 \text{ lbf/in}^2) \times 1.69 / 1.47 = 3.2 \text{ MPa } (470 \text{ lbf/in}^2)$$

The pressure also is adjusted to account for a centrifugal pump with a head-flow characteristic that rises continuously to pump shutoff. Figure 5-1 shows a typical pump/system curve. For a centrifugal pump, a typical rise from operating point to shut-off is approximately 30%. Therefore, the new discharge pressure is:

$$3.2 \text{ MPa } (470 \text{ lbf/in}^2) \times 1.3 = 4.2 \text{ MPa } (611 \text{ lbf/in}^2)$$

Based on the above, the design pressure of the piping system would be specified as 4.5 MPa (650 lbf/in^2). The higher pressure will allow for some variability in waste density and provide some margin for the design of the pump. The pump would be designed to operate at 10 L/s (160 gal/min) at a discharge head of 195 m (640 ft), with a shut-off head not to exceed a head of 268 m (880 ft). Installation of a lift station or staging through AP farm would require upgrading the transfer system to a design pressure of 4.5 MPa (650 lbf/in^2). However, the waste-transfer system would have some design margin, and no further work would have to be performed to better characterize the waste. Other actions that are associated with this alternative include verifying that the jumper connectors and existing system can operate at 4.5 MPa (650 lbf/in^2).

Figure 5-1. Typical Pump/System Curve.



Alternative 4

A fourth alternative is to place more emphasis on defining the waste properties for each specific transfer. The analysis results demonstrated that reducing the conservatism of the waste stream characterization data will reduce the amount of pipe rework required significantly. This alternative requires obtaining additional waste characterization data to be able to accurately predict the waste composition for Phase 1B and Phase 2 waste feeds. It also assumes that changes in the retrieval sequence will not affect the waste composition for a particular transfer significantly.

Alternative 5

A fifth alternative is to inspect the pipelines that have been identified as exceeding the design pressure to determine the actual surface roughness of the pipes. A reduction in the assumed roughness of the pipe will provide a direct reduction in the pressure drop through the carbon steel transfer lines.

5.2 RECOMMENDATIONS

Evaluation of the waste-transfer system begins with an accurate characterization of the waste. It also requires accurate information regarding the condition of the existing pipeline. Preparation of specifications to procure waste-transfer system equipment before having accurate characterization data involves the risk that the equipment will not meet the transfer system requirements. It also can lead to unnecessarily modifying or replacing portions of the transfer system that may be adequate if accurate waste characterization data were available.

The results of the analysis using the three data sets indicate that the existing transfer system can not reliably deliver slurry waste to the privatization contractor. It is recommended that several parallel paths be pursued to meet program needs and to evaluate the adequacy of the waste-transfer system more accurately. The first recommendation addresses the immediate need of providing a basis for the design of the transfer system pipe and transfer pumps. Recommendations 2 through 4 involve additional investigations to determine the structural capability of the existing transfer system. Recommendations 5 through 8 address activities that have the potential to reduce the uncertainties associated with this analysis.

Recommendation 1

Alternative 3 calls for adding a lift station. If no additional information is made available regarding waste properties or the condition of the existing pipe, Alternative 3 provides a technical solution that will meet the waste feed delivery system requirements. It is recommended that the waste properties, pipe, and pump design criteria from this analysis be used as a basis for the DST Subsystem specifications. Use of these criteria will allow conceptual design to proceed based on a technically defensible solution. As additional waste characterization data are obtained, it is highly likely that the pressure requirements will decrease rather than increase. This recommendation provides a near-term path forward while minimizing impacts to projects currently in conceptual design. These criteria should be used only for planning and conceptual design until more accurate information is available on which to base detailed design. Table 5-1 is a list of the waste-property design criteria.

Table 5-1. Waste-Property Design Criteria.

Liquid Density	1.21 to 1.46 kg/L
Liquid Viscosity	0.01 to 0.1 g/cm-s (1 to 10 cP)
Solids Density	2.5 to 3.00 kg/L
Solids Mean Diameter	40 to 400 μm
Solids Volume Percent	10 to 30 %

Because the transfer pump is selected based on the pressure drop in the system and the pressure drop is a function of waste properties, the pipe and pump sizing information should also be used only for planning and conceptual design. Table 5-2 is a list of criteria for the pipe and pump.

Table 5-2. Pipe and Pump Design Criteria.

Pipe Design Pressure	4.5 MPa (650 lbf/in^2)
Pump Shutoff Head	not to exceed 268 m (880 ft)
Pump Operating Point	10 L/s (160 gal/min) at a discharge head of 195 m (640 ft)
Waste Density	1.69 kg/L
Viscosity	10 cP
Solids Content	15% by volume
Surface Roughness, Carbon Steel	51 to 3810 μm (2 to 150 mil)
Surface Roughness, Stainless Steel	51 to 254 μm (2 to 10 mil)

Recommendation 2

The viability of increasing the design pressure rating of existing pipe rated at 1.9 MPa (275 lbf/in^2) should be investigated. Unless there is a substantial change in the waste properties used in this analysis, the design pressure of these lines is not high enough to support waste feed delivery. If the pressure rating of the lines cannot be increased, the lines will have to be replaced.

Recommendation 3

The design capacity of the Project W-314 pipe should be evaluated to determine if it can operate at a pressure higher than 2.7 MPa (400 lbf/in^2). Figure B-7 of Appendix B shows that the scope of Project W-314 comprises a substantial portion of the waste-transfer system. If the design pressure of the system must be increased, it would be prudent to establish the capacity of the pipe before it is installed.

Recommendation 4

Because the PUREX connectors are an integral part of the transfer system, a concurrent assessment was performed (*Waste Feed Delivery PUREX Process Connector Design Pressure* [RPP-5793]) to determine their design pressure retaining capacity, which was found to be 2.7 MPa (400 lbf/in^2). If the pipe design pressure ultimately must be increased, this maximum design pressure will be challenged. A test program will be required to establish a design pressure higher than the generally accepted maximum pressure of 400 psig.

Recommendation 5

Alternative 2 addresses a more intensive evaluation of particle properties. A reduction in the size or density of the particles will reduce the critical velocity and the pressure drop in the system. Reductions in particle size and density have the potential to significantly reduce the number of lines that exceed their design pressure at the critical velocity. It is recommended that particle data and the particle measurement procedure be reviewed to identify methods of reducing the uncertainty associated with the size and density of the particles. The measurement procedure should simulate the shearing that is inherent in mixing and pumping the waste. It is also recommended that the difference between measured values of solids density and calculated values of solids density be investigated.

Recommendation 6

The inside of the existing transfer pipelines should be inspected. If increasing the pressure rating of the existing pipelines is a viable alternative, some type of inspection will be required to establish a baseline condition of the pipe. Inspection should be performed after it has been confirmed by analysis that the pipe pressure rating can be increased. Additionally, if the existing level of corrosion is less than assumed, many of the transfer lines will be acceptable. If the projected corrosion is as extensive as assumed, a knowledgeable decision can then be made on the most cost-effective way to proceed.

Recommendation 7

Additional data are required for evaluating the transfer system performance. Information such as supernatant viscosity, bulk viscosity, and density gradients in mixed tanks are required to confirm that the proper hydraulic models are being used and to perform the critical velocity and pressure-drop analyses. The characterization data should be requested when sampling the tanks, in addition to data typically obtained. Neither the Oroskar and Turien model, used to predict critical velocity, not the Wasp model used to predicted pressure drop have been validated for Hanford wastes. Validation of these models with actual waste or with simulant material under controlled conditions is recommended.

Recommendation 8

Changes in some waste properties have a more significant impact on pressure drop in the pipeline than others. Discussions should be initiated with the Process Development group to determine the feasibility of limiting or controlling these properties before the transfer of waste. An example would be solids volume fraction in the waste. Increases in solids volume fraction directly increase the pressure drop in the pipeline, yet solids volume fraction can be adjusted. A reduction in this value will reduce the pressure drop in the transfer lines and provide an expanded operating range.

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APPENDIX A

HANFORD TANK WASTE PHYSICAL PROPERTY ESTIMATES

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MEMORANDUM **CH2MHILL**

74B50-00-001R2

ALTERNATIVES GENERATION AND ANALYSIS FOR WASTE FEED DELIVERY TRANSFER PUMP DISCHARGE PRESSURE: HANFORD TANK WASTE PHYSICAL PROPERTY ESTIMATES

TO:	W. L. Willis	R3-73
COPIES:	T. J. Conrads	R3-73
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	D. A. Reynolds	R2-11
	SDE LB/File	
FROM:	Process Control	
DATE:	April 10, 2000	

References:

(1) Internal Memorandum, "Alternatives Generation and Analysis for Waste Feed Delivery Transfer Pump Discharge Pressure: Hanford Tank Waste Physical Property Estimates," memorandum number 74B50-00-001R1, dated February 11, 2000.

(2) Internal Memorandum, "Memorandum of Understanding Requirements Action Memo for the Alternatives Generation and Analysis for Feed Delivery Transfer Pump Discharge Pressure Control," memorandum number 82400-99-093, dated December 30, 1999.

(3) Textbook, Shook, C.A. & M.C. Rocco, "*Slurry Flow - Principles and Practice*," Butterworth-Heineman, Stoneham, Massachusetts," published 1991.

(4) Handbook, Weast, C.W. & M.J. Astle, "*CRC Handbook of Chemistry and Physics*," 61st ed., CRC Press, Boca Raton, Florida," published 1980.

This memorandum revises Reference (1) that was created in response to Reference (2) direction. This revision incopropates text changes and corrects information presented in the Attachment.

74B50-00-001-R2.DOC

Pipeline transport of wastes containing solids (a slurry) can be considered a two-phase flow, as required to estimate a critical velocity. Additionally, such a slurry can be considered to have bulk, or homogeneous properties, that are useful in (but not the only method available for) determining pressure drops and power requirements for the respective piping system. This memo attempts to give bounds and best estimates of the waste properties at shear rates applicable to typical Hanford pipeline transport velocities.

The following definitions are needed to describe both two-phase and homogeneous slurry flow:

Subscript "$_c$" indicates the carrier liquid (i.e., the continuous phase) of the slurry. Also included in the carrier liquid are any dissolved soluble solids.

Subscript "$_d$" indicates the solid particulates (i.e., the dispersed phase) in the slurry. These particles can be both insoluble solids and precipitated soluble solids.

Subscript "$_m$" indicates the bulk property of the slurry (i.e., the mixed property of the two-phase fluid).

D = diameter of the spherical solid particulates in the waste

α = volume fraction

ρ = density

μ = **Newtonian** dynamic viscosity (this estimate does not describe the potential non-Newtonian behavior of some of the Hanford tank wastes. However, the non-Newtonian nature of these wastes should not be such as to create conditions that could terminate a waste transfer provided the waste can be initially mobilized and kept in suspension via sufficient flow velocity for the duration of the transfer.)

Physical Relationships

$$\alpha_c = \alpha_{water} + \alpha_{dissolved\ solids}$$
$$\alpha_d = \alpha_{insoluble\ solids} + \alpha_{precipitated\ soluble\ solids}$$
$$\alpha_c + \alpha_d = 1$$
$$\rho_m = \alpha_c\rho_c + \alpha_d\rho_d$$

The summary of the nominal and bounding **in-situ** waste properties are shown in Table 1:

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Table 1: Slurry Physical Properties

Case ⇒ Property ⇓	Nominal	Bounding
D_d ①	40 μm	400 μm
α_c	0.85	0.70
α_d	0.15	0.30
ρ_c②	1.21	1.46
ρ_d③	2.50	3.00
ρ_m	1.40	1.92
μ_c	④	④
μ_m	⑤	⑤

Notes

① These solid particulate diameters are stated as the **median** of the distribution, meaning that one-half of the total particulate mass is contained in particles with diameters smaller than the stated diameter, with the other half of the total particulate mass being contained in particles with a larger diameter.

The solid particulates in the waste are assumed to be spherical. The spherical shape gives the minimum isotropic drag coefficient for a particle of a given mass. This property should result in minimizing slurry flow pressure drop (a non-conservative result) while maximizing slurry flow critical velocity (a conservative result). There are many Hanford tank waste solids size distribution data available that indicate, at least in a qualitative sense, that the mass distribution of the majority of solids are under 40 μm in size. However, there is data suggesting particulate sizes exist at, and may exceed, the limit of instrument detection (in some cases, approximately 1 mm - see Attachment).

② Values from analysis of Tank Characterization Data (TCD) liquid wastes with the nominal value corresponding to the 50th percentile and the bounding value corresponding to the 90th percentile. (see Attachment)

③ Waste true solids densities qualitatively estimated as an engineering judgement. As a comparison, densities of some dominant chemical constituents that are known to or may exist as solids in the tank wastes are shown in Table 2:

Table 2: True (Particulate) Solid Densities (gm/cc)*

Anion⇒ Cation⇓	$(OH)_x$	NO_3	NO_2	PO_4	C_2O_4	CO_3	$Fe(CN_6)$
Na_x	2.13	2.26	2.17	1.62	1.46	1.44 - 2.53	2.34
Al_x	2.42	?	?	2.57	?	?	?
Fe_x	3.40	~1.68	?	2.58 - 2.74	2.28	?	1.60
Cr_x	?	?	?	2.12 - 2.42	~2.47	?	?
$(NH_3)_x$	?	1.73	1.69	1.80 - 2.21	1.50	?	?

*density ranges indicates various waters of hydration
? density is unknown or compound is not documented

Table 2 gives some idea of a qualitative comparison to the estimated nominal and bounding solid densities of 2.50 and 3.00 gm/cc.

④ These μ_c estimates are conservative for pressure drop calculations but are not conservative for typical critical velocity correlations. In determining critical velocities, the most conservative assumption for μ_c is that it is equivalent to water. In contrast, for pressure drop calculations, higher values of μ_c result in higher pressure drops.

The viscosity of the carrier liquid is stated as:

$$\mu_c = \mu_{water}\left((x_{salt})*\left(1+1.071*\left(\frac{\rho_c}{\rho_{water}}-1\right)\right) + (x_{caustic})*\exp\left(\left(7.143*\left(\frac{\rho_c}{\rho_{water}}-1\right)\right)^{1.15}\right)\right)$$

utilizing the following definitions:

x_{salt} = the fraction of **dissolved solids** composed of sodium nitrate, sodium nitrite, and other water soluble salts.

$x_{caustic}$ = the fraction of **dissolved solids** composed of sodium hydroxide.

Assume: $x_{salt} = 0.9;\ x_{caustic} = 0.1;\ (x_{salt} + x_{caustic}) = 1$

Over the temperature range of 0°C to 100°C, this assumption gives:

$$\rho_c = \rho_{water} * (1 + 0.00848 * (\text{wt\% dissolved solids}))$$

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Over the temperature range of 0°C to 100°C (from Reference 4):

$$\rho_{water} = \frac{999.83952+16.945176(T)-7.9870401\bullet 10^{-3}(T)^2-46.170461\bullet 10^{-6}(T)^3+105.56302\bullet 10^{-9}(T)^4-280.54253\bullet 10^{-12}(T)^5}{1000\bullet(1+16.879850\bullet 10^{-3}(T)^1)}$$

Over the temperature range of 0°C to 20°C (from Reference 4):

$$\mu_{water} = 100 * cP * \exp\left(\frac{2996}{998.333+8.1855*(T-20)+0.00585*(T-20)^2}-7.60390\right)$$

And, over the temperature range of 20°C to 100°C (from Reference 4):

$$\mu_{water} = 1.002 * cP * \exp\left(\frac{3.0560(20-T)-0.002425(T-20)^2}{T+105}\right)$$

⑤ No exact method exists for determining μ_m. Various researchers have proposed models that predict μ_m as a function of one or more variables in addition to μ_c, and the resultant value of μ_m is typically expressed as a multiple of μ_c. If the model utilizes only one variable, it is usually α_d.

As an example, several slurry viscosity models are documented in Reference (3). These include models from Einstein, Eiler, Thomas, Kreiger, and Vocadlo. For these referenced models that are applicable to concentrated slurries, a reasonable selection of the independent variables predicts results within a factor of 2.0 for a slurry when $\alpha_d = 0.3$.

The model of Thomas is reproduced here because it has only one independent variable (α_d):

$$\mu_m = \mu_c * \left(1+2.5*\alpha_d+10.05*\alpha_d^{\ 2}+0.00273*\exp(16.6*\alpha_d)\right)$$

S. D. Estey, Engineer
Process Control

sde/mjg

Attachment

Attachment to 74B50-00-001-R2

Comments by L. Jensen, February 8, 2000

This following summary data for PARTICLE VOLUME DISTRIBUTION is from Table 2-2, HNF-2728 by S Estey and AT Hu. The units are μm.

SST	Mean(μm)	min(μm)	max(μm)	date	Lab
B-106	3.64	0.2	6	1997	LANL
B-111	3.66	0.4	9	1995	PNL
BX-103	1.5	0.2	7	1997	LANL
BX-107	5.67	0.4	35	1995	PNL
BY-104	6.98	0.4	75	1996	PNL
BY-108	6.53	0.2	39	1997	PNL
BY-110	6.15	0.25	40	1996	PNL
C-103	1.06	0.4	2	1995	PNL
C-104	2.05	0.2	7	1997	LANL
C-105	2.16	0.2	7	1997	LANL
S-101	6.8	0.29	38	1997	PNL
S-104	6.78	0.2	30	1997	PNL
S-107	13.48	0.35	100	1996	PNL
S-111	47.7	0.9	120	1997	PNL
SX-108	12.8	0.2	112	1996	PNL
SX-113	1.84	0.2	6	1997	LANL
T-104	4.85	0.4	13	1995	PNL
T-111	4.82	0.4	12	1995	PNL
DST	Mean(um)	min(um)	max(um)	date	Lab
AN-104	5.68	0.7	19	1997	PNL
SY-102	9.32	0.2	105	1996	PNL
SY-103	9.71	0.4	30	1995	PNL

The follwing summary data for PARTICLE VOLUME DISTRIBUTION is from multiple internal memos by JF O'Rourke. The units are μm.

DST	median(μm)	sd(μm)	mode(μm)	mean(μm)	min(μm)	max(μm)	date	Inst.Max	Lab	Comments	
SY-101	183.60	82.70	237.80	164.80	0.22	451	1999	1020	222S		replicate
SY-101	125.80	264.10	159.00	197.30	0.19	1019	1999	1020	222S		samples?
AW-101	314.00	162.00	427.00	307.00	6.7	1020	1999	1020	222S	undiluted	
AW-101	946.00	224.00	952.00	884.00	29.9	1020	1999	1020	222S	diluted	replicate
AW-101	940.00	283.00	952.00	833.00	11	1020	1999	1020	222S	diluted	samples?
AN-104	4.85	12.80	31.30	13.40	0.5	31	1998	150	222S		
AN-105	4.28	13.48	41.61	10.47	0.5	45	1998	150	222S		replicate
AN-105	5.76	23.80	66.90	19.35	0.5	70	1997	150	222S		samples?
AN-105	3.24	2.87	4.25	3.72	0.5	30	1997	150	222S		
AN-105	4.95	12.35	31.30	12.00	0.5	50	1997	150	222S		
AN-105	4.48	14.70	45.70	12.40	0.5	50	1997	150	222S		
SST	median(μm)	sd(μm)	mode(μm)	mean(μm)	min(μm)	max(μm)	date	Inst.Max	Lab	Comments	
S-111	107.40	46.60	156.60	100.00	7.7	174.6	1999	1020	222S		replicate
S-111	190.00	79.70	235.40	168.10	11.6	451	1999	1020	222S		samples?
S-111	92.90	58.00	121.60	92.10	6.7	592	1999	1020	222S		
U-109	13.16	5.90	18.60	12.80	2.2	26	1999	150	222S		replicate
U-109	17.30	9.00	24.60	15.90	2.6	34.3	1999	150	222S		samples?
C-106	1.74	2.20	1.25	2.74	0.5	11	1996	150	222S		replicate
C-106	4.00	5.26	4.75	6.40	0.5	28	1996	150	222S		samples?

Comments:

1. There are not very many tanks with particle distribution data.
2. The analytical methods do not give results greater than 150 and 1020 μm. There may be particles larger than 150 and 1020, but not detected by the analytical method.
3. The DSTs appear to be separated in to two classes, one with a small median μm and the other with a large median μm. The reason is unknown.
4. The bounding value of 200 μm. is an underestimate of the median particle volume distribution or the maximum value. The analytical method maximum value of 1020 is reported for four samples.
5. Without having electronic copies of the original particle size data, it is not possible to give statistical measures of uncertainty associated with particle quantiles such as the median (50th percentile of the distribution) or values for the 25th or 75th percentile of the distribution.

Summary of Specific Gravity Results from the Tank Characterization Database.

A comparison between the (nominal, conservative, and bounding) density values given in memorandum 74B50-00-001, and the analytical results from the Tank Characterization Database (TCD) has been completed. The values in the memorandum compare well with the 50th, 75th, and 90th percentiles of values from laboratory assays.

The tanks used in the analysis were those which had liquid results for the following eight constituents: aluminum, hydroxide, nitrate, nitrite, percent water, sodium, specific gravity, and total organic carbon. Twenty-one single shell, and twenty double shell tanks, met this criteria. These tanks are listed in Table 1.

Table 1. Tanks used in Analysis.

Single Shell Tanks	Double Shell Tanks
241-A-101	241-AN-101
241-AX-101	241-AN-102
241-BY-103	241-AP-101
241-BY-105	241-AP-102
241-BY-106	241-AP-103
241-S-102	241-AP-104
241-S-103	241-AP-105
241-S-104	241-AP-106
241-S-106	241-AP-107
241-S-109	241-AP-108
241-S-111	241-AW-102
241-SX-101	241-AW-103
241-SX-103	241-AW-104
241-SX-105	241-AW-105
241-SX-106	241-AW-106
241-U-102	241-AY-101
241-U-103	241-AY-102
241-U-105	241-AZ-101
241-U-107	241-AZ-102
241-U-108	241-SY-102
241-U-109	

The pairwise correlations of the eight constituents are given in Table 2. A correlation of one (or negative one) indicate that the constituents have a linear relationship. When this occurs, the value of one constituent can be used to predict the value of another. As an example, the –0.98 correlation between percent water and sodium, means that percent water decreases, in a predictable manner, as sodium increases. Similarly, the 0.92 correlation between specific gravity and sodium, means that specific gravity increases as the sodium concentration increases.

Note that many of the constituents have correlations of 0.75 or greater. This is an indication that the waste tends to be either dilute, or concentrated, while the ratios of individual values to one another are fairly constant (at least for the analytes with large concentrations).

Table 2. Correlations.

Constituent	Al	OH	NO3	NO2	H2O	Na	SPG	TOC
Aluminum	1.00	0.76	0.52	0.7	-0.80	0.80	0.80	0.081
Hydroxide	0.76	1.00	0.62	0.62	-0.77	0.78	0.75	-0.005
Nitrate	0.52	0.62	1.00	0.71	-0.84	0.85	0.77	0.30
Nitrite	0.70	0.62	0.71	1.00	-0.85	0.85	0.80	0.38
Percent Water	-0.80	-0.77	-0.84	-0.85	1.00	-0.98	-0.95	-0.34
Sodium	0.80	0.78	0.85	0.85	-0.98	1.00	0.92	0.35
Specific gravity	0.80	0.75	0.77	0.80	-0.95	0.92	1.00	0.28
Total organic carbon	0.081	-0.005	0.30	0.38	-0.34	0.35	0.28	1.00

The strong correlations given in Table 2 suggest that percentile estimates, calculated on a constituent by constituent basis, can be combined to produce reasonable estimates of dilute, or concentrated, waste.

Table 3. Percentile Estimates for Dilute, or Concentrated, Waste*.

Constituent	10th	25th	50th	75th	90th
Aluminum	0.01%	0.14%	0.97%	2.50%	3.19%
Hydroxide	0.11%	0.36%	1.40%	2.89%	3.60%
Nitrate	0.67%	2.78%	8.28%	12.72%	15.71%
Nitrite	0.13%	1.17%	3.68%	6.60%	9.67%
Percent Water	96.2%	85.9%	63.1%	51.0%	47.3%
Sodium	1.02%	4.12%	11.81%	15.69%	17.12%
Total organic carbon	0.02%	0.05%	0.14%	0.27%	0.40%
Specific gravity	1.01	1.08	1.28	1.43	1.47

- Results are on a weight basis.

By using the results in Table 3, and the equation on page three of the memorandum, viscosity estimates were calculated. The results are given in Table 4 (the weight percentages are approximate). Note that the viscosity associated with the 50th percentile, and the viscosity associated with the 90th percentile, are reasonably close to the "conservative" and "bounding" values given in the memorandum (1.7 versus 1.86 and 3.3 versus 3.04 respectively).

Table 4. Viscosity Estimates.

Constituent	10th	25th	50th	75th	90th
NaOH	0.44%	1.7%	5.3%	8.1%	9.3%
NaNO2 + NaNO3	1.48%	10.9%	19.8%	29.7%	36.8%
Percent Water	96.2%	85.9%	63.1%	51.0%	47.3%
Viscosity*	1.05	1.28	1.86	2.58	3.04

- Multiply this number by the viscosity of water.

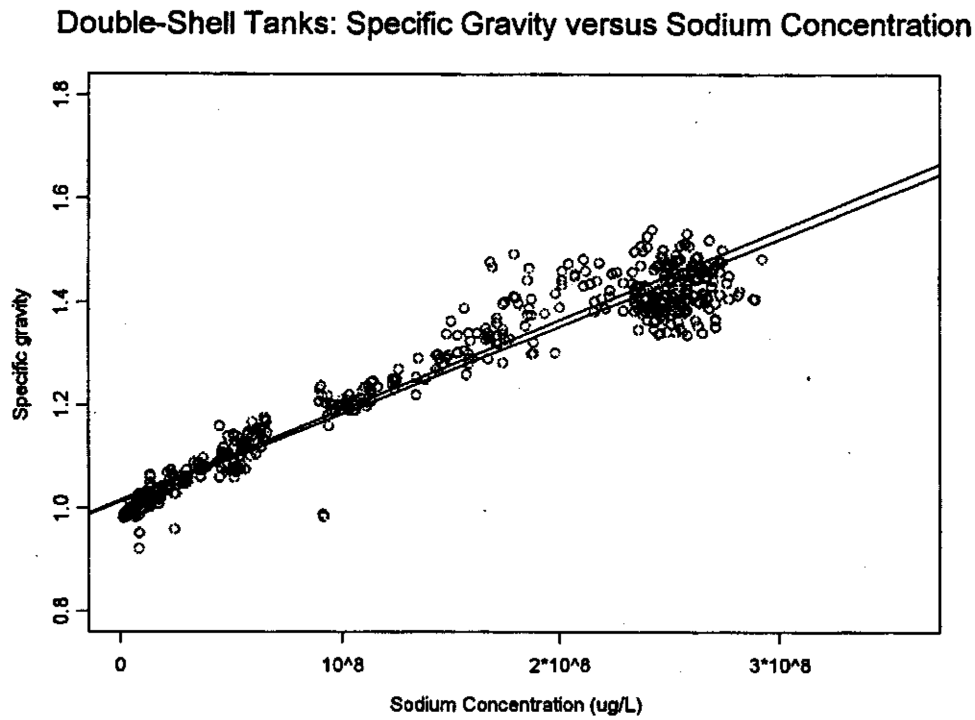
In the preceding analysis, all of the results from the 21 single shell, and 20 double shell tanks were combined. The 41 tanks used in the calculations were tanks that had data for each of eight major constituents.

An examination of all specific gravity results on TCD was also made. Except for tanks AN-106 and SY-103, all of the double-shell tanks had specific gravity data. In addition, fifty four of the 149 single shell tanks had specific gravity measurements. Note that the 75^{th} and 90^{th} percentiles are similar for the two tank types, but the double shell tanks have lower values for the other percentiles. These results indicate that, if the results above are applied to double shell tanks only, then the 10^{th}, 25^{th}, and 50^{th} percentiles may be biased high (i.e. they are "conservative" estimates)

Table 5. Specific Gravity Results, All Tanks.

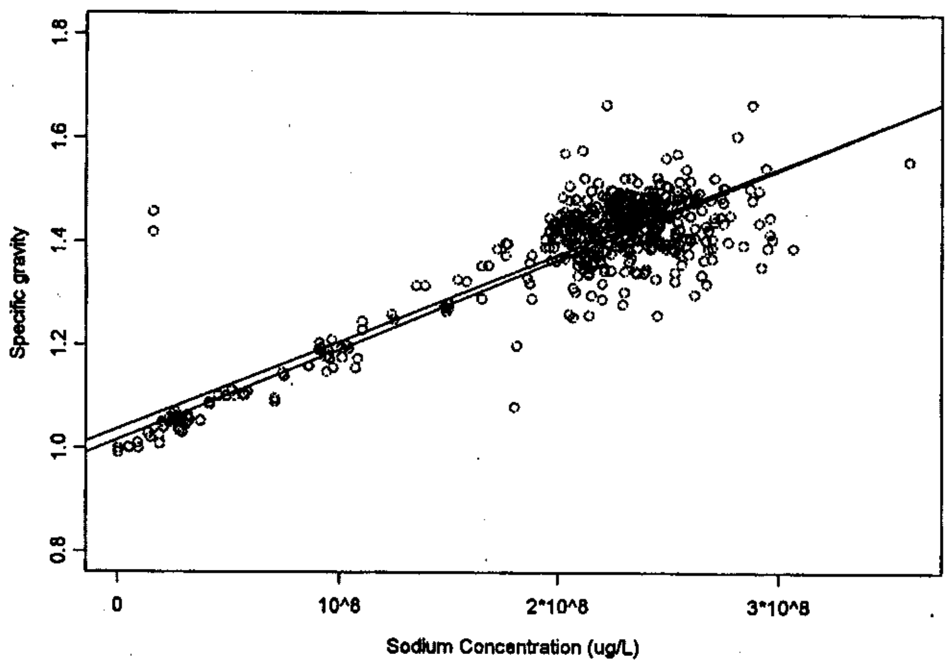
Tank Type	10th	25th	50th	75th	90th
Single Shell Tank	1.15	1.35	1.43	1.46	1.49
Double Shell Tank	1.00	1.05	1.21	1.40	1.46

Attachment to 74B50-00-001-R2



Attachment to 74B50-00-001-R2

Single-Shell Tanks: Specific Gravity versus Sodium Concentration



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TRANSFER ROUTES IN 200 EAST AREA

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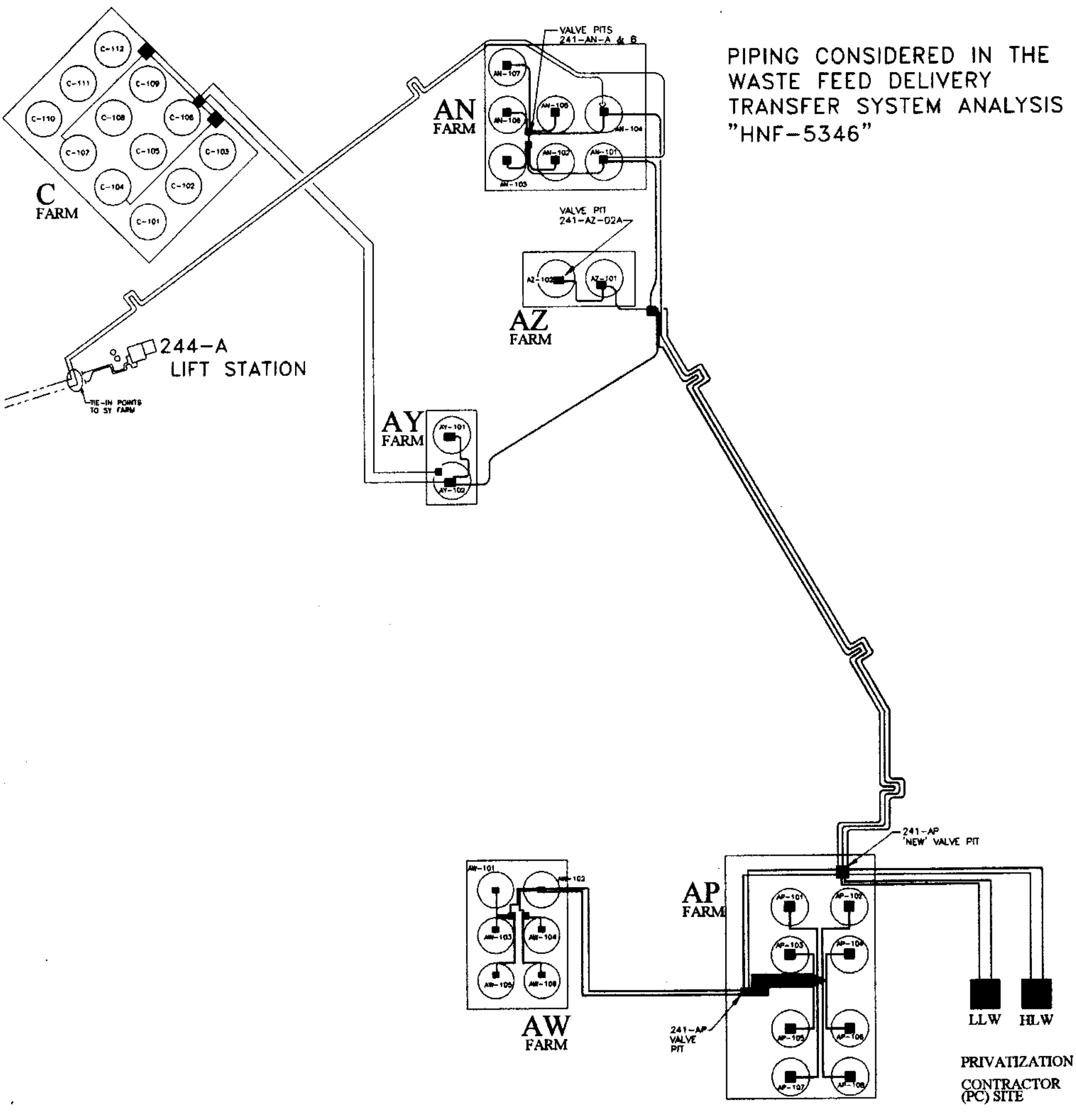
Figure B-1. Waste Transfer System.



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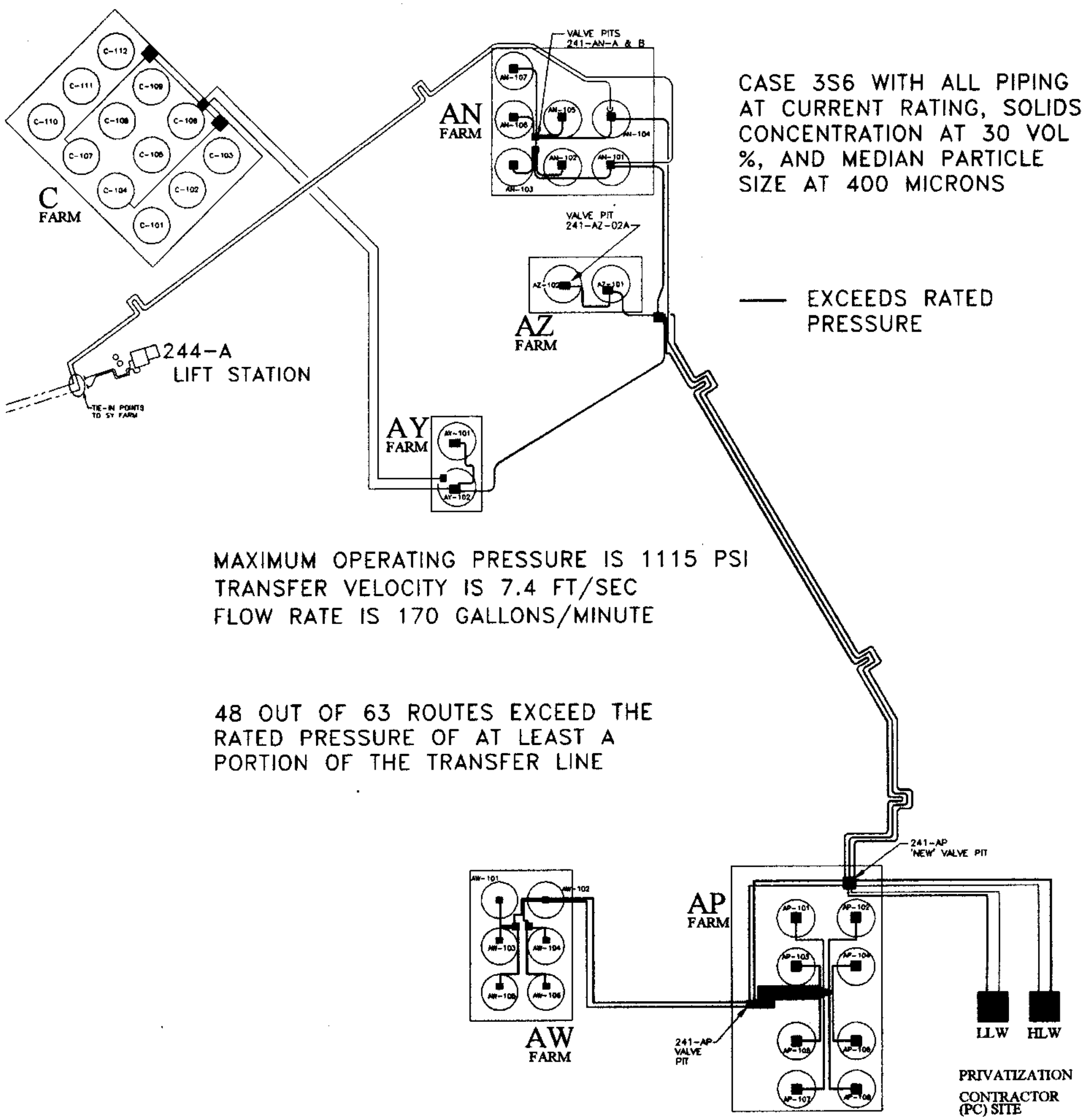


3S630%400ASIS.DWG

Figure B-3. 15 Volume Percent Solids/No Pipe Upgrades.

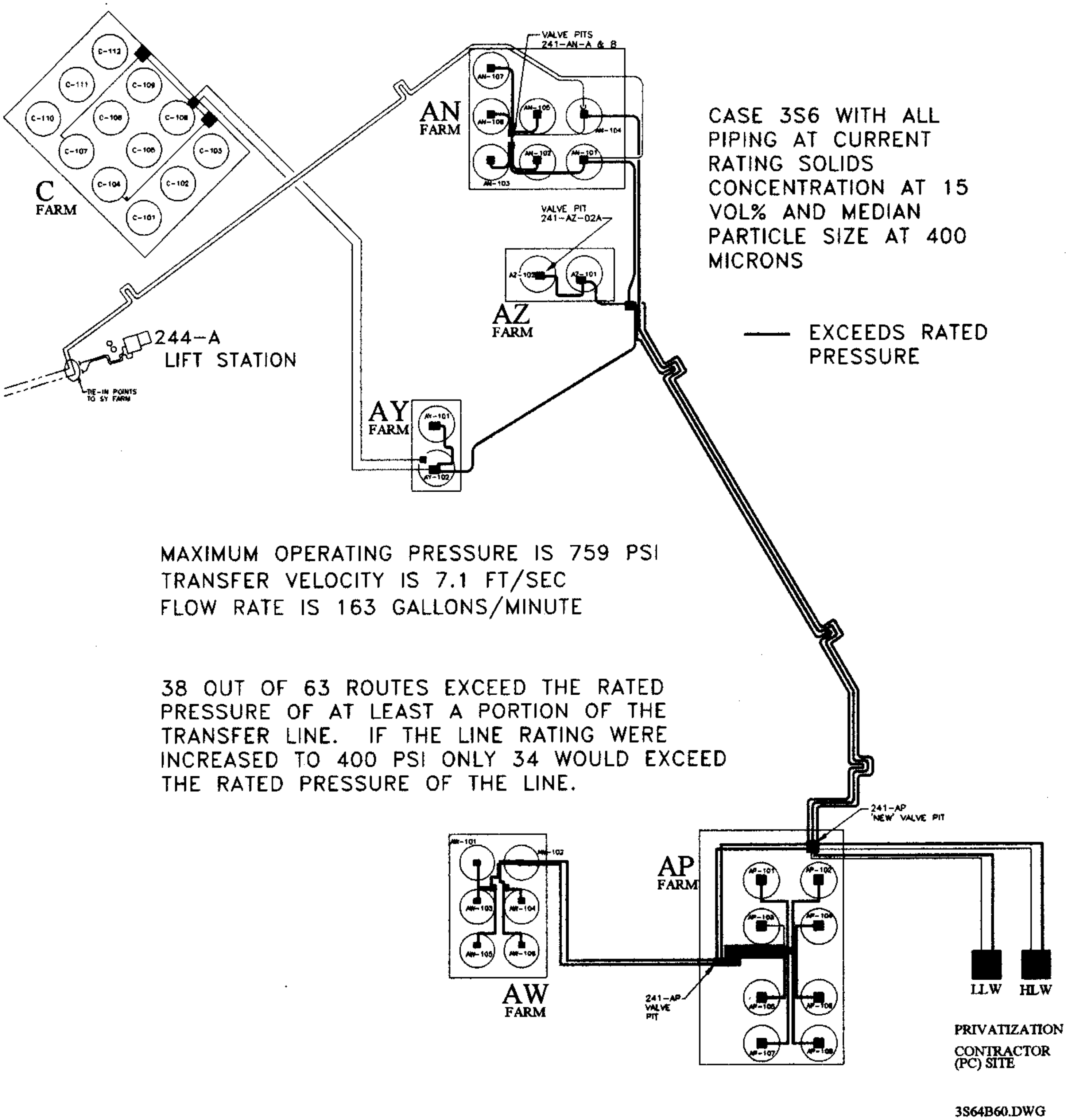


Figure B-4. 15 Volume Percent Solids/Pipe Upgraded to 400 lbf/in^2.

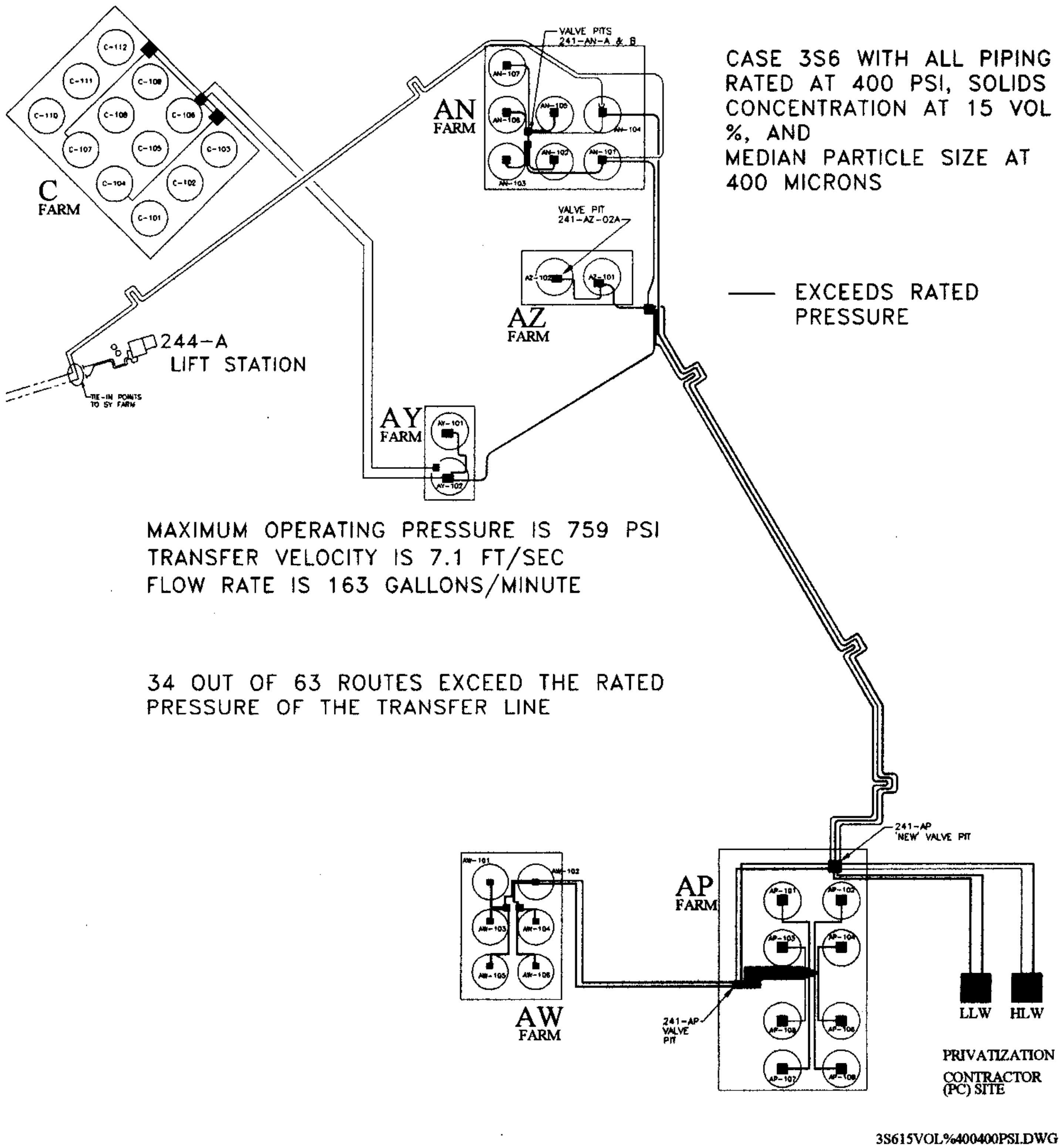


Figure B-5. 10 Volume Percent Solids/No Pipe Upgrades.

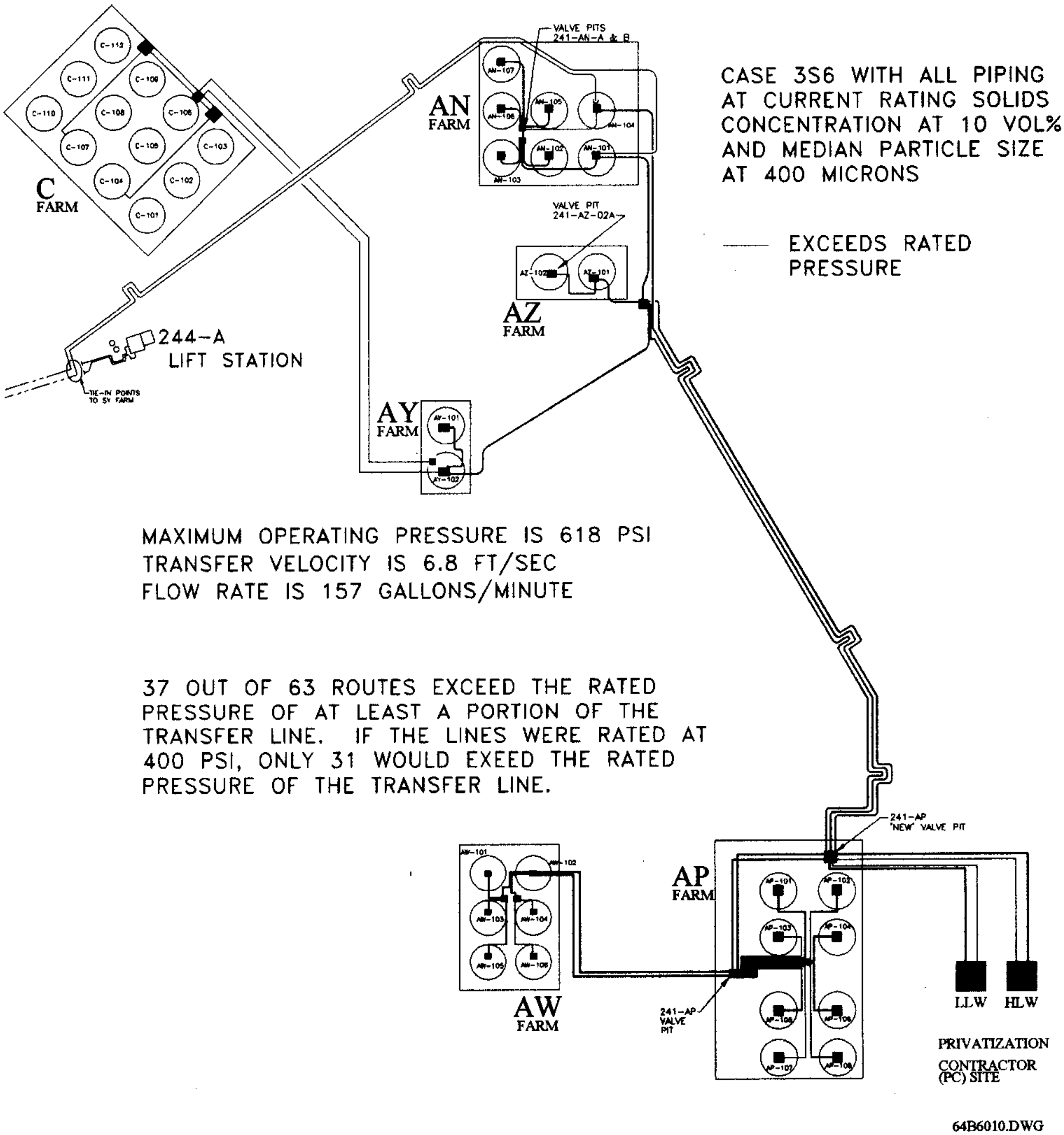


Figure B-6. 10 Volume Percent Solids/ Pipe Upgraded to 400lbf/in^2.

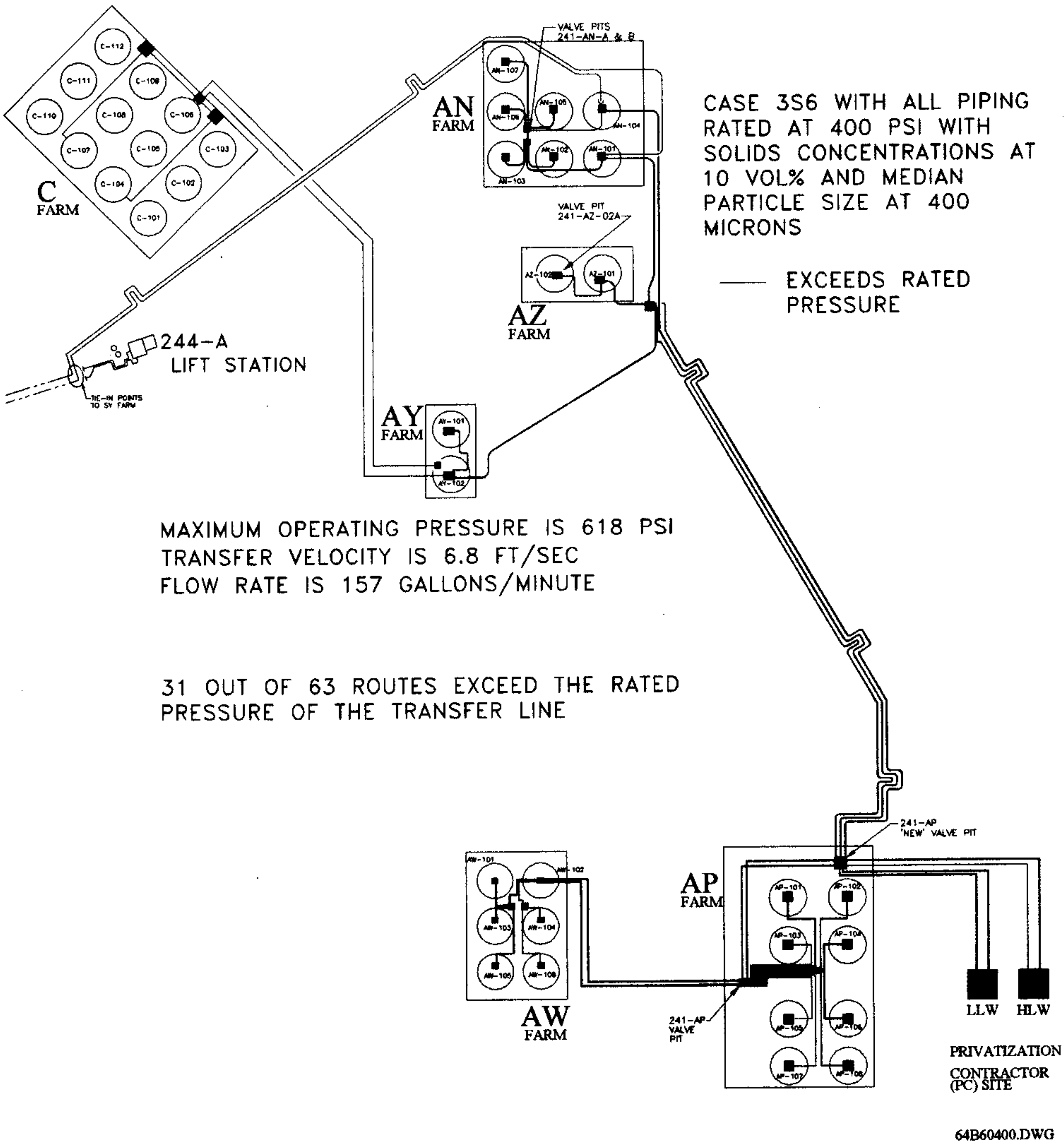
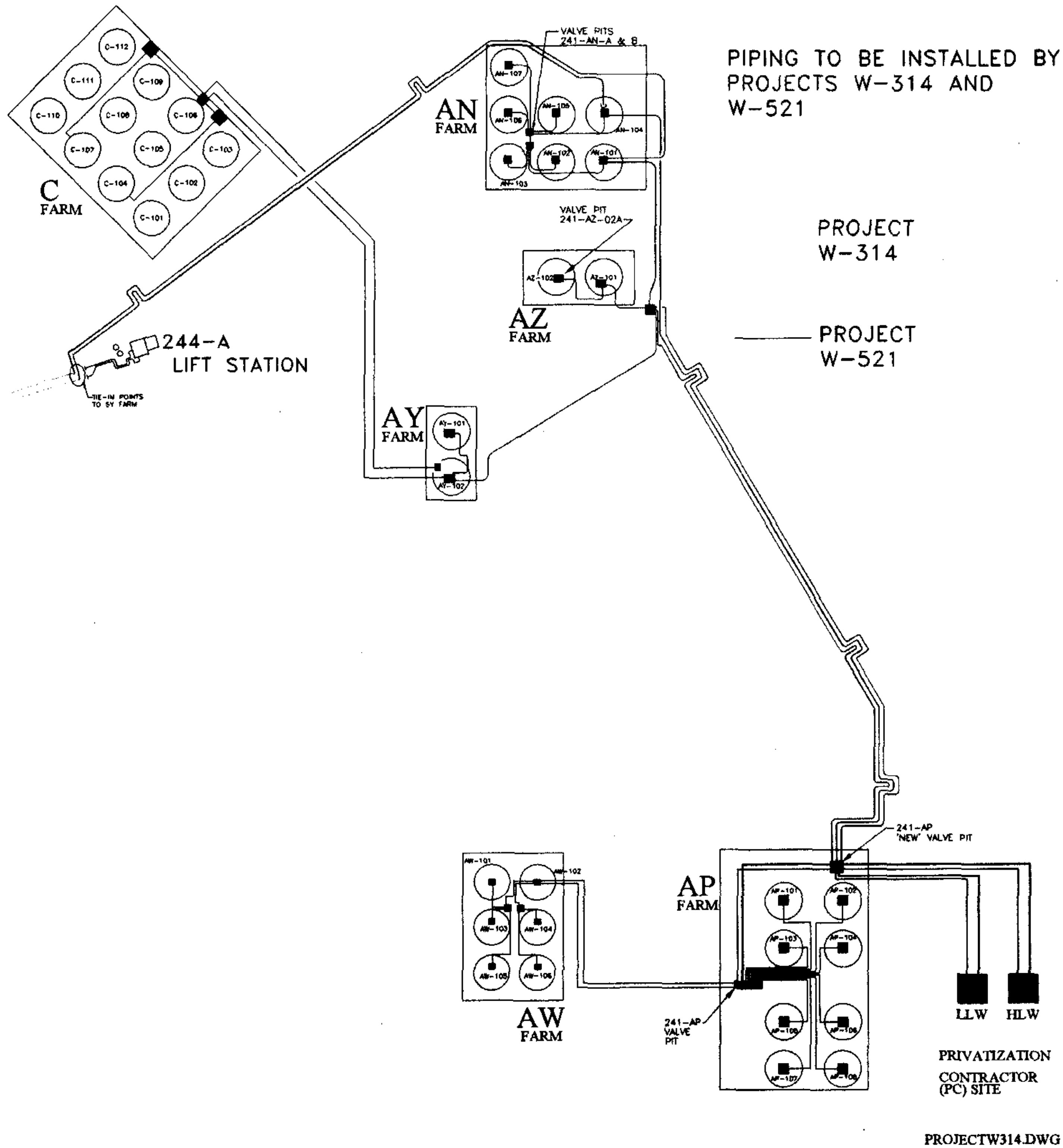


Figure B-7. Projects W-314 and W-521.



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APPENDIX C

SURFACE ROUGHNESS OF CARBON STEEL AND STAINLESS STEEL WASTE TRANSFER LINES CAUSED BY CORROSION AND SCALING

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APPENDIX C

SURFACE ROUGHNESS OF CARBON STEEL AND STAINLESS STEEL WASTE TRANSFER LINES CAUSED BY CORROSION AND SCALING

November 5, 1999

Prepared By:

R. P. Anantatmula
And
J. R. Divine

LOCKHEED MARTIN HANFORD CORPORATION
for the
U.S. Department of Energy
Richland Operations Office

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SURFACE ROUGHNESS OF CARBON STEEL AND STAINLESS STEEL WASTE TRANSFER LINES CAUSED BY CORROSION AND SCALING

C1.0 INTRODUCTION

The waste transfer system in the 200 East Area of the Hanford Site operated by Lockheed Martin Hanford Corporation (LMHC) has several pipelines of carbon steel and stainless steel. The two materials are mixed in some pipelines while other lines are of one material only. The waste transfer system contains 1000 ft of 3 in. carbon steel pipe and 6000 ft of 3 in. stainless steel pipe believed to be AISI Type 304 or 304L. Much of the line has been used for up to fifteen years and plans are to use it for an additional 35 years. Both radioactive waste and "raw" water, essentially untreated Columbia River water, will be passed through the lines which will then be drained before being used again. Because pump requirements depend strongly on the pipe roughness, LMHC has requested information on changes in roughness due to corrosion and scaling. Surface roughness estimates were requested over a time period of 50 years for carbon steel and over a period of 40 years for stainless steel. This report discusses the contributions to surface roughness from corrosion and scaling.

C2.0 BACKGROUND

The waste transfer lines from Tank Farms to British Nuclear Fuel Limited, Inc. (BNFL) will be used more than three times annually, while the intertank pipelines will be used on an average once per year. The transfer piping is sloped in such a way that at the end of the waste transfer the waste water will drain into the tank in which the transfer is made with no possibility of stagnant water remaining in the pipe. Each waste transfer campaign is expected to last a total of ten days. The raw water will be heated in skid-mounted "boilers" and hot water will be used when it is deemed necessary. Corrosion inhibitors will be added to the water prior to its being pumped into the transfer lines. No heating, other than perhaps trace-heating to maintain the temperature, will be done on the line. There are two types of wastes that will be processed through the system: a high level waste (HLW) feed at 80°C containing 5 vol% solids and a low activity waste (LAW) feed at 45°C containing 2 vol% solids. The pH of the waste solutions is expected to be > 7. The waste solutions are generally expected to be $\geq$1M $NaNO_2$, $\geq$3M $NaNO_3$ and $\geq$3M NaOH. Between waste transfers, however, flush water containing raw water (Columbia River water) inhibited with 0.01M NaOH and 0.011M $NaNO_2$ will be used to flush the transfer lines after each transfer.

C3.0 CORROSION

C3.1 CORROSION BEHAVIOR OF CARBON AND STAINLESS STEELS

At the compositions quoted above, the waste solutions are benign toward carbon steel from a corrosion perspective (Anantatmula et al. 1994). Corrosion of stainless steel is expected to be negligible at the high pH and low temperature of the waste solutions containing low amounts of chloride. The inhibited flush water will not be aggressive toward carbon steel resulting in negligible corrosion. Raw water is usually corrosive to carbon steel unless it is inhibited or there is significant amounts of calcium and magnesium salts in the water that will form a protective scale. The Columbia River water, based on 1991 and 1994 analyses and the analysis in the scaling section of this report, has a Langelier index value of < 0 and Ryznar index value of > 6. Waters with Langelier index value of < 0 and Ryznar index value of > 6 tend not to form scales and be corrosive to steel (a discussion of Langelier and Ryznar indices is given in section 4.2). However, the addition of inhibitors to the raw water is expected to make the flush water benign towards steel. Therefore, only the carbon steel pipeline carrying the raw water to the inhibitor feed point will be subjected to a high general corrosion rate of ~ 4 mils per year (0.1 mm/y) [1mil = 0.001 in.] (Truitt and Wagner 1985). Stainless steel corrodes at a low general corrosion rate of < 0.1 mil per year (0.0025 mm/y) when exposed to fresh water at normal temperatures. The presence of inhibitors in the water is not expected to have any deleterious effects on the stainless steel, because the material has excellent resistance to general corrosion in solutions containing hydroxide, nitrate and nitrite. The chloride content and temperature of the raw water and waste solution is low enough to preclude pitting and stress corrosion cracking (SCC) of stainless steel pipe and preserve its integrity.

Corrosion of materials in aqueous systems is influenced by the following factors:

- Physical configuration of the system
- Water chemistry
- Presence of solids in the water
- Flow rate
- Temperature and
- Presence of microbes.

For the present surface roughness assessment, contribution to corrosion by microbes will be ignored since microbial corrosion primarily involves pitting corrosion. Depending on their abrasiveness, the presence of solids in the water is generally presumed to have a profound effect on corrosion if flow rates are high. However, studies performed by Pacific Northwest Laboratory (Smith and Elmore 1992) on simulated aging wastes at up to 15 ft/sec fluid velocity indicated that the corrosion products were not removed from the carbon steel surface in spite of an increase in corrosion rate. The increase in corrosion rate was attributed to the ease with which fresh reactants were brought to the corroded surface by flowing waste as a result of a thinner boundary layer.

C3.2 SURFACE ROUGHNESS ESTIMATES - CORROSION

C3.2.1 Carbon Steel

The millscale (produced during hot rolling and forging) on carbon steel consists of three superimposed layers of iron oxides, viz., ferrous oxide (FeO) on the inside, magnetite (Fe_3O_4) in the middle, and ferric oxide (Fe_2O_3) on the outside. The relative portions of the three oxides vary with rolling temperature. A typical millscale on 9.5 mm plate would be about 50 μm thick and contains approximately 70% FeO, 20% Fe_3O_4, and 10% Fe_2O_3. Therefore, the surface roughness of as-received carbon steel pipe is ~ 2 mils (0.05 mm).

The contribution to transfer pipe surface roughness from corrosion is primarily from general corrosion mechanism, although from structural integrity standpoint pitting and SCC are very important mechanisms. Because higher corrosion rates will be experienced by the least used carbon steel transfer lines, to retain conservatism, it will be assumed that the waste transfer system will be used on an average once per year. Furthermore, each campaign is expected to last ten days. Because the waste solutions are compliant with double-shell tank waste specifications and the flush water is inhibited, with the exception of the short length of carbon steel pipeline carrying raw water, the general corrosion of carbon steel pipelines will be minimal. The corrosion contribution to surface roughness primarily occurs during the long waiting periods between the waste transfers. Immediately after the waste transfer, the flush water is drained into the receiving tank. The presence of any stagnant water in the pipe is detrimental to carbon steel because the inhibition characteristics of the water will be lost by a reaction of carbon dioxide in the air in the pipe with the hydroxide in the water. This could lead to pitting of carbon steel in near neutral pHs and if the water contains small amounts of chloride, pitting of the stainless steel is possible. Moreover, raw water may contain sufficient sulfate reducing bacteria to cause microbiologically influenced corrosion (MIC) in the stainless steel line. Savannah River Site and others have had MIC penetrate a pipe from the inside in a matter of weeks.

Assuming all the water drains into the receiving tank, a moist film of inhibited water will be left on the pipe surface. Some of the inhibition characteristics of the film will quickly be lost by a reaction of carbon dioxide in the air in the pipe with the hydroxide in the film. The effectiveness of the residual nitrite in the film as an inhibitor, however, is unknown. Because the pipe is open to the receiving tank, the interior of the pipe will be exposed to humid air conditions with a high relative humidity (RH).

Surface roughness of carbon steel under the humid air conditions described above can be estimated from the humid air corrosion models developed for carbon steel in the literature (Lee et al. 1996). The model, as modified by Anantatmula and Ohl (1996) was used for the estimates. The penetration by general corrosion is expressed as a function of time, RH and temperature as follows:

$$\ln D_g = a_0 + a_1 \ln(t) + a_2/RH + a_3/T$$

where D_g is corrosion depth in µm, t is time in years, T is temperature in °K, and a_0, a_1, a_2 and a_3 are constants with the following values:

$a_0 = 16.9865$
$a_1 = 0.6113$
$a_2 = -893.76$ and
$a_3 = -833.53$

The depth of penetration was calculated for times up to 50 years assuming 98% RH. An average temperature of 35°C was assumed although the temperature of waste solutions is expected to be in the range 45°-80°C. This is because the total waste transfer operation lasts for ten days and the pipe temperature is expected to drop to ambient temperature well before the next waste transfer.

Based on the above assumptions, the depth of penetration was calculated for carbon steel as a function of time from the model equation above. Depending on the availability of oxygen, the corrosion product on the inside surface of the carbon steel transfer lines could be either Fe_3O_4 or Fe_2O_3. Regardless of which oxide is assumed to be formed, the corrosion product thickness will be approximately twice that of the thickness of the metal lost. Using this information, conservative surface roughness estimates were made for the carbon steel pipe and are listed as a function of time in Table 1.

Table 1. Surface Roughness as a Function of Time for Carbon Steel.

Time (years)	Surface Roughness (mils)
15	70
20	85
25	100
30	110
35	120
40	130
45	140
50	150

The surface roughness values in the above table should be considered conservative because the tanks are ventilated resulting possibly in < 98% RH in the transfer pipes. In addition, at the present time, it is not known just how long the moist nitrite film will protect the carbon steel after each waste transfer. For the present calculations, it has been assumed that the nitrite film will not offer any protection. Based on a limited number of visual examinations, the roughness may be much less than estimated in Table 1.

C3.2.2 Stainless Steel

Unlike carbon steel, negligible amount of millscale is expected on as-received stainless steel pipe since the surface is normally protected by a chromium oxide film. Based on the foregoing, stainless steel corrodes at a low general corrosion rate of < 0.1 mpy (0.003 mm/y) when exposed to fresh water at normal temperatures including temperatures above 100°C. Assuming a maximum general corrosion rate of 0.1 mpy (0.003 mm/y), a surface roughness value of 8 mils (0.203 mm) is estimated for a 40-yr time period. Including the thickness of the millscale on the as-received pipe, a maximum surface roughness value of 10 mils (0.254 mm) is predicted for the stainless steel line through 40 years of waste transfer operations.

C4.0 SCALING

C4.1 SCALING PROCESSES

Scaling is the deposition of soluble products from the liquid. When a chemical species exceeds its solubility limit, it has a tendency to precipitate. This tendency is increased by the amount the solubility is exceeded and by the presence of deposition nuclei. Other factors will include temperature and liquid shear forces (Becker 1998; Lane 1993).

If the precipitation occurs in the bulk liquid and forms a slurry, then deposits will be loose and easily removed unless they agglomerate while on the surface. On the other hand, if the deposition nucleus is on the surface, then the deposit will occur there and be more firmly attached.

- Waste Composition

As mentioned earlier, the waste composition is very benign from a corrosion standpoint. It is known that if the temperature of the waste stream is too low, some waste components will precipitate. In discussions with Mr D. A. Reynolds, LMHC, it was determined that flushing with hot water will remove such precipitates.

- Water Composition

The composition of the river water varies with the season and exact location of the sampling as well as uses of the river and surrounding lands change. Table 2 shows a composition measured in 1994.

Table 2. Columbia River Water Composition.

Component	Concentration
Calcium, as $CaCO_3$	47.50 ppm (mg/l)
Magnesium, as equivalent $CaCO_3$	18.50
Bicarbonate, as equivalent $CaCO_3$	67.6
Chloride	1.00
Nitrate	<1.00
Sulfate	9.00
Silica, as SiO_2	6.20
Total Dissolved Solids, TDS	71.1
Methyl Orange alkalinity, as $CaCO_3$	55.4
pH	7.90

Laboratory Analysis 94-08393, ID 260170072, Collected 05/15/94, 200E Raw Water. Analyzed by WR Grace & Co., Lake Zurich, IL 60047.

- Solubility Effects

The solubility of most compounds increases with increasing temperature. $CaSO_4$ solubility, however, increases to about 40°C and then decreases with increasing temperature (Latimer and Hildebrand 1951); the solubility is about the same at both 25 and 60°C. Above about 63.5°C, the solubility decreases rapidly. At 25°C, the solubilities of $CaSO_4$ and $CaCO_3$ are given in Table 3. The solubility product of $Fe(OH)_3$ is also listed.

Table 3. Solubility Products.

Compound	Solubility Product[1]
$CaSO_4$	4.93×10^{-5}
$CaCO_3$	2.8×10^{-9}
$Fe(OH)_3$	2.79×10^{-39}

[1]Dean 1999

The solubility of Ca^{+2}, given in Table 2 is expressed in terms of $CaCO_3$. Expressing it as Ca^{+2}, the concentration is about 19 mg/l or 4.8×10^{-7} mol/l. Sulfate, $SO_4^{=}$, is 9 mg/l or about 9.4×10^{-8} mol/l. Thus the product of the calcium and sulfate concentrations is 4.5×10^{-14} which is much less than the solubility product for $CaSO_4$ given in Table 3. Consequently no $CaSO_4$ is expected to precipitate from the Hanford Raw Water.

In a similar calculation, $Fe(OH)_3$ is expected to be effectively totally insoluble. With a pH of 7.9, the OH^- concentration will be about 8×10^{-7} mol/l. As a result, the concentration of Fe^{+3} will not exceed about 5×10^{-21} mol/l which, effectively, is zero. Thus all the iron that corrodes will react with excess oxygen and precipitate in the immediate location of the corrosion site and form scale.

C4.2 DISCUSSION OF SCALING

Based on information from the various sources, it is not believed that scaling from the waste will be a problem because it is feasible to re-dissolve the material with hot water.

Langelier developed an empirical relationship to predict the potential for scaling. It considers carbonate solubility, pH, conductivity, and temperature. It is a crude estimate because other factors such as other salts are ignored. Ryznar modified the relationship for use in flowing streams. There are also modifications for use when the total dissolved salts exceed about 7,000 ppm.

These empirical relationships are called the Langelier Index and the Ryznar Index and provide very crude estimates. When using them it is best to err on the conservative side so that only if the prediction is strongly in favor of scaling should it be assumed to occur. Calculating the Langelier (stagnant or low flow rate water) and the Ryznar (flowing water) Indices (Kemmer 1998) for the raw water, the following were obtained, Table 4.

Table 4. Scaling Indices.

Temperature	Langelier	Ryznar
10°C	-.7	9.3
50°C	0.12	8.4
90°C	0.7	7.4

If the Langelier Index is negative, the water is considered non-scaling and corrosive. If the Ryznar Index is >6.0, the water is considered non-scaling and corrosive.

Because the water and the pipe will be hot only when the water is flowing, the conclusion is that the water will be somewhat corrosive (towards carbon steel) and non-scaling.

Consequently, most of the scaling due to carbonates would be expected to occur in the "boiler".

C5.0 CONCLUSIONS AND RECOMMENDATIONS

The surface roughness from corrosion for carbon steel is conservatively estimated as 150 mils for 50 years of waste transfer operations, while the corresponding value for stainless steel is expected to be a maximum of 10 mils. Scaling due to deposition from fluids in the pipe will not be a serious concern in the piping.

Based on the above estimates, the majority of the pressure drop will occur as a result of flow through the carbon steel part of the transfer pipeline. In order to check the validity of the estimates for carbon steel, it is recommended to inspect the inside surfaces of the carbon steel pipes that have been in operation for a known time period. Air drying of the pipes between waste transfers is recommended to reduce the surface roughness of the carbon steel pipes. The short section of carbon steel pipe carrying the raw water should also be checked periodically for its integrity. It is recommended to not let stagnant water remain in the transfer pipes, especially the stainless steel lines. Finally, if pressure drop must be minimized by minimizing the surface roughness of the transfer pipes, it is recommended to replace the carbon steel portion of the transfer line with stainless steel.

C6.0 REFERENCES

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ATTACHMENT C-1

SUMMARY OF SEARCH FOR TRANSFER LINE SOLIDS BUILDUP/SCALING INFORMATION

OCTOBER 1999

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Summary of Search for Transfer Line Solids Buildup/Scaling Information, October 1999

Because of the long length of the transfer route, the pipe internal roughness is a major factor in determining the pump and piping design. For new lines, a significant increase in surface roughness with time in operation will significantly increase the pressure drop and must be accounted for in the design specification. Since there is no readily available information about the change in pipe roughness with time for a caustic waste transfer line, a brief and focused effort was made to find such information. The change in pipe roughness due to corrosion is investigated in a separate report.

Several sources of information were investigated and the results are included in the attached pages.

- Expert opinion and experience were collected from personnel at Hanford, Savannah River, and Idaho Falls.
- Hanford transfer line failure studies were reviewed
- Savannah River transfer line failure studies were discussed
- Hanford internal video inspections of transfer lines (no videos made available)

No quantitative information was found. However, there was also no event reported of chronic scale buildup.

To continue this effort to provide quantitative information, the following are recommended:

1. Review video inspections of Hanford transfer lines for evidence of adherent solids.
2. Evaluate two-phase transport of food products (sugars, salts, etc.) and problems/solutions to transport mechanisms.
3. Evaluate crystal formation, crystal size, adherence and solubility of waste salts.
4. Evaluate chemical production in high percent solids liquors and resultant production concerns (i.e., electro-chemical chlorine production in ½ NaCl, ½ NaOH solution).
5. Evaluate pipe linings and resistance to abrasion (in high percent solids), temperature, and thermal cycling and solids adherence after prolonged periods of non-use.
6. Evaluate available pipe interior finishes for weldments and general piping including mechanical and acid etching as a means to reduce solids adherence.
7. Evaluate stainless steel 300 series as the piping material of choice providing definitive data on its performance to: a) chloride attack in neutral or low pH solutions, b) scaling/solids build-up as related to increase in flow resistance, and c) solids build-up after long periods of non-use and dissolution of solids in water rinses.

HANFORD TRANSFER LINE PIPE ROUGHNESS AND SCALING ADHERENCE PROPERTIES AFFECTING PUMPING EQUIPMENT AND LINE SELECTION

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HANFORD TRANSFER LINE PIPE ROUGHNESS AND SCALING ADHERENCE PROPERTIES AFFECTING PUMPING EQUIPMENT AND LINE SELECTION

TELEPHONE CONFERENCE WITH:

Charles Jenkins, SRS 803/725-1699

Finally got through to Chuck on October 13, 1999 to discuss Savannah River's transfer line scaling, related to roughness and line type. Chuck indicated that all cross-site or inter-area transfer lines are 304L stainless steel. A few intra-tank farm transfer lines are carbon steel. Stainless steel, by its nature, will not allow scaling buildup at the temperatures waste will be transferred under. If the temperature were 800° C, where oxidation could occur, scaling would be a significant problem.

Three stainless steel transfer lines have failed over the years, while no carbon steel lines have failed. The first SST line failure was due to chloride stress corrosion cracking. The transfer line was hydro-tested and the water was drained but the line was never dried, as called for in procedures. The pipe passed testing and set unused for years. The line was poorly sloped and was near the surface in 60 to 70 °F soil. Retesting of the line prior to use showed the line had failed. The results of the inspection indicated chloride stress corrosion cracking caused the transfer pipe failure. The second incident of stainless steel transfer pipe failure was a result of a steam leak. A steam line leak had occurred near a transfer pipe and heated the surrounding soil for some time. The heating and evaporation of water from within and outside the transfer line caused failure. The failure was most probably due to continued chloride attack over several months and the resultant stress corrosion cracking. (This failure is most likely the same as reported in the Wiersma write-up.) The third failure of a stainless steel transfer line was caused by thermal fatigue from continued pipe expansion and subsequent contraction. Waste transfers at SRS are conducted using a steam-lift principle. Steam is injected into the waste and the resultant vacuum lifts the liquid waste. Therefore, steam becomes part of the liquid waste stream. The continued expansion and contraction of transfer piping lead to the thermal failure. The cause of this failure, transfer lines too rigidly attached, has since been corrected at SRS.

Chuck also provided some general information: (1) all inspected transfer lines at SRS have appeared clean and clear of build-up, (2) SRS always flushes lines after transfers with several volumes of water, (3) SRS would never consider installation of anything other than a stainless steel for a waste transfer line, (4) certain pipe lines that will see high levels of chloride will be fabricated from Hastelloy C or other high Ni alloys, (5) no scaling on stainless steel lines has been observed and (6) for caustic waste transfers use a 300 series, 304L, stainless steel pipe.

HANFORD TRANSFER LINE PIPE ROUGHNESS AND SCALING ADHERENCE PROPERTIES AFFECTING PUMPING EQUIPMENT AND LINE SELECTION

TELEPHONE CONFERENCE WITH:

Bruce Wiersma, SRS 803/725-5439

Finally got with Bruce on October 12, 1999 to discuss any knowledge he has on waste transfer line scaling buildup as it relates to pipe roughness and adherence properties. Bruce indicated he is aware of only two instances of transfer pipe plugging or failure at SRS. The first instance concerned the plugging of a stainless steel gravity drain line from the evaporator. (Bruce noted that all waste transfer lines at SRS are stainless steel.) An inspection using an in-line viewing camera was conducted of the plugged line and concluded the evaporator clean out liquor was drained into the line where it cooled rapidly and crystallized, plugging the line. The internal surfaces of the pipe did not show any damage and in fact appeared quite smooth and clean.

The second waste transfer pipe mishap occurred when a steam line broke and caused a thermal failure in the pipe. An adjacent steam line that heated the stainless steel waste transfer line failed. The steam line heated the ground around the pipe and caused evaporation of the water flush in the transfer pipe. The high chloride attacked the piping welds causing stress corrosion cracking and failure of the pipe. The waste transfer pipe was made of 304L stainless steel. A write-up of the pipe failure and inspection is contained in the SRS internal report WSRC-TR-960356.

HANFORD TRANSFER LINE PIPE ROUGHNESS AND SCALING ADHERENCE PROPERTIES AFFECTING PUMPING EQUIPMENT AND LINE SELECTION

TELEPHONE CONFERENCE WITH:

Scott Werry, LMHC, Richland, WA 509/373-1831

I had called Dave Smet to inquire about videos of waste transfer lines. Dave indicated that I should speak with Scott Werry concerning any video work. I finally spoke with Scott on October 12, 1999 about any videos he may have of tank transfer line inspections or in-line inspections. Scott indicated his database consists of tank and pit inspections and does not contain any transfer line inspections. We spoke of the SL-119 work and he again indicated that video work is not in his database. He indicated that if any NDE inspection equipment was put in transfer lines it would have to pass the flammable gas controls and the line would have to be purged, which would go through Scott. Also the Flammable Gas Board would review and approve the work and most probably a USQ would have been conducted. Scott recalls no such actions ever being conducted. Scott indicated that several years ago, under Westinghouse, he was in the process of assembling the entire video library of all tank farm work. After the site contract change, that effort was split and now no central group possess all the videos or even knows of their whereabouts. Scott suggested I call Mike Sumsion (376-4643) for additional 200 East Area videos and Joe Gonzalez (373-3056) for 200 West Area videos.

Scott called back and indicated there was a document that had "TEEM" in the title by EJ Walter that was done in the early 1990s that may be of some help. (The document was WHC-SD-WM-TEEM-001, *Pressure Testing of Underground Transfer Piping for Single-Shell Tank Salt Well.*) He also indicated that another document, HNF-SD-WM-ER-623, Rev 0 may have some data in a table at the end of the document. Scott again called and said I might also call Dan Pfluger (376-6164) as a source for additional information.

HANFORD TRANSFER LINE PIPE ROUGHNESS AND SCALING ADHERENCE PROPERTIES AFFECTING PUMPING EQUIPMENT AND LINE SELECTION

TELEPHONE CONFERENCE WITH:

Earl Schwenk, COGEMA Engineering, Richland, WA 943-4438

Talked with Earl on October 12,1999 and he indicated that he had conducted a failure analysis of a stainless steel transfer line about 20 years ago and the line was smooth other than the pitting. The analysis did not involve evaluation of pipe scaling, pipe roughness and associated adherence or pipe plugging but was a corrosion assessment. Earl provided an assessment of conditions that needed to be met, both materials and conditions, to assure successful transfer in waste piping. He first pointed out that stainless steel should be the pipe material of choice. Stainless steel will show very little general corrosion attack over time and therefore should provide no surface anomalies for scaling or solids build-up. No carbon steel should be used as it will pit and corrode too badly. A 300 series (304L or 316) stainless steel may not be the best choice of stainless if high chloride and neutral pH conditions may occur. A stainless steel that is higher in Ni or Cr may be needed to combat these conditions. The pH must be maintained well above 8.0. Even pH in the neutral range (6.0 -7.0) can cause chloride stress corrosion cracking and pitting, degradation of welds, and pipe failure. Suspended solids at 30 wt% will require turbulent flow for transfer. If waste streams with this amount of solids are transferred in laminar flow the solids will undoubtedly settle out or collect. Special piping, such Teflon-lined, would undoubtedly suffer from abrasion with all the solids and Earl has no quantitative date on how such lined piping would hold up in this condition. It was agreed that a smooth surface of the piping would be essential for transfer of the tank wastes. Earl indicated Jim Divine would know much more concerning tank waste transfer line attack by chloride and corrosion cracking in neutral pH conditions and I should contact Jim for more on that subject. Earl also suggested I contact previous Grout Project engineers to ascertain what wt% solids and what specific conditions of the waste or equipment bounded grout waste transfers. Earl indicated I should also contact other industries to obtain two-phase material transfer data.

HANFORD TRANSFER LINE PIPE ROUGHNESS AND SCALING ADHERENCE PROPERTIES AFFECTING PUMPING EQUIPMENT AND LINE SELECTION

TELEPHONE CONFERENCE WITH:

Richard W. Johnson, INEEL 208/526-0955

A phone conversation was held with Richard on October 6, 1999 to discuss pipe roughness and adherence properties that may be in the *Handbook Of Fluid Dynamics* he had recently edited. (Richard's name was given to me by Jim Divine, ChemMet LTD, as a possible contact that may have information on caustic waste transport issues.) Richard indicated no such material is contained in the edition and he has no knowledge or working experience with caustic waste transport, pipe roughness or piping adherence properties. Richard did indicate that I might check with Dick Rice, INEEL, (208/526-1992) who has worked in the field of two-phase transport and may have some information that may be of help to me.

HANFORD TRANSFER LINE PIPE ROUGHNESS AND SCALING ADHERENCE PROPERTIES AFFECTING PUMPING EQUIPMENT AND LINE SELECTION

TELEPHONE CONFERENCE WITH:

Fred Reich, COGEMA Engineering, Richland, WA 509/371-8046

I talked with Fred on October 12, 1999 about any past experience he may have had with NDE testing of waste transfer lines and results he obtained concerning detection of corrosion, scaling products, etc. Fred indicated his only experience has been in the petrol-chemical field detecting corrosion in iron piping. A pipe crawler using pulse-echo ultrasonics was used in petroleum cross-site transfer lines to detect pitting and general corrosion. No work was ever done for the detection of corrosion products or scaling buildup. In petroleum lines "sour crude" contained sulfur that would react with the iron creating corrosion. The crawler was designed to operate in 18-inch, or larger lines, while oil, gasoline, or diesel were running in the lines. Fred indicated no work was done with stainless steel pipe lines. Fred has had no experience with external NDE of waste transfer lines and does not know of anyone who has had such experience.

HANFORD TRANSFER LINE PIPE ROUGHNESS AND SCALING ADHERENCE PROPERTIES AFFECTING PUMPING EQUIPMENT AND LINE SELECTION

TELEPHONE CONFERENCE WITH:

Dick Rice, INEEL, Idaho Falls, ID 208/526-1992

On October 6, 1999 I left a message for Dick to call me on his two-phase transport work as it may relate to caustic waste transfer. On October 7, Tish Stoots (208/526-1764) returned my call to obtain more information for Dick. Tish indicated she would get back to me with any information on the subject. On October 12, I again called Tish to inquire of any progress on the subject. She indicated she had spoken with Dick and he had no quantitative data on two-phase transport that would support Hanford high-level waste transport.

HANFORD TRANSFER LINE PIPE ROUGHNESS AND SCALING ADHERENCE PROPERTIES AFFECTING PUMPING EQUIPMENT AND LINE SELECTION

TELEPHONE CONFERENCE WITH:

James Divine, ChemMet Ltd, West Richland, WA 509/967-2309

On October 4, 1999 I spoke with Jim Divine concerning his knowledge of scaling products deposition in tank transfer lines and associated roughness and adherence properties. Jim indicated that that no PNL studies were done in the past to evaluate the type of corrosion and resultant deposition. He indicated that if the transfer piping were to be made of stainless steel there would be no pitting corrosion only deposit accumulation. A carbon steel transfer line would exhibit pitting corrosion over time. Jim has had experience in the 300 Area with 6 and 8-inch water lines that have closed to 2-inch with deposition but nothing akin to tank wastes. Jim indicated that I should call Richard W. Johnson at INEEL since he had either written or edited a *Handbook of Fluid Dynamics* and may have some information.

On October 5, 1999 Jim called back to state he didn't know of other contacts at any other DOE sites that would have any quantitative data concerning this subject. Jim did suggest that some simple experiments could be proposed that would produce data on pipe roughness and scale adherence affects on pump pressure output. But these data would be nothing different than calculations found in standard publications on momentum transfer.

Jim was very confident that no quantitative data exists on tank waste transfer lines scaling and adherence properties and was not aware of any specific work on adherence to stainless steel.

HANFORD TRANSFER LINE PIPE ROUGHNESS AND SCALING ADHERENCE PROPERTIES AFFECTING PUMPING EQUIPMENT AND LINE SELECTION

TELEPHONE CONFERENCE WITH:

Darrel Duncan, NHC, Richland, WA 509/372-1013

On October 4, 1999 I spoke with Darrel Duncan concerning his Hanford corrosion history and any knowledge he may have concerning tank transfer line corrosion product buildup or assessments done on removed piping. Darrel's pre-Hanford experience was in the petrol-chemical industry determining pipeline corrosion and weld longevity. At Hanford his corrosion work has centered on materials, container integrity and longevity and has not involved any work with tank transfer lines. He indicated that any scaling data from removed piping would be suspect because of the many flushes required to reduce the dose so that the material could be examined. These repeated flushes would undoubtedly remove much of the scale buildup rendering results questionable.

We spoke of previous NDE work and came to the conclusion that it was doubtful that any inline transfer data gathered could be quantitative. He indicated I should still speak with the NDE group in the 306 Building.

HANFORD TRANSFER LINE PIPE ROUGHNESS AND SCALING ADHERENCE PROPERTIES AFFECTING PUMPING EQUIPMENT AND LINE SELECTION

TELEPHONE CONFERENCE WITH:

David Lini, SAIC, Richland, WA 509/373-9102

On October 5, 1999 Dave returned my call to discuss his 1975 document *"Compilation of Hanford Corrosion Studies"*, ARH-ST-111. Dave indicated the corrosion assessment in the document was centered on finding data to support either the "leave in place option" or the "retrieval option" for wastes contained in the high-level waste tanks. These two options were on the forefront at Hanford since deactivation of the 149 single-shell tanks was underway and future storage of all high-level liquid wastes was designated for double-shell tanks. The document focused on tank integrity assessments in an attempt to determine tank longevity. As Dave remembers, there is no information on tank transfer lines or any assessment of transfer line corrosion, product buildup and subsequent line plugging, or transfer line failure within the document. Dave did not know of any work done with caustic waste transfer lines concerning scaling buildup or transfer line pipe roughness assessments nor did he know of anyone on site that had such information.

HANFORD TRANSFER LINE PIPE ROUGHNESS AND SCALING ADHERENCE PROPERTIES AFFECTING PUMPING EQUIPMENT AND LINE SELECTION

TELEPHONE CONFERENCE WITH:

Wesley Nelson (509/376-5403) and John Keve (509/376-8061), COGEMA Engineering Corporation, Richland, WA

On October 6, 1999 I spoke with John and Wes concerning their work experience concerning any non-destructive examinations of removed or in-place tank transfer line piping. Neither had any experience conducting such examinations and stated that the 306 NDE shop had never done this type of work for tank transfer piping.

HANFORD TRANSFER LINE PIPE ROUGHNESS AND SCALING ADHERENCE PROPERTIES AFFECTING PUMPING EQUIPMENT AND LINE SELECTION

TELEPHONE CONFERENCE WITH:

Daniel Reynolds, LMHC, Richland, WA 509/373-3115

Finally caught up with Dan on October 13, 1999. Dan indicated that almost all waste transfers in the last several years have been evaporator feed that contain very little solids. Volume % solids have not been traditionally reported in waste transfers. In approximately the last five years compatibility assessments of the transfer and receiving tanks are to be done. The assessment may contain SPG but claim no solids. A grab sample may be taken but is not necessarily representative since mixer pumps do not have to run for any period of time. Tank 101-SY solution transfer will utilize bulk density versus solution density to determine volume % suspended solids. Inline dilution instrumentation will be utilized to maintain the slurry <25 vol% solids. It is assumed that 60% of the solids in 101-SY, mainly $NaNO_3$ and $NaNO_2$, will dissolve as water is added. Tank C106 will be monitored for % solids as it is sluiced out. The same vol% solids measuring system will be used as 101-SY. However, the solids will be maintained at <15 vol% during the transfer of the C106 slurry.

HANFORD TRANSFER LINE PIPE ROUGHNESS AND SCALING ADHERENCE PROPERTIES AFFECTING PUMPING EQUIPMENT AND LINE SELECTION

TELEPHONE CONFERENCE WITH:

Jim Douglas, COGEMA Engineering, Richland, WA 509/372-0989

I spoke with Jim on October 7, 1999 to find out what data was provided concerning waste tank transfers. The data Jim has been provided as he has compiled tank waste characterization documentation are:

- Total alpha
- Sodium (Na)
- Aluminum (Al)
- Nitrate (NO3)
- Nitrite (NO2)
- Hydroxide (OH)
- Specific gravity
- Sulfate (SO4)
- Phosphate (PO4)

Jim believes the average temperature for waste being transferred is approximately 75 °C. He indicated I should contact Jim Field of LMHC to double check the data provided with waste transfers. Jim indicated he has never seen a wt% solids value in any of the waste transfer data.

HANFORD TRANSFER LINE PIPE ROUGHNESS AND SCALING ADHERENCE PROPERTIES AFFECTING PUMPING EQUIPMENT AND LINE SELECTION

TELEPHONE CONFERENCE WITH:

Jim Field, LMHC, Richland, WA 509/376-3753

Talked with Jim on October 13, 1999 concerning data available concerning waste transfers. Jim supported Jim Douglas's conversation in the constituents reported in waste transfers. Jim did indicate that grab samples were conducted to determine % solids. He also indicated that following waste transfers, three pipe volumes of water are used to flush the line(s). Flush volumes are being contested in lines that are of great length. Jim also stated that recommendations are continually made to turn on transfer line trace heaters to match the temperature of the tank the transfer is coming from. Average transfer temperature is something hard to quantify. The range of transfer liquids can vary by almost 150 °F as line length, trace heater condition/settings, initial waste temperature, water added to waste prior to transfer and other parameters can affect delivery temperature.

HANFORD TRANSFER LINE PIPE ROUGHNESS AND SCALING ADHERENCE PROPERTIES AFFECTING PUMPING EQUIPMENT AND LINE SELECTION

TELEPHONE CONFERENCE WITH:

Bill Morris, LMHC, Richland, WA 509/372-3724

Bill called on October 13, 1999 and indicated Joe Gonzalez had no knowledge of transfer line videos but he did. Bill is the camera group lead and recalls videos of the east-west transfer line video and the AY Tank Farm transfer line video inspection with a boroscope. He recalls that the videos were taken in the early 1990s. Bill will review his video records on transfer line inspections this afternoon and call me back with information concerning the videos.

LIST OF DOCUMENTS CONCERNING INSPECTIONS OR TESTING OF UNDERGROUND WASTE TRANSFER LINES

1. WHC-SD-WM-ANAL-014, 1994, *S Tank Farm SL-119 Saltwell Piping Failure Analysis Report*, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

2. WHC-SD-WM-ES-259, 1993, *Single-Shell Saltwell Transfer Piping Evaluation*, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

3. WHC-SD-WM-TEEM-001, 1992, *Pressure Testing of Underground Transfer Piping for Single-Shell Tank Saltwell*, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

4. HNF-SD-WM-ER-623, 1997, *DST Waste Transfer Piping and Pit System Integrity Assessment Report*, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

5. WSRC-TR-96-0356, 1996, *Materials Degradation Evaluation of High Level Waste Transfer Line System (U)*, Westinghouse Savannah River Company, Aiken, South Carolina.

APPENDIX D

CRITICAL VELOCITY AND PRESSURE LOSS EVALUATION RESULTS FOR DOUBLE-SHELL TANK TRANSFER PIPING IN 200 EAST AREA FOR TANK-TO-TANK AND TANK-TO-BNFL INC. TRANSFERS BASED ON HANFORD TANK WASTE OPERATION SIMULATOR CASES 3S4 AND 3S6 DISTINCT TRANSFER ROUTE IDENTIFICATION FOR PROPOSED PHASE 1B WASTE FEED DELIVERY TRANSFERS

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CONVERSIONS

ft	feet = 0.3048 meter (m)
in.	inch = 2.54 centimeters (cm)
lbf/in^2	pounds per square inch = 0.06895 megapascals (MPa)
mils	0.001 in. = 0.0254 millimeter (mm)
gpm	0.0631 liter/second (L/s)
cP	centipose = 0.001 kilogram/meter-second (kg/m-s)

Table D-1. 3S4 Case Summary.

Case	Group 1 Properties: Liquid ρ_L Density (kg/L)	Group 1 Solids: ρ_s Density (kg/L)	Group 1 Solids: C_s Volume (%)	Group 1 Solids: d_p Median Dia. (μm)	ρ_m Bulk Density (kg/L)	Results: Critical Velocity (ft/s), Temperature (°C) 10	Results: Critical Velocity (ft/s), Temperature (°C) 60	Group 2 Properties: Liquid ρ_L Density (kg/L)	Group 2 Solids: ρ_s Density (kg/L)	Group 2 Solids: C_s Volume (%)	Group 2 Solids: d_p Median Dia. (μm)	ρ_m Bulk Density (kg/L)	Results: Critical Velocity (ft/s), Temperature (°C) 10	Results: Critical Velocity (ft/s), Temperature (°C) 60	Table
1a	1.21	2.5	15	5	1.4	2.6	2.8	1.46	3	30	10	1.92	2.7	2.9	D-2
1b	1.1				1.31	2.9	3.2	1.2				1.74	3.7	4	D-3
1c	1.21		1.5 x HTWOS		1.21-1.35	0.3-2.5	0.1-2.7	1.46		2.0 x HTWOS		1.46-1.68	1.0-2.6	0.4-2.8	D-4
1d	1.1				1.1-1.25	0.2-2.8	0.1-3.1	1.2				1.2-1.45	0.3-3.5	0.1-3.8	D-5
2a	1.21	2.5	15	40	1.4	3.7	4	1.46	3	30	100	1.92	4	4.3	D-6
2b	1.1				1.31	4.1	4.5	1.2				1.74	5.4	5.9	D-7
2c	1.21		1.5 x HTWOS		1.21-1.35	0.3-3.6	0.1-3.9	1.46		2.0 x HTWOS		1.46-1.68	1.0-3.8	0.4-4.1	D-8
2d	1.1				1.1-1.25	0.2-4.0	0.1-4.4	1.2				1.2-1.45	0.3-5.2	0.1-5.6	D-9
3a	1.21	2.5	15	200	1.4	4.8	5.3	1.46	3	30	400	1.92	5	5.4	D-10
3b	1.1				1.31	5.4	5.9	1.2				1.74	6.8	7.4	D-11
3c	1.21		1.5 x HTWOS		1.21-1.35	0.3-4.7	0.1-5.1	1.46		2.0 x HTWOS		1.46-1.68	1.0-4.8	0.4-5.2	D-12
3d	1.1				1.1-1.25	0.2-5.2	0.1-5.7	1.2				1.2-1.45	0.3-6.5	0.1-7.1	D-13
4	1.2	3	10	400	1.38	6.3	6.8	1.2	3	15	400	1.47	6.5	7.1	D-14
	3S4 HTWOS		0.0-7.07			1 ft/s = 0.3048 m/s									

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Table D-2. 3S4 Case 1a.

CASE 3S4 Transfer List - Tank-to-Tank

Transfer: 3-in. Schedule-40 Pipe (3.068 in. inside dia.)

Row	From Tank	To Tank	Tank Farm Built (Yr)	#	Dates (M/Yr) Start	Dates (M/Yr) End	Design Pressure (lbf/in²)	Carbon Steel Length (ft)	Stainless Steel Length (ft)	Total Change in Elevation (ft)
6	AN-101	AP-103	83-86	1	3/03	3/03	400	306	2,774	12
7		AN-106	80-81	2	3/03	3/03		442	626	0
8		AN-107	80-81	3	9/05	8/12		557	626	0
9		BNFL		4	10/08	12/14	400	0	6,413	40
10	AN-102	AN-106	80-81	1	8/06	8/06		319	626	0
11		AN-101	80-81	1	10/08	10/08		405	421	0
12		AN-105	80-81	1	12/12	12/12		329	626	0
13	AN-103	AN-105	80-81	1	10/11	10/11		300	626	0
14		BNFL		2	5/13	5/18		376	6,823	40
15	AN-104	AN-101	80-81	4	9/05	5/15		526	626	0
16		BNFL		2	6/09	4/11	400	0	6,275	40
17		AZ-101	71	1	6/09	6/09	400	562	1,560	5
18		AN-107	80-81	1	6/09	6/09		489	421	0
19		AN-102	80-81	1	4/11	4/11		439	626	0
20		AW-103	78-80	2	4/11	9/11		1,012	3,046	21
21		AW-101	78-80	4	8/12	8/16		994	3,046	21
22		AN-103	80-81	2	6/13	10/13		410	626	0
23		AN-106	80-81	2	1/14	5/14		374	421	0
24		AW-104	78-80	2	5/15	7/15		1,003	3,046	21
25		AN-105	80-81	2	11/15	12/15		384	421	0
26		AP-101	83-86	2	2/17	2/17	400	419	2,636	12
27		AP-105	83-86	1	12/17	12/17	400	302	2,636	12
28		AW-105	78-80	1	3/18	3/18		1,125	3,046	21
29		AP-102	83-86	1	4/19	4/19	400	431	2,636	12
30		AW-106	78-80	1	10/19	10/19		1,114	3,046	21
31	AN-105	AN-104	80-81	1	6/09	6/09		384	421	0
32		BNFL		3	10/11	11/15		452	7,028	40
33	AN-106	AP-107	83-86	1	9/05	9/05		865	3,389	12
34		BNFL		4	8/06	1/14		442	7,028	40
35		AN-107	80-81	2	2/10	4/12		269	421	0
36	AN-107	AN-106	80-81	2	9/05	9/05		269	421	0
37		AW-102	78-80	1	10/10	10/10		1,357	3,006	21
38	AP-101	AP-104	83-86	1	8/16	8/16	400	733	421	0
39		AP-102	83-86	1	2/17	2/17	400	850	421	0
40	AP-102	AN-106	80-81	1	2/10	2/10		883	3,389	-12
41		AN-107	80-81	3	10/10	2/17		988	3,389	-12
42		BNFL		5	6/15	4/19	400	431	5,370	28
43	AP-104	AP-102	83-86	1	6/15	6/15	400	745	421	0
44		BNFL		3	8/16	10/18	400	314	5,370	28
45	AP-105	AP-104	83-86	1	7/17	7/17	400	618	421	0
46		AP-102	83-86	1	12/17	12/17	400	733	421	0
47	AP-107	AW-102	78-80	10	9/00	9/05		1,223	421	9
48	AP-108	AP-107	83-86	2	9/01	9/02	400	666	421	0
49	AW-101	AN-106	80-81	1	4/12	4/12		1,436	3,799	-21
50		AN-101	80-81	1	8/12	8/12		994	3,184	-21
51		AP-102	83-86	1	4/16	4/16		1,425	831	-9
52	AW-103	AY-102	68-70	1	7/07	7/07		1,012	3,320	-10
53		AY-101	68-70	1	3/08	3/08		1,012	3,695	-10
54		AZ-101	71	1	10/10	10/10		1,012	2,942	-17
55	AW-104	AP-102	83-86	1	10/10	10/10		1,434	831	-9
56		AZ-102	77	1	5/13	5/13		1,003	3,327	-17
57		AY-101	68-70	1	5/15	5/15		1,003	3,695	-10
58	AW-105	AZ-101	71	1	10/16	10/16		1,125	2,942	-17
59		AZ-102	77	1	3/18	3/18		1,125	3,327	-17
60	AW-106	AP-107	83-86	1	9/05	9/05		1,537	831	-9
61		AN-102	80-81	1	12/12	12/12		1,519	3,594	-21
62		AW-102	78-80	2	9/00	10/10		314	421	0
63		AW-104	78-80	1	10/00	10/00		341	421	0
64		AP-101	83-86	2	10/00	8/01		1,533	831	-9
65		AP-104	83-86	1	10/01	10/01		1,428	831	-9
66		AW-105	78-80	2	10/01	1/02		2,239	1,241	0
67		AP-108	83-86	1	2/05	2/05		1,557	831	-9
68	AY-101	AN-107	80-81	1	3/07	3/07		557	2,313	-11
69		BNFL		16	11/09	1/18	400	0	6,924	30
70	AY-102	BNFL		6	1/08	10/09	400	0	6,549	30
71		AY-101	68-70	1	2/12	2/12	400	0	386	0
72		AZ-102	77	1	6/17	6/17	400	0	1,466	-8
73		AP-101	83-86	1	10/17	10/17	400	128	2,910	2
74		AP-105	83-86	1	12/17	12/17	400	302	2,910	2
75		AN-103	80-81	1	6/18	6/18		376	1,733	-11
76		AP-104	83-86	1	10/18	10/18	400	314	2,910	2
77		AN-107	80-81	1	10/19	10/19		557	1,733	-11
78		AW-102	78-80	1	10/19	10/19		761	2,910	10
79	AZ-101	BNFL		18	10/04	4/19	400	0	6,171	36
80	AZ-102	BNFL		18	11/06	11/91	400	0	6,556	36
81	BNFL internal equivalent pipe length and elevation								884	45

Case 1a. Critical velocity by Oroskar and Turian (1980) empirical correlation (β_{cv} = 1.2). Pressure drop by Wasp et al. (1977) method with lognormal particle size distribution.

Group 1 Properties; Critical (κ_{cv} = 1.30, κ_f = 1)

Row	Liquid ρ_L Density (kg/L)	Solids ρ_s Density (kg/L)	Solids C_s Volume (%)	Solids d_p Median Dia. (µm)	ρ_m Bulk Density (kg/L)	Temp. 10 °C Critical Velocity (ft/s)	Temp. 10 °C Critical Flow Rate (gpm)	Total Pressure Drop (lbf/in²) New	Total Pressure Drop (lbf/in²) EOL	Flow Rate at a Pipe Design Pressure of 400 lbf/in² (gpm) New	Flow Rate (gpm) EOL	Temp. 60 °C Critical Velocity (ft/s)	Temp. 60 °C Critical Flow Rate (gpm)	Total Pressure Drop (lbf/in²) New	Total Pressure Drop (lbf/in²) EOL	Flow Rate at a Pipe Design Pressure of 400 lbf/in² (gpm) New	Flow Rate (gpm) EOL
6	1.21	2.50	15	5	1.40	2.6	60	27	35	299	237	2.8	65	27	38	311	240
7	1.21	2.50	15	5	1.40	2.6	60	7	13	525	343	2.8	65	7	15	539	345
8	1.21	2.50	15	5	1.40	2.6	60	8	15	498	317	2.8	65	8	17	511	319
9	1.21	2.50	15	5	1.40	2.6	60	66	75	198	171	2.8	65	66	79	208	175
10	1.21	2.50	15	5	1.40	2.6	60	6	11	559	379	2.8	65	6	12	573	381
11	1.21	2.50	15	5	1.40	2.6	60	5	11	599	377	2.8	65	5	12	614	378
12	1.21	2.50	15	5	1.40	2.6	60	6	11	556	375	2.8	65	6	12	570	377
13	1.21	2.50	15	5	1.40	2.6	60	6	10	565	385	2.8	65	6	12	579	387
14	1.21	2.50	15	5	1.40	2.6	60	71	85	186	155	2.8	65	71	91	196	158
15	1.21	2.50	15	5	1.40	2.6	60	7	14	505	324	2.8	65	7	16	518	325
16	1.21	2.50	15	5	1.40	2.6	60	65	74	200	173	2.8	65	65	78	210	177
17	1.21	2.50	15	5	1.40	2.6	60	17	25	365	261	2.8	65	17	28	378	263
18	1.21	2.50	15	5	1.40	2.6	60	6	12	570	352	2.8	65	6	14	585	353
19	1.21	2.50	15	5	1.40	2.6	60	7	13	526	344	2.8	65	7	15	540	345
20	1.21	2.50	15	5	1.40	2.6	60	39	55	256	187	2.8	65	39	60	268	189
21	1.21	2.50	15	5	1.40	2.6	60	39	55	257	188	2.8	65	39	60	268	190
22	1.21	2.50	15	5	1.40	2.6	60	7	12	533	351	2.8	65	7	14	547	353
23	1.21	2.50	15	5	1.40	2.6	60	5	10	611	387	2.8	65	5	12	626	389
24	1.21	2.50	15	5	1.40	2.6	60	39	55	257	187	2.8	65	39	60	268	189
25	1.21	2.50	15	5	1.40	2.6	60	5	10	608	384	2.8	65	5	12	622	385
26	1.21	2.50	15	5	1.40	2.6	60	27	36	300	232	2.8	65	27	39	312	235
27	1.21	2.50	15	5	1.40	2.6	60	27	34	306	243	2.8	65	26	36	318	245
28	1.21	2.50	15	5	1.40	2.6	60	40	57	253	182	2.8	65	40	63	264	184
29	1.21	2.50	15	5	1.40	2.6	60	27	36	299	231	2.8	65	27	39	311	234
30	1.21	2.50	15	5	1.40	2.6	60	40	57	253	183	2.8	65	40	62	264	185
31	1.21	2.50	15	5	1.40	2.6	60	5	10	608	384	2.8	65	5	12	622	385
32	1.21	2.50	15	5	1.40	2.6	60	73	88	182	151	2.8	65	73	94	192	154
33	1.21	2.50	15	5	1.40	2.6	60	35	50	252	189	2.8	65	35	55	263	191
34	1.21	2.50	15	5	1.40	2.6	60	73	88	182	152	2.8	65	73	94	192	155
35	1.21	2.50	15	5	1.40	2.6	60	4	8	658	432	2.8	65	4	9	673	434
36	1.21	2.50	15	5	1.40	2.6	60	4	8	658	432	2.8	65	4	9	673	434
37	1.21	2.50	15	5	1.40	2.6	60	41	61	247	174	2.8	65	41	67	258	176
38	1.21	2.50	15	5	1.40	2.6	60	7	17	504	300	2.8	65	7	19	518	301
39	1.21	2.50	15	5	1.40	2.6	60	8	19	479	282	2.8	65	8	22	493	283
40	1.21	2.50	15	5	1.40	2.6	60	20	35	256	191	2.8	65	20	40	268	194
41	1.21	2.50	15	5	1.40	2.6	60	21	37	253	187	2.8	65	21	42	264	189
42	1.21	2.50	15	5	1.40	2.6	60	55	67	211	173	2.8	65	55	72	221	175
43	1.21	2.50	15	5	1.40	2.6	60	8	17	501	298	2.8	65	8	19	515	299
44	1.21	2.50	15	5	1.40	2.6	60	54	65	213	177	2.8	65	54	69	224	180
45	1.21	2.50	15	5	1.40	2.6	60	7	14	533	322	2.8	65	7	17	547	323
46	1.21	2.50	15	5	1.40	2.6	60	7	17	504	300	2.8	65	7	19	518	301
47	1.21	2.50	15	5	1.40	2.6	60	16	31	416	239	2.8	65	16	35	429	240
48	1.21	2.50	15	5	1.40	2.6	60	8	19	476	280	2.8	65	8	22	490	281
49	1.21	2.50	15	5	1.40	2.6	60	21	43	232	167	2.8	65	21	50	243	169
50	1.21	2.50	15	5	1.40	2.6	60	14	30	281	192	2.8	65	14	35	272	194
51	1.21	2.50	15	5	1.40	2.6	60	9	27	358	216	2.8	65	9	32	370	217
52	1.21	2.50	15	5	1.40	2.6	60	22	38	254	187	2.8	65	22	44	265	189
53	1.21	2.50	15	5	1.40	2.6	60	24	41	243	181	2.8	65	24	47	254	183
54	1.21	2.50	15	5	1.40	2.6	60	15	31	268	194	2.8	65	15	36	279	196
55	1.21	2.50	15	5	1.40	2.6	60	9	27	357	215	2.8	65	9	32	370	216
56	1.21	2.50	15	5	1.40	2.6	60	18	34	256	188	2.8	65	18	39	267	190
57	1.21	2.50	15	5	1.40	2.6	60	24	41	243	181	2.8	65	24	47	254	184
58	1.21	2.50	15	5	1.40	2.6	60	16	33	264	189	2.8	65	16	39	275	191
59	1.21	2.50	15	5	1.40	2.6	60	19	36	252	183	2.8	65	18	42	263	185
60	1.21	2.50	15	5	1.40	2.6	60	10	29	349	209	2.8	65	10	34	361	210
61	1.21	2.50	15	5	1.40	2.6	60	20	43	235	167	2.8	65	20	50	246	169
62	1.21	2.50	15	5	1.40	2.6	60	5	9	637	411	2.8	65	5	10	652	413
63	1.21	2.50	15	5	1.40	2.6	60	5	9	625	400	2.8	65	5	11	640	402
64	1.21	2.50	15	5	1.40	2.6	60	10	29	349	209	2.8	65	10	34	362	210
65	1.21	2.50	15	5	1.40	2.6	60	9	27	358	216	2.8	65	9	32	370	217
66	1.21	2.50	15	5	1.40	2.6	60	23	50	283	171	2.8	65	22	58	295	172
67	1.21	2.50	15	5	1.40	2.6	60	10	29	347	208	2.8	65	10	35	360	209
68	1.21	2.50	15	5	1.40	2.6	60	12	21	316	236	2.8	65	12	25	328	238
69	1.21	2.50	15	5	1.40	2.6	60	63	72	192	166	2.8	65	63	77	202	169
70	1.21	2.50	15	5	1.40	2.6	60	61	69	198	171	2.8	65	60	74	208	174
71	1.21	2.50	15	5	1.40	2.6	60	3	3	887	738	2.8	65	2	3	903	742
72	1.21	2.50	15	5	1.40	2.6	60	5	7	448	378	2.8	65	5	8	461	382
73	1.21	2.50	15	5	1.40	2.6	60	21	26	304	251	2.8	65	21	28	315	254
74	1.21	2.50	15	5	1.40	2.6	60	22	29	295	235	2.8	65	22	32	307	238
75	1.21	2.50	15	5	1.40	2.6	60	7	14	371	278	2.8	65	7	16	384	281
76	1.21	2.50	15	5	1.40	2.6	60	22	29	294	234	2.8	65	22	32	306	237
77	1.21	2.50	15	5	1.40	2.6	60	8	17	356	257	2.8	65	8	20	368	259
78	1.21	2.50	15	5	1.40	2.6	60	30	43	273	203	2.8	65	30	47	284	205
79	1.21	2.50	15	5	1.40	2.6	60	62	70	203	175	2.8	65	62	75	213	179
80	1.21	2.50	15	5	1.40	2.6	60	65	73	196	170	2.8	65	64	78	206	173
81	included in BNFL routes							Exceeds 275 lbf/in²						Exceeds 400 lbf/in²			

Group 2 Properties; Critical (κ_{cv} = 1.30, κ_f = 1)

Row	Liquid ρ_L Density (kg/L)	Solids ρ_s Density (kg/L)	Solids C_s Volume (%)	Solids d_p Median Dia. (µm)	ρ_m Bulk Density (kg/L)	Temp. 10 °C Critical Velocity (ft/s)	Temp. 10 °C Critical Flow Rate (gpm)	Total Pressure Drop (lbf/in²) New	Total Pressure Drop (lbf/in²) EOL	Flow Rate at a Pipe Design Pressure of 400 lbf/in² (gpm) New	Flow Rate (gpm) EOL	Temp. 60 °C Critical Velocity (ft/s)	Temp. 60 °C Critical Flow Rate (gpm)	Total Pressure Drop (lbf/in²) New	Total Pressure Drop (lbf/in²) EOL	Flow Rate at a Pipe Design Pressure of 400 lbf/in² (gpm) New	Flow Rate (gpm) EOL
6	1.46	3.00	30	10	1.92	2.7	62	54	62	216	188	2.9	67	50	61	237	196
7	1.46	3.00	30	10	1.92	2.7	62	15	22	395	284	2.9	67	14	23	425	290
8	1.46	3.00	30	10	1.92	2.7	62	17	26	373	263	2.9	67	15	27	402	268
9	1.46	3.00	30	10	1.92	2.7	62	126	133			2.9	67	117	129	153	
10	1.46	3.00	30	10	1.92	2.7	62	14	19	423	313	2.9	67	12	19	453	320
11	1.46	3.00	30	10	1.92	2.7	62	12	18	455	314	2.9	67	11	19	487	319
12	1.46	3.00	30	10	1.92	2.7	62	14	19	420	310	2.9	67	12	20	451	317
13	1.46	3.00	30	10	1.92	2.7	62	13	18	427	318	2.9	67	12	19	458	325
14	1.46	3.00	30	10	1.92	2.7	62	137	150			2.9	67	127	147	144	
15	1.46	3.00	30	10	1.92	2.7	62	17	25	379	268	2.9	67	15	26	408	273
16	1.46	3.00	30	10	1.92	2.7	62	124	131			2.9	67	115	127	155	
17	1.46	3.00	30	10	1.92	2.7	62	35	45	268	211	2.9	67	32	45	292	218
18	1.46	3.00	30	10	1.92	2.7	62	13	21	431	293	2.9	67	12	22	463	298
19	1.46	3.00	30	10	1.92	2.7	62	15	22	396	285	2.9	67	14	23	425	290
20	1.46	3.00	30	10	1.92	2.7	62	76	94	183	149	2.9	67	70	95	201	155
21	1.46	3.00	30	10	1.92	2.7	62	75	93	184	149	2.9	67	70	94	202	155
22	1.46	3.00	30	10	1.92	2.7	62	15	21	402	291	2.9	67	13	22	432	297
23	1.46	3.00	30	10	1.92	2.7	62	11	17	465	323	2.9	67	10	18	497	328
24	1.46	3.00	30	10	1.92	2.7	62	76	93	183	149	2.9	67	70	95	202	155
25	1.46	3.00	30	10	1.92	2.7	62	12	18	461	320	2.9	67	10	18	494	325
26	1.46	3.00	30	10	1.92	2.7	62	54	63	217	185	2.9	67	50	63	238	193
27	1.46	3.00	30	10	1.92	2.7	62	52	60	222	192	2.9	67	48	59	243	201
28	1.46	3.00	30	10	1.92	2.7	62	77	97	180	145	2.9	67	72	98	198	151
29	1.46	3.00	30	10	1.92	2.7	62	54	63	217	184	2.9	67	50	63	237	192
30	1.46	3.00	30	10	1.92	2.7	62	77	97	181	145	2.9	67	72	98	199	151
31	1.46	3.00	30	10	1.92	2.7	62	12	18	461	320	2.9	67	10	18	494	325
32	1.46	3.00	30	10	1.92	2.7	62	141	155			2.9	67	131	152	141	
33	1.46	3.00	30	10	1.92	2.7	62	71	87	180	150	2.9	67	66	88	198	156
34	1.46	3.00	30	10	1.92	2.7	62	141	155			2.9	67	131	152	141	
35	1.46	3.00	30	10	1.92	2.7	62	10	14	502	359	2.9	67	9	15	536	366
36	1.46	3.00	30	10	1.92	2.7	62	10	14	502	359	2.9	67	9	15	536	366
37	1.46	3.00	30	10	1.92	2.7	62	80	103	176		2.9	67	74	105	194	145
38	1.46	3.00	30	10	1.92	2.7	62	17	27	379	250	2.9	67	15	29	407	254
39	1.46	3.00	30	10	1.92	2.7	62	18	31	359	235	2.9	67	17	33	387	239
40	1.46	3.00	30	10	1.92	2.7	62	51	67	185	153	2.9	67	45	68	204	160
41	1.46	3.00	30	10	1.92	2.7	62	53	70	183	150	2.9	67	47	71	201	156
42	1.46	3.00	30	10	1.92	2.7	62	107	119	148		2.9	67	99	117	164	141
43	1.46	3.00	30	10	1.92	2.7	62	17	28	376	249	2.9	67	15	30	405	252
44	1.46	3.00	30	10	1.92	2.7	62	105	115	150		2.9	67	97	113	166	144
45	1.46	3.00	30	10	1.92	2.7	62	15	24	401	268	2.9	67	13	26	431	272
46	1.46	3.00	30	10	1.92	2.7	62	17	27	379	250	2.9	67	15	29	407	254
47	1.46	3.00	30	10	1.92	2.7	62	31	49	308	199	2.9	67	29	52	334	202
48	1.46	3.00	30	10	1.92	2.7	62	18	31	356	234	2.9	67	17	34	384	237
49	1.46	3.00	30	10	1.92	2.7	62	57	82	167		2.9	67	51	84	184	140
50	1.46	3.00	30	10	1.92	2.7	62	42	60	189	154	2.9	67	37	61	208	161
51	1.46	3.00	30	10	1.92	2.7	62	25	46	264	179	2.9	67	22	50	287	183
52	1.46	3.00	30	10	1.92	2.7	62	54	72	183	150	2.9	67	48	73	201	156
53	1.46	3.00	30	10	1.92	2.7	62	59	78	175	145	2.9	67	53	79	193	151
54	1.46	3.00	30	10	1.92	2.7	62	43	60	194	157	2.9	67	37	62	213	163
55	1.46	3.00	30	10	1.92	2.7	62	25	47	263	179	2.9	67	22	50	286	182
56	1.46	3.00	30	10	1.92	2.7	62	48	66	185	151	2.9	67	42	67	203	157
57	1.46	3.00	30	10	1.92	2.7	62	59	78	175	145	2.9	67	53	78	193	151
58	1.46	3.00	30	10	1.92	2.7	62	44	64	191	153	2.9	67	39	65	210	159
59	1.46	3.00	30	10	1.92	2.7	62	50	70	182	147	2.9	67	44	71	200	154
60	1.46	3.00	30	10	1.92	2.7	62	27	49	257	174	2.9	67	23	54	279	177
61	1.46	3.00	30	10	1.92	2.7	62	56	81	169		2.9	67	49	84	186	140
62	1.46	3.00	30	10	1.92	2.7	62	11	15	485	342	2.9	67	10	16	518	348
63	1.46	3.00	30	10	1.92	2.7	62	11	16	475	333	2.9	67	10	17	508	339
64	1.46	3.00	30	10	1.92	2.7	62	27	49	257	174	2.9	67	23	54	280	177
65	1.46	3.00	30	10	1.92	2.7	62	25	46	263	179	2.9	67	22	50	287	183
66	1.46	3.00	30	10	1.92	2.7	62	50	83	205	141	2.9	67	45	89	224	145
67	1.46	3.00	30	10	1.92	2.7	62	27	50	255	173	2.9	67	24	54	278	176
68	1.46	3.00	30	10	1.92	2.7	62	32	42	231	190	2.9	67	28	43	252	198
69	1.46	3.00	30	10	1.92	2.7	62	124	132			2.9	67	115	127	149	
70	1.46	3.00	30	10	1.92	2.7	62	119	126			2.9	67	110	122	153	
71	1.46	3.00	30	10	1.92	2.7	62	6	6	688	606	2.9	67	5	6	729	621
72	1.46	3.00	30	10	1.92	2.7	62	15	16	335	303	2.9	67	13	15	361	316
73	1.46	3.00	30	10	1.92	2.7	62	45	50	221	198	2.9	67	41	49	241	208
74	1.46	3.00	30	10	1.92	2.7	62	47	55	214	186	2.9	67	43	54	234	195
75	1.46	3.00	30	10	1.92	2.7	62	21	28	274	225	2.9	67	18	28	298	234
76	1.46	3.00	30	10	1.92	2.7	62	48	55	213	186	2.9	67	43	54	234	194
77	1.46	3.00	30	10	1.92	2.7	62	24	33	262	209	2.9	67	21	34	285	216
78	1.46	3.00	30	10	1.92	2.7	62	61	75	196	162	2.9	67	56	76	215	169
79	1.46	3.00	30	10	1.92	2.7	62	119	126	142		2.9	67	111	122	157	142
80	1.46	3.00	30	10	1.92	2.7	62	124	132			2.9	67	116	128	152	
81	Supernate liquid only transfer									Less than 140 gpm							

Notes

New = new or like new pipeline with maximum expected pipe roughness of 2 mils (0.002 inches).

EOL = pipeline at end of life (50 years for carbon steel line, 40 years for stainless steel line) with pipe roughness due to corrosion estimated at *150 mils for carbon steel* and 10 mils for stainless steel.

Design Pressure = All stainless steel pipelines have a design pressure of 400 lbf/in². The design pressure of carbon steel pipelines are either 275 or 400 lbf/in² as indicated.

The predicted flow rate at design pressure given in this table assumes that all pipelines are or can be qualified to the higher 400 lbf/in² design pressure.

Table D-3. 3S4 Case 1b.

CASE 3S4 Transfer List - Tank-to-Tank — Case 1b

Critical velocity by Oroskar and Turian (1980) empirical correlation (β_{cv} = 1.2). Pressure drop by Wasp et al. (1977) method with lognormal particle size distribution.

Transfer pipe: 3-in. Schedule-40 Pipe (3.068 in. inside dia.)

Group 1 Properties: Liquid (K), Solids (L–N), Bulk (O). Temperature = 10 °C: P–U; Temperature = 60 °C: V–AA. Group 2 Properties: Liquid (AB), Solids (AC–AE), Bulk (AF). Temperature = 10 °C: AG–AL; Temperature = 60 °C: AM–AR. Critical (K_{cv} = 1.30, K_f = 1).

Row	From Tank (A)	To Tank (B)	Tank Farm Built (Yr) (C)	# (D)	Dates (M/Yr) Start (E)	Dates (M/Yr) End (F)	Design Pressure (lbf/in²)* (G)	Carbon Steel Length (ft) (H)	Stainless Steel Length (ft) (I)	Total Change in Elevation (ft) (J)	ρ_L Density (kg/L) (K)	ρ_s Density (kg/L) (L)	C_v Volume (%) (M)	d_p Median Dia. (μm) (N)	ρ_m Bulk Density (kg/L) (O)	10 °C Critical Velocity (ft/s) (P)	10 °C Critical Flow Rate (gpm) (Q)	10 °C Total Pressure Drop (lbf/in²) New (R)	EOL (S)	10 °C Flow Rate at a Pipe Design Pressure of 400 lbf/in² (gpm) New (T)	EOL (U)	60 °C Critical Velocity (ft/s) (V)	60 °C Critical Flow Rate (gpm) (W)	60 °C Total Pressure Drop (lbf/in²) New (X)	EOL (Y)	60 °C Flow Rate at 400 lbf/in² (gpm) New (Z)	EOL (AA)	ρ_L Density (kg/L) (AB)	ρ_s Density (kg/L) (AC)	C_v Volume (%) (AD)	d_p Median Dia. (μm) (AE)	ρ_m Bulk Density (kg/L) (AF)	10 °C Critical Velocity (ft/s) (AG)	10 °C Critical Flow Rate (gpm) (AH)	10 °C Total Pressure Drop (lbf/in²) New (AI)	EOL (AJ)	10 °C Flow Rate at 400 lbf/in² (gpm) New (AK)	EOL (AL)	60 °C Critical Velocity (ft/s) (AM)	60 °C Critical Flow Rate (gpm) (AN)	60 °C Total Pressure Drop (lbf/in²) New (AO)	EOL (AP)	60 °C Flow Rate at 400 lbf/in² (gpm) New (AQ)	EOL (AR)
6	AN-101	AP-103	83-86	1	3/03	3/03	400	306	2,774	12	1.10	2.50	15	5	1.31	2.9	67	29	38	314	247	3.2	74	29	42	324	249	1.20	3.00	30	10	1.74	3.7	84	58	76	261	211	4.0	92	58	83	274	215
7		AN-106	80-81	2	3/03	3/03		442	626	0	1.10	2.50	15	5	1.31	2.9	67	8	15	548	356	3.2	74	8	17	560	357	1.20	3.00	30	10	1.74	3.7	84	17	31	462	307	4.0	92	17	36	479	309
8		AN-107	80-81	3	9/05	8/12		557	626	0	1.10	2.50	15	5	1.31	2.9	67	8	17	520	329	3.2	74	9	20	532	330	1.20	3.00	30	10	1.74	3.7	84	19	37	438	284	4.0	92	19	42	455	286
9		BNFL		4	10/08	12/14	400	0	6,413	40	1.10	2.50	15	5	1.31	2.9	67	69	80	209	179	3.2	74	70	86	218	182	1.20	3.00	30	10	1.74	3.7	84	132	153	171	150	4.0	92	131	163	182	155
10	AN-102	AN-106	80-81	1	8/06	8/06		319	626	0	1.10	2.50	15	5	1.31	2.9	67	7	12	584	393	3.2	74	7	14	596	394	1.20	3.00	30	10	1.74	3.7	84	15	26	492	339	4.0	92	15	30	510	341
11		AN-101	80-81	1	10/08	10/08		405	421	0	1.10	2.50	15	5	1.31	2.9	67	6	12	626	390	3.2	74	6	14	638	392	1.20	3.00	30	10	1.74	3.7	84	13	26	528	337	4.0	92	13	30	547	339
12		AN-105	80-81	1	12/12	12/12		329	626	0	1.10	2.50	15	5	1.31	2.9	67	7	12	581	389	3.2	74	7	14	593	391	1.20	3.00	30	10	1.74	3.7	84	15	26	489	336	4.0	92	15	30	508	338
13	AN-103	AN-105	80-81	1	10/11	10/11		300	626	0	1.10	2.50	15	5	1.31	2.9	67	7	12	590	400	3.2	74	7	14	602	401	1.20	3.00	30	10	1.74	3.7	84	15	25	497	345	4.0	92	15	29	516	347
14		BNFL		2	5/13	5/18		376	6,823	40	1.10	2.50	15	5	1.31	2.9	67	74	91	196	162	3.2	74	75	99	205	165	1.20	3.00	30	10	1.74	3.7	84	144	177	160		4.0	92	144	191	171	140
15	AN-104	AN-101	80-81	4	9/05	5/15		526	626	0	1.10	2.50	15	5	1.31	2.9	67	8	17	527	335	3.2	74	8	19	539	337	1.20	3.00	30	10	1.74	3.7	84	18	35	444	290	4.0	92	18	40	461	292
16		BNFL		2	6/09	4/11	400	0	6,275	40	1.10	2.50	15	5	1.31	2.9	67	68	78	211	181	3.2	74	69	85	220	184	1.20	3.00	30	10	1.74	3.7	84	129	150	173	152	4.0	92	129	161	184	157
17		AZ-101	71	1	6/09	6/09	400	562	1,560	5	1.10	2.50	15	5	1.31	2.9	67	18	29	383	271	3.2	74	18	32	394	273	1.20	3.00	30	10	1.74	3.7	84	37	58	320	233	4.0	92	37	65	335	235
18		AN-107	80-81	1	6/09	6/09		489	421	0	1.10	2.50	15	5	1.31	2.9	67	6	14	595	364	3.2	74	7	16	608	366	1.20	3.00	30	10	1.74	3.7	84	14	30	502	315	4.0	92	14	34	520	317
19		AN-102	80-81	1	4/11	4/11		439	626	0	1.10	2.50	15	5	1.31	2.9	67	8	15	561	356	3.2	74	8	17	561	358	1.20	3.00	30	10	1.74	3.7	84	17	31	462	308	4.0	92	17	36	480	310
20		AW-103	78-80	2	4/11	9/11		1,012	3,046	21	1.10	2.50	15	5	1.31	2.9	67	41	60	270	194	3.2	74	42	67	280	196	1.20	3.00	30	10	1.74	3.7	84	80	119	223	166	4.0	92	80	132	236	169
21		AW-101	78-80	4	8/12	8/16		994	3,046	21	1.10	2.50	15	5	1.31	2.9	67	41	60	270	195	3.2	74	41	67	280	197	1.20	3.00	30	10	1.74	3.7	84	80	118	223	167	4.0	92	80	131	236	169
22		AN-103	80-81	2	6/13	10/13		410	626	0	1.10	2.50	15	5	1.31	2.9	67	7	14	557	364	3.2	74	8	16	569	366	1.20	3.00	30	10	1.74	3.7	84	16	30	469	314	4.0	92	16	34	487	317
23		AN-106	80-81	2	1/14	5/14		374	421	0	1.10	2.50	15	5	1.31	2.9	67	6	12	638	402	3.2	74	6	13	651	403	1.20	3.00	30	10	1.74	3.7	84	13	25	539	347	4.0	92	13	26	557	349
24		AW-104	78-80	2	5/15	7/15		1,003	3,046	21	1.10	2.50	15	5	1.31	2.9	67	41	60	270	195	3.2	74	41	67	280	197	1.20	3.00	30	10	1.74	3.7	84	80	118	223	166	4.0	92	80	131	236	169
25		AN-105	80-81	2	11/15	12/15		384	421	0	1.10	2.50	15	5	1.31	2.9	67	6	12	634	398	3.2	74	6	14	647	399	1.20	3.00	30	10	1.74	3.7	84	13	25	535	344	4.0	92	13	29	554	346
26		AP-101	83-86	2	2/17	2/17	400	419	2,636	12	1.10	2.50	15	5	1.31	2.9	67	29	39	315	242	3.2	74	29	43	325	244	1.20	3.00	30	10	1.74	3.7	84	57	78	262	207	4.0	92	57	86	276	210
27		AP-105	83-86	1	12/17	12/17	400	302	2,636	12	1.10	2.50	15	5	1.31	2.9	67	28	37	321	252	3.2	74	28	40	332	255	1.20	3.00	30	10	1.74	3.7	84	56	73	267	215	4.0	92	56	80	281	219
28		AW-105	78-80	1	3/18	3/18		1,125	3,046	21	1.10	2.50	15	5	1.31	2.9	67	42	63	266	190	3.2	74	42	70	276	191	1.20	3.00	30	10	1.74	3.7	84	82	124	220	162	4.0	92	82	138	232	165
29		AP-102	83-86	1	4/19	4/19	400	431	2,636	12	1.10	2.50	15	5	1.31	2.9	67	29	39	314	241	3.2	74	29	44	325	243	1.20	3.00	30	10	1.74	3.7	84	58	79	261	206	4.0	92	58	86	275	209
30		AW-106	78-80	1	10/19	10/19		1,114	3,046	21	1.10	2.50	15	5	1.31	2.9	67	42	62	266	190	3.2	74	42	70	276	192	1.20	3.00	30	10	1.74	3.7	84	82	123	220	162	4.0	92	81	137	233	165
31	AN-105	AN-104	80-81	1	6/09	6/09		384	421	0	1.10	2.50	15	5	1.31	2.9	67	6	12	634	398	3.2	74	6	14	647	399	1.20	3.00	30	10	1.74	3.7	84	13	25	535	344	4.0	92	13	29	554	346
32		BNFL		3	10/11	11/15		452	7,028	40	1.10	2.50	15	5	1.31	2.9	67	76	95	192	158	3.2	74	77	103	201	161	1.20	3.00	30	10	1.74	3.7	84	148	184	157		4.0	92	148	200	168	
33	AN-106	AP-107	83-86	1	9/05	9/05		865	3,389	12	1.10	2.50	15	5	1.31	2.9	67	37	55	265	196	3.2	74	38	62	275	198	1.20	3.00	30	10	1.74	3.7	84	76	112	219	168	4.0	92	76	124	232	171
34		BNFL		4	8/06	1/14		442	7,028	40	1.10	2.50	15	5	1.31	2.9	67	76	94	193	158	3.2	74	77	103	201	161	1.20	3.00	30	10	1.74	3.7	84	148	184	157		4.0	92	148	199	168	
35		AN-107	80-81	2	2/10	4/12		269	421	0	1.10	2.50	15	5	1.31	2.9	67	5	9	686	448	3.2	74	5	11	699	450	1.20	3.00	30	10	1.74	3.7	84	11	20	580	387	4.0	92	11	23	599	389
36	AN-107	AN-106	80-81	2	9/05	9/05		269	421	0	1.10	2.50	15	5	1.31	2.9	67	5	9	686	448	3.2	74	5	11	699	450	1.20	3.00	30	10	1.74	3.7	84	11	20	580	387	4.0	92	11	23	599	389
37		AW-102	78-80	1	10/10	10/10		1,357	3,006	21	1.10	2.50	15	5	1.31	2.9	67	43	67	259	181	3.2	74	44	75	269	183	1.20	3.00	30	10	1.74	3.7	84	85	133	214	155	4.0	92	85	149	227	157
38	AP-101	AP-104	83-86	1	8/16	8/16	400	733	421	0	1.10	2.50	15	5	1.31	2.9	67	8	19	527	311	3.2	74	8	22	539	312	1.20	3.00	30	10	1.74	3.7	84	18	40	443	269	4.0	92	18	47	461	270
39		AP-102	83-86	1	2/17	2/17	400	850	421	0	1.10	2.50	15	5	1.31	2.9	67	9	22	501	292	3.2	74	9	25	513	293	1.20	3.00	30	10	1.74	3.7	84	20	46	421	253	4.0	92	20	53	438	254
40	AP-102	AN-106	80-81	1	2/10	2/10		883	3,389	-12	1.10	2.50	15	5	1.31	2.9	67	23	42	269	199	3.2	74	24	48	279	201	1.20	3.00	30	10	1.74	3.7	84	58	94	224	171	4.0	92	58	107	237	174
41		AN-107	80-81	3	10/10	2/17		988	3,389	-12	1.10	2.50	15	5	1.31	2.9	67	24	44	266	194	3.2	74	25	51	276	196	1.20	3.00	30	10	1.74	3.7	84	60	99	221	167	4.0	92	60	112	234	170
42		BNFL		5	6/15	4/19	400	431	5,370	28	1.10	2.50	15	5	1.31	2.9	67	57	73	222	180	3.2	74	58	79	232	183	1.20	3.00	30	10	1.74	3.7	84	113	143	183	152	4.0	92	113	155	194	156
43	AP-104	AP-102	83-86	1	6/15	6/15	400	745	421	0	1.10	2.50	15	5	1.31	2.9	67	8	19	524	309	3.2	74	8	23	536	310	1.20	3.00	30	10	1.74	3.7	84	18	41	441	267	4.0	92	18	47	458	268
44		BNFL		3	8/16	10/18	400	314	5,370	28	1.10	2.50	15	5	1.31	2.9	67	57	70	225	184	3.2	74	57	77	234	187	1.20	3.00	30	10	1.74	3.7	84	111	137	185	156	4.0	92	111	149	196	160
45	AP-105	AP-104	83-86	1	7/17	7/17	400	616	421	0	1.10	2.50	15	5	1.31	2.9	67	7	17	556	333	3.2	74	8	19	569	334	1.20	3.00	30	10	1.74	3.7	84	16	35	469	288	4.0	92	16	41	487	290
46		AP-102	83-86	1	12/17	12/17	400	733	421	0	1.10	2.50	15	5	1.31	2.9	67	8	19	527	311	3.2	74	8	22	539	312	1.20	3.00	30	10	1.74	3.7	84	18	40	443	269	4.0	92	18	47	461	270
47	AP-107	AW-102	78-80	10	9/00	9/05		1,223	421	9	1.10	2.50	15	5	1.31	2.9	67	17	35	436	248	3.2	74	17	40	447	249	1.20	3.00	30	10	1.74	3.7	84	33	69	365	214	4.0	92	33	79	381	215
48	AP-108	AP-107	83-86	2	9/01	9/02	400	866	421	0	1.10	2.50	15	5	1.31	2.9	67	9	22	498	290	3.2	74	9	26	510	291	1.20	3.00	30	10	1.74	3.7	84	20	46	419	251	4.0	92	20	54	436	252
49	AW-101	AN-106	80-81	1	4/12	4/12		1,436	3,799	-21	1.10	2.50	15	5	1.31	2.9	67	25	52	243	174	3.2	74	26	61	253	176	1.20	3.00	30	10	1.74	3.7	84	67	120	203	150	4.0	92	67	137	215	152
50		AN-101	80-81	1	8/12	8/12		994	3,184	-21	1.10	2.50	15	5	1.31	2.9	67	18	37	274	199	3.2	74	18	44	284	201	1.20	3.00	30	10	1.74	3.7	84	50	89	229	171	4.0	92	50	102	242	174
51		AP-102	83-86	1	4/16	4/16		1,425	831	-9	1.10	2.50	15	5	1.31	2.9	67	11	32	375	224	3.2	74	11	39	386	224	1.20	3.00	30	10	1.74	3.7	84	29	72	314	193	4.0	92	29	85	329	195
52	AW-103	AY-102	68-70	1	7/07	7/07		1,012	3,320	-10	1.10	2.50	15	5	1.31	2.9	67	25	45	267	194	3.2	74	26	52	277	196	1.20	3.00	30	10	1.74	3.7	84	61	101	222	167	4.0	92	61	114	235	170
53		AY-101	68-70	1	3/08	3/08		1,012	3,695	-10	1.10	2.50	15	5	1.31	2.9	67	28	48	255	188	3.2	74	29	56	265	190	1.20	3.00	30	10	1.74	3.7	84	67	108	212	162	4.0	92	67	122	225	165
54		AZ-101	71	1	10/10	10/10		1,012	2,942	-17	1.10	2.50	15	5	1.31	2.9	67	19	38	281	202	3.2	74	19	44	291	204	1.20	3.00	30	10	1.74	3.7	84	50	88	235	174	4.0	92	49	101	248	177
55	AW-104	AP-102	83-86	1	10/10	10/10		1,434	831	-9	1.10	2.50	15	5	1.31	2.9	67	11	33	374	223	3.2	74	11	39	385	224	1.20	3.00	30	10	1.74	3.7	84	29	73	313	193	4.0	92	29	85	328	194
56		AZ-102	77	1	5/13	5/13		1,003	3,327	-17	1.10	2.50	15	5	1.31	2.9	67	21	41	268	195	3.2	74	22	48	278	197	1.20	3.00	30	10	1.74	3.7	84	55	95	224	168	4.0	92	55	108	237	171
57		AY-101	68-70	1	5/15	5/15		1,003	3,695	-10	1.10	2.50	15	5	1.31	2.9	67	28	48	255	189	3.2	74	29	56	265	190	1.20	3.00	30	10	1.74	3.7	84	67	107	213	162	4.0	92	67	121	225	165
58	AW-105	AZ-101	71	1	10/16	10/16		1,125	2,942	-17	1.10	2.50	15	5	1.31	2.9	67	19	40	277	197	3.2	74	20	47	287	198	1.20	3.00	30	10	1.74	3.7	84	51	93	231	169	4.0	92	51	107	245	172
59		AZ-102	77	1	3/18	3/18		1,125	3,327	-17	1.10	2.50	15	5	1.31	2.9	67	22	43	264	190	3.2	74	23	51	274	192	1.20	3.00	30	10	1.74	3.7	84	57	100	220	164	4.0	92	57	115	233	167
60	AW-106	AP-107	83-86	1	9/05	9/05		1,537	831	-9	1.10	2.50	15	5	1.31	2.9	67	12	35	365	217	3.2	74	12	41	376	218	1.20	3.00	30	10	1.74	3.7	84	31	77	306	188	4.0	92	31	90	321	189
61		AN-102	80-81	1	12/12	12/12		1,519	3,594	-21	1.10	2.50	15	5	1.31	2.9	67	24	52	246	174	3.2	74	25	61	256	175	1.20	3.00	30	10	1.74	3.7	84	65	120	205	150	4.0	92	65	138	218	152
62		AW-102	78-80	2	9/00	10/10		314	421	0	1.10	2.50	15	5	1.31	2.9	67	5	10	664	426	3.2	74	5	12	677	428	1.20	3.00	30	10	1.74	3.7	84	12	22	561	368	4.0	92	12	25	580	370
63		AW-104	78-80	1	10/00	10/00		341	421	0	1.10	2.50	15	5	1.31	2.9	67	5	11	652	415	3.2	74	6	13	665	416	1.20	3.00	30	10	1.74	3.7	84	12	23	551	358	4.0	92	12	26	570	360
64		AP-101	83-86	2	10/00	8/01		1,533	831	-9	1.10	2.50	15	5	1.31	2.9	67	12	35	366	217	3.2	74	12	41	377	218	1.20	3.00	30	10	1.74	3.7	84	31	77	306	188	4.0	92	31	90	321	189
65		AP-104	83-86	1	10/01	10/01		1,428	831	-9	1.10	2.50	15	5	1.31	2.9	67	11	32	374	223	3.2	74	11	39	385	224	1.20	3.00	30	10	1.74	3.7	84	29	72	314	193	4.0	92	29	85	329	195
66		AW-105	78-80	2	10/01	1/02		2,239	1,241	0	1.10	2.50	15	5	1.31	2.9	67	25	58	297	178	3.2	74	25	68	307	179	1.20	3.00	30	10	1.74	3.7	84	55	123	247	153	4.0	92	55	142	261	155
67		AP-108	83-86	1	2/05	2/05		1,557	831	-9	1.10	2.50	15	5	1.31	2.9	67	12	35	364	216	3.2	74	12	42	375	216	1.20	3.00	30	10	1.74	3.7	84	31	78	305	187	4.0	92	31	91	320	188
68	AY-101	AN-107	80-81	1	3/07	3/07		557	2,313	-11	1.10	2.50	15	5	1.31	2.9	67	14	28	331	245	3.2	74	15	30	342	247	1.20	3.00	30	10	1.74	3.7	84	37	60	277	211	4.0	92	37	68	291	214
69		BNFL		16	11/09	1/18	400	0	6,924	30	1.10	2.50	15	5	1.31	2.9	67	66	78	202	173	3.2	74	67	85	211	176	1.20	3.00	30	10	1.74	3.7	84	132	154	166	146	4.0	92	131	166	177	151
70	AY-102	BNFL		6	1/08	10/09	400	0	6,549	30	1.10	2.50	15	5	1.31	2.9	67	64	75	208	178	3.2	74	65	81	217	181	1.20	3.00	30	10	1.74	3.7	84	126	147	171	151	4.0	92	126	158	182	155
71		AY-101	68-70	1	2/12	2/12	400	0	388	0	1.10	2.50	15	5	1.31	2.9	67	3	3	924	765	3.2	74	3	4	938	769	1.20	3.00	30	10	1.74	3.7	84	6	7	785	659	4.0	92	6	8	806	665
72		AZ-102	77	1	6/17	6/17	400	0	1,468	-8	1.10	2.50	15	5	1.31	2.9	67	6	9	468	392	3.2	74	6	10	480	396	1.20	3.00	30	10	1.74	3.7	84	17	22	394	337	4.0	92	17	25	410	342
73		AP-101	83-86	1	10/17	10/17	400	128	2,910	2	1.10	2.50	15	5	1.31	2.9	67	23	29	318	261	3.2	74	23	33	329	264	1.20	3.00	30	10	1.74	3.7	84	49	62	265	223	4.0	92	49	68	279	228
74		AP-105	83-86	1	12/17	12/17	400	302	2,910	2	1.10	2.50	15	5	1.31	2.9	67	24	33	309	244	3.2	74	24	37	320	247	1.20	3.00	30	10	1.74	3.7	84	52	70	258	209	4.0	92	52	77	271	213
75		AN-103	80-81	1	6/18	6/18		376	1,733	-11	1.10	2.50	15	5	1.31	2.9	67	9	17	389	289	3.2	74	9	20	400	291	1.20	3.00	30	10	1.74	3.7	84	25	41	326	249	4.0	92	25	47	342	252
76		AP-104	83-86	1	10/18	10/18	400	314	2,910	2	1.10	2.50	15	5	1.31	2.9	67	24	33	309	243	3.2	74	24	37	319	246	1.20	3.00	30	10	1.74	3.7	84	52	70	257	208	4.0	92	52	78	271	212
77		AN-107	80-81	1	10/19	10/19		557	1,733	-11	1.10	2.50	15	5	1.31	2.9	67	10	21	372	267	3.2	74	10	25	383	269	1.20	3.00	30	10	1.74	3.7	84	28	49	312	230	4.0	92	28	56	327	233
78		AW-102	78-80	1	10/19	10/19		761	2,910	10	1.10	2.50	15	5	1.31	2.9	67	32	48	286	211	3.2	74	33	53	297	213	1.20	3.00	30	10	1.74	3.7	84	66	97	238	181	4.0	92	66	108	251	184
79	AZ-101	BNFL		18	10/04	4/19	400	0	6,171	36	1.10	2.50	15	5	1.31	2.9	67	65	75	214	183	3.2	74	66	81	223	186	1.20	3.00	30	10	1.74	3.7	84	125	145	175	154	4.0	92	125	155	187	159
80	AZ-102	BNFL		18	11/06	11/91	400	0	6,556	36	1.10	2.50	15	5	1.31	2.9	67	67	79	207	177	3.2	74	68	85	216	180	1.20	3.00	30	10	1.74	3.7	84	131	152	169	149	4.0	92	131	163	181	154
81	BNFL internal equivalent pipe length and elevation								884	45	included in BNFL routes						Exceeds 275 lbf/in²						Exceeds 400 lbf/in²							Supernate liquid only transfer										Less than 140 gpm				

Notes (AS):

New = new or like new pipeline with maximum expected pipe roughness of 2 mils (0.002 inches).

EOL = pipeline at end of life (50 years for carbon steel line, 40 years for stainless steel line) with pipe roughness due to corrosion estimated at 150 mils for carbon steel and 10 mils for stainless steel.

***Design Pressure** = All stainless steel pipelines have a design pressure of 400 lbf/in². The design pressure of carbon steel pipelines are either 275 or 400 lbf/in² as indicated. The predicted flow rate at design pressure given in this table assumes that all pipelines are or can be qualified to the higher 400 lbf/in² design pressure.

Table D-4. 3S4 Case 1c.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL	AM	AN	AO	AP	AQ	AR
1	CASE 3S4 Transfer List - Tank-to-Tank										Case 1c	Critical velocity by Oroskar and Turian (1980) empirical correlation (β_{cv} = 1.2). Pressure drop by Wasp et al. (1977) method with lognormal particle size distribution.																																
2											Group 1 Properties					Temperature = 10 °C						Temperature = 60 °C						Group 2 Properties					Temperature = 10 °C						Temperature = 60 °C					
3	Transfer		Tank Farm Built (Yr)		Transfer			3-in. Schedule-40 Pipe (3.068 in. inside dia.)		Total Change in Elevation (ft)	Liquid	Solids			ρ_m Bulk Density (kg/L)	Critical (κ_{cv} = 1.30, κ_f = 1)				Flow Rate at a Pipe Design Pressure of 400 lbf/in² (gpm)		Critical (κ_{cv} = 1.30, κ_f = 1)				Flow Rate at a Pipe Design Pressure of 400 lbf/in² (gpm)		Liquid	Solids			ρ_m Bulk Density (kg/L)	Critical (κ_{cv} = 1.30, κ_f = 1)				Flow Rate at a Pipe Design Pressure of 400 lbf/in² (gpm)		Critical (κ_{cv} = 1.30, κ_f = 1)				Flow Rate at a Pipe Design Pressure of 400 lbf/in² (gpm)	
4	From Tank	To Tank		#	Dates (M/Yr)		Design Pressure* (lbf/in²)	Carbon Steel Length (ft)	Stainless Steel Length (ft)		ρ_L Density (kg/L)	ρ_s Density (kg/L)	C_s Volume (%) times	d_p Median Dia. (μm)		Velocity (ft/s)	Flow Rate (gpm)	Total Pressure Drop (lbf/in²)				Velocity (ft/s)	Flow Rate (gpm)	Total Pressure Drop (lbf/in²)				ρ_L Density (kg/L)	ρ_s Density (kg/L)	C_s Volume (%) times	d_p Median Dia. (μm)		Velocity (ft/s)	Flow Rate (gpm)	Total Pressure Drop (lbf/in²)				Velocity (ft/s)	Flow Rate (gpm)	Total Pressure Drop (lbf/in²)			
5					Start	End							1.5					New	EOL	New	EOL			New	EOL	New	EOL			2.0					New	EOL	New	EOL			New	EOL	New	EOL
6	AN-101	AP-103	83-86	1	3/03	3/03	400	306	2,774	12	1.21	2.50	0.00	5	1.21	0.3	7	7	7	328	257	0.1	3	6	6	338	260	1.46	3.00	0.00	10	1.46	1.0	22	12	13	275	227	0.4	10	9	9	292	232
7		AN-106	80-81	2	3/03	3/03		442	626	0	1.21	2.50	0.00	5	1.21	0.3	7	0	0	573	370	0.1	3	0	0	584	371	1.46	3.00	0.00	10	1.46	1.0	22	2	2	492	333	0.4	10	0	0	513	336
8		AN-107	80-81	3	9/05	8/12		557	626	0	1.21	2.50	0.03	5	1.21	1.1	24	1	2	543	342	1.2	27	1	3	554	343	1.46	3.00	0.04	10	1.46	1.1	26	2	3	485	308	1.2	28	2	3	487	311
9		BNFL		4	10/08	12/14	400	0	6,413	40	1.21	2.50	0.29	5	1.21	1.5	35	34	36	219	187	1.6	38	34	37	227	189	1.46	3.00	0.38	10	1.47	1.6	36	48	50	179	161	1.7	39	46	49	192	167
10	AN-102	AN-106	80-81	1	8/06	8/06		319	626	0	1.21	2.50	0.24	5	1.21	1.5	34	2	3	609	408	1.6	37	2	3	620	410	1.46	3.00	0.32	10	1.46	1.5	35	3	4	524	367	1.6	38	3	5	546	370
11		AN-101	80-81	1	10/08	10/08		405	421	0	1.21	2.50	0.24	5	1.21	1.5	34	2	3	653	406	1.6	37	2	3	664	407	1.46	3.00	0.32	10	1.46	1.5	35	3	4	562	366	1.6	38	3	5	585	369
12		AN-105	80-81	1	12/12	12/12		329	626	0	1.21	2.50	1.26	5	1.23	1.9	43	3	5	602	403	2.0	47	3	6	614	404	1.46	3.00	1.68	10	1.49	2.0	45	5	7	516	361	2.1	49	5	8	539	365
13	AN-103	AN-105	80-81	1	10/11	10/11		300	626	0	1.21	2.50	0.20	5	1.21	1.4	33	2	3	616	416	1.5	36	2	3	627	417	1.46	3.00	0.26	10	1.46	1.5	34	3	4	529	373	1.6	37	3	4	552	377
14		BNFL		2	5/13	5/18		376	6,823	40	1.21	2.50	1.10	5	1.22	1.8	42	42	48	205	168	2.0	46	42	50	213	171	1.46	3.00	1.46	10	1.48	1.9	44	62	67	167	145	2.1	48	59	68	179	150
15	AN-104	AN-101	80-81	4	9/05	5/15		526	626	0	1.21	2.50	1.29	5	1.23	1.9	43	3	7	547	347	2.1	47	3	8	558	348	1.46	3.00	1.72	10	1.49	2.0	45	6	10	467	311	2.1	49	6	10	488	314
16		BNFL		2	6/09	4/11	400	0	6,275	40	1.21	2.50	0.71	5	1.22	1.7	40	37	40	221	188	1.9	43	37	42	229	191	1.46	3.00	0.94	10	1.47	1.8	41	53	56	181	162	1.9	45	51	56	194	168
17		AZ-101	71	1	6/09	6/09	400	562	1,560	5	1.21	2.50	4.01	5	1.26	2.2	51	12	17	391	276	2.4	56	12	19	402	278	1.46	3.00	5.34	10	1.54	2.3	53	19	25	326	244	2.5	57	18	26	345	248
18		AN-107	80-81	1	6/09	6/09		489	421	0	1.21	2.50	0.66	5	1.22	1.7	39	2	5	620	378	1.9	43	2	5	631	379	1.46	3.00	0.88	10	1.47	1.8	41	4	7	532	340	1.9	44	4	7	555	343
19		AN-102	80-81	1	4/11	4/11		439	626	0	1.21	2.50	7.32	5	1.30	2.4	55	5	10	550	357	2.6	60	5	12	562	358	1.46	3.00	9.76	10	1.61	2.5	57	9	15	461	316	2.7	62	9	16	484	320
20		AW-103	78-80	2	4/11	9/11		1,012	3,046	21	1.21	2.50	7.26	5	1.30	2.4	55	32	45	270	195	2.6	60	32	49	280	197	1.46	3.00	9.68	10	1.61	2.5	57	50	64	218	169	2.7	62	48	67	234	173
21		AW-101	78-80	4	8/12	8/16		994	3,046	21	1.21	2.50	2.78	5	1.25	2.1	49	26	36	278	201	2.3	53	27	39	288	202	1.46	3.00	3.70	10	1.52	2.2	51	40	50	229	176	2.4	55	38	52	245	180
22		AN-103	80-81	2	6/13	10/13		410	626	0	1.21	2.50	1.20	5	1.23	1.9	43	3	6	578	377	2.0	47	3	6	589	378	1.46	3.00	1.60	10	1.48	1.9	45	5	8	494	338	2.1	48	5	9	516	341
23		AN-106	80-81	2	1/14	5/14		374	421	0	1.21	2.50	1.17	5	1.23	1.9	43	2	4	662	416	2.0	47	2	5	674	417	1.46	3.00	1.56	10	1.48	1.9	45	4	6	569	374	2.1	48	4	7	593	377
24		AW-104	78-80	2	5/15	7/15		1,003	3,046	21	1.21	2.50	1.29	5	1.23	1.9	43	23	30	281	202	2.1	47	23	33	290	203	1.46	3.00	1.72	10	1.49	2.0	45	35	42	232	178	2.1	49	33	44	248	181
25		AN-105	80-81	2	11/15	12/15		384	421	0	1.21	2.50	1.29	5	1.23	1.9	43	2	5	657	411	2.1	47	2	5	669	413	1.46	3.00	1.72	10	1.49	2.0	45	4	7	565	370	2.1	49	4	7	588	373
26		AP-101	83-86	2	2/17	2/17	400	419	2,636	12	1.21	2.50	3.15	5	1.25	2.1	49	19	24	323	248	2.3	54	19	26	333	250	1.46	3.00	4.20	10	1.52	2.2	52	29	34	268	217	2.4	56	27	35	285	222
27		AP-105	83-86	1	12/17	12/17	400	302	2,636	12	1.21	2.50	4.77	5	1.27	2.3	52	20	25	327	256	2.5	57	20	27	337	259	1.46	3.00	6.36	10	1.56	2.4	55	31	36	270	223	2.5	59	29	37	287	229
28		AW-105	78-80	1	3/18	3/18		1,125	3,046	21	1.21	2.50	4.77	5	1.27	2.3	52	30	42	270	193	2.5	57	30	46	280	194	1.46	3.00	6.36	10	1.56	2.4	55	46	59	221	168	2.5	59	44	62	236	172
29		AP-102	83-86	1	4/19	4/19	400	431	2,636	12	1.21	2.50	3.36	5	1.25	2.2	50	19	24	322	246	2.4	54	19	26	332	249	1.46	3.00	4.48	10	1.53	2.3	52	29	35	267	216	2.4	56	28	36	284	221
30		AW-106	78-80	1	10/19	10/19		1,114	3,046	21	1.21	2.50	2.87	5	1.25	2.1	49	27	37	274	195	2.3	53	27	41	283	197	1.46	3.00	3.82	10	1.52	2.2	51	41	52	225	171	2.4	55	39	54	241	175
31	AN-105	AN-104	80-81	1	6/09	6/09		384	421	0	1.21	2.50	0.18	5	1.21	1.4	32	1	3	662	414	1.5	35	1	3	673	415	1.46	3.00	0.24	10	1.46	1.5	34	2	4	570	373	1.6	36	2	4	594	376
32		BNFL		3	10/11	11/15		452	7,028	40	1.21	2.50	1.22	5	1.23	1.9	43	43	50	201	164	2.0	47	43	53	209	166	1.46	3.00	1.62	10	1.48	2.0	45	64	71	163	141	2.1	48	62	71	176	146
33	AN-106	AP-107	83-86	1	9/05	9/05		865	3,389	12	1.21	2.50	0.00	5	1.21	0.3	7	7	7	278	205	0.1	3	7	7	287	206	1.46	3.00	0.00	10	1.46	1.0	22	14	16	231	181	0.4	10	9	9	246	185
34		BNFL		4	8/06	1/14		442	7,028	40	1.21	2.50	0.56	5	1.22	1.7	38	39	44	202	165	1.8	42	39	46	210	167	1.46	3.00	0.74	10	1.47	1.7	40	56	61	164	142	1.9	43	54	62	177	147
35		AN-107	80-81	2	2/10	4/12		269	421	0	1.21	2.50	0.05	5	1.21	1.1	26	1	1	717	466	1.2	28	1	2	728	468	1.46	3.00	0.06	10	1.46	1.2	27	1	2	620	420	1.3	29	1	2	644	423
36	AN-107	AN-106	80-81	2	9/05	9/05		269	421	0	1.21	2.50	0.33	5	1.21	1.5	35	1	2	715	466	1.7	39	1	3	727	467	1.46	3.00	0.44	10	1.47	1.6	37	2	4	618	419	1.7	40	2	4	642	423
37		AW-102	78-80	1	10/10	10/10		1,357	3,006	21	1.21	2.50	0.11	5	1.21	1.3	30	18	22	272	189	1.4	32	17	23	281	190	1.46	3.00	0.14	10	1.46	1.3	31	25	29	226	167	1.5	33	24	30	241	170
38	AP-101	AP-104	83-86	1	8/16	8/16	400	733	421	0	1.21	2.50	0.00	5	1.21	0.3	7	0	0	551	323	0.1	3	0	0	561	324	1.46	3.00	0.00	10	1.46	1.0	22	2	3	472	292	0.4	10	0	1	493	294
39		AP-102	83-86	1	2/17	2/17	400	850	421	0	1.21	2.50	0.00	5	1.21	0.3	7	0	0	524	304	0.1	3	0	0	535	305	1.46	3.00	0.00	10	1.46	1.0	22	2	3	448	274	0.4	10	0	1	469	276
40	AP-102	AN-106	80-81	1	2/10	2/10		883	3,389	-12	1.21	2.50	0.00	5	1.21	0.3	7	-6	-6	282	207	0.1	3	-6	-6	291	209	1.46	3.00	0.00	10	1.46	1.0	22	-1	0	235	184	0.4	10	-7	-6	251	188
41		AN-107	80-81	3	10/10	2/17		988	3,389	-12	1.21	2.50	0.05	5	1.21	1.1	26	-1	1	278	202	1.2	28	-1	2	287	204	1.46	3.00	0.06	10	1.46	1.2	27	1	4	232	179	1.3	29	1	4	247	183
42		BNFL		5	6/15	4/19	400	431	5,370	28	1.21	2.50	0.29	5	1.21	1.5	35	26	29	233	188	1.6	38	26	31	241	190	1.46	3.00	0.38	10	1.47	1.6	36	38	41	192	163	1.7	39	36	41	205	168
43	AP-104	AP-102	83-86	1	6/15	6/15	400	745	421	0	1.21	2.50	0.00	5	1.21	0.3	7	0	0	548	321	0.1	3	0	0	559	322	1.46	3.00	0.00	10	1.46	1.0	22	2	3	469	290	0.4	10	0	1	490	292
44		BNFL		3	8/16	10/18	400	314	5,370	28	1.21	2.50	0.24	5	1.21	1.5	34	25	28	235	192	1.6	37	25	29	244	195	1.46	3.00	0.32	10	1.46	1.5	35	36	39	194	167	1.6	38	35	39	208	172
45	AP-105	AP-104	83-86	1	7/17	7/17	400	616	421	0	1.21	2.50	0.24	5	1.21	1.5	34	2	4	581	346	1.6	37	2	5	592	347	1.46	3.00	0.32	10	1.46	1.5	35	3	6	498	312	1.6	38	3	6	520	315
46		AP-102	83-86	1	12/17	12/17	400	733	421	0	1.21	2.50	0.24	5	1.21	1.5	34	2	5	550	323	1.6	37	2	5	561	324	1.46	3.00	0.32	10	1.46	1.5	35	4	7	471	291	1.6	38	3	7	492	293
47	AP-107	AW-102	78-80	10	9/00	9/05		1,223	421	9	1.21	2.50	0.00	5	1.21	0.3	7	5	5	456	258	0.1	3	5	5	466	259	1.46	3.00	0.00	10	1.46	1.0	22	8	10	387	233	0.4	10	6	6	407	234
48	AP-108	AP-107	83-86	2	9/01	9/02	400	866	421	0	1.21	2.50	0.00	5	1.21	0.3	7	0	0	520	302	0.1	3	0	0	531	302	1.46	3.00	0.00	10	1.46	1.0	22	2	3	445	272	0.4	10	0	1	466	274
49	AW-101	AN-106	80-81	1	4/12	4/12		1,436	3,799	-21	1.21	2.50	0.23	5	1.21	1.4	33	-1	4	254	181	1.6	36	-2	6	263	182	1.46	3.00	0.30	10	1.46	1.5	35	3	10	212	160	1.6	38	2	10	226	164
50		AN-101	80-81	1	8/12	8/12		994	3,184	-21	1.21	2.50	0.29	5	1.21	1.5	35	-3	1	286	207	1.6	38	-3	3	295	208	1.46	3.00	0.38	10	1.47	1.6	36	1	6	239	183	1.7	39	0	6	255	187
51		AP-102	83-86	1	4/16	4/16		1,425	831	-9	1.21	2.50	0.29	5	1.21	1.5	35	0	5	391	232	1.6	38	0	6	401	233	1.46	3.00	0.38	10	1.47	1.6	36	2	8	331	209	1.7	39	2	9	349	211
52	AW-103	AY-102	68-70	1	7/07	7/07		1,012	3,320	-10	1.21	2.50	7.44	5	1.31	2.4	56	16	29	267	194	2.6	61	16	34	276	196	1.46	3.00	9.92	10	1.61	2.5	58	31	46	217	169	2.7	62	29	48	233	174
53		AY-101	68-70	1	3/08	3/08		1,012	3,695	-10	1.21	2.50	7.44	5	1.31	2.4	56	18	32	255	188	2.6	61	18	36	265	190	1.46	3.00	9.92	10	1.61	2.5	58	35	49	207	164	2.7	62	32	52	223	168
54		AZ-101	71	1	10/10	10/10		1,012	2,942	-17	1.21	2.50	7.44	5	1.31	2.4	56	10	23	281	202	2.6	61	11	27	291	204	1.46	3.00	9.92	10	1.61	2.5	58	23	37	229	176	2.7	62	21	40	246	181
55	AW-104	AP-102	83-86	1	10/10	10/10		1,434	831	-9	1.21	2.50	0.24	5	1.21	1.5	34	0	4	390	232	1.6	37	0	6	400	232	1.46	3.00	0.32	10	1.46	1.5	35	2	7	330	209	1.6	38	1	8	348	211
56		AZ-102	77	1	5/13	5/13		1,003	3,327	-17	1.21	2.50	4.55	5	1.27	2.3	52	9	21	273	198	2.5	57	10	24	282	200	1.46	3.00	6.06	10	1.55	2.4	54	21	33	225	174	2.5	58	19	36	240	178
57		AY-101	68-70	1	5/15	5/15		1,003	3,695	-10	1.21	2.50	4.55	5	1.27	2.3	52	15	26	260	192	2.5	57	15	30	270	193	1.46	3.00	6.06	10	1.55	2.4	54	29	41	213	168	2.5	58	26	43	229	172
58	AW-105	AZ-101	71	1	10/16	10/16		1,125	2,942	-17	1.21	2.50	2.96	5	1.25	2.1	49	6	16	285	201	2.3	53	6	20	294	203	1.46	3.00	3.94	10	1.52	2.2	51	16	27	236	178	2.4	55	14	29	252	182
59		AZ-102	77	1	3/18	3/18		1,125	3,327	-17	1.21	2.50	2.96	5	1.25	2.1	49	8	18	272	195	2.3	53	8	22	281	197	1.46	3.00	3.94	10	1.52	2.2	51	18	30	225	172	2.4	55	16	32	240	176
60	AW-106	AP-107	83-86	1	9/05	9/05		1,537	831	-9	1.21	2.50	0.00	5	1.21	0.3	7	-4	-4	382	225	0.1	3	-5	-5	392	226	1.46	3.00	0.00	10	1.46	1.0	22	-2	0	323	203	0.4	10	-5	-5	341	205
61		AN-102	80-81	1	12/12	12/12		1,519	3,594	-21	1.21	2.50	0.00	5	1.21	0.3	7	-10	-10	258	181	0.1	3	-11	-11	267	182	1.46	3.00	0.00	10	1.46	1.0	22	-6	-3	215	161	0.4	10	-12	-11	229	164
62		AW-102	78-80	2	9/00	10/10		314	421	0	1.21	2.50	0.00	5	1.21	0.3	7	0	0	694	444	0.1	3	0	0	706	445	1.46	3.00	0.00	10	1.46	1.0	22	1	2	600	400	0.4	10	0	0	623	403
63		AW-104	78-80	1	10/00	10/00		341	421	0	1.21	2.50	0.00	5	1.21	0.3	7	0	0	681	432	0.1	3	0	0	693	433	1.46	3.00	0.00	10	1.46	1.0	22	1	2	588	389	0.4	10	0	0	612	392
64		AP-101	83-86	2	10/00	8/01		1,533	831	-9	1.21	2.50	0.00	5	1.21	0.3	7	-4	-4	382	226	0.1	3	-5	-5	392	226	1.46	3.00	0.00	10	1.46	1.0	22	-2	0	323	203	0.4	10	-5	-5	341	205
65		AP-104	83-86	1	10/01	10/01		1,428	831	-9	1.21	2.50	0.00	5	1.21	0.3	7	-4	-4	391	232	0.1	3	-5	-5	402	233	1.46	3.00	0.00	10	1.46	1.0	22	-2	0	332	209	0.4	10	-5	-5	350	211
66		AW-105	78-80	2	10/01	1/02		2,239	1,241	0	1.21	2.50	0.00	5	1.21	0.3	7	0	1	311	185	0.1	3	0	0	320	186	1.46	3.00	0.00	10	1.46	1.0	22	5	8	260	166	0.4	10	1	2	276	168
67		AP-108	83-86	1	2/05	2/05		1,557	831	-9	1.21	2.50	0.00	5	1.21	0.3	7	-4	-4	380	224	0.1	3	-5	-5	390	225	1.46	3.00	0.00	10	1.46	1.0	22	-2	0	322	202	0.4	10	-5	-5	340	204
68	AY-101	AN-107	80-81	1	3/07	3/07		557	2,313	-11	1.21	2.50	0.00	5	1.21	0.3	7	-6	-5	346	255	0.1	3	-6	-6	356	257	1.46	3.00	0.00	10	1.46	1.0	22	-3	-2	292	227	0.4	10	-6	-6	309	231
69		BNFL		16	11/09	1/18	400	0	6,924	30	1.21	2.50	8.34	5	1.32	2.4	56	53	61	201	173	2.7	61	54	65	210	176	1.46	3.00	11.12	10	1.63	2.5	58	85	92	159	145	2.7	63	81	92	173	152
70	AY-102	BNFL		6	1/08	10/09	400	0	6,549	30	1.21	2.50	5.43	5	1.28	2.3	53	46	53	211	181	2.5	58	47	56	220	183	1.46	3.00	7.24	10	1.57	2.4	55	72	78	170	153	2.6	60	69	78	183	160
71		AY-101	68-70	1	2/12	2/12	400	0	386	0	1.21	2.50	10.81	5	1.35	2.5	58	2	3	909	754	2.7	63	2	3	923	758	1.46	3.00	14.14	10	1.68	2.6	60	4	4	789	681	2.8	64	4	4	800	672
72		AZ-102	77	1	6/17	6/17	400	0	1,466	-8	1.21	2.50	5.84	5	1.29	2.3	54	3	4	473	396	2.5	59	3	5	484	399	1.46	3.00	7.78	10	1.58	2.4	56	7	8	396	347	2.6	60	6	8	418	355
73		AP-101	83-86	1	10/17	10/17	400	128	2,910	2	1.21	2.50	1.44	5	1.23	1.9	44	10	13	330	270	2.1	48	10	14	340	272	1.46	3.00	1.92	10	1.49	2.0	46	17	20	276	237	2.2	50	16	20	293	243
74		AP-105	83-86	1	12/17	12/17	400	302	2,910	2	1.21	2.50	1.44	5	1.23	1.9	44	11	14	321	253	2.1	48	11	16	331	255	1.46	3.00	1.92	10	1.49	2.0	46	18	22	268	222	2.2	50	17	22	284	228
75		AN-103	80-81	1	6/18	6/18		376	1,733	-11	1.21	2.50	0.14	5	1.21	1.3	31	-3	-1	406	301	1.5	34	-3	-1	416	303	1.46	3.00	0.18	10	1.46	1.4	32	-1	0	344	268	1.5	35	-2	1	363	272
76		AP-104	83-86	1	10/18	10/18	400	314	2,910	2	1.21	2.50	0.14	5	1.21	1.3	31	6	8	323	254	1.5	34	6	8	332	256	1.46	3.00	0.18	10	1.46	1.4	32	10	12	271	224	1.5	35	9	12	287	229
77		AN-107	80-81	1	10/19	10/19		557	1,733	-11	1.21	2.50	0.09	5	1.21	1.3	29	-3	-1	399	278	1.4	32	-3	0	389	279	1.46	3.00	0.12	10	1.46	1.3	30	-1	1	329	248	1.4	33	-2	1	348	252
78		AW-102	78-80	1	10/19	10/19		761	2,910	10	1.21	2.50	0.09	5	1.21	1.3	29	11	13	300	220	1.4	32	11	14	309	222	1.46	3.00	0.12	10	1.46	1.3	30	16	18	250	195	1.4	33	15	19	266	199
79	AZ-101	BNFL		18	10/04	4/19	400	0	6,171	36	1.21	2.50	5.96	5	1.29	2.3	54	49	56	216	185	2.6	59	50	59	225	188	1.46	3.00	7.94	10	1.58	2.4	56	76	81	173	157	2.6	60	72	81	187	163
80	AZ-102	BNFL		18	11/06	11/91	400	0	6,556	36	1.21	2.50	7.86	5	1.31	2.4	56	54	62	206	177	2.6	61	55	66	215	180	1.46	3.00	10.48	10	1.62	2.5	58	85	91	164	149	2.7	62	81	91	178	156
81	BNFL internal equivalent pipe length and elevation								884	45	Included in BNFL routes						Exceeds 275 lbf/in²						Exceeds 400 lbf/in²								Supernate liquid only transfer							Less than 140 gpm						

Notes (column AS):

New = new or like new pipeline with maximum expected pipe roughness of 2 mils (0.002 inches).

EOL = pipeline at end of life (50 years for carbon steel line, 40 years for stainless steel line) with pipe roughness due to corrosion estimated at 150 mils for carbon steel and 10 mils for stainless steel.

***Design Pressure** = All stainless steel pipelines have a design pressure of 400 lbf/in². The *design pressure of* carbon steel pipelines are either 275 or 400 lbf/in² as indicated. The predicted flow rate at design pressure given in this table assumes that all pipelines are or can be qualified to the higher 400 lbf/in² design pressure.

Table D-5. 3S4 Case 1d.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL	AM	AN	AO	AP	AQ	AR
1	CASE 3S4 Transfer List - Tank-to-Tank										Case 1d	Critical velocity by Oroskar and Turian (1980) empirical correlation (β_{cv} = 1.2). Pressure drop by Wasp et al. (1977) method with lognormal particle size distribution.																																
2												Group 1 Properties				Temperature = 10 °C						Temperature = 60 °C						Group 2 Properties					Temperature = 10 °C						Temperature = 60 °C					
3	Transfer				Transfer			3-in. Schedule-40 Pipe (3.068 in. inside dia.)		Total Change in Elevation (ft)	Liquid	Solids				Critical (k_{cv} = 1.30, x_f = 1)				Flow Rate at a Pipe Design Pressure of 400 lbf/in² (gpm)		Critical (k_{cv} = 1.30, x_f = 1)				Flow Rate at a Pipe Design Pressure of 400 lbf/in² (gpm)		Liquid	Solids				Critical (k_{cv} = 1.30, x_f = 1)				Flow Rate at a Pipe Design Pressure of 400 lbf/in² (gpm)		Critical (k_{cv} = 1.30, x_f = 1)				Flow Rate at a Pipe Design Pressure of 400 lbf/in² (gpm)	
4	From Tank	To Tank	Tank Farm Built (Yr)	#	Dates (M/Yr)		Design Pressure (lbf/in²)*	Carbon Steel Length (ft)	Stainless Steel Length (ft)		ρ_L Density (kg/L)	ρ_s Density (kg/L)	C_s Volume (%) times	d_p Median Dia. (μm)	ρ_m Bulk Density (kg/L)	Velocity (ft/s)	Flow Rate (gpm)	Total Pressure Drop (lbf/in²)				Velocity (ft/s)	Flow Rate (gpm)	Total Pressure Drop (lbf/in²)				ρ_L Density (kg/L)	ρ_s Density (kg/L)	C_s Volume (%) times	d_p Median Dia. (μm)	ρ_m Bulk Density (kg/L)	Velocity (ft/s)	Flow Rate (gpm)	Total Pressure Drop (lbf/in²)				Velocity (ft/s)	Flow Rate (gpm)	Total Pressure Drop (lbf/in²)			
5					Start	End							1.5					New	EOL	New	EOL			New	EOL	New	EOL			2.0					New	EOL	New	EOL			New	EOL	New	EOL
6	AN-101	AP-103	83-86	1	3/03	3/03	400	306	2,774	12	1.10	2.50	0.00	5	1.10	0.2	6	6	6	348	271	0.1	2	6	6	357	273	1.20	3.00	0.00	10	1.20	0.3	7	7	7	330	259	0.1	2	6	6	340	261
7		AN-106	80-81	2	3/03	3/03		442	626	0	1.10	2.50	0.00	5	1.10	0.2	6	0	0	605	389	0.1	2	0	0	614	390	1.20	3.00	0.00	10	1.20	0.3	7	0	0	576	372	0.1	2	0	0	587	373
8		AN-107	80-81	3	9/05	8/12		557	626	0	1.10	2.50	0.03	5	1.10	1.2	27	1	2	574	359	1.3	30	1	3	583	360	1.20	3.00	0.04	10	1.20	1.5	35	2	4	546	344	1.6	38	2	5	557	345
9		BNFL		4	10/08	12/14	400	0	6,413	40	1.10	2.50	0.29	5	1.10	1.7	39	33	36	233	197	1.8	42	33	37	241	199	1.20	3.00	0.38	10	1.21	2.1	49	44	49	220	187	2.3	53	45	52	228	190
10	AN-102	AN-106	80-81	1	8/06	8/06		319	626	0	1.10	2.50	0.24	5	1.10	1.6	38	2	3	643	429	1.8	41	2	4	653	430	1.20	3.00	0.32	10	1.21	2.1	48	3	6	611	410	2.3	52	3	7	623	411
11		AN-101	80-81	1	10/08	10/08		405	421	0	1.10	2.50	0.24	5	1.10	1.6	38	2	3	688	426	1.8	41	2	4	698	427	1.20	3.00	0.32	10	1.21	2.1	48	3	6	655	407	2.3	52	3	7	666	408
12		AN-105	80-81	1	12/12	12/12		329	626	0	1.10	2.50	1.26	5	1.12	2.1	48	3	6	635	422	2.3	53	3	6	645	423	1.20	3.00	1.68	10	1.23	2.7	61	5	10	602	402	2.9	67	5	11	613	403
13	AN-103	AN-105	80-81	1	10/11	10/11		300	626	0	1.10	2.50	0.20	5	1.10	1.6	37	2	3	649	436	1.7	40	2	3	660	438	1.20	3.00	0.26	10	1.20	2.0	46	3	5	618	417	2.2	50	3	6	629	419
14		BNFL		2	5/13	5/18		376	6,823	40	1.10	2.50	1.10	5	1.12	2.1	47	42	49	218	178	2.3	52	42	52	226	180	1.20	3.00	1.46	10	1.23	2.6	60	60	72	205	168	2.8	65	61	78	213	171
15	AN-104	AN-101	80-81	4	9/05	5/15		526	626	0	1.10	2.50	1.29	5	1.12	2.1	49	4	7	577	364	2.3	53	4	9	586	365	1.20	3.00	1.72	10	1.23	2.7	61	6	13	546	346	2.9	67	7	15	557	347
16		BNFL		2	6/09	4/11	400	0	6,275	40	1.10	2.50	0.71	5	1.11	1.9	44	36	40	235	199	2.1	49	37	43	243	201	1.20	3.00	0.94	10	1.22	2.4	56	51	58	221	189	2.7	61	51	61	230	191
17		AZ-101	71	1	6/09	6/09	400	562	1,560	5	1.10	2.50	4.01	5	1.16	2.5	57	12	19	412	289	2.7	63	12	21	422	290	1.20	3.00	5.34	10	1.30	3.1	72	20	32	386	272	3.4	79	20	36	396	274
18		AN-107	80-81	1	6/09	6/09		489	421	0	1.10	2.50	0.66	5	1.11	1.9	44	2	5	653	397	2.1	48	2	6	663	397	1.20	3.00	0.88	10	1.22	2.4	56	4	9	621	378	2.6	61	4	10	632	379
19		AN-102	80-81	1	4/11	4/11		439	626	0	1.10	2.50	7.32	5	1.20	2.7	62	6	12	577	372	2.9	68	6	13	587	374	1.20	3.00	9.76	10	1.38	3.4	78	10	21	535	348	3.7	85	11	24	547	349
20		AW-103	78-80	2	4/11	9/11		1,012	3,046	21	1.10	2.50	7.26	5	1.20	2.7	62	33	49	285	204	2.9	68	34	54	294	205	1.20	3.00	9.68	10	1.37	3.4	78	52	80	262	190	3.7	85	53	89	272	191
21		AW-101	78-80	4	8/12	8/16		994	3,046	21	1.10	2.50	2.78	5	1.14	2.4	54	27	38	295	211	2.6	60	27	42	303	212	1.20	3.00	3.70	10	1.27	3.0	69	40	60	276	199	3.2	75	41	66	286	201
22		AN-103	80-81	2	6/13	10/13		410	626	0	1.10	2.50	1.20	5	1.12	2.1	48	3	6	609	395	2.3	53	3	7	619	396	1.20	3.00	1.60	10	1.23	2.6	61	6	11	577	376	2.9	66	6	13	589	378
23		AN-106	80-81	2	1/14	5/14		374	421	0	1.10	2.50	1.17	5	1.12	2.1	48	2	5	698	436	2.3	52	3	6	708	437	1.20	3.00	1.56	10	1.23	2.6	61	4	9	662	415	2.9	66	4	10	673	416
24		AW-104	78-80	2	5/15	7/15		1,003	3,046	21	1.10	2.50	1.29	5	1.12	2.1	49	23	32	297	212	2.3	53	24	35	306	214	1.20	3.00	1.72	10	1.23	2.7	61	34	49	281	202	2.9	67	34	54	290	203
25		AN-105	80-81	2	11/15	12/15		384	421	0	1.10	2.50	1.29	5	1.12	2.1	49	3	5	693	431	2.3	53	3	6	703	432	1.20	3.00	1.72	10	1.23	2.7	61	5	9	657	411	2.9	67	5	11	668	412
26		AP-101	83-86	2	2/17	2/17	400	419	2,636	12	1.10	2.50	3.15	5	1.14	2.4	55	19	25	342	260	2.6	61	19	28	351	262	1.20	3.00	4.20	10	1.28	3.0	70	29	40	320	245	3.3	76	30	45	330	247
27		AP-105	83-86	1	12/17	12/17	400	302	2,636	12	1.10	2.50	4.77	5	1.17	2.5	59	20	26	345	268	2.8	64	21	29	354	271	1.20	3.00	6.36	10	1.31	3.2	74	32	43	321	252	3.5	80	33	47	331	254
28		AW-105	78-80	1	3/18	3/18		1,125	3,046	21	1.10	2.50	4.77	5	1.17	2.5	59	31	45	286	202	2.8	64	31	50	294	203	1.20	3.00	6.36	10	1.31	3.2	74	47	73	266	189	3.5	80	48	82	275	191
29		AP-102	83-86	1	4/19	4/19	400	431	2,636	12	1.10	2.50	3.36	5	1.15	2.4	56	19	26	341	259	2.7	61	20	28	349	260	1.20	3.00	4.48	10	1.28	3.1	70	30	41	319	244	3.3	77	31	46	329	246
30		AW-106	78-80	1	10/19	10/19		1,114	3,046	21	1.10	2.50	2.87	5	1.14	2.4	55	27	39	290	205	2.6	60	28	44	299	206	1.20	3.00	3.82	10	1.27	3.0	69	41	63	272	193	3.3	75	42	70	281	195
31	AN-105	AN-104	80-81	1	6/09	6/09		384	421	0	1.10	2.50	0.18	5	1.10	1.6	36	1	3	698	434	1.7	39	1	3	708	435	1.20	3.00	0.24	10	1.20	2.0	46	3	5	664	415	2.2	50	3	6	676	416
32		BNFL		3	10/11	11/15		452	7,028	40	1.10	2.50	1.22	5	1.12	2.1	48	43	51	213	173	2.3	53	44	55	221	175	1.20	3.00	1.62	10	1.23	2.6	61	63	77	201	164	2.9	66	64	83	209	166
33	AN-106	AP-107	83-86	1	9/05	9/05		865	3,389	12	1.10	2.50	0.00	5	1.10	0.2	6	6	6	294	215	0.1	2	6	6	303	217	1.20	3.00	0.00	10	1.20	0.3	7	7	7	279	206	0.1	2	6	6	288	207
34		BNFL		4	8/06	1/14		442	7,028	40	1.10	2.50	0.56	5	1.11	1.9	43	38	44	215	174	2.0	47	39	47	222	176	1.20	3.00	0.74	10	1.21	2.3	54	54	65	202	165	2.6	59	54	70	210	168
35		AN-107	80-81	2	2/10	4/12		269	421	0	1.10	2.50	0.05	5	1.10	1.3	29	1	2	756	490	1.4	32	1	2	766	491	1.20	3.00	0.06	10	1.20	1.6	37	1	3	720	468	1.7	40	1	3	731	470
36	AN-107	AN-106	80-81	2	9/05	9/05		269	421	0	1.10	2.50	0.33	5	1.10	1.7	40	2	3	754	489	1.9	43	2	3	764	490	1.20	3.00	0.44	10	1.21	2.2	50	3	5	718	467	2.4	55	3	6	729	468
37		AW-102	78-80	1	10/10	10/10		1,357	3,006	21	1.10	2.50	0.11	5	1.10	1.4	33	17	22	289	199	1.6	36	17	23	297	200	1.20	3.00	0.14	10	1.20	1.8	42	23	31	273	190	2.0	46	23	34	282	191
38	AP-101	AP-104	83-86	1	8/16	8/16	400	733	421	0	1.10	2.50	0.00	5	1.10	0.2	6	0	0	581	339	0.1	2	0	0	591	340	1.20	3.00	0.00	10	1.20	0.3	7	0	0	553	325	0.1	2	0	0	564	326
39		AP-102	83-86	1	2/17	2/17	400	850	421	0	1.10	2.50	0.00	5	1.10	0.2	6	0	0	553	319	0.1	2	0	0	563	320	1.20	3.00	0.00	10	1.20	0.3	7	0	0	526	305	0.1	2	0	0	537	306
40	AP-102	AN-106	80-81	1	2/10	2/10		883	3,389	-12	1.10	2.50	0.00	5	1.10	0.2	6	-6	-5	298	218	0.1	2	-6	-6	306	219	1.20	3.00	0.00	10	1.20	0.3	7	-6	-6	283	208	0.1	2	-6	-6	292	210
41		AN-107	80-81	3	10/10	2/17		988	3,389	-12	1.10	2.50	0.05	5	1.10	1.3	29	0	3	294	213	1.4	32	0	4	303	214	1.20	3.00	0.06	10	1.20	1.6	37	3	8	279	203	1.7	40	3	10	288	205
42		BNFL		5	6/15	4/19	400	431	5,370	28	1.10	2.50	0.29	5	1.10	1.7	39	26	30	247	198	1.8	42	26	32	255	200	1.20	3.00	0.38	10	1.21	2.1	49	36	43	234	188	2.3	53	36	46	242	190
43	AP-104	AP-102	83-86	1	6/15	6/15	400	745	421	0	1.10	2.50	0.00	5	1.10	0.2	6	0	0	578	337	0.1	2	0	0	588	338	1.20	3.00	0.00	10	1.20	0.3	7	0	0	550	323	0.1	2	0	0	561	323
44		BNFL		3	8/16	10/18	400	314	5,370	28	1.10	2.50	0.24	5	1.10	1.6	38	25	28	250	203	1.8	41	25	30	258	205	1.20	3.00	0.32	10	1.21	2.1	48	34	40	236	193	2.3	52	34	43	245	195
45	AP-105	AP-104	83-86	1	7/17	7/17	400	616	421	0	1.10	2.50	0.24	5	1.10	1.6	38	2	4	613	364	1.8	41	2	5	623	364	1.20	3.00	0.32	10	1.21	2.1	48	4	8	583	348	2.3	52	4	9	594	348
46		AP-102	83-86	1	12/17	12/17	400	733	421	0	1.10	2.50	0.24	5	1.10	1.6	38	2	5	580	339	1.8	41	2	6	590	340	1.20	3.00	0.32	10	1.21	2.1	48	4	9	552	324	2.3	52	4	10	563	325
47	AP-107	AW-102	78-80	10	9/00	9/05		1,223	421	9	1.10	2.50	0.00	5	1.10	0.2	6	4	4	482	271	0.1	2	4	4	491	272	1.20	3.00	0.00	10	1.20	0.3	7	5	5	458	259	0.1	2	5	5	469	260
48	AP-108	AP-107	83-86	2	9/01	9/02	400	666	421	0	1.10	2.50	0.00	5	1.10	0.2	6	0	0	550	317	0.1	2	0	0	559	317	1.20	3.00	0.00	10	1.20	0.3	7	0	0	523	303	0.1	2	0	0	534	304
49	AW-101	AN-106	80-81	1	4/12	4/12		1,436	3,799	-21	1.10	2.50	0.23	5	1.10	1.6	37	0	7	269	190	1.8	41	0	9	277	191	1.20	3.00	0.30	10	1.21	2.0	47	7	18	255	181	2.2	51	7	22	264	183
50		AN-101	80-81	1	8/12	8/12		994	3,184	-21	1.10	2.50	0.29	5	1.10	1.7	39	-1	4	303	217	1.8	42	-1	6	311	218	1.20	3.00	0.38	10	1.21	2.1	49	4	13	287	207	2.3	53	4	17	296	209
51		AP-102	83-86	1	4/18	4/18		1,425	831	-9	1.10	2.50	0.29	5	1.10	1.7	39	1	6	413	244	1.8	42	1	8	422	244	1.20	3.00	0.38	10	1.21	2.1	49	4	14	393	233	2.3	53	4	17	403	234
52	AW-103	AY-102	68-70	1	7/07	7/07		1,012	3,320	-10	1.10	2.50	7.44	5	1.20	2.7	62	19	35	281	203	3.0	68	20	40	290	204	1.20	3.00	9.92	10	1.38	3.4	78	37	65	259	189	3.7	85	38	75	269	191
53		AY-101	68-70	1	3/08	3/08		1,012	3,695	-10	1.10	2.50	7.44	5	1.20	2.7	62	21	37	269	197	3.0	68	22	43	278	198	1.20	3.00	9.92	10	1.38	3.4	78	40	70	248	183	3.7	85	42	80	258	185
54		AZ-101	71	1	10/10	10/10		1,012	2,942	-17	1.10	2.50	7.44	5	1.20	2.7	62	13	28	296	211	3.0	68	14	34	305	212	1.20	3.00	9.92	10	1.38	3.4	78	29	56	274	197	3.7	85	30	66	284	199
55	AW-104	AP-102	83-86	1	10/10	10/10		1,434	831	-9	1.10	2.50	0.24	5	1.10	1.6	38	0	6	412	243	1.8	41	0	8	422	244	1.20	3.00	0.32	10	1.21	2.1	48	3	13	392	232	2.3	52	3	16	402	233
56		AZ-102	77	1	5/13	5/13		1,003	3,327	-17	1.10	2.50	4.55	5	1.16	2.5	58	12	25	288	206	2.8	64	12	30	296	209	1.20	3.00	6.06	10	1.31	3.2	73	28	50	269	196	3.5	80	27	59	278	197
57		AY-101	68-70	1	5/15	5/15		1,003	3,695	-10	1.10	2.50	4.55	5	1.16	2.5	58	17	31	275	201	2.8	64	18	36	283	202	1.20	3.00	6.06	10	1.31	3.2	73	33	58	256	189	3.5	80	35	67	266	190
58	AW-105	AZ-101	71	1	10/16	10/16		1,125	2,942	-17	1.10	2.50	2.96	5	1.14	2.4	55	8	21	301	211	2.6	60	9	25	309	212	1.20	3.00	3.94	10	1.27	3.0	69	20	42	282	200	3.3	75	21	49	292	201
59		AZ-102	77	1	3/18	3/18		1,125	3,327	-17	1.10	2.50	2.96	5	1.14	2.4	55	10	22	287	204	2.6	60	10	27	295	206	1.20	3.00	3.94	10	1.27	3.0	69	23	45	269	193	3.3	75	24	53	279	195
60	AW-106	AP-107	83-86	1	9/05	9/05		1,537	831	-9	1.10	2.50	0.00	5	1.10	0.2	6	-4	-4	404	237	0.1	2	-4	-4	413	237	1.20	3.00	0.00	10	1.20	0.3	7	-4	-4	384	226	0.1	2	-5	-5	394	227
61		AN-102	80-81	1	12/12	12/12		1,519	3,594	-21	1.10	2.50	0.00	5	1.10	0.2	6	-10	-10	273	190	0.1	2	-10	-10	281	191	1.20	3.00	0.00	10	1.20	0.3	7	-10	-10	259	182	0.1	2	-11	-11	268	183
62		AW-102	78-80	2	9/00	10/10		314	421	0	1.10	2.50	0.00	5	1.10	0.2	6	0	0	732	466	0.1	2	0	0	742	467	1.20	3.00	0.00	10	1.20	0.3	7	0	0	697	446	0.1	2	0	0	709	447
63		AW-104	78-80	1	10/00	10/00		341	421	0	1.10	2.50	0.00	5	1.10	0.2	6	0	0	718	453	0.1	2	0	0	729	454	1.20	3.00	0.00	10	1.20	0.3	7	0	0	685	434	0.1	2	0	0	696	435
64		AP-101	83-86	2	10/00	8/01		1,533	831	-9	1.10	2.50	0.00	5	1.10	0.2	6	-4	-4	404	237	0.1	2	-4	-4	413	238	1.20	3.00	0.00	10	1.20	0.3	7	-4	-4	384	227	0.1	2	-5	-5	394	227
65		AP-104	83-86	1	10/01	10/01		1,428	831	-9	1.10	2.50	0.00	5	1.10	0.2	6	-4	-4	414	244	0.1	2	-4	-4	423	245	1.20	3.00	0.00	10	1.20	0.3	7	-4	-4	393	233	0.1	2	-5	-5	403	234
66		AW-105	78-80	2	10/01	1/02		2,239	1,241	0	1.10	2.50	0.00	5	1.10	0.2	6	0	0	329	194	0.1	2	0	0	338	195	1.20	3.00	0.00	10	1.20	0.3	7	0	1	313	186	0.1	2	0	0	322	187
67		AP-108	83-86	1	2/05	2/05		1,557	831	-9	1.10	2.50	0.00	5	1.10	0.2	6	-4	-4	402	235	0.1	2	-4	-4	411	236	1.20	3.00	0.00	10	1.20	0.3	7	-4	-4	382	225	0.1	2	-5	-5	392	226
68	AY-101	AN-107	80-81	1	3/07	3/07		557	2,313	-11	1.10	2.50	0.00	5	1.10	0.2	6	-5	-5	366	268	0.1	2	-5	-5	375	270	1.20	3.00	0.00	10	1.20	0.3	7	-6	-5	348	256	0.1	2	-6	-6	358	258
69		BNFL		16	11/09	1/18	400	0	6,924	30	1.10	2.50	8.34	5	1.22	2.7	63	55	65	212	181	3.0	69	57	71	221	184	1.20	3.00	11.12	10	1.40	3.4	79	89	107	194	167	3.7	86	91	117	203	170
70	AY-102	BNFL		6	1/08	10/09	400	0	6,549	30	1.10	2.50	5.43	5	1.18	2.6	60	48	56	223	190	2.8	65	49	61	231	192	1.20	3.00	7.24	10	1.33	3.3	75	75	90	207	177	3.6	82	77	98	215	180
71		AY-101	68-70	1	2/12	2/12	400	0	386	0	1.10	2.50	10.61	5	1.25	2.8	65	2	3	949	785	3.1	71	2	3	962	788	1.20	3.00	14.14	10	1.45	3.5	81	4	5	873	725	3.8	88	4	6	888	730
72		AZ-102	77	1	6/17	6/17	400	0	1,466	-8	1.10	2.50	5.84	5	1.18	2.6	60	4	5	497	414	2.9	66	4	7	507	417	1.20	3.00	7.78	10	1.34	3.3	76	9	12	463	388	3.6	83	9	14	474	391
73		AP-101	83-86	1	10/17	10/17	400	128	2,910	2	1.10	2.50	1.44	5	1.12	2.1	49	11	14	349	283	2.3	54	11	16	358	286	1.20	3.00	1.92	10	1.23	2.7	62	18	24	330	269	3.0	68	19	27	339	272
74		AP-105	83-86	1	12/17	12/17	400	302	2,910	2	1.10	2.50	1.44	5	1.12	2.1	49	11	16	339	266	2.3	54	12	18	348	268	1.20	3.00	1.92	10	1.23	2.7	62	19	27	320	252	3.0	68	20	30	330	255
75		AN-103	80-81	1	6/18	6/18		376	1,733	-11	1.10	2.50	0.14	5	1.10	1.5	35	-2	0	429	316	1.6	38	-2	1	438	317	1.20	3.00	0.18	10	1.20	1.9	44	0	3	408	302	2.1	48	0	5	418	304
76		AP-104	83-86	1	10/18	10/18	400	314	2,910	2	1.10	2.50	0.14	5	1.10	1.5	35	6	8	342	287	1.6	38	6	9	350	289	1.20	3.00	0.18	10	1.20	1.9	44	10	14	324	255	2.1	48	10	15	334	257
77		AN-107	80-81	1	10/19	10/19		557	1,733	-11	1.10	2.50	0.09	5	1.10	1.4	32	-2	0	411	291	1.5	35	-2	1	420	293	1.20	3.00	0.12	10	1.20	1.8	41	0	4	391	279	1.9	45	0	5	401	280
78		AW-102	78-80	1	10/19	10/19		761	2,910	10	1.10	2.50	0.09	5	1.10	1.4	32	11	13	318	232	1.5	35	11	14	326	233	1.20	3.00	0.12	10	1.20	1.8	41	15	20	301	221	1.9	45	15	22	311	223
79	AZ-101	BNFL		18	10/04	4/19	400	0	6,171	36	1.10	2.50	5.96	5	1.18	2.6	60	50	58	228	194	2.9	66	51	63	237	197	1.20	3.00	7.94	10	1.34	3.3	76	77	92	211	181	3.6	83	79	100	220	184
80	AZ-102	BNFL		18	11/06	11/91	400	0	6,556	36	1.10	2.50	7.86	5	1.21	2.7	63	56	65	218	186	3.0	69	57	71	227	188	1.20	3.00	10.48	10	1.39	3.4	78	88	104	200	172	3.7	86	90	114	209	175
81	BNFL internal equivalent pipe length and elevation								884	45	included in BNFL routes							Exceeds 275 lbf/in²						Exceeds 400 lbf/in²						Supernate liquid only transfer						Less than 140 gpm								

Notes (column AS):

New = new or like new pipeline with maximum expected pipe roughness of 2 mils (0.002 inches).

EOL = pipeline at end of life (50 years for carbon steel line, 40 years for stainless steel line) with pipe roughness due to corrosion estimated at 150 mils for carbon steel and 10 mils for stainless steel.

***Design Pressure** = All stainless steel pipelines have a design pressure of 400 lbf/in². The design pressure of carbon steel pipelines are either 275 or 400 lbf/in² as indicated. The predicted flow rate at design pressure given in this table assumes that all pipelines are or can be qualified to the higher 400 lbf/in² design pressure.

Table D-6. 3S4 Case 2a.

CASE 3S4 Transfer List - Tank-to-Tank — Case 2a

Critical velocity by Oroskar and Turian (1980) empirical correlation (β_{cv} = 1.2). Pressure drop by Wasp et al. (1977) method with lognormal particle size distribution.

Transfer pipe: 3-in. Schedule-40 Pipe (3.068 in. inside dia.). Critical velocity: (κ_{cv} = 1.30, κ_f = 1).

Row	A: Transfer From Tank	B: Transfer To Tank	C: Tank Farm Built (Yr)	D: #	E: Dates (M/Yr) Start	F: Dates (M/Yr) End	G: Design Pressure (lbf/in²)	H: Carbon Steel Length (ft)	I: Stainless Steel Length (ft)	J: Total Change in Elevation (ft)	K: Group 1 Liquid ρ_L Density (kg/L)	L: Group 1 Solids ρ_s Density (kg/L)	M: Group 1 Solids C_v Volume (%)	N: Group 1 Solids d_p Median Dia. (μm)	O: Group 1 ρ_m Bulk Density (kg/L)	P: 10 °C Critical Velocity (ft/s)	Q: 10 °C Critical Flow Rate (gpm)	R: 10 °C Total Pressure Drop (lbf/in²) New	S: 10 °C Total Pressure Drop (lbf/in²) EOL	T: 10 °C Flow Rate at a Pipe Design Pressure of 400 lbf/in² (gpm) New	U: 10 °C Flow Rate at 400 lbf/in² (gpm) EOL	V: 60 °C Critical Velocity (ft/s)	W: 60 °C Critical Flow Rate (gpm)	X: 60 °C Total Pressure Drop (lbf/in²) New	Y: 60 °C Total Pressure Drop (lbf/in²) EOL	Z: 60 °C Flow Rate at 400 lbf/in² (gpm) New	AA: 60 °C Flow Rate at 400 lbf/in² (gpm) EOL	AB: Group 2 Liquid ρ_L Density (kg/L)	AC: Group 2 Solids ρ_s Density (kg/L)	AD: Group 2 Solids C_v Volume (%)	AE: Group 2 Solids d_p Median Dia. (μm)	AF: Group 2 ρ_m Bulk Density (kg/L)	AG: 10 °C Critical Velocity (ft/s)	AH: 10 °C Critical Flow Rate (gpm)	AI: 10 °C Total Pressure Drop (lbf/in²) New	AJ: 10 °C Total Pressure Drop (lbf/in²) EOL	AK: 10 °C Flow Rate at 400 lbf/in² (gpm) New	AL: 10 °C Flow Rate at 400 lbf/in² (gpm) EOL	AM: 60 °C Critical Velocity (ft/s)	AN: 60 °C Critical Flow Rate (gpm)	AO: 60 °C Total Pressure Drop (lbf/in²) New	AP: 60 °C Total Pressure Drop (lbf/in²) EOL	AQ: 60 °C Flow Rate at 400 lbf/in² (gpm) New	AR: 60 °C Flow Rate at 400 lbf/in² (gpm) EOL
6	AN-101	AP-103	83-86	1	3/03	3/03	400	306	2,774	12	1.21	2.50	15	40	1.40	3.7	85	45	60	299	238	4.0	93	46	67	312	241	1.46	3.00	30	100	1.92	4.0	92	93	112	218	189	4.3	99	87	114	240	198
7		AN-106	80-81	2	3/03	3/03		442	626	0	1.21	2.50	15	40	1.40	3.7	85	13	25	525	343	4.0	93	13	29	540	345	1.46	3.00	30	100	1.92	4.0	92	29	45	397	285	4.3	99	27	49	428	291
8		AN-107	80-81	3	9/05	8/12		557	626	0	1.21	2.50	15	40	1.40	3.7	85	14	29	498	318	4.0	93	15	34	513	319	1.46	3.00	30	100	1.92	4.0	92	32	52	375	264	4.3	99	30	56	405	269
9		BNFL		4	10/08	12/14	400	0	6,413	40	1.21	2.50	15	40	1.40	3.7	85	102	121	199	172	4.0	93	105	133	209	176	1.46	3.00	30	100	1.92	4.0	92	207	225			4.3	99	194	225	156	140
10	AN-102	AN-106	80-81	1	8/06	8/06		319	626	0	1.21	2.50	15	40	1.40	3.7	85	11	21	560	379	4.0	93	12	24	575	381	1.46	3.00	30	100	1.92	4.0	92	26	38	424	314	4.3	99	24	40	456	321
11		AN-101	80-81	1	10/08	10/08		405	421	0	1.21	2.50	15	40	1.40	3.7	85	10	21	600	377	4.0	93	10	24	615	379	1.46	3.00	30	100	1.92	4.0	92	22	37	457	315	4.3	99	21	40	490	320
12		AN-105	80-81	1	12/12	12/12		329	626	0	1.21	2.50	15	40	1.40	3.7	85	12	21	557	376	4.0	93	12	25	572	378	1.46	3.00	30	100	1.92	4.0	92	26	38	422	311	4.3	99	24	41	454	318
13	AN-103	AN-105	80-81	1	10/11	10/11		300	626	0	1.21	2.50	15	40	1.40	3.7	85	11	20	566	386	4.0	93	12	23	581	388	1.46	3.00	30	100	1.92	4.0	92	25	37	429	319	4.3	99	23	39	461	326
14		BNFL		2	5/13	5/18		376	6,823	40	1.21	2.50	15	40	1.40	3.7	85	111	141	187	156	4.0	93	114	156	197	159	1.46	3.00	30	100	1.92	4.0	92	228	260			4.3	99	214	262	147	
15	AN-104	AN-101	80-81	4	9/05	5/15		526	626	0	1.21	2.50	15	40	1.40	3.7	85	14	28	505	324	4.0	93	14	33	520	326	1.46	3.00	30	100	1.92	4.0	92	31	50	381	269	4.3	99	29	54	411	275
16		BNFL		2	6/09	4/11	400	0	6,275	40	1.21	2.50	15	40	1.40	3.7	85	100	119	201	174	4.0	93	103	130	212	177	1.46	3.00	30	100	1.92	4.0	92	203	221	142		4.3	99	191	221	158	142
17		AZ-101	71	1	6/09	6/09	400	562	1,560	5	1.21	2.50	15	40	1.40	3.7	85	29	47	366	261	4.0	93	30	53	379	264	1.46	3.00	30	100	1.92	4.0	92	62	85	270	212	4.3	99	57	89	295	220
18		AN-107	80-81	1	6/09	6/09		489	421	0	1.21	2.50	15	40	1.40	3.7	85	11	24	571	352	4.0	93	11	28	586	354	1.46	3.00	30	100	1.92	4.0	92	25	42	433	294	4.3	99	23	46	465	299
19		AN-102	80-81	1	4/11	4/11		439	626	0	1.21	2.50	15	40	1.40	3.7	85	13	25	526	344	4.0	93	13	29	541	346	1.46	3.00	30	100	1.92	4.0	92	29	45	398	285	4.3	99	27	48	428	291
20		AW-103	78-80	2	4/11	9/11		1,012	3,046	21	1.21	2.50	15	40	1.40	3.7	85	62	95	257	187	4.0	93	63	107	269	190	1.46	3.00	30	100	1.92	4.0	92	127	169	185	150	4.3	99	119	177	205	156
21		AW-101	78-80	4	8/12	8/16		994	3,046	21	1.21	2.50	15	40	1.40	3.7	85	62	94	258	188	4.0	93	63	107	269	191	1.46	3.00	30	100	1.92	4.0	92	127	168	186	150	4.3	99	119	176	205	157
22		AN-103	80-81	2	6/13	10/13		410	626	0	1.21	2.50	15	40	1.40	3.7	85	13	24	534	352	4.0	93	13	28	548	354	1.46	3.00	30	100	1.92	4.0	92	28	43	404	291	4.3	99	26	46	435	298
23		AN-106	80-81	2	1/14	5/14		374	421	0	1.21	2.50	15	40	1.40	3.7	85	10	20	612	388	4.0	93	10	23	627	390	1.46	3.00	30	100	1.92	4.0	92	21	35	466	323	4.3	99	20	38	500	329
24		AW-104	78-80	2	5/15	7/15		1,003	3,046	21	1.21	2.50	15	40	1.40	3.7	85	62	95	257	188	4.0	93	63	107	269	190	1.46	3.00	30	100	1.92	4.0	92	127	169	185	150	4.3	99	119	176	205	157
25		AN-105	80-81	2	11/15	12/15		384	421	0	1.21	2.50	15	40	1.40	3.7	85	10	20	608	384	4.0	93	10	23	623	386	1.46	3.00	30	100	1.92	4.0	92	22	36	463	320	4.3	99	20	39	497	326
26		AP-101	83-86	2	2/17	2/17	400	419	2,636	12	1.21	2.50	15	40	1.40	3.7	85	44	62	301	233	4.0	93	46	70	313	236	1.46	3.00	30	100	1.92	4.0	92	93	114	219	186	4.3	99	87	117	241	194
27		AP-105	83-86	1	12/17	12/17	400	302	2,636	12	1.21	2.50	15	40	1.40	3.7	85	43	58	307	243	4.0	93	44	65	319	246	1.46	3.00	30	100	1.92	4.0	92	90	107	224	193	4.3	99	84	109	246	203
28		AW-105	78-80	1	3/18	3/18		1,125	3,046	21	1.21	2.50	15	40	1.40	3.7	85	63	99	253	183	4.0	93	65	112	265	185	1.46	3.00	30	100	1.92	4.0	92	130	176	182	146	4.3	99	122	184	202	152
29		AP-102	83-86	1	4/19	4/19	400	431	2,636	12	1.21	2.50	15	40	1.40	3.7	85	45	63	300	232	4.0	93	46	70	312	235	1.46	3.00	30	100	1.92	4.0	92	93	115	219	185	4.3	99	87	118	240	194
30		AW-106	78-80	1	10/19	10/19		1,114	3,046	21	1.21	2.50	15	40	1.40	3.7	85	63	99	254	183	4.0	93	65	112	265	185	1.46	3.00	30	100	1.92	4.0	92	130	176	183	146	4.3	99	122	184	202	153
31	AN-105	AN-104	80-81	1	6/09	6/09		384	421	0	1.21	2.50	15	40	1.40	3.7	85	10	20	608	384	4.0	93	10	23	623	386	1.46	3.00	30	100	1.92	4.0	92	22	36	463	320	4.3	99	20	39	497	326
32		BNFL		3	10/11	11/15		452	7,028	40	1.21	2.50	15	40	1.40	3.7	85	115	146	183	152	4.0	93	118	162	193	155	1.46	3.00	30	100	1.92	4.0	92	236	271			4.3	99	221	274	143	
33	AN-106	AP-107	83-86	1	9/05	9/05		865	3,389	12	1.21	2.50	15	40	1.40	3.7	85	59	89	253	189	4.0	93	61	102	264	192	1.46	3.00	30	100	1.92	4.0	92	125	164	182	151	4.3	99	117	170	201	158
34		BNFL		4	8/06	1/14		442	7,028	40	1.21	2.50	15	40	1.40	3.7	85	115	146	183	152	4.0	93	118	162	193	155	1.46	3.00	30	100	1.92	4.0	92	235	270			4.3	99	221	273	144	
35		AN-107	80-81	2	2/10	4/12		269	421	0	1.21	2.50	15	40	1.40	3.7	85	8	16	658	433	4.0	93	9	19	674	435	1.46	3.00	30	100	1.92	4.0	92	19	29	504	360	4.3	99	17	31	539	367
36	AN-107	AN-106	80-81	2	9/05	9/05		269	421	0	1.21	2.50	15	40	1.40	3.7	85	8	16	658	433	4.0	93	9	19	674	435	1.46	3.00	30	100	1.92	4.0	92	19	29	504	360	4.3	99	17	31	539	367
37		AW-102	78-80	1	10/10	10/10		1,357	3,006	21	1.21	2.50	15	40	1.40	3.7	85	66	107	248	175	4.0	93	67	121	259	177	1.46	3.00	30	100	1.92	4.0	92	135	189	178	140	4.3	99	127	199	197	146
38	AP-101	AP-104	83-86	1	8/16	8/16	400	733	421	0	1.21	2.50	15	40	1.40	3.7	85	14	33	505	300	4.0	93	14	38	519	302	1.46	3.00	30	100	1.92	4.0	92	31	57	380	251	4.3	99	29	62	410	255
39		AP-102	83-86	1	2/17	2/17	400	850	421	0	1.21	2.50	15	40	1.40	3.7	85	15	37	480	282	4.0	93	16	43	494	284	1.46	3.00	30	100	1.92	4.0	92	34	64	361	236	4.3	99	32	70	390	240
40	AP-102	AN-106	80-81	1	2/10	2/10		883	3,389	-12	1.21	2.50	15	40	1.40	3.7	85	44	75	257	192	4.0	93	46	87	269	195	1.46	3.00	30	100	1.92	4.0	92	105	144	187	154	4.3	99	97	150	207	161
41		AN-107	80-81	3	10/10	2/17		988	3,389	-12	1.21	2.50	15	40	1.40	3.7	85	45	79	254	187	4.0	93	47	92	265	190	1.46	3.00	30	100	1.92	4.0	92	108	150	184	151	4.3	99	99	158	204	158
42		BNFL		5	6/15	4/19	400	431	5,370	28	1.21	2.50	15	40	1.40	3.7	85	87	113	212	173	4.0	93	89	126	222	176	1.46	3.00	30	100	1.92	4.0	92	180	210	150		4.3	99	169	213	167	143
43	AP-104	AP-102	83-86	1	6/15	6/15	400	745	421	0	1.21	2.50	15	40	1.40	3.7	85	14	33	502	298	4.0	93	15	39	517	300	1.46	3.00	30	100	1.92	4.0	92	31	57	378	249	4.3	99	29	63	408	253
44		BNFL		3	8/16	10/18	400	314	5,370	28	1.21	2.50	15	40	1.40	3.7	85	86	109	214	177	4.0	93	88	121	225	181	1.46	3.00	30	100	1.92	4.0	92	177	203	152		4.3	99	166	205	169	146
45	AP-105	AP-104	83-86	1	7/17	7/17	400	616	421	0	1.21	2.50	15	40	1.40	3.7	85	13	28	533	322	4.0	93	13	33	548	323	1.46	3.00	30	100	1.92	4.0	92	28	50	403	269	4.3	99	26	54	434	273
46		AP-102	83-86	1	12/17	12/17	400	733	421	0	1.21	2.50	15	40	1.40	3.7	85	14	33	505	300	4.0	93	14	38	519	302	1.46	3.00	30	100	1.92	4.0	92	31	57	380	251	4.3	99	29	62	410	255
47	AP-107	AW-102	78-80	10	9/00	9/05		1,223	421	9	1.21	2.50	15	40	1.40	3.7	85	25	56	417	240	4.0	93	26	65	431	241	1.46	3.00	30	100	1.92	4.0	92	52	93	310	200	4.3	99	49	103	337	203
48	AP-108	AP-107	83-86	2	9/01	9/02	400	866	421	0	1.21	2.50	15	40	1.40	3.7	85	16	37	477	280	4.0	93	16	44	491	281	1.46	3.00	30	100	1.92	4.0	92	35	65	358	234	4.3	99	32	71	387	238
49	AW-101	AN-106	80-81	1	4/12	4/12		1,436	3,799	-21	1.21	2.50	15	40	1.40	3.7	85	50	96	233	168	4.0	93	52	113	244	170	1.46	3.00	30	100	1.92	4.0	92	124	182	169		4.3	99	114	193	187	141
50		AN-101	80-81	1	8/12	8/12		994	3,184	-21	1.21	2.50	15	40	1.40	3.7	85	38	71	262	192	4.0	93	39	83	274	194	1.46	3.00	30	100	1.92	4.0	92	95	137	191	155	4.3	99	87	145	211	162
51		AP-102	83-86	1	4/16	4/16		1,425	831	-9	1.21	2.50	15	40	1.40	3.7	85	22	58	359	216	4.0	93	23	69	372	217	1.46	3.00	30	100	1.92	4.0	92	54	103	266	180	4.3	99	49	114	290	184
52	AW-103	AY-102	68-70	1	7/07	7/07		1,012	3,320	-10	1.21	2.50	15	40	1.40	3.7	85	46	80	255	187	4.0	93	48	93	266	190	1.46	3.00	30	100	1.92	4.0	92	109	152	185	151	4.3	99	100	159	205	158
53		AY-101	68-70	1	3/08	3/08		1,012	3,695	-10	1.21	2.50	15	40	1.40	3.7	85	51	86	244	181	4.0	93	53	99	255	184	1.46	3.00	30	100	1.92	4.0	92	119	163	177	146	4.3	99	110	170	196	152
54		AZ-101	71	1	10/10	10/10		1,012	2,942	-17	1.21	2.50	15	40	1.40	3.7	85	37	70	269	195	4.0	93	39	82	281	197	1.46	3.00	30	100	1.92	4.0	92	93	135	196	158	4.3	99	85	142	216	164
55	AW-104	AP-102	83-86	1	10/10	10/10		1,434	831	-9	1.21	2.50	15	40	1.40	3.7	85	22	59	358	215	4.0	93	23	70	371	217	1.46	3.00	30	100	1.92	4.0	92	54	104	265	179	4.3	99	49	114	289	183
56		AZ-102	77	1	5/13	5/13		1,003	3,327	-17	1.21	2.50	15	40	1.40	3.7	85	42	76	256	189	4.0	93	44	89	268	191	1.46	3.00	30	100	1.92	4.0	92	103	146	187	152	4.3	99	94	153	206	159
57		AY-101	68-70	1	5/15	5/15		1,003	3,695	-10	1.21	2.50	15	40	1.40	3.7	85	51	86	244	182	4.0	93	53	99	256	184	1.46	3.00	30	100	1.92	4.0	92	119	162	177	146	4.3	99	109	170	196	153
58	AW-105	AZ-101	71	1	10/16	10/16		1,125	2,942	-17	1.21	2.50	15	40	1.40	3.7	85	39	74	265	190	4.0	93	40	87	277	192	1.46	3.00	30	100	1.92	4.0	92	96	141	193	154	4.3	99	88	150	213	160
59		AZ-102	77	1	3/18	3/18		1,125	3,327	-17	1.21	2.50	15	40	1.40	3.7	85	43	80	253	184	4.0	93	45	94	264	186	1.46	3.00	30	100	1.92	4.0	92	106	153	184	148	4.3	99	97	161	203	155
60	AW-106	AP-107	83-86	1	9/05	9/05		1,537	831	-9	1.21	2.50	15	40	1.40	3.7	85	23	62	350	209	4.0	93	24	74	363	211	1.46	3.00	30	100	1.92	4.0	92	57	110	259	174	4.3	99	52	121	282	178
61		AN-102	80-81	1	12/12	12/12		1,519	3,594	-21	1.21	2.50	15	40	1.40	3.7	85	49	96	235	168	4.0	93	51	113	247	170	1.46	3.00	30	100	1.92	4.0	92	121	181	171		4.3	99	111	192	189	142
62		AW-102	78-80	2	9/00	10/10		314	421	0	1.21	2.50	15	40	1.40	3.7	85	9	18	637	412	4.0	93	9	20	653	414	1.46	3.00	30	100	1.92	4.0	92	20	31	487	343	4.3	99	18	34	521	349
63		AW-104	78-80	1	10/00	10/00		341	421	0	1.21	2.50	15	40	1.40	3.7	85	9	19	626	400	4.0	93	10	22	641	402	1.46	3.00	30	100	1.92	4.0	92	21	33	477	334	4.3	99	19	36	511	340
64		AP-101	83-86	2	10/00	8/01		1,533	831	-9	1.21	2.50	15	40	1.40	3.7	85	23	62	350	210	4.0	93	24	74	363	211	1.46	3.00	30	100	1.92	4.0	92	56	109	259	175	4.3	99	52	121	283	178
65		AP-104	83-86	1	10/01	10/01		1,428	831	-9	1.21	2.50	15	40	1.40	3.7	85	22	58	358	216	4.0	93	23	70	371	217	1.46	3.00	30	100	1.92	4.0	92	54	103	265	180	4.3	99	49	114	290	184
66		AW-105	78-80	2	10/01	1/02		2,239	1,241	0	1.21	2.50	15	40	1.40	3.7	85	42	99	284	172	4.0	93	43	116	296	173	1.46	3.00	30	100	1.92	4.0	92	94	171	207	142	4.3	99	87	188	228	145
67		AP-108	83-86	1	2/05	2/05		1,557	831	-9	1.21	2.50	15	40	1.40	3.7	85	23	63	348	208	4.0	93	24	75	361	210	1.46	3.00	30	100	1.92	4.0	92	57	111	257	174	4.3	99	52	123	281	177
68	AY-101	AN-107	80-81	1	3/07	3/07		557	2,313	-11	1.21	2.50	15	40	1.40	3.7	85	28	48	317	236	4.0	93	29	56	329	239	1.46	3.00	30	100	1.92	4.0	92	68	93	233	191	4.3	99	63	97	256	199
69		BNFL		16	11/09	1/18	400	0	6,924	30	1.21	2.50	15	40	1.40	3.7	85	102	122	192	167	4.0	93	104	135	203	170	1.46	3.00	30	100	1.92	4.0	92	212	232			4.3	99	198	231	152	
70	AY-102	BNFL		6	1/08	10/09	400	0	6,549	30	1.21	2.50	15	40	1.40	3.7	85	97	116	198	171	4.0	93	100	129	209	175	1.46	3.00	30	100	1.92	4.0	92	202	221	140		4.3	99	189	220	156	140
71		AY-101	68-70	1	2/12	2/12	400	0	386	0	1.21	2.50	15	40	1.40	3.7	85	5	6	888	738	4.0	93	5	7	904	743	1.46	3.00	30	100	1.92	4.0	92	10	12	690	607	4.3	99	10	12	731	623
72		AZ-102	77	1	6/17	6/17	400	0	1,466	-8	1.21	2.50	15	40	1.40	3.7	85	13	17	448	378	4.0	93	14	20	462	383	1.46	3.00	30	100	1.92	4.0	92	33	38	336	304	4.3	99	30	37	364	318
73		AP-101	83-86	1	10/17	10/17	400	128	2,910	2	1.21	2.50	15	40	1.40	3.7	85	38	49	304	251	4.0	93	39	56	317	255	1.46	3.00	30	100	1.92	4.0	92	83	98	222	199	4.3	99	77	97	244	210
74		AP-105	83-86	1	12/17	12/17	400	302	2,910	2	1.21	2.50	15	40	1.40	3.7	85	40	56	295	236	4.0	93	41	63	308	239	1.46	3.00	30	100	1.92	4.0	92	88	106	216	187	4.3	99	82	108	237	197
75		AN-103	80-81	1	6/18	6/18		376	1,733	-11	1.21	2.50	15	40	1.40	3.7	85	19	33	372	279	4.0	93	20	38	385	282	1.46	3.00	30	100	1.92	4.0	92	48	65	276	227	4.3	99	44	68	301	235
76		AP-104	83-86	1	10/18	10/18	400	314	2,910	2	1.21	2.50	15	40	1.40	3.7	85	40	56	295	235	4.0	93	41	63	307	238	1.46	3.00	30	100	1.92	4.0	92	88	107	215	187	4.3	99	82	109	237	196
77		AN-107	80-81	1	10/19	10/19		557	1,733	-11	1.21	2.50	15	40	1.40	3.7	85	21	39	356	257	4.0	93	22	46	369	260	1.46	3.00	30	100	1.92	4.0	92	53	76	264	210	4.3	99	48	80	288	217
78		AW-102	78-80	1	10/19	10/19		761	2,910	10	1.21	2.50	15	40	1.40	3.7	85	51	77	273	204	4.0	93	52	88	285	206	1.46	3.00	30	100	1.92	4.0	92	108	141	198	163	4.3	99	101	147	219	170
79	AZ-101	BNFL		18	10/04	4/19	400	0	6,171	36	1.21	2.50	15	40	1.40	3.7	85	97	115	203	176	4.0	93	99	126	214	180	1.46	3.00	30	100	1.92	4.0	92	197	215	144		4.3	99	185	214	160	144
80	AZ-102	BNFL		18	11/06	11/91	400	0	6,556	36	1.21	2.50	15	40	1.40	3.7	85	101	121	197	170	4.0	93	104	133	208	174	1.46	3.00	30	100	1.92	4.0	92	207	226			4.3	99	194	226	155	
81	BNFL internal equivalent pipe length and elevation								884	45	included in BNFL routes						Exceeds 275 lbf/in²						Exceeds 400 lbf/in²							Supernate liquid only transfer										Less than 140 gpm					

Notes:

New = new or like new pipeline with maximum expected pipe roughness of 2 mils (0.002 inches).

EOL = pipeline at end of life (50 years for carbon steel line, 40 years for stainless steel line) with pipe roughness due to corrosion estimated at 150 mils for carbon steel and 10 mils for stainless steel.

Design Pressure = All stainless steel pipelines have a design pressure of 400 lbf/in². The design pressure of carbon steel pipelines are either 275 or 400 lbf/in² as indicated.

The predicted flow rate at design pressure given in this table assumes that all pipelines are or can be qualified to the higher 400 lbf/in² design pressure.

Table D-7. 3S4 Case 2b.

CASE 3S4 Transfer List - Tank-to-Tank — Case 2b

Critical velocity by Oroskar and Turian (1980) empirical correlation (β_{cv} = 1.2). Pressure drop by Wasp et al. (1977) method with lognormal particle size distribution.

Group 1 Properties: Liquid, Solids; Temperature = 10 °C and Temperature = 60 °C, Critical (k_{cv} = 1.30, k_f = 1). Group 2 Properties: Liquid, Solids; Temperature = 10 °C and Temperature = 60 °C, Critical (k_{cv} = 1.30, k_f = 1). Pipe: 3-in. Schedule-40 Pipe (3.068 in. inside dia.)

Row	A From Tank	B To Tank	C Tank Farm Built (Yr)	D #	E Dates (M/Yr) Start	F Dates (M/Yr) End	G Design Pressure* (lbf/in²)	H Carbon Steel Length (ft)	I Stainless Steel Length (ft)	J Total Change in Elevation (ft)	K G1 ρ_L Density (kg/L)	L G1 ρ_s Density (kg/L)	M G1 C_s Volume (%)	N G1 d_p Median Dia. (µm)	O G1 ρ_m Bulk Density (kg/L)	P G1 10 °C Velocity (ft/s)	Q G1 10 °C Flow Rate (gpm)	R G1 10 °C Total Pressure Drop (lbf/in²) New	S G1 10 °C Total Pressure Drop (lbf/in²) EOL	T G1 10 °C Flow Rate at a Pipe Design Pressure of 400 lbf/in² (gpm) New	U G1 10 °C Flow Rate at 400 lbf/in² (gpm) EOL	V G1 60 °C Velocity (ft/s)	W G1 60 °C Flow Rate (gpm)	X G1 60 °C Total Pressure Drop New	Y G1 60 °C Total Pressure Drop EOL	Z G1 60 °C Flow Rate at 400 lbf/in² New	AA G1 60 °C Flow Rate at 400 lbf/in² EOL	AB G2 ρ_L Density (kg/L)	AC G2 ρ_s Density (kg/L)	AD G2 C_s Volume (%)	AE G2 d_p Median Dia. (µm)	AF G2 ρ_m Bulk Density (kg/L)	AG G2 10 °C Velocity (ft/s)	AH G2 10 °C Flow Rate (gpm)	AI G2 10 °C Total Pressure Drop New	AJ G2 10 °C Total Pressure Drop EOL	AK G2 10 °C Flow Rate at 400 lbf/in² New	AL G2 10 °C Flow Rate at 400 lbf/in² EOL	AM G2 60 °C Velocity (ft/s)	AN G2 60 °C Flow Rate (gpm)	AO G2 60 °C Total Pressure Drop New	AP G2 60 °C Total Pressure Drop EOL	AQ G2 60 °C Flow Rate at 400 lbf/in² New	AR G2 60 °C Flow Rate at 400 lbf/in² EOL
6	AN-101	AP-103	83-86	1	3/03	3/03	400	306	2,774	12	1.10	2.50	15	40	1.31	4.1	95	48	67	314	248	4.5	104	51	77	326	251	1.20	3.00	30	100	1.74	5.4	124	105	149	286	214	5.9	135	122	186	284	219
7		AN-106	80-81	2	3/03	3/03		442	626	0	1.10	2.50	15	40	1.31	4.1	95	14	29	549	356	4.5	104	15	35	562	358	1.20	3.00	30	100	1.74	5.4	124	33	67	467	310	5.9	135	39	86	490	315
8		AN-107	80-81	3	9/05	8/12		557	626	0	1.10	2.50	15	40	1.31	4.1	95	16	34	521	329	4.5	104	17	40	534	331	1.20	3.00	30	100	1.74	5.4	124	37	78	443	287	5.9	135	43	100	465	291
9		BNFL		4	10/08	12/14	400	0	6,413	40	1.10	2.50	15	40	1.31	4.1	95	109	133	210	180	4.5	104	114	149	220	183	1.20	3.00	30	100	1.74	5.4	124	231	285	175	153	5.9	135	265	352	185	150
10	AN-102	AN-106	80-81	1	8/06	8/06		319	626	0	1.10	2.50	15	40	1.31	4.1	95	13	24	585	393	4.5	104	13	28	598	396	1.20	3.00	30	100	1.74	5.4	124	29	55	498	342	5.9	135	34	71	521	347
11		AN-101	80-81	1	10/08	10/08		405	421	0	1.10	2.50	15	40	1.31	4.1	95	11	24	627	391	4.5	104	12	29	640	393	1.20	3.00	30	100	1.74	5.4	124	26	56	534	340	5.9	135	30	71	557	345
12		AN-105	80-81	1	12/12	12/12		329	626	0	1.10	2.50	15	40	1.31	4.1	95	13	25	582	390	4.5	104	14	29	595	392	1.20	3.00	30	100	1.74	5.4	124	30	56	495	339	5.9	135	35	72	518	344
13	AN-103	AN-105	80-81	1	10/11	10/11		300	626	0	1.10	2.50	15	40	1.31	4.1	95	12	23	591	400	4.5	104	13	27	604	403	1.20	3.00	30	100	1.74	5.4	124	29	54	503	348	5.9	135	34	69	526	353
14		BNFL		2	5/13	5/18		376	6,823	40	1.10	2.50	15	40	1.31	4.1	95	119	155	197	163	4.5	104	125	176	207	166	1.20	3.00	30	100	1.74	5.4	124	255		165		5.9	135			173	
15	AN-104	AN-101	80-81	4	9/05	5/15		526	626	0	1.10	2.50	15	40	1.31	4.1	95	15	33	528	336	4.5	104	16	39	541	338	1.20	3.00	30	100	1.74	5.4	124	36	75	449	292	5.9	135	42	97	471	297
16		BNFL		2	6/09	4/11	400	0	6,275	40	1.10	2.50	15	40	1.31	4.1	95	107	130	212	182	4.5	104	112	147	222	185	1.20	3.00	30	100	1.74	5.4	124	226	279	177	154	5.9	135	260	345	188	152
17		AZ-101	71	1	6/09	6/09	400	562	1,560	5	1.10	2.50	15	40	1.31	4.1	95	31	53	384	271	4.5	104	33	62	396	274	1.20	3.00	30	100	1.74	5.4	124	70	120	326	236	5.9	135	81	152	345	240
18		AN-107	80-81	1	6/09	6/09		489	421	0	1.10	2.50	15	40	1.31	4.1	95	12	28	596	365	4.5	104	13	33	610	367	1.20	3.00	30	100	1.74	5.4	124	28	64	508	318	5.9	135	33	82	531	322
19		AN-102	80-81	1	4/11	4/11		439	626	0	1.10	2.50	15	40	1.31	4.1	95	14	29	550	357	4.5	104	15	34	563	359	1.20	3.00	30	100	1.74	5.4	124	33	67	468	310	5.9	135	39	86	490	315
20		AW-103	78-80	2	4/11	9/11		1,012	3,046	21	1.10	2.50	15	40	1.31	4.1	95	66	107	271	195	4.5	104	70	123	281	197	1.20	3.00	30	100	1.74	5.4	124	143	234	228	168	5.9	135	164		244	167
21		AW-101	78-80	4	8/12	8/16		994	3,046	21	1.10	2.50	15	40	1.31	4.1	95	66	106	271	196	4.5	104	69	122	282	198	1.20	3.00	30	100	1.74	5.4	124	142	232	229	169	5.9	135	163		244	168
22		AN-103	80-81	2	6/13	10/13		410	626	0	1.10	2.50	15	40	1.31	4.1	95	14	28	558	365	4.5	104	15	33	571	367	1.20	3.00	30	100	1.74	5.4	124	32	64	475	317	5.9	135	38	82	497	322
23		AN-106	80-81	2	1/14	5/14		374	421	0	1.10	2.50	15	40	1.31	4.1	95	11	23	639	402	4.5	104	11	27	653	404	1.20	3.00	30	100	1.74	5.4	124	25	53	544	350	5.9	135	29	67	568	355
24		AW-104	78-80	2	5/15	7/15		1,003	3,046	21	1.10	2.50	15	40	1.31	4.1	95	66	106	271	195	4.5	104	70	123	282	198	1.20	3.00	30	100	1.74	5.4	124	142	233	229	168	5.9	135	164		244	168
25		AN-105	80-81	2	11/15	12/15		384	421	0	1.10	2.50	15	40	1.31	4.1	95	11	23	635	398	4.5	104	11	28	649	400	1.20	3.00	30	100	1.74	5.4	124	25	54	541	347	5.9	135	29	69	564	351
26		AP-101	83-86	2	2/17	2/17	400	419	2,636	12	1.10	2.50	15	40	1.31	4.1	95	48	70	316	242	4.5	104	50	80	327	245	1.20	3.00	30	100	1.74	5.4	124	105	154	267	210	5.9	135	121	193	285	214
27		AP-105	83-86	1	12/17	12/17	400	302	2,636	12	1.10	2.50	15	40	1.31	4.1	95	46	65	322	253	4.5	104	49	74	334	256	1.20	3.00	30	100	1.74	5.4	124	101	143	273	219	5.9	135	117	179	291	223
28		AW-105	78-80	1	3/18	3/18		1,125	3,046	21	1.10	2.50	15	40	1.31	4.1	95	68	111	267	190	4.5	104	71	129	278	192	1.20	3.00	30	100	1.74	5.4	124	146	245	225	164	5.9	135	168		240	162
29		AP-102	83-86	1	4/19	4/19	400	431	2,636	12	1.10	2.50	15	40	1.31	4.1	95	48	70	315	241	4.5	104	51	81	327	244	1.20	3.00	30	100	1.74	5.4	124	105	155	267	209	5.9	135	121	195	284	213
30		AW-106	78-80	1	10/19	10/19		1,114	3,046	21	1.10	2.50	15	40	1.31	4.1	95	68	111	267	191	4.5	104	71	128	278	193	1.20	3.00	30	100	1.74	5.4	124	146	244	225	164	5.9	135	168		241	163
31	AN-105	AN-104	80-81	1	6/09	6/09		384	421	0	1.10	2.50	15	40	1.31	4.1	95	11	23	635	398	4.5	104	11	28	649	400	1.20	3.00	30	100	1.74	5.4	124	25	54	541	347	5.9	135	29	69	564	351
32		BNFL		3	10/11	11/15		452	7,028	40	1.10	2.50	15	40	1.31	4.1	95	123	162	193	159	4.5	104	129	184	203	162	1.20	3.00	30	100	1.74	5.4	124	264		161		5.9	135			169	
33	AN-106	AP-107	83-86	1	9/05	9/05		865	3,389	12	1.10	2.50	15	40	1.31	4.1	95	64	101	266	197	4.5	104	68	117	277	199	1.20	3.00	30	100	1.74	5.4	124	142	227	225	170	5.9	135	165		240	170
34		BNFL		4	8/06	1/14		442	7,028	40	1.10	2.50	15	40	1.31	4.1	95	123	162	194	159	4.5	104	129	184	203	162	1.20	3.00	30	100	1.74	5.4	124	264		161		5.9	135			169	
35		AN-107	80-81	2	2/10	4/12		269	421	0	1.10	2.50	15	40	1.31	4.1	95	9	18	687	449	4.5	104	10	22	701	451	1.20	3.00	30	100	1.74	5.4	124	22	43	586	389	5.9	135	25	54	609	395
36	AN-107	AN-106	80-81	2	9/05	9/05		269	421	0	1.10	2.50	15	40	1.31	4.1	95	9	18	687	449	4.5	104	10	22	701	451	1.20	3.00	30	100	1.74	5.4	124	22	43	586	389	5.9	135	25	54	609	395
37		AW-102	78-80	1	10/10	10/10		1,357	3,006	21	1.10	2.50	15	40	1.31	4.1	95	70	120	260	182	4.5	104	74	140	271	184	1.20	3.00	30	100	1.74	5.4	124	152	265	220	157	5.9	135	175		235	154
38	AP-101	AP-104	83-86	1	8/16	8/16	400	733	421	0	1.10	2.50	15	40	1.31	4.1	95	15	38	528	311	4.5	104	16	45	541	313	1.20	3.00	30	100	1.74	5.4	124	36	87	449	271	5.9	135	42	112	471	274
39		AP-102	83-86	1	2/17	2/17	400	850	421	0	1.10	2.50	15	40	1.31	4.1	95	17	43	502	293	4.5	104	18	51	515	294	1.20	3.00	30	100	1.74	5.4	124	40	98	427	255	5.9	135	46	126	449	258
40	AP-102	AN-106	80-81	1	2/10	2/10		883	3,389	-12	1.10	2.50	15	40	1.31	4.1	95	50	88	270	200	4.5	104	54	104	281	202	1.20	3.00	30	100	1.74	5.4	124	124	210	230	173	5.9	135	147	270	245	173
41		AN-107	80-81	3	10/10	2/17		988	3,389	-12	1.10	2.50	15	40	1.31	4.1	95	52	92	267	195	4.5	104	55	110	277	197	1.20	3.00	30	100	1.74	5.4	124	127	220	227	169	5.9	135	151		242	169
42		BNFL		5	6/15	4/19	400	431	5,370	28	1.10	2.50	15	40	1.31	4.1	95	93	126	223	181	4.5	104	99	144	233	184	1.20	3.00	30	100	1.74	5.4	124	202	275	188	154	5.9	135	233	344	199	152
43	AP-104	AP-102	83-86	1	6/15	6/15	400	745	421	0	1.10	2.50	15	40	1.31	4.1	95	16	38	525	309	4.5	104	17	46	538	311	1.20	3.00	30	100	1.74	5.4	124	36	88	447	269	5.9	135	43	113	469	273
44		BNFL		3	8/16	10/18	400	314	5,370	28	1.10	2.50	15	40	1.31	4.1	95	92	121	226	185	4.5	104	97	138	236	188	1.20	3.00	30	100	1.74	5.4	124	199	264	190	158	5.9	135	229	330	202	157
45	AP-105	AP-104	83-86	1	7/17	7/17	400	616	421	0	1.10	2.50	15	40	1.31	4.1	95	14	33	557	334	4.5	104	15	39	571	335	1.20	3.00	30	100	1.74	5.4	124	32	76	475	291	5.9	135	38	97	497	294
46		AP-102	83-86	1	12/17	12/17	400	733	421	0	1.10	2.50	15	40	1.31	4.1	95	15	38	528	311	4.5	104	16	45	541	313	1.20	3.00	30	100	1.74	5.4	124	36	87	449	271	5.9	135	42	112	471	274
47	AP-107	AW-102	78-80	10	9/00	9/05		1,223	421	9	1.10	2.50	15	40	1.31	4.1	95	27	64	437	249	4.5	104	28	75	449	250	1.20	3.00	30	100	1.74	5.4	124	58	141	370	216	5.9	135	67	179	391	218
48	AP-108	AP-107	83-86	2	9/01	9/02	400	666	421	0	1.10	2.50	15	40	1.31	4.1	95	17	44	499	290	4.5	104	18	52	512	292	1.20	3.00	30	100	1.74	5.4	124	40	100	424	253	5.9	135	47	128	446	256
49	AW-101	AN-106	80-81	1	4/12	4/12		1,436	3,799	-21	1.10	2.50	15	40	1.31	4.1	95	58	113	244	174	4.5	104	63	135	255	176	1.20	3.00	30	100	1.74	5.4	124	147	273	208	151	5.9	135	175		222	147
50		AN-101	80-81	1	8/12	8/12		994	3,184	-21	1.10	2.50	15	40	1.31	4.1	95	44	84	275	199	4.5	104	48	101	286	202	1.20	3.00	30	100	1.74	5.4	124	114	206	234	174	5.9	135	137	267	250	174
51		AP-102	83-86	1	4/16	4/16		1,425	831	-9	1.10	2.50	15	40	1.31	4.1	95	25	69	376	224	4.5	104	27	83	388	225	1.20	3.00	30	100	1.74	5.4	124	64	163	320	196	5.9	135	76	212	339	196
52	AW-103	AY-102	68-70	1	7/07	7/07		1,012	3,320	-10	1.10	2.50	15	40	1.31	4.1	95	52	94	268	195	4.5	104	56	111	278	197	1.20	3.00	30	100	1.74	5.4	124	128	221	228	169	5.9	135	151		243	168
53		AY-101	68-70	1	3/08	3/08		1,012	3,695	-10	1.10	2.50	15	40	1.31	4.1	95	57	100	256	189	4.5	104	61	118	267	191	1.20	3.00	30	100	1.74	5.4	124	139	236	218	164	5.9	135	164		233	162
54		AZ-101	71	1	10/10	10/10		1,012	2,942	-17	1.10	2.50	15	40	1.31	4.1	95	43	83	282	202	4.5	104	47	99	293	205	1.20	3.00	30	100	1.74	5.4	124	111	201	240	176	5.9	135	132	260	257	176
55	AW-104	AP-102	83-86	1	10/10	10/10		1,434	831	-9	1.10	2.50	15	40	1.31	4.1	95	25	69	375	223	4.5	104	27	84	387	225	1.20	3.00	30	100	1.74	5.4	124	64	164	319	195	5.9	135	76	213	338	196
56		AZ-102	77	1	5/13	5/13		1,003	3,327	-17	1.10	2.50	15	40	1.31	4.1	95	48	89	269	196	4.5	104	52	107	280	198	1.20	3.00	30	100	1.74	5.4	124	122	215	229	170	5.9	135	145		245	170
57		AY-101	68-70	1	5/15	5/15		1,003	3,695	-10	1.10	2.50	15	40	1.31	4.1	95	57	100	256	189	4.5	104	61	118	267	191	1.20	3.00	30	100	1.74	5.4	124	139	235	218	164	5.9	135	164		233	163
58	AW-105	AZ-101	71	1	10/16	10/16		1,125	2,942	-17	1.10	2.50	15	40	1.31	4.1	95	45	88	278	197	4.5	104	48	105	289	199	1.20	3.00	30	100	1.74	5.4	124	114	212	237	172	5.9	135	136	274	253	171
59		AZ-102	77	1	3/18	3/18		1,125	3,327	-17	1.10	2.50	15	40	1.31	4.1	95	50	94	265	191	4.5	104	54	113	276	193	1.20	3.00	30	100	1.74	5.4	124	126	227	226	166	5.9	135	150		241	165
60	AW-106	AP-107	83-86	1	9/05	9/05		1,537	831	-9	1.10	2.50	15	40	1.31	4.1	95	27	74	366	217	4.5	104	29	89	378	218	1.20	3.00	30	100	1.74	5.4	124	67	174	312	190	5.9	135	80	225	331	190
61		AN-102	80-81	1	12/12	12/12		1,519	3,594	-21	1.10	2.50	15	40	1.31	4.1	95	56	113	247	174	4.5	104	61	135	258	176	1.20	3.00	30	100	1.74	5.4	124	144	272	211	151	5.9	135	171		225	147
62		AW-102	78-80	2	9/00	10/10		314	421	0	1.10	2.50	15	40	1.31	4.1	95	10	20	665	427	4.5	104	10	24	679	429	1.20	3.00	30	100	1.74	5.4	124	23	47	567	371	5.9	135	27	60	591	376
63		AW-104	78-80	1	10/00	10/00		341	421	0	1.10	2.50	15	40	1.31	4.1	95	10	22	653	415	4.5	104	11	25	667	417	1.20	3.00	30	100	1.74	5.4	124	24	49	557	361	5.9	135	28	63	580	366
64		AP-101	83-86	2	10/00	8/01		1,533	831	-9	1.10	2.50	15	40	1.31	4.1	95	27	74	367	217	4.5	104	29	89	379	219	1.20	3.00	30	100	1.74	5.4	124	67	174	312	190	5.9	135	80	225	331	190
65		AP-104	83-86	1	10/01	10/01		1,428	831	-9	1.10	2.50	15	40	1.31	4.1	95	25	69	375	224	4.5	104	27	83	387	225	1.20	3.00	30	100	1.74	5.4	124	64	163	319	195	5.9	135	76	212	339	196
66		AW-105	78-80	2	10/01	1/02		2,239	1,241	0	1.10	2.50	15	40	1.31	4.1	95	47	115	298	178	4.5	104	50	137	309	179	1.20	3.00	30	100	1.74	5.4	124	109	284	253	155	5.9	135	127		270	151
67		AP-108	83-86	1	2/05	2/05		1,557	831	-9	1.10	2.50	15	40	1.31	4.1	95	27	75	365	216	4.5	104	29	90	377	217	1.20	3.00	30	100	1.74	5.4	124	68	176	310	189	5.9	135	81	228	330	189
68	AY-101	AN-107	80-81	1	3/07	3/07		557	2,313	-11	1.10	2.50	15	40	1.31	4.1	95	32	57	332	246	4.5	104	35	67	344	248	1.20	3.00	30	100	1.74	5.4	124	81	137	283	214	5.9	135	96	177	301	217
69		BNFL		16	11/09	1/18	400	0	6,924	30	1.10	2.50	15	40	1.31	4.1	95	109	135	203	174	4.5	104	115	153	213	178	1.20	3.00	30	100	1.74	5.4	124	238	297	170	148	5.9	135	275	370	179	144
70	AY-102	BNFL		6	1/08	10/09	400	0	6,549	30	1.10	2.50	15	40	1.31	4.1	95	104	129	209	179	4.5	104	110	146	219	183	1.20	3.00	30	100	1.74	5.4	124	227	282	175	153	5.9	135	261	351	186	150
71		AY-101	68-70	1	2/12	2/12	400	0	386	0	1.10	2.50	15	40	1.31	4.1	95	5	7	925	766	4.5	104	5	8	940	771	1.20	3.00	30	100	1.74	5.4	124	12	15	790	663	5.9	135	14	19	816	674
72		AZ-102	77	1	6/17	6/17	400	0	1,466	-8	1.10	2.50	15	40	1.31	4.1	95	15	21	469	393	4.5	104	17	25	482	397	1.20	3.00	30	100	1.74	5.4	124	40	52	400	341	5.9	135	48	68	421	350
73		AP-101	83-86	1	10/17	10/17	400	128	2,910	2	1.10	2.50	15	40	1.31	4.1	95	42	56	319	262	4.5	104	44	65	331	265	1.20	3.00	30	100	1.74	5.4	124	96	129	271	227	5.9	135	112	163	289	232
74		AP-105	83-86	1	12/17	12/17	400	302	2,910	2	1.10	2.50	15	40	1.31	4.1	95	44	63	310	245	4.5	104	47	74	322	248	1.20	3.00	30	100	1.74	5.4	124	101	146	263	212	5.9	135	118	185	281	217
75		AN-103	80-81	1	6/18	6/18		376	1,733	-11	1.10	2.50	15	40	1.31	4.1	95	22	39	390	290	4.5	104	24	47	402	293	1.20	3.00	30	100	1.74	5.4	124	57	96	332	252	5.9	135	69	125	352	258
76		AP-104	83-86	1	10/18	10/18	400	314	2,910	2	1.10	2.50	15	40	1.31	4.1	95	44	64	310	244	4.5	104	47	74	321	247	1.20	3.00	30	100	1.74	5.4	124	102	147	263	212	5.9	135	119	186	280	216
77		AN-107	80-81	1	10/19	10/19		557	1,733	-11	1.10	2.50	15	40	1.31	4.1	95	24	47	373	267	4.5	104	26	56	385	270	1.20	3.00	30	100	1.74	5.4	124	63	114	318	233	5.9	135	75	148	337	237
78		AW-102	78-80	1	10/19	10/19		761	2,910	10	1.10	2.50	15	40	1.31	4.1	95	55	88	287	212	4.5	104	58	102	299	214	1.20	3.00	30	100	1.74	5.4	124	122	196	243	183	5.9	135	142	248	260	184
79	AZ-101	BNFL		18	10/04	4/19	400	0	6,171	36	1.10	2.50	15	40	1.31	4.1	95	103	126	215	184	4.5	104	108	142	225	187	1.20	3.00	30	100	1.74	5.4	124	220	272	180	157	5.9	135	253	337	191	155
80	AZ-102	BNFL		18	11/06	11/91	400	0	6,556	36	1.10	2.50	15	40	1.31	4.1	95	108	133	208	178	4.5	104	114	150	218	182	1.20	3.00	30	100	1.74	5.4	124	232	287	174	152	5.9	135	267	356	184	149
81	BNFL internal equivalent pipe length and elevation								884	45	Included in BNFL routes						Exceeds 275 lbf/in²						Exceeds 400 lbf/in²											Supernate liquid only transfer						Less than 140 gpm					

Notes:

New = new or like new pipeline with maximum expected pipe roughness of 2 mils (0.002 inches).

EOL = pipeline at end of life (50 years for carbon steel line, 40 years for stainless steel line) with pipe roughness due to corrosion estimated at 150 mils for carbon steel and 10 mils for stainless steel.

***Design Pressure** = All stainless steel pipelines have a design pressure of 400 lbf/in². The design pressure of carbon steel pipelines are either 275 or 400 lbf/in² as indicated. The predicted flow rate at design pressure given in this table assumes that all pipelines are or can be qualified to the higher 400 lbf/in² design pressure.

Table D-8. 3S4 Case 2c.

CASE 3S4 Transfer List - Tank-to-Tank. Case 2c. Critical velocity by Oroskar and Turian (1980) empirical correlation (β_{cv} = 1.2). Pressure drop by Wasp et al. (1977) method with lognormal particle size distribution.

Part 1 (columns A–O): Transfer, pipe and Group 1 properties. Column H and I pipe: 3-in. Schedule-40 Pipe (3.068 in. inside dia.)

Row	A From Tank	B To Tank	C Tank Farm Built (Yr)	D #	E Dates (M/Yr) Start	F Dates (M/Yr) End	G Design Pressure (lbf/in²)	H Carbon Steel Length (ft)	I Stainless Steel Length (ft)	J Total Change in Elevation (ft)	K Liquid ρ_L Density (kg/L)	L Solids ρ_s Density (kg/L)	M C_v Volume (%) times 1.5	N d_p Median Dia. (μm)	O ρ_m Bulk Density (kg/L)
6	AN-101	AP-103	83-86	1	3/03	3/03	400	306	2,774	12	1.21	2.50	0.00	40	1.21
7		AN-106	80-81	2	3/03	3/03		442	626	0	1.21	2.50	0.00	40	1.21
8		AN-107	80-81	3	9/05	8/12		557	626	0	1.21	2.50	0.03	40	1.21
9		BNFL		4	10/08	12/14	400	0	6,413	40	1.21	2.50	0.29	40	1.21
10	AN-102	AN-106	80-81	1	8/06	8/06		319	626	0	1.21	2.50	0.24	40	1.21
11		AN-101	80-81	1	10/08	10/08		405	421	0	1.21	2.50	0.24	40	1.21
12		AN-105	80-81	1	12/12	12/12		329	626	0	1.21	2.50	1.26	40	1.23
13	AN-103	AN-105	80-81	1	10/11	10/11		300	626	0	1.21	2.50	0.20	40	1.21
14		BNFL		2	5/13	5/18		376	6,823	40	1.21	2.50	1.10	40	1.22
15	AN-104	AN-101	80-81	4	9/05	5/15		526	626	0	1.21	2.50	1.29	40	1.23
16		BNFL		2	6/09	4/11	400	0	6,275	40	1.21	2.50	0.71	40	1.22
17		AZ-101	71	1	6/09	6/09	400	562	1,560	5	1.21	2.50	4.01	40	1.26
18		AN-107	80-81	1	6/09	6/09		489	421	0	1.21	2.50	0.66	40	1.22
19		AN-102	80-81	1	4/11	4/11		439	626	0	1.21	2.50	7.32	40	1.30
20		AW-103	78-80	2	4/11	9/11		1,012	3,046	21	1.21	2.50	7.26	40	1.30
21		AW-101	78-80	4	8/12	8/16		994	3,046	21	1.21	2.50	2.78	40	1.25
22		AN-103	80-81	2	6/13	10/13		410	626	0	1.21	2.50	1.20	40	1.23
23		AN-106	80-81	2	1/14	5/14		374	421	0	1.21	2.50	1.17	40	1.23
24		AW-104	78-80	2	5/15	7/15		1,003	3,046	21	1.21	2.50	1.29	40	1.23
25		AN-105	80-81	2	11/15	12/15		384	421	0	1.21	2.50	1.29	40	1.23
26		AP-101	83-86	2	2/17	2/17	400	419	2,636	12	1.21	2.50	3.15	40	1.25
27		AP-105	83-86	1	12/17	12/17	400	302	2,636	12	1.21	2.50	4.77	40	1.27
28		AW-105	78-80	1	3/18	3/18		1,125	3,046	21	1.21	2.50	4.77	40	1.27
29		AP-102	83-86	1	4/19	4/19	400	431	2,636	12	1.21	2.50	3.36	40	1.25
30		AW-106	78-80	1	10/19	10/19		1,114	3,046	21	1.21	2.50	2.87	40	1.25
31	AN-105	AN-104	80-81	1	6/09	6/09		384	421	0	1.21	2.50	0.18	40	1.21
32		BNFL		3	10/11	11/15		452	7,028	40	1.21	2.50	1.22	40	1.23
33	AN-106	AP-107	83-86	1	9/05	9/05		865	3,389	12	1.21	2.50	0.00	40	1.21
34		BNFL		4	8/06	1/14		442	7,028	40	1.21	2.50	0.56	40	1.22
35		AN-107	80-81	2	2/10	4/12		269	421	0	1.21	2.50	0.05	40	1.21
36	AN-107	AN-106	80-81	2	9/05	9/05		269	421	0	1.21	2.50	0.33	40	1.21
37		AW-102	78-80	1	10/10	10/10		1,357	3,006	21	1.21	2.50	0.11	40	1.21
38	AP-101	AP-104	83-86	1	8/16	8/16	400	733	421	0	1.21	2.50	0.00	40	1.21
39		AP-102	83-86	1	2/17	2/17	400	850	421	0	1.21	2.50	0.00	40	1.21
40	AP-102	AN-106	80-81	1	2/10	2/10		883	3,389	-12	1.21	2.50	0.00	40	1.21
41		AN-107	80-81	3	10/10	2/17		988	3,389	-12	1.21	2.50	0.05	40	1.21
42		BNFL		5	6/15	4/19	400	431	5,370	28	1.21	2.50	0.29	40	1.21
43	AP-104	AP-102	83-86	1	6/15	6/15	400	745	421	0	1.21	2.50	0.00	40	1.21
44		BNFL		3	8/16	10/18	400	314	5,370	28	1.21	2.50	0.24	40	1.21
45	AP-105	AP-104	83-86	1	7/17	7/17	400	616	421	0	1.21	2.50	0.24	40	1.21
46		AP-102	83-86	1	12/17	12/17	400	733	421	0	1.21	2.50	0.24	40	1.21
47	AP-107	AW-102	78-80	10	9/00	9/05		1,223	421	9	1.21	2.50	0.00	40	1.21
48	AP-108	AP-107	83-86	2	9/01	9/02	400	866	421	0	1.21	2.50	0.00	40	1.21
49	AW-101	AN-106	80-81	1	4/12	4/12		1,436	3,799	-21	1.21	2.50	0.23	40	1.21
50		AN-101	80-81	1	8/12	8/12		994	3,184	-21	1.21	2.50	0.29	40	1.21
51		AP-102	83-86	1	4/16	4/16		1,425	831	-9	1.21	2.50	0.29	40	1.21
52	AW-103	AY-102	68-70	1	7/07	7/07		1,012	3,320	-10	1.21	2.50	7.44	40	1.31
53		AY-101	68-70	1	3/08	3/08		1,012	3,695	-10	1.21	2.50	7.44	40	1.31
54		AZ-101	71	1	10/10	10/10		1,012	2,942	-17	1.21	2.50	7.44	40	1.31
55	AW-104	AP-102	83-86	1	10/10	10/10		1,434	831	-9	1.21	2.50	0.24	40	1.21
56		AZ-102	77	1	5/13	5/13		1,003	3,327	-17	1.21	2.50	4.55	40	1.27
57		AY-101	68-70	1	5/15	5/15		1,003	3,695	-10	1.21	2.50	4.55	40	1.27
58	AW-105	AZ-101	71	1	10/16	10/16		1,125	2,942	-17	1.21	2.50	2.96	40	1.25
59		AZ-102	77	1	3/18	3/18		1,125	3,327	-17	1.21	2.50	2.96	40	1.25
60	AW-106	AP-107	83-86	1	9/05	9/05		1,537	831	-9	1.21	2.50	0.00	40	1.21
61		AN-102	80-81	1	12/12	12/12		1,519	3,594	-21	1.21	2.50	0.00	40	1.21
62		AW-102	78-80	2	9/00	10/10		314	421	0	1.21	2.50	0.00	40	1.21
63		AW-104	78-80	1	10/00	10/00		341	421	0	1.21	2.50	0.00	40	1.21
64		AP-101	83-86	2	10/00	8/01		1,533	831	-9	1.21	2.50	0.00	40	1.21
65		AP-104	83-86	1	10/01	10/01		1,428	831	-9	1.21	2.50	0.00	40	1.21
66		AW-105	78-80	2	10/01	1/02		2,239	1,241	0	1.21	2.50	0.00	40	1.21
67		AP-108	83-86	1	2/05	2/05		1,557	831	-9	1.21	2.50	0.00	40	1.21
68	AY-101	AN-107	80-81	1	3/07	3/07		557	2,313	-11	1.21	2.50	0.00	40	1.21
69		BNFL		16	11/09	1/18	400	0	6,924	30	1.21	2.50	8.34	40	1.32
70	AY-102	BNFL		6	1/08	10/09	400	0	6,549	30	1.21	2.50	5.43	40	1.28
71		AY-101	68-70	1	2/12	2/12	400	0	386	0	1.21	2.50	10.61	40	1.35
72		AZ-102	77	1	6/17	6/17	400	0	1,466	-8	1.21	2.50	5.84	40	1.29
73		AP-101	83-86	1	10/17	10/17	400	128	2,910	2	1.21	2.50	1.44	40	1.23
74		AP-105	83-86	1	12/17	12/17	400	302	2,910	2	1.21	2.50	1.44	40	1.23
75		AN-103	80-81	1	6/18	6/18		376	1,733	-11	1.21	2.50	0.14	40	1.21
76		AP-104	83-86	1	10/18	10/18	400	314	2,910	2	1.21	2.50	0.14	40	1.21
77		AN-107	80-81	1	10/19	10/19		557	1,733	-11	1.21	2.50	0.09	40	1.21
78		AW-102	78-80	1	10/19	10/19		761	2,910	10	1.21	2.50	0.09	40	1.21
79	AZ-101	BNFL		18	10/04	4/19	400	0	6,171	36	1.21	2.50	5.96	40	1.29
80	AZ-102	BNFL		18	11/06	11/91	400	0	6,556	36	1.21	2.50	7.86	40	1.31
81	BNFL internal equivalent pipe length and elevation								884	45	included in BNFL routes				

Part 2 (columns P–AR): Group 1 at 10 °C and 60 °C, Group 2 properties, Group 2 at 10 °C and 60 °C. Critical conditions (k_{cv} = 1.30, k_f = 1). Flow rate at a pipe design pressure of 400 lbf/in² (gpm). Group 2 C_v Volume (%) times 2.0.

Row	P G1 10 °C Velocity (ft/s)	Q G1 10 °C Flow Rate (gpm)	R G1 10 °C Total Pressure Drop (lbf/in²) New	S EOL	T G1 10 °C Flow Rate at 400 lbf/in² (gpm) New	U EOL	V G1 60 °C Velocity (ft/s)	W G1 60 °C Flow Rate (gpm)	X G1 60 °C Pressure Drop New	Y EOL	Z G1 60 °C Flow Rate at 400 lbf/in² New	AA EOL	AB Liquid ρ_L Density (kg/L)	AC Solids ρ_s Density (kg/L)	AD C_v Volume (%) times 2.0	AE d_p Median Dia. (μm)	AF ρ_m Bulk Density (kg/L)	AG G2 10 °C Velocity (ft/s)	AH G2 10 °C Flow Rate (gpm)	AI G2 10 °C Pressure Drop New	AJ EOL	AK G2 10 °C Flow Rate at 400 lbf/in² New	AL EOL	AM G2 60 °C Velocity (ft/s)	AN G2 60 °C Flow Rate (gpm)	AO G2 60 °C Pressure Drop New	AP EOL	AQ G2 60 °C Flow Rate at 400 lbf/in² New	AR EOL
6	0.3	7	7	7	328	257	0.1	3	6	6	338	260	1.46	3.00	0.00	100	1.46	1.0	22	12	13	275	227	0.4	10	9	9	292	232
7	0.3	7	0	0	573	370	0.1	3	0	0	584	371	1.46	3.00	0.00	100	1.46	1.0	22	2	2	492	333	0.4	10	0	0	513	336
8	1.5	35	2	4	543	342	1.6	38	2	5	554	343	1.46	3.00	0.04	100	1.46	1.6	38	4	7	465	308	1.8	41	4	7	487	311
9	2.1	49	45	50	219	187	2.3	53	45	53	227	189	1.46	3.00	0.38	100	1.47	2.3	53	69	74	179	161	2.5	57	66	74	192	167
10	2.1	48	3	6	609	408	2.3	52	3	7	620	410	1.46	3.00	0.32	100	1.46	2.2	52	6	9	524	367	2.4	56	6	10	546	371
11	2.1	48	3	6	653	406	2.3	52	3	7	664	407	1.46	3.00	0.32	100	1.46	2.2	52	5	9	562	366	2.4	56	5	10	585	369
12	2.7	61	5	10	602	403	2.9	67	5	11	614	404	1.46	3.00	1.68	100	1.49	2.9	66	10	15	516	361	3.1	72	9	16	539	365
13	2.0	46	3	5	616	416	2.2	50	3	6	627	417	1.46	3.00	0.26	100	1.46	2.2	50	6	8	530	373	2.3	54	5	9	552	377
14	2.6	60	60	73	205	168	2.8	65	61	79	213	171	1.46	3.00	1.46	100	1.48	2.8	65	96	109	167	145	3.0	70	93	113	180	150
15	2.7	61	6	13	547	347	2.9	67	7	15	558	348	1.46	3.00	1.72	100	1.49	2.9	67	12	20	467	311	3.1	72	11	22	489	314
16	2.4	56	51	58	221	188	2.7	61	52	62	229	191	1.46	3.00	0.94	100	1.47	2.6	61	80	86	181	162	2.8	66	77	88	194	166
17	3.1	72	19	31	391	276	3.4	79	20	36	402	278	1.46	3.00	5.34	100	1.54	3.4	78	33	48	327	244	3.7	84	32	52	346	249
18	2.4	56	4	9	620	378	2.6	61	4	10	631	379	1.46	3.00	0.88	100	1.47	2.6	60	8	14	532	341	2.8	65	7	15	555	343
19	3.4	78	10	20	550	357	3.7	86	10	23	563	359	1.46	3.00	9.76	100	1.61	3.7	84	18	31	462	317	3.9	91	18	34	486	321
20	3.4	78	50	77	270	195	3.7	85	52	87	281	197	1.46	3.00	9.68	100	1.61	3.7	84	84	116	219	170	3.9	91	82	125	236	174
21	3.0	69	40	59	279	201	3.3	75	41	66	288	202	1.46	3.00	3.70	100	1.52	3.2	74	65	88	230	176	3.5	80	63	94	246	180
22	2.6	61	6	11	578	377	2.9	66	6	13	589	378	1.46	3.00	1.60	100	1.48	2.9	66	10	17	495	338	3.1	71	10	18	517	341
23	2.6	61	4	9	662	416	2.9	66	4	10	674	417	1.46	3.00	1.56	100	1.48	2.9	66	8	13	570	374	3.1	71	8	15	593	377
24	2.7	61	34	49	281	202	2.9	67	35	55	290	204	1.46	3.00	1.72	100	1.49	2.9	67	55	73	233	178	3.1	72	53	77	248	182
25	2.7	61	5	9	657	411	2.9	67	5	11	669	413	1.46	3.00	1.72	100	1.49	2.9	67	8	14	565	370	3.1	72	8	16	589	373
26	3.0	70	29	40	324	248	3.3	76	30	45	334	250	1.46	3.00	4.20	100	1.52	3.3	76	48	61	269	217	3.5	82	47	64	286	223
27	3.2	74	31	42	327	256	3.5	81	32	46	338	259	1.46	3.00	6.36	100	1.56	3.5	80	52	64	270	224	3.7	86	51	68	288	230
28	3.2	74	46	71	271	193	3.5	81	47	80	280	195	1.46	3.00	6.36	100	1.56	3.5	80	76	107	221	169	3.7	86	74	115	238	173
29	3.1	71	29	41	323	247	3.3	77	30	46	333	249	1.46	3.00	4.48	100	1.53	3.3	76	49	62	268	216	3.6	82	48	66	285	222
30	3.0	69	41	62	274	195	3.3	75	42	70	284	197	1.46	3.00	3.82	100	1.52	3.2	75	67	93	226	172	3.5	81	65	100	242	175
31	2.0	46	3	5	662	414	2.2	50	3	6	673	415	1.46	3.00	0.24	100	1.46	2.1	50	5	8	570	373	2.3	53	5	9	594	376
32	2.6	61	63	77	201	164	2.9	66	64	84	209	166	1.46	3.00	1.62	100	1.48	2.9	66	101	116	163	141	3.1	71	98	120	176	147
33	0.3	7	7	7	278	205	0.1	3	7	7	287	206	1.46	3.00	0.00	100	1.46	1.0	22	14	16	231	181	0.4	10	9	9	246	185
34	2.3	54	54	65	202	165	2.6	59	55	70	210	167	1.46	3.00	0.74	100	1.47	2.5	59	86	98	164	142	2.7	63	83	100	177	147
35	1.6	37	2	3	717	466	1.7	40	2	3	728	468	1.46	3.00	0.06	100	1.46	1.7	40	3	4	620	420	1.9	43	3	5	644	423
36	2.2	50	3	5	715	466	2.4	55	3	6	727	467	1.46	3.00	0.44	100	1.47	2.4	54	5	8	618	419	2.5	59	5	8	642	423
37	1.8	42	23	31	272	189	2.0	46	23	34	281	190	1.46	3.00	0.14	100	1.46	2.0	46	36	46	226	167	2.1	49	34	48	241	170
38	0.3	7	0	0	551	323	0.1	3	0	0	561	324	1.46	3.00	0.00	100	1.46	1.0	22	2	3	472	292	0.4	10	0	1	493	294
39	0.3	7	0	0	524	304	0.1	3	0	0	535	305	1.46	3.00	0.00	100	1.46	1.0	22	2	3	448	274	0.4	10	0	1	469	276
40	0.3	7	-6	-6	282	207	0.1	3	-6	-6	291	209	1.46	3.00	0.00	100	1.46	1.0	22	-1	0	235	184	0.4	10	-7	-6	251	188
41	1.6	37	3	8	278	202	1.7	40	3	10	287	204	1.46	3.00	0.06	100	1.46	1.7	40	10	16	232	179	1.9	43	9	17	247	183
42	2.1	49	36	43	233	188	2.3	53	36	46	241	190	1.46	3.00	0.38	100	1.47	2.3	53	57	65	192	163	2.5	57	55	66	205	168
43	0.3	7	0	0	548	321	0.1	3	0	0	559	322	1.46	3.00	0.00	100	1.46	1.0	22	2	3	469	290	0.4	10	0	1	490	292
44	2.1	48	35	41	235	192	2.3	52	35	43	244	195	1.46	3.00	0.32	100	1.46	2.2	52	54	61	194	167	2.4	56	52	62	208	172
45	2.1	48	4	8	581	346	2.3	52	4	9	592	347	1.46	3.00	0.32	100	1.46	2.2	52	7	12	498	312	2.4	56	6	13	520	315
46	2.1	48	4	9	550	323	2.3	52	4	10	561	324	1.46	3.00	0.32	100	1.46	2.2	52	7	14	471	291	2.4	56	7	15	492	293
47	0.3	7	5	5	456	258	0.1	3	5	5	466	259	1.46	3.00	0.00	100	1.46	1.0	22	8	10	387	233	0.4	10	6	6	407	234
48	0.3	7	0	0	520	302	0.1	3	0	0	531	302	1.46	3.00	0.00	100	1.46	1.0	22	2	3	445	272	0.4	10	0	1	466	274
49	2.0	47	7	19	254	181	2.2	51	7	23	263	182	1.46	3.00	0.30	100	1.46	2.2	51	20	34	212	160	2.4	55	18	37	226	164
50	2.1	49	4	13	286	207	2.3	53	4	17	295	208	1.46	3.00	0.38	100	1.47	2.3	53	15	26	239	183	2.5	57	13	28	255	187
51	2.1	49	4	14	391	232	2.3	53	4	17	401	233	1.46	3.00	0.38	100	1.47	2.3	53	10	22	331	209	2.5	57	9	25	349	211
52	3.4	79	36	63	267	195	3.7	86	37	74	277	197	1.46	3.00	9.92	100	1.61	3.7	85	67	101	218	170	4.0	91	65	109	234	174
53	3.4	79	39	67	256	189	3.7	86	41	79	266	191	1.46	3.00	9.92	100	1.61	3.7	85	74	108	208	164	4.0	91	71	117	224	169
54	3.4	79	28	54	281	202	3.7	86	30	64	292	204	1.46	3.00	9.92	100	1.61	3.7	85	56	88	230	177	4.0	91	54	97	248	182
55	2.1	48	3	13	390	232	2.3	52	3	16	400	233	1.46	3.00	0.32	100	1.46	2.2	52	9	21	330	209	2.4	56	8	24	349	211
56	3.2	74	26	49	273	199	3.5	80	27	58	283	201	1.46	3.00	6.06	100	1.55	3.5	80	52	80	225	175	3.7	86	50	88	241	179
57	3.2	74	33	57	260	192	3.5	80	34	66	270	194	1.46	3.00	6.06	100	1.55	3.5	80	62	91	214	168	3.7	86	60	99	230	173
58	3.0	69	20	41	285	202	3.3	76	21	49	295	203	1.46	3.00	3.94	100	1.52	3.3	75	41	67	236	178	3.5	81	39	74	253	182
59	3.0	69	23	45	272	195	3.3	76	24	53	281	197	1.46	3.00	3.94	100	1.52	3.3	75	46	73	225	172	3.5	81	44	80	241	176
60	0.3	7	-4	-4	382	225	0.1	3	-5	-5	392	226	1.46	3.00	0.00	100	1.46	1.0	22	-2	0	323	203	0.4	10	-5	-5	341	205
61	0.3	7	-10	-10	258	181	0.1	3	-11	-11	267	182	1.46	3.00	0.00	100	1.46	1.0	22	-6	-3	215	161	0.4	10	-12	-11	229	164
62	0.3	7	0	0	694	444	0.1	3	0	0	706	445	1.46	3.00	0.00	100	1.46	1.0	22	1	2	600	400	0.4	10	0	0	623	403
63	0.3	7	0	0	681	432	0.1	3	0	0	693	433	1.46	3.00	0.00	100	1.46	1.0	22	1	2	588	389	0.4	10	0	0	612	392
64	0.3	7	-4	-4	382	226	0.1	3	-5	-5	392	226	1.46	3.00	0.00	100	1.46	1.0	22	-2	0	323	203	0.4	10	-5	-5	341	205
65	0.3	7	-4	-4	391	232	0.1	3	-5	-5	402	233	1.46	3.00	0.00	100	1.46	1.0	22	-2	0	332	209	0.4	10	-5	-5	350	211
66	0.3	7	0	1	311	185	0.1	3	0	0	320	186	1.46	3.00	0.00	100	1.46	1.0	22	5	8	260	166	0.4	10	1	2	276	168
67	0.3	7	-4	-4	380	224	0.1	3	-5	-5	390	225	1.46	3.00	0.00	100	1.46	1.0	22	-2	0	322	202	0.4	10	-5	-5	340	204
68	0.3	7	-6	-5	346	255	0.1	3	-6	-6	356	257	1.46	3.00	0.00	100	1.46	1.0	22	-3	-2	292	227	0.4	10	-6	-6	309	231
69	3.5	80	85	103	201	173	3.8	87	88	114	211	176	1.46	3.00	11.12	100	1.63	3.7	86	145	162	160	146	4.0	92	140	168	174	153
70	3.3	75	73	87	211	181	3.6	82	75	96	220	184	1.46	3.00	7.24	100	1.57	3.5	81	122	136	170	154	3.8	88	118	141	184	161
71	3.6	82	4	5	909	755	3.9	89	4	6	924	759	1.46	3.00	14.14	100	1.68	3.8	88	8	9	770	662	4.1	95	7	9	802	673
72	3.3	76	9	12	473	396	3.6	83	9	14	485	400	1.46	3.00	7.78	100	1.58	3.6	82	18	21	397	348	3.8	89	17	23	419	356
73	2.7	62	18	24	330	270	3.0	68	19	27	340	273	1.46	3.00	1.92	100	1.49	2.9	68	33	39	276	237	3.2	73	32	40	293	243
74	2.7	62	19	27	321	253	3.0	68	20	30	331	255	1.46	3.00	1.92	100	1.49	2.9	68	35	43	268	222	3.2	73	33	45	285	228
75	1.9	44	0	3	406	301	2.1	48	0	5	416	303	1.46	3.00	0.18	100	1.46	2.1	47	4	8	344	268	2.2	51	4	9	363	273
76	1.9	44	10	14	323	254	2.1	48	10	15	332	256	1.46	3.00	0.18	100	1.46	2.1	47	19	23	271	224	2.2	51	18	23	287	229
77	1.8	41	0	4	389	278	1.9	45	0	5	399	279	1.46	3.00	0.12	100	1.46	1.9	45	4	8	329	248	2.1	48	3	9	348	252
78	1.8	41	15	20	300	220	1.9	45	15	22	309	222	1.46	3.00	0.12	100	1.46	1.9	45	25	31	250	195	2.1	48	24	32	266	199
79	3.3	76	75	89	216	185	3.6	83	77	98	225	188	1.46	3.00	7.94	100	1.58	3.6	82	123	137	174	157	3.9	89	120	142	188	164
80	3.4	79	84	100	207	177	3.7	86	87	110	216	181	1.46	3.00	10.48	100	1.62	3.7	85	140	156	165	150	4.0	92	136	162	179	157
81		Exceeds 275 lbf/in²						Exceeds 400 lbf/in²								Supernate liquid only transfer									Less than 140 gpm					

Notes (column AS):

New = new or like new pipeline with maximum expected pipe roughness of 2 mils (0.002 inches).

EOL = pipeline at end of life (50 years for carbon steel line, 40 years for stainless steel line) with pipe roughness due to corrosion estimated at 150 mils for carbon steel and 10 mils for stainless steel.

Design Pressure = All stainless steel pipelines have a design pressure of 400 lbf/in². The design pressure of carbon steel pipelines are either 275 or 400 lbf/in² as indicated. The predicted flow rate at design pressure given in this table assumes that all pipelines are or can be qualified to the higher 400 lbf/in² design pressure.

Table D-9. 3S4 Case 2d.

CASE 3S4 Transfer List - Tank-to-Tank

Case 2d. Critical velocity by Oroskar and Turian (1980) empirical correlation (β_{cv} = 1.2). Pressure drop by Wasp et al. (1977) method with lognormal particle size distribution.

Row	A: Transfer From Tank	B: Transfer To Tank	C: Tank Farm Built (Yr)	D: #	E: Transfer Dates (M/Yr) Start	F: Transfer Dates (M/Yr) End	G: Design Pressure* (lbf/in²)	H: 3-in. Schedule-40 Pipe (3.068 in. inside dia.) Carbon Steel Length (ft)	I: Stainless Steel Length (ft)	J: Total Change in Elevation (ft)	K: Group 1 Liquid ρ_L Density (kg/L)	L: Solids ρ_s Density (kg/L)	M: C_v Volume (%) times 1.5	N: d_p Median Dia. (μm)	O: ρ_m Bulk Density (kg/L)
6	AN-101	AP-103	83-86	1	3/03	3/03	400	306	2,774	12	1.10	2.50	0.00	40	1.10
7		AN-106	80-81	2	3/03	3/03		442	626	0	1.10	2.50	0.00	40	1.10
8		AN-107	80-81	3	9/05	8/12		557	626	0	1.10	2.50	0.03	40	1.10
9		BNFL		4	10/08	12/14	400	0	6,413	40	1.10	2.50	0.29	40	1.10
10	AN-102	AN-106	80-81	1	8/06	8/06		319	626	0	1.10	2.50	0.24	40	1.10
11		AN-101	80-81	1	10/08	10/08		405	421	0	1.10	2.50	0.24	40	1.10
12		AN-105	80-81	1	12/12	12/12		329	626	0	1.10	2.50	1.26	40	1.12
13	AN-103	AN-105	80-81	1	10/11	10/11		300	626	0	1.10	2.50	0.20	40	1.10
14		BNFL		2	5/13	5/18		376	6,823	40	1.10	2.50	1.10	40	1.12
15	AN-104	AN-101	80-81	4	9/05	5/15		526	626	0	1.10	2.50	1.29	40	1.12
16		BNFL		2	6/09	4/11	400	0	6,275	40	1.10	2.50	0.71	40	1.11
17		AZ-101	71	1	6/09	6/09	400	562	1,560	5	1.10	2.50	4.01	40	1.16
18		AN-107	80-81	1	6/09	6/09		489	421	0	1.10	2.50	0.66	40	1.11
19		AN-102	80-81	1	4/11	4/11		439	626	0	1.10	2.50	7.32	40	1.20
20		AW-103	78-80	2	4/11	9/11		1,012	3,046	21	1.10	2.50	7.26	40	1.20
21		AW-101	78-80	4	8/12	8/16		994	3,046	21	1.10	2.50	2.78	40	1.14
22		AN-103	80-81	2	6/13	10/13		410	626	0	1.10	2.50	1.20	40	1.12
23		AN-106	80-81	2	1/14	5/14		374	421	0	1.10	2.50	1.17	40	1.12
24		AW-104	78-80	2	5/15	7/15		1,003	3,046	21	1.10	2.50	1.29	40	1.12
25		AN-105	80-81	2	11/15	12/15		384	421	0	1.10	2.50	1.29	40	1.12
26		AP-101	83-86	2	2/17	2/17	400	419	2,636	12	1.10	2.50	3.15	40	1.14
27		AP-105	83-86	1	12/17	12/17	400	302	2,636	12	1.10	2.50	4.77	40	1.17
28		AW-105	78-80	1	3/18	3/18		1,125	3,046	21	1.10	2.50	4.77	40	1.17
29		AP-102	83-86	1	4/19	4/19	400	431	2,636	12	1.10	2.50	3.36	40	1.15
30		AW-106	78-80	1	10/19	10/19		1,114	3,046	21	1.10	2.50	2.87	40	1.14
31	AN-105	AN-104	80-81	1	6/09	6/09		384	421	0	1.10	2.50	0.18	40	1.10
32		BNFL		3	10/11	11/15		452	7,028	40	1.10	2.50	1.22	40	1.12
33	AN-106	AP-107	83-86	1	9/05	9/05		865	3,389	12	1.10	2.50	0.00	40	1.10
34		BNFL		4	8/06	1/14		442	7,028	40	1.10	2.50	0.56	40	1.11
35		AN-107	80-81	2	2/10	4/12		269	421	0	1.10	2.50	0.05	40	1.10
36	AN-107	AN-106	80-81	2	9/05	9/05		269	421	0	1.10	2.50	0.33	40	1.10
37		AW-102	78-80	1	10/10	10/10		1,357	3,006	21	1.10	2.50	0.11	40	1.10
38	AP-101	AP-104	83-86	1	8/16	8/16	400	733	421	0	1.10	2.50	0.00	40	1.10
39		AP-102	83-86	1	2/17	2/17	400	850	421	0	1.10	2.50	0.00	40	1.10
40	AP-102	AN-106	80-81	1	2/10	2/10		883	3,389	-12	1.10	2.50	0.00	40	1.10
41		AN-107	80-81	3	10/10	2/17		988	3,389	-12	1.10	2.50	0.05	40	1.10
42		BNFL		5	6/15	4/19	400	431	5,370	28	1.10	2.50	0.29	40	1.10
43	AP-104	AP-102	83-86	1	6/15	6/15	400	745	421	0	1.10	2.50	0.00	40	1.10
44		BNFL		3	8/16	10/18	400	314	5,370	28	1.10	2.50	0.24	40	1.10
45	AP-105	AP-104	83-86	1	7/17	7/17	400	616	421	0	1.10	2.50	0.24	40	1.10
46		AP-102	83-86	1	12/17	12/17	400	733	421	0	1.10	2.50	0.24	40	1.10
47	AP-107	AW-102	78-80	10	9/00	9/05		1,223	421	9	1.10	2.50	0.00	40	1.10
48	AP-108	AP-107	83-86	2	9/01	9/02	400	666	421	0	1.10	2.50	0.00	40	1.10
49	AW-101	AN-106	80-81	1	4/12	4/12		1,436	3,799	-21	1.10	2.50	0.23	40	1.10
50		AN-101	80-81	1	8/12	8/12		994	3,184	-21	1.10	2.50	0.29	40	1.10
51		AP-102	83-86	1	4/16	4/16		1,425	831	-9	1.10	2.50	0.29	40	1.10
52	AW-103	AY-102	68-70	1	7/07	7/07		1,012	3,320	-10	1.10	2.50	7.44	40	1.20
53		AY-101	68-70	1	3/08	3/08		1,012	3,695	-10	1.10	2.50	7.44	40	1.20
54		AZ-101	71	1	10/10	10/10		1,012	2,942	-17	1.10	2.50	7.44	40	1.20
55	AW-104	AP-102	83-86	1	10/10	10/10		1,434	831	-9	1.10	2.50	0.24	40	1.10
56		AZ-102	77	1	5/13	5/13		1,003	3,327	-17	1.10	2.50	4.55	40	1.16
57		AY-101	68-70	1	5/15	5/15		1,003	3,695	-10	1.10	2.50	4.55	40	1.16
58	AW-105	AZ-101	71	1	10/16	10/16		1,125	2,942	-17	1.10	2.50	2.96	40	1.14
59		AZ-102	77	1	3/18	3/18		1,125	3,327	-17	1.10	2.50	2.96	40	1.14
60	AW-106	AP-107	83-86	1	9/05	9/05		1,537	831	-9	1.10	2.50	0.00	40	1.10
61		AN-102	80-81	1	12/12	12/12		1,519	3,594	-21	1.10	2.50	0.00	40	1.10
62		AW-102	78-80	2	9/00	10/10		314	421	0	1.10	2.50	0.00	40	1.10
63		AW-104	78-80	1	10/00	10/00		341	421	0	1.10	2.50	0.00	40	1.10
64		AP-101	83-86	2	10/00	8/01		1,533	831	-9	1.10	2.50	0.00	40	1.10
65		AP-104	83-86	1	10/01	10/01		1,428	831	-9	1.10	2.50	0.00	40	1.10
66		AW-105	78-80	2	10/01	1/02		2,239	1,241	0	1.10	2.50	0.00	40	1.10
67		AP-108	83-86	1	2/05	2/05		1,557	831	-9	1.10	2.50	0.00	40	1.10
68	AY-101	AN-107	80-81	1	3/07	3/07		557	2,313	-11	1.10	2.50	0.00	40	1.10
69		BNFL		16	11/09	1/18	400	0	6,924	30	1.10	2.50	8.34	40	1.22
70	AY-102	BNFL		6	1/08	10/09	400	0	6,549	30	1.10	2.50	5.43	40	1.18
71		AY-101	68-70	1	2/12	2/12	400	0	386	0	1.10	2.50	10.81	40	1.25
72		AZ-102	77	1	6/17	6/17	400	0	1,466	-8	1.10	2.50	5.84	40	1.18
73		AP-101	83-86	1	10/17	10/17	400	128	2,910	2	1.10	2.50	1.44	40	1.12
74		AP-105	83-86	1	12/17	12/17	400	302	2,910	2	1.10	2.50	1.44	40	1.12
75		AN-103	80-81	1	6/18	6/18		376	1,733	-11	1.10	2.50	0.14	40	1.10
76		AP-104	83-86	1	10/18	10/18	400	314	2,910	2	1.10	2.50	0.14	40	1.10
77		AN-107	80-81	1	10/19	10/19		557	1,733	-11	1.10	2.50	0.09	40	1.10
78		AW-102	78-80	1	10/19	10/19		761	2,910	10	1.10	2.50	0.09	40	1.10
79	AZ-101	BNFL		18	10/04	4/19	400	0	6,171	36	1.10	2.50	5.94	40	1.18
80	AZ-102	BNFL		18	11/06	11/91	400	0	6,556	36	1.10	2.50	7.86	40	1.21
81	BNFL internal equivalent pipe length and elevation								884	45	Included in BNFL routes				

Row	P: Temp. = 10 °C Critical (k_{cv} = 1.30, k_f = 1) Velocity (ft/s)	Q: Flow Rate (gpm)	R: Total Pressure Drop (lbf/in²) New	S: EOL	T: Flow Rate at a Pipe Design Pressure of 400 lbf/in² (gpm) New	U: EOL	V: Temp. = 60 °C Critical (k_{cv} = 1.30, k_f = 1) Velocity (ft/s)	W: Flow Rate (gpm)	X: Total Pressure Drop (lbf/in²) New	Y: EOL	Z: Flow Rate at a Pipe Design Pressure of 400 lbf/in² (gpm) New	AA: EOL
6	0.2	6	6	6	348	271	0.1	2	6	6	357	273
7	0.2	6	0	0	605	389	0.1	2	0	0	614	390
8	1.7	39	2	5	574	359	1.8	42	3	6	583	360
9	2.4	55	45	51	233	197	2.6	60	46	55	241	200
10	2.3	53	4	7	643	429	2.5	58	4	8	653	430
11	2.3	53	3	7	688	426	2.5	58	3	8	699	427
12	3.0	69	6	11	635	422	3.3	75	6	13	645	424
13	2.2	52	3	6	650	436	2.5	57	3	7	660	438
14	2.9	67	61	77	218	178	3.2	73	64	85	226	180
15	3.0	69	7	15	577	364	3.3	75	7	17	587	365
16	2.7	63	52	60	235	199	3.0	69	53	66	243	201
17	3.5	81	21	35	412	289	3.9	89	22	41	422	291
18	2.7	62	5	10	653	397	3.0	68	5	12	663	397
19	3.8	88	11	23	577	373	4.2	96	12	27	589	374
20	3.8	88	53	85	285	204	4.2	96	56	98	295	206
21	3.3	77	41	64	295	211	3.7	84	43	73	304	212
22	3.0	68	6	12	609	395	3.2	74	7	14	619	396
23	2.9	68	5	10	698	436	3.2	74	5	12	708	437
24	3.0	69	35	53	298	212	3.3	75	36	60	306	214
25	3.0	69	5	11	693	431	3.3	75	5	12	703	433
26	3.4	78	30	43	342	260	3.7	86	32	50	351	262
27	3.6	83	33	46	345	269	3.9	91	35	52	355	271
28	3.6	83	48	78	286	202	3.9	91	51	90	295	204
29	3.4	79	31	45	341	259	3.8	87	33	51	350	261
30	3.4	77	43	68	290	205	3.7	85	45	78	299	207
31	2.2	51	3	6	698	434	2.4	56	3	7	708	435
32	3.0	68	64	82	213	173	3.2	75	67	91	221	175
33	0.2	6	6	6	294	215	0.1	2	6	6	303	217
34	2.6	61	55	68	215	174	2.9	66	57	75	222	176
35	1.8	41	2	3	756	490	2.0	45	2	3	766	491
36	2.4	56	3	6	754	489	2.7	61	3	6	764	490
37	2.0	47	23	33	289	199	2.2	51	23	36	297	200
38	0.2	6	0	0	581	339	0.1	2	0	0	591	340
39	0.2	6	0	0	553	319	0.1	2	0	0	563	320
40	0.2	6	-6	-5	298	218	0.1	2	-6	-6	306	219
41	1.8	41	4	11	294	213	2.0	45	5	13	303	214
42	2.4	55	36	45	247	198	2.6	60	37	49	255	200
43	0.2	6	0	0	578	337	0.1	2	0	0	588	338
44	2.3	53	35	42	250	203	2.5	58	36	46	258	205
45	2.3	53	4	9	613	364	2.5	58	4	10	623	364
46	2.3	53	4	10	580	339	2.5	58	5	12	590	340
47	0.2	6	4	4	482	271	0.1	2	4	4	491	272
48	0.2	6	0	0	550	317	0.1	2	0	0	559	317
49	2.3	53	9	23	269	190	2.5	58	10	28	277	191
50	2.4	55	6	17	303	217	2.6	60	7	22	311	218
51	2.4	55	5	17	413	244	2.6	60	5	20	422	244
52	3.8	88	40	73	281	203	4.2	96	43	87	291	205
53	3.8	88	44	78	269	197	4.2	96	48	93	279	199
54	3.8	88	32	64	296	211	4.2	96	35	77	306	213
55	2.3	53	4	16	412	243	2.5	58	5	19	422	244
56	3.6	83	30	58	288	208	3.9	90	33	69	297	210
57	3.6	83	37	66	275	201	3.9	90	40	78	284	203
58	3.4	78	23	49	301	211	3.7	85	25	59	310	213
59	3.4	78	26	52	287	205	3.7	85	29	63	296	206
60	0.2	6	-4	-4	404	237	0.1	2	-4	-4	413	237
61	0.2	6	-10	-10	273	190	0.1	2	-10	-10	281	191
62	0.2	6	0	0	732	466	0.1	2	0	0	742	467
63	0.2	6	0	0	718	453	0.1	2	0	0	729	454
64	0.2	6	-4	-4	404	237	0.1	2	-4	-4	413	238
65	0.2	6	-4	-4	414	244	0.1	2	-4	-4	423	245
66	0.2	6	0	0	329	194	0.1	2	0	0	338	195
67	0.2	6	-4	-4	402	235	0.1	2	-4	-4	411	236
68	0.2	6	-5	-5	366	268	0.1	2	-5	-5	375	270
69	3.9	89	91	112	213	181	4.2	98	96	128	222	184
70	3.7	85	77	95	224	190	4.0	92	81	107	232	193
71	4.0	92	5	6	950	785	4.4	100	5	7	963	790
72	3.7	85	10	14	497	415	4.1	93	11	17	508	418
73	3.0	70	20	27	349	284	3.3	77	21	30	358	286
74	3.0	70	21	30	339	266	3.3	77	22	35	348	268
75	2.1	49	1	5	429	316	2.3	53	2	7	438	317
76	2.1	49	11	15	342	267	2.3	53	11	17	350	269
77	2.0	46	1	5	411	291	2.2	50	1	7	420	293
78	2.0	46	15	22	318	232	2.2	50	16	24	326	233
79	3.7	86	79	96	229	194	4.1	94	83	108	238	197
80	3.8	89	89	109	219	186	4.2	97	94	123	228	189
81		Exceeds 275 lbf/in²						Exceeds 400 lbf/in²				

Row	AB: Group 2 Liquid ρ_L Density (kg/L)	AC: Solids ρ_s Density (kg/L)	AD: C_v Volume (%) times 2.0	AE: d_p Median Dia. (μm)	AF: ρ_m Bulk Density (kg/L)	AG: Temp. = 10 °C Critical (k_{cv} = 1.30, k_f = 1) Velocity (ft/s)	AH: Flow Rate (gpm)	AI: Total Pressure Drop (lbf/in²) New	AJ: EOL	AK: Flow Rate at a Pipe Design Pressure of 400 lbf/in² (gpm) New	AL: EOL	AM: Temp. = 60 °C Critical (k_{cv} = 1.30, k_f = 1) Velocity (ft/s)	AN: Flow Rate (gpm)	AO: Total Pressure Drop (lbf/in²) New	AP: EOL	AQ: Flow Rate at a Pipe Design Pressure of 400 lbf/in² (gpm) New	AR: EOL
6	1.20	3.00	0.00	100	1.20	0.3	7	7	7	330	259	0.1	2	6	6	340	261
7	1.20	3.00	0.00	100	1.20	0.3	7	0	0	576	372	0.1	2	0	0	587	373
8	1.20	3.00	0.04	100	1.20	2.2	51	5	9	546	344	2.4	56	5	11	557	345
9	1.20	3.00	0.38	100	1.21	3.1	72	69	81	220	187	3.4	78	71	90	228	190
10	1.20	3.00	0.32	100	1.21	3.0	70	7	12	612	410	3.3	76	7	14	623	411
11	1.20	3.00	0.32	100	1.21	3.0	70	6	12	655	407	3.3	76	6	15	667	409
12	1.20	3.00	1.68	100	1.23	3.9	90	11	21	603	403	4.3	98	12	25	614	404
13	1.20	3.00	0.26	100	1.20	2.9	68	6	11	618	417	3.2	74	6	13	630	419
14	1.20	3.00	1.46	100	1.23	3.8	88	101	130	205	169	4.2	96	108	150	214	171
15	1.20	3.00	1.72	100	1.23	3.9	90	13	28	547	347	4.3	98	15	34	559	348
16	1.20	3.00	0.94	100	1.22	3.6	82	82	98	222	189	3.9	90	87	111	230	191
17	1.20	3.00	5.34	100	1.30	4.6	106	38	66	388	274	5.0	116	43	81	400	276
18	1.20	3.00	0.88	100	1.22	3.5	82	9	19	621	379	3.9	89	9	23	633	380
19	1.20	3.00	9.76	100	1.38	5.0	114	21	45	539	350	5.4	125	25	57	554	353
20	1.20	3.00	9.68	100	1.37	5.0	114	94	157	266	191	5.4	124	107	195	277	192
21	1.20	3.00	3.70	100	1.27	4.4	101	71	115	278	200	4.8	110	78	139	288	201
22	1.20	3.00	1.60	100	1.23	3.9	89	12	24	578	377	4.2	97	13	29	590	379
23	1.20	3.00	1.56	100	1.23	3.9	89	9	19	662	416	4.2	97	10	23	675	417
24	1.20	3.00	1.72	100	1.23	3.9	90	58	93	281	202	4.3	98	63	109	291	203
25	1.20	3.00	1.72	100	1.23	3.9	90	9	20	658	411	4.3	98	10	24	670	413
26	1.20	3.00	4.20	100	1.28	4.4	103	53	79	322	247	4.9	112	59	95	333	249
27	1.20	3.00	6.36	100	1.31	4.7	108	58	83	324	254	5.1	118	66	102	336	257
28	1.20	3.00	6.36	100	1.31	4.7	108	85	144	268	191	5.1	118	95	176	279	192
29	1.20	3.00	4.48	100	1.28	4.5	103	55	81	321	245	4.9	113	61	98	332	248
30	1.20	3.00	3.82	100	1.27	4.4	101	73	122	273	194	4.8	110	81	147	283	196
31	1.20	3.00	0.24	100	1.20	2.9	67	5	11	664	415	3.2	73	5	13	676	417
32	1.20	3.00	1.62	100	1.23	3.9	89	107	140	201	164	4.2	98	115	162	209	166
33	1.20	3.00	0.00	100	1.20	0.3	7	7	7	279	206	0.1	2	6	6	288	207
34	1.20	3.00	0.74	100	1.21	3.5	80	88	114	203	166	3.8	87	93	129	211	168
35	1.20	3.00	0.06	100	1.20	2.4	54	3	6	720	468	2.6	59	3	7	731	470
36	1.20	3.00	0.44	100	1.21	3.2	74	5	10	718	467	3.5	80	6	12	730	469
37	1.20	3.00	0.14	100	1.20	2.7	62	35	54	273	190	2.9	67	36	61	282	191
38	1.20	3.00	0.00	100	1.20	0.3	7	0	0	553	325	0.1	2	0	0	564	326
39	1.20	3.00	0.00	100	1.20	0.3	7	0	0	526	305	0.1	2	0	0	537	306
40	1.20	3.00	0.00	100	1.20	0.3	7	-6	-6	283	208	0.1	2	-6	-6	292	210
41	1.20	3.00	0.06	100	1.20	2.4	54	13	24	279	203	2.6	59	13	29	288	205
42	1.20	3.00	0.38	100	1.21	3.1	72	58	74	234	188	3.4	78	60	84	243	190
43	1.20	3.00	0.00	100	1.20	0.3	7	0	0	550	323	0.1	2	0	0	561	323
44	1.20	3.00	0.32	100	1.21	3.0	70	55	69	237	193	3.3	76	57	77	245	195
45	1.20	3.00	0.32	100	1.21	3.0	70	7	17	583	348	3.3	76	8	20	594	349
46	1.20	3.00	0.32	100	1.21	3.0	70	8	19	552	324	3.3	76	9	23	563	325
47	1.20	3.00	0.00	100	1.20	0.3	7	5	5	458	259	0.1	2	5	5	469	260
48	1.20	3.00	0.00	100	1.20	0.3	7	0	0	523	303	0.1	2	0	0	534	304
49	1.20	3.00	0.30	100	1.21	3.0	69	25	52	256	181	3.3	76	27	63	264	183
50	1.20	3.00	0.38	100	1.21	3.1	72	20	41	287	207	3.4	78	22	50	297	209
51	1.20	3.00	0.38	100	1.21	3.1	72	12	35	393	233	3.4	78	13	43	403	234
52	1.20	3.00	9.92	100	1.38	5.0	114	82	147	263	191	5.4	125	96	187	274	192
53	1.20	3.00	9.92	100	1.38	5.0	114	90	157	252	185	5.4	125	105	199	263	186
54	1.20	3.00	9.92	100	1.38	5.0	114	70	133	277	199	5.4	125	83	170	289	200
55	1.20	3.00	0.32	100	1.21	3.0	70	11	33	392	233	3.3	76	12	40	402	233
56	1.20	3.00	6.06	100	1.31	4.7	108	65	119	271	197	5.1	117	75	151	282	198
57	1.20	3.00	6.06	100	1.31	4.7	108	75	132	259	190	5.1	117	87	165	269	191
58	1.20	3.00	3.94	100	1.27	4.4	102	51	101	284	201	4.8	111	59	126	294	202
59	1.20	3.00	3.94	100	1.27	4.4	102	57	108	271	194	4.8	111	66	135	281	196
60	1.20	3.00	0.00	100	1.20	0.3	7	-4	-4	384	226	0.1	2	-5	-5	394	227
61	1.20	3.00	0.00	100	1.20	0.3	7	-10	-10	259	182	0.1	2	-11	-11	268	183
62	1.20	3.00	0.00	100	1.20	0.3	7	0	0	697	446	0.1	2	0	0	709	447
63	1.20	3.00	0.00	100	1.20	0.3	7	0	0	685	434	0.1	2	0	0	696	435
64	1.20	3.00	0.00	100	1.20	0.3	7	-4	-4	384	227	0.1	2	-5	-5	394	227
65	1.20	3.00	0.00	100	1.20	0.3	7	-4	-4	393	233	0.1	2	-5	-5	403	234
66	1.20	3.00	0.00	100	1.20	0.3	7	0	1	313	186	0.1	2	0	0	322	187
67	1.20	3.00	0.00	100	1.20	0.3	7	-4	-4	382	225	0.1	2	-5	-5	392	226
68	1.20	3.00	0.00	100	1.20	0.3	7	-6	-5	348	256	0.1	2	-6	-6	358	258
69	1.20	3.00	11.12	100	1.40	5.0	116	164	208	197	169	5.5	126	189	256	206	170
70	1.20	3.00	7.24	100	1.33	4.8	110	136	172	209	179	5.2	120	154	208	218	180
71	1.20	3.00	14.14	100	1.45	5.2	119	9	12	878	730	5.6	130	10	15	897	738
72	1.20	3.00	7.78	100	1.34	4.8	111	23	31	466	391	5.3	121	27	40	480	396
73	1.20	3.00	1.92	100	1.23	4.0	92	37	50	331	270	4.3	100	41	60	341	273
74	1.20	3.00	1.92	100	1.23	4.0	92	39	57	321	253	4.3	100	43	68	331	255
75	1.20	3.00	0.18	100	1.20	2.8	64	7	14	408	302	3.0	70	7	17	418	304
76	1.20	3.00	0.18	100	1.20	2.8	64	20	28	324	255	3.0	70	21	32	334	257
77	1.20	3.00	0.12	100	1.20	2.6	60	6	14	391	279	2.9	66	7	17	401	280
78	1.20	3.00	0.12	100	1.20	2.6	60	25	37	302	221	2.9	66	26	41	311	223
79	1.20	3.00	7.92	100	1.34	4.8	111	137	172	214	182	5.3	122	155	207	223	184
80	1.20	3.00	10.48	100	1.39	5.0	115	157	198	203	174	5.5	126	180	242	212	175
81			Supernate liquid only transfer										Less than 140 gpm				

Notes (AS)

New = new or like new pipeline with maximum expected pipe roughness of 2 mils (0.002 inches).

EOL = pipeline at end of life (50 years for carbon steel line, 40 years for stainless steel line) with pipe roughness due to corrosion estimated at 150 mils for carbon steel and 10 mils for stainless steel.

***Design Pressure** = All stainless steel pipelines have a design pressure of 400 lbf/in². The design pressure of carbon steel pipelines are either 275 or 400 lbf/in² as indicated. The predicted flow rate at design pressure given in this table assumes that all pipelines are or can be qualified to the higher 400 lbf/in² design pressure.

Table D-10. 3S4 Case 3a.

CASE 3S4 Transfer List - Tank-to-Tank — Case 3a — Critical velocity by Oroskar and Turian (1980) empirical correlation (β_{cv} = 1.2). Pressure drop by Wasp et al. (1977) method with lognormal particle size distribution.

Transfer; 3-in. Schedule-40 Pipe (3.068 in. inside dia.); Group 1 Properties (Liquid, Solids); Critical (κ_{cv} = 1.30, κ_f = 1).

Row	A: From Tank	B: To Tank	C: Tank Farm Built (Yr)	D: #	E: Dates (M/Yr) Start	F: Dates (M/Yr) End	G: Design Pressure* (lbf/in²)	H: Carbon Steel Length (ft)	I: Stainless Steel Length (ft)	J: Total Change in Elevation (ft)	K: Group 1 Liquid ρ_L Density (kg/L)	L: Solids ρ_s Density (kg/L)	M: C_v Volume (%)	N: d_p Median Dia. (μm)	O: ρ_m Bulk Density (kg/L)	P: 10 °C Velocity (ft/s)	Q: 10 °C Critical Flow Rate (gpm)	R: 10 °C Total Pressure Drop (lbf/in²) New	S: EOL	T: 10 °C Flow Rate at a Pipe Design Pressure of 400 lbf/in² (gpm) New	U: EOL	V: 60 °C Velocity (ft/s)	W: 60 °C Critical Flow Rate (gpm)	X: 60 °C Total Pressure Drop (lbf/in²) New	Y: EOL	Z: 60 °C Flow Rate at a Pipe Design Pressure of 400 lbf/in² (gpm) New	AA: EOL
6	AN-101	AP-103	83-86	1	3/03	3/03	400	306	2,774	12	1.21	2.50	15	200	1.40	4.8	111	75	107	307	242	5.3	121	93	144	320	244
7		AN-106	80-81	2	3/03	3/03		442	626	0	1.21	2.50	15	200	1.40	4.8	111	24	48	534	347	5.3	121	30	66	552	351
8		AN-107	80-81	3	9/05	8/12		557	626	0	1.21	2.50	15	200	1.40	4.8	111	26	56	506	322	5.3	121	33	77	525	325
9		**BNFL**		4	10/08	12/14	400	0	6,413	40	1.21	2.50	15	200	1.40	4.8	111	166	207	203	173	5.3	121	203	271	210	169
10	AN-102	AN-106	80-81	1	8/06	8/06		319	626	0	1.21	2.50	15	200	1.40	4.8	111	21	40	568	384	5.3	121	26	55	587	388
11		AN-101	80-81	1	10/08	10/08		405	421	0	1.21	2.50	15	200	1.40	4.8	111	18	40	608	381	5.3	121	23	55	628	385
12		AN-105	80-81	1	12/12	12/12		329	626	0	1.21	2.50	15	200	1.40	4.8	111	21	40	565	380	5.3	121	27	56	584	385
13	AN-103	AN-105	80-81	1	10/11	10/11		300	626	0	1.21	2.50	15	200	1.40	4.8	111	20	38	574	390	5.3	121	26	53	593	395
14		**BNFL**		2	5/13	5/18		376	6,823	40	1.21	2.50	15	200	1.40	4.8	111	184	245	191	156	5.3	121	225		196	148
15	AN-104	AN-101	80-81	4	9/05	5/15		526	626	0	1.21	2.50	15	200	1.40	4.8	111	25	54	513	328	5.3	121	32	74	532	331
16		**BNFL**		2	6/09	4/11	400	0	6,275	40	1.21	2.50	15	200	1.40	4.8	111	163	203	206	175	5.3	121	199	266	213	172
17		AZ-101	71	1	6/09	6/09	400	562	1,560	5	1.21	2.50	15	200	1.40	4.8	111	50	86	374	265	5.3	121	62	117	390	267
18		AN-107	80-81	1	6/09	6/09		489	421	0	1.21	2.50	15	200	1.40	4.8	111	20	45	579	356	5.3	121	25	63	598	359
19		AN-102	80-81	1	4/11	4/11		439	626	0	1.21	2.50	15	200	1.40	4.8	111	24	48	534	348	5.3	121	30	66	553	352
20		AW-103	78-80	2	4/11	9/11		1,012	3,046	21	1.21	2.50	15	200	1.40	4.8	111	102	169	264	189	5.3	121	126	227	275	187
21		AW-101	78-80	4	8/12	8/16		994	3,046	21	1.21	2.50	15	200	1.40	4.8	111	102	168	264	190	5.3	121	125	225	276	188
22		AN-103	80-81	2	6/13	10/13		410	626	0	1.21	2.50	15	200	1.40	4.8	111	23	46	542	356	5.3	121	29	63	561	360
23		AN-106	80-81	2	1/14	5/14		374	421	0	1.21	2.50	15	200	1.40	4.8	111	18	38	620	392	5.3	121	22	52	640	396
24		AW-104	78-80	2	5/15	7/15		1,003	3,046	21	1.21	2.50	15	200	1.40	4.8	111	102	168	264	190	5.3	121	125	226	276	187
25		AN-105	80-81	2	11/15	12/15		384	421	0	1.21	2.50	15	200	1.40	4.8	111	18	38	616	389	5.3	121	22	53	636	393
26		AP-101	83-86	2	2/17	2/17	400	419	2,636	12	1.21	2.50	15	200	1.40	4.8	111	75	111	308	237	5.3	121	92	149	322	238
27		AP-105	83-86	1	12/17	12/17	400	302	2,636	12	1.21	2.50	15	200	1.40	4.8	111	72	103	314	247	5.3	121	89	138	328	250
28		AW-105	78-80	1	3/18	3/18		1,125	3,046	21	1.21	2.50	15	200	1.40	4.8	111	105	177	260	184	5.3	121	129	238	271	181
29		AP-102	83-86	1	4/19	4/19	400	431	2,636	12	1.21	2.50	15	200	1.40	4.8	111	75	112	307	236	5.3	121	93	150	321	237
30		AW-106	78-80	1	10/19	10/19		1,114	3,046	21	1.21	2.50	15	200	1.40	4.8	111	105	176	260	185	5.3	121	129	237	272	182
31	AN-105	AN-104	80-81	1	6/09	6/09		384	421	0	1.21	2.50	15	200	1.40	4.8	111	18	38	616	389	5.3	121	22	53	636	393
32		**BNFL**		3	10/11	11/15		452	7,028	40	1.21	2.50	15	200	1.40	4.8	111	190	256	187	151	5.3	121	233		192	142
33	AN-106	AP-107	83-86	1	9/05	9/05		865	3,389	12	1.21	2.50	15	200	1.40	4.8	111	101	163	259	191	5.3	121	126	221	270	189
34		**BNFL**		4	8/06	1/14		442	7,028	40	1.21	2.50	15	200	1.40	4.8	111	190	255	187	152	5.3	121	232		192	143
35		AN-107	80-81	2	2/10	4/12		269	421	0	1.21	2.50	15	200	1.40	4.8	111	15	30	667	437	5.3	121	19	42	687	442
36	AN-107	AN-106	80-81	2	9/05	9/05		269	421	0	1.21	2.50	15	200	1.40	4.8	111	15	30	667	437	5.3	121	19	42	687	442
37		AW-102	78-80	1	10/10	10/10		1,357	3,006	21	1.21	2.50	15	200	1.40	4.8	111	109	191	254	176	5.3	121	134	258	265	171
38	AP-101	AP-104	83-86	1	8/16	8/16	400	733	421	0	1.21	2.50	15	200	1.40	4.8	111	25	62	513	304	5.3	121	32	86	531	306
39		AP-102	83-86	1	2/17	2/17	400	850	421	0	1.21	2.50	15	200	1.40	4.8	111	28	70	488	286	5.3	121	35	97	506	288
40	AP-102	AN-106	80-81	1	2/10	2/10		883	3,389	-12	1.21	2.50	15	200	1.40	4.8	111	87	150	264	194	5.3	121	111	207	275	192
41		AN-107	80-81	3	10/10	2/17		988	3,389	-12	1.21	2.50	15	200	1.40	4.8	111	89	157	260	189	5.3	121	114	217	272	187
42		**BNFL**		5	6/15	4/19	400	431	5,370	28	1.21	2.50	15	200	1.40	4.8	111	145	200	217	174	5.3	121	178	265	225	170
43	AP-104	AP-102	83-86	1	6/15	6/15	400	745	421	0	1.21	2.50	15	200	1.40	4.8	111	26	63	510	302	5.3	121	32	87	529	304
44		**BNFL**		3	8/16	10/18	400	314	5,370	28	1.21	2.50	15	200	1.40	4.8	111	143	192	219	179	5.3	121	175	254	228	176
45	AP-105	AP-104	83-86	1	7/17	7/17	400	616	421	0	1.21	2.50	15	200	1.40	4.8	111	23	54	542	326	5.3	121	29	75	560	329
46		AP-102	83-86	1	12/17	12/17	400	733	421	0	1.21	2.50	15	200	1.40	4.8	111	25	62	513	304	5.3	121	32	86	531	306
47	AP-107	AW-102	78-80	10	9/00	9/05		1,223	421	9	1.21	2.50	15	200	1.40	4.8	111	42	101	425	242	5.3	121	51	139	442	243
48	AP-108	AP-107	83-86	2	9/01	9/02	400	866	421	0	1.21	2.50	15	200	1.40	4.8	111	28	71	485	283	5.3	121	36	99	503	285
49	AW-101	AN-106	80-81	1	4/12	4/12		1,436	3,799	-21	1.21	2.50	15	200	1.40	4.8	111	103	194	239	168	5.3	121	133	271	248	163
50		AN-101	80-81	1	8/12	8/12		994	3,184	-21	1.21	2.50	15	200	1.40	4.8	111	79	146	269	194	5.3	121	103	205	280	192
51		AP-102	83-86	1	4/16	4/16		1,425	831	-9	1.21	2.50	15	200	1.40	4.8	111	44	116	366	218	5.3	121	57	163	382	218
52	AW-103	AY-102	68-70	1	7/07	7/07		1,012	3,320	-10	1.21	2.50	15	200	1.40	4.8	111	90	158	261	189	5.3	121	114	219	273	187
53		AY-101	68-70	1	3/08	3/08		1,012	3,695	-10	1.21	2.50	15	200	1.40	4.8	111	98	169	250	183	5.3	121	125	233	261	180
54		AZ-101	71	1	10/10	10/10		1,012	2,942	-17	1.21	2.50	15	200	1.40	4.8	111	77	143	276	197	5.3	121	100	200	288	195
55	AW-104	AP-102	83-86	1	10/10	10/10		1,434	831	-9	1.21	2.50	15	200	1.40	4.8	111	45	117	365	218	5.3	121	58	164	381	217
56		AZ-102	77	1	5/13	5/13		1,003	3,327	-17	1.21	2.50	15	200	1.40	4.8	111	85	153	263	191	5.3	121	110	214	274	188
57		AY-101	68-70	1	5/15	5/15		1,003	3,695	-10	1.21	2.50	15	200	1.40	4.8	111	98	168	250	183	5.3	121	125	232	261	180
58	AW-105	AZ-101	71	1	10/16	10/16		1,125	2,942	-17	1.21	2.50	15	200	1.40	4.8	111	80	151	272	192	5.3	121	103	211	284	190
59		AZ-102	77	1	3/18	3/18		1,125	3,327	-17	1.21	2.50	15	200	1.40	4.8	111	88	161	259	185	5.3	121	113	225	270	182
60	AW-106	AP-107	83-86	1	9/05	9/05		1,537	831	-9	1.21	2.50	15	200	1.40	4.8	111	47	124	357	212	5.3	121	60	174	372	210
61		AN-102	80-81	1	12/12	12/12		1,519	3,594	-21	1.21	2.50	15	200	1.40	4.8	111	100	194	242	168	5.3	121	129	271	252	163
62		AW-102	78-80	2	9/00	10/10		314	421	0	1.21	2.50	15	200	1.40	4.8	111	16	34	646	416	5.3	121	20	46	666	421
63		AW-104	78-80	1	10/00	10/00		341	421	0	1.21	2.50	15	200	1.40	4.8	111	17	35	634	405	5.3	121	21	49	654	409
64		AP-101	83-86	2	10/00	8/01		1,533	831	-9	1.21	2.50	15	200	1.40	4.8	111	47	123	357	212	5.3	121	60	173	373	211
65		AP-104	83-86	1	10/01	10/01		1,428	831	-9	1.21	2.50	15	200	1.40	4.8	111	45	116	366	218	5.3	121	57	163	381	217
66		AW-105	78-80	2	10/01	1/02		2,239	1,241	0	1.21	2.50	15	200	1.40	4.8	111	77	189	291	172	5.3	121	97	262	304	167
67		AP-108	83-86	1	2/05	2/05		1,557	831	-9	1.21	2.50	15	200	1.40	4.8	111	47	125	356	210	5.3	121	61	176	371	209
68	AY-101	AN-107	80-81	1	3/07	3/07		557	2,313	-11	1.21	2.50	15	200	1.40	4.8	111	57	97	324	240	5.3	121	73	136	338	242
69		**BNFL**		16	11/09	1/18	400	0	6,924	30	1.21	2.50	15	200	1.40	4.8	111	171	215	197	168	5.3	121	211	285	203	163
70	AY-102	**BNFL**		6	1/08	10/09	400	0	6,549	30	1.21	2.50	15	200	1.40	4.8	111	163	205	203	173	5.3	121	200	270	210	169
71		AY-101	68-70	1	2/12	2/12	400	0	386	0	1.21	2.50	15	200	1.40	4.8	111	9	11	896	745	5.3	121	11	15	918	755
72		AZ-102	77	1	6/17	6/17	400	0	1,468	-8	1.21	2.50	15	200	1.40	4.8	111	28	37	456	384	5.3	121	38	52	474	392
73		AP-101	83-86	1	10/17	10/17	400	128	2,910	2	1.21	2.50	15	200	1.40	4.8	111	68	93	312	256	5.3	121	85	125	325	259
74		AP-105	83-86	1	12/17	12/17	400	302	2,910	2	1.21	2.50	15	200	1.40	4.8	111	72	105	303	240	5.3	121	90	142	316	242
75		AN-103	80-81	1	6/18	6/18		376	1,733	-11	1.21	2.50	15	200	1.40	4.8	111	40	68	380	283	5.3	121	52	96	396	287
76		AP-104	83-86	1	10/18	10/18	400	314	2,910	2	1.21	2.50	15	200	1.40	4.8	111	72	105	302	239	5.3	121	91	143	315	241
77		AN-107	80-81	1	10/19	10/19		557	1,733	-11	1.21	2.50	15	200	1.40	4.8	111	44	81	364	261	5.3	121	57	113	380	264
78		AW-102	78-80	1	10/19	10/19		761	2,910	10	1.21	2.50	15	200	1.40	4.8	111	87	141	280	206	5.3	121	108	191	293	206
79	AZ-101	**BNFL**		18	10/04	4/19	400	0	6,171	36	1.21	2.50	15	200	1.40	4.8	111	158	198	208	178	5.3	121	194	260	216	174
80	AZ-102	**BNFL**		18	11/06	11/91	400	0	6,556	36	1.21	2.50	15	200	1.40	4.8	111	167	209	202	172	5.3	121	204	274	208	168
81	BNFL internal equivalent pipe length and elevation								884	45	Included in BNFL routes						Exceeds 275 lbf/in²						Exceeds 400 lbf/in²				

Group 2 Properties (Liquid, Solids); Critical (κ_{cv} = 1.30, κ_f = 1).

Row	AB: Group 2 Liquid ρ_L Density (kg/L)	AC: Solids ρ_s Density (kg/L)	AD: C_v Volume (%)	AE: d_p Median Dia. (μm)	AF: ρ_m Bulk Density (kg/L)	AG: 10 °C Velocity (ft/s)	AH: 10 °C Critical Flow Rate (gpm)	AI: 10 °C Total Pressure Drop (lbf/in²) New	AJ: EOL	AK: 10 °C Flow Rate at a Pipe Design Pressure of 400 lbf/in² (gpm) New	AL: EOL	AM: 60 °C Velocity (ft/s)	AN: 60 °C Critical Flow Rate (gpm)	AO: 60 °C Total Pressure Drop (lbf/in²) New	AP: EOL	AQ: 60 °C Flow Rate at a Pipe Design Pressure of 400 lbf/in² (gpm) New	AR: EOL
6	1.46	3.00	30	400	1.92	5.0	115	138	176	232	196	5.4	124	160	223	257	202
7	1.46	3.00	30	400	1.92	5.0	115	44	76	412	292	5.4	124	52	101	452	301
8	1.46	3.00	30	400	1.92	5.0	115	49	88	391	270	5.4	124	57	117	429	278
9	1.46	3.00	30	400	1.92	5.0	115	300	343	147		5.4	124	345		151	
10	1.46	3.00	30	400	1.92	5.0	115	39	63	440	321	5.4	124	46	83	480	332
11	1.46	3.00	30	400	1.92	5.0	115	34	62	472	321	5.4	124	40	83	514	330
12	1.46	3.00	30	400	1.92	5.0	115	40	64	437	319	5.4	124	46	85	478	329
13	1.46	3.00	30	400	1.92	5.0	115	39	61	445	327	5.4	124	45	81	485	338
14	1.46	3.00	30	400	1.92	5.0	115					5.4	124				
15	1.46	3.00	30	400	1.92	5.0	115	48	85	396	276	5.4	124	56	113	435	284
16	1.46	3.00	30	400	1.92	5.0	115	295	337	149		5.4	124	338		154	
17	1.46	3.00	30	400	1.92	5.0	115	93	138	286	219	5.4	124	107	179	316	226
18	1.46	3.00	30	400	1.92	5.0	115	38	71	449	300	5.4	124	44	95	490	308
19	1.46	3.00	30	400	1.92	5.0	115	44	76	413	292	5.4	124	52	100	452	301
20	1.46	3.00	30	400	1.92	5.0	115	186	269	198	152	5.4	124	214		217	145
21	1.46	3.00	30	400	1.92	5.0	115	186	268	198	153	5.4	124	213		218	146
22	1.46	3.00	30	400	1.92	5.0	115	43	73	419	299	5.4	124	50	96	459	308
23	1.46	3.00	30	400	1.92	5.0	115	33	59	482	330	5.4	124	39	79	524	340
24	1.46	3.00	30	400	1.92	5.0	115	186	268	198	153	5.4	124	214		217	146
25	1.46	3.00	30	400	1.92	5.0	115	33	60	479	327	5.4	124	39	80	521	337
26	1.46	3.00	30	400	1.92	5.0	115	137	181	233	193	5.4	124	158	230	258	197
27	1.46	3.00	30	400	1.92	5.0	115	132	169	238	201	5.4	124	153	214	264	208
28	1.46	3.00	30	400	1.92	5.0	115	191		195	148	5.4	124	220		213	
29	1.46	3.00	30	400	1.92	5.0	115	138	182	233	192	5.4	124	159	232	258	196
30	1.46	3.00	30	400	1.92	5.0	115	191		195	148	5.4	124	219		214	
31	1.46	3.00	30	400	1.92	5.0	115	33	60	479	327	5.4	124	39	80	521	337
32	1.46	3.00	30	400	1.92	5.0	115					5.4	124				
33	1.46	3.00	30	400	1.92	5.0	115	187	263	195	154	5.4	124	217		213	148
34	1.46	3.00	30	400	1.92	5.0	115					5.4	124				
35	1.46	3.00	30	400	1.92	5.0	115	29	48	519	367	5.4	124	33	64	563	379
36	1.46	3.00	30	400	1.92	5.0	115	29	48	519	367	5.4	124	33	64	563	379
37	1.46	3.00	30	400	1.92	5.0	115	199		190	141	5.4	124	229		208	
38	1.46	3.00	30	400	1.92	5.0	115	48	96	396	257	5.4	124	56	130	434	262
39	1.46	3.00	30	400	1.92	5.0	115	53	108	376	241	5.4	124	62	146	414	246
40	1.46	3.00	30	400	1.92	5.0	115	167	245	200	158	5.4	124	197		220	153
41	1.46	3.00	30	400	1.92	5.0	115	172	256	197	154	5.4	124	202		216	148
42	1.46	3.00	30	400	1.92	5.0	115	265	327	159		5.4	124	305		169	
43	1.46	3.00	30	400	1.92	5.0	115	48	97	394	255	5.4	124	57	131	432	260
44	1.46	3.00	30	400	1.92	5.0	115	260	315	161		5.4	124	299	396	171	
45	1.46	3.00	30	400	1.92	5.0	115	43	84	419	275	5.4	124	50	113	458	282
46	1.46	3.00	30	400	1.92	5.0	115	48	96	396	257	5.4	124	56	130	434	262
47	1.46	3.00	30	400	1.92	5.0	115	76	154	325	204	5.4	124	87	206	359	205
48	1.46	3.00	30	400	1.92	5.0	115	54	110	374	239	5.4	124	62	148	411	244
49	1.46	3.00	30	400	1.92	5.0	115	200		180		5.4	124	236		195	
50	1.46	3.00	30	400	1.92	5.0	115	156	239	204	159	5.4	124	185		225	154
51	1.46	3.00	30	400	1.92	5.0	115	86	180	281	184	5.4	124	102	245	311	182
52	1.46	3.00	30	400	1.92	5.0	115	172	257	198	154	5.4	124	202		217	147
53	1.46	3.00	30	400	1.92	5.0	115	187	275	189	148	5.4	124	220		206	
54	1.46	3.00	30	400	1.92	5.0	115	150	233	210	161	5.4	124	178		231	158
55	1.46	3.00	30	400	1.92	5.0	115	87	181	280	183	5.4	124	102	247	310	181
56	1.46	3.00	30	400	1.92	5.0	115	166	250	199	155	5.4	124	196		219	150
57	1.46	3.00	30	400	1.92	5.0	115	187	274	189	148	5.4	124	220		207	
58	1.46	3.00	30	400	1.92	5.0	115	155	244	206	157	5.4	124	183		227	152
59	1.46	3.00	30	400	1.92	5.0	115	171	263	196	151	5.4	124	202		215	143
60	1.46	3.00	30	400	1.92	5.0	115	91	192	274	178	5.4	124	107	261	303	175
61	1.46	3.00	30	400	1.92	5.0	115	195		182		5.4	124	230		198	
62	1.46	3.00	30	400	1.92	5.0	115	31	53	502	350	5.4	124	36	70	545	360
63	1.46	3.00	30	400	1.92	5.0	115	32	56	493	341	5.4	124	37	74	536	351
64	1.46	3.00	30	400	1.92	5.0	115	91	191	274	178	5.4	124	107	261	304	175
65	1.46	3.00	30	400	1.92	5.0	115	87	181	281	183	5.4	124	102	246	311	182
66	1.46	3.00	30	400	1.92	5.0	115	145		220	142	5.4	124	169		244	
67	1.46	3.00	30	400	1.92	5.0	115	92	194	272	177	5.4	124	108	264	302	174
68	1.46	3.00	30	400	1.92	5.0	115	110	160	248	198	5.4	124	130	211	274	203
69	1.46	3.00	30	400	1.92	5.0	115	313	359	141		5.4	124	360		144	
70	1.46	3.00	30	400	1.92	5.0	115	297	341	147		5.4	124	342		152	
71	1.46	3.00	30	400	1.92	5.0	115	16	19	705	617	5.4	124	19	24	755	640
72	1.46	3.00	30	400	1.92	5.0	115	55	64	352	315	5.4	124	65	83	388	333
73	1.46	3.00	30	400	1.92	5.0	115	128	155	237	208	5.4	124	149	197	262	216
74	1.46	3.00	30	400	1.92	5.0	115	135	173	230	195	5.4	124	157	222	254	201
75	1.46	3.00	30	400	1.92	5.0	115	78	113	292	235	5.4	124	93	150	323	244
76	1.46	3.00	30	400	1.92	5.0	115	135	174	229	194	5.4	124	158	223	254	200
77	1.46	3.00	30	400	1.92	5.0	115	86	132	279	217	5.4	124	102	175	309	223
78	1.46	3.00	30	400	1.92	5.0	115	161	228	212	168	5.4	124	187		233	166
79	1.46	3.00	30	400	1.92	5.0	115	287	328	151		5.4	124	329		158	
80	1.46	3.00	30	400	1.92	5.0	115	303	347	145		5.4	124	348		150	
81	Supernate liquid only transfer											Less than 140 gpm					

AS: Notes

New = new or like new pipeline with maximum expected pipe roughness of 2 mils (0.002 inches).

EOL = pipeline at end of life (50 years for carbon steel line, 40 years for stainless steel line) with pipe roughness due to corrosion estimated at *150 mils for carbon steel* and 10 mils for stainless steel.

***Design Pressure** = All stainless steel pipelines have a design pressure of 400 lbf/in². The design pressure of carbon steel pipelines are either 275 or 400 lbf/in² as indicated. The predicted flow rate at design pressure given in this table assumes that all pipelines are or can be qualified to the higher 400 lbf/in² design pressure.

Table D-11. 3S4 Case 3b.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL	AM	AN	AO	AP	AQ	AR
1	CASE 3S4 Transfer List - Tank-to-Tank										Case 3b	Critical velocity by Oroskar and Turian (1980) empirical correlation (β_{cv} = 1.2). Pressure drop by Wasp et al. (1977) method with lognormal particle size distribution.																																
2											Group 1 Properties					Temperature = 10 °C						Temperature = 60 °C						Group 2 Properties					Temperature = 10 °C						Temperature = 60 °C					
3	Transfer		Tank Farm Built (Yr)	Transfer				3-in. Schedule-40 Pipe (3.068 in. inside dia.)		Total Change in Elevation (ft)	Liquid	Solids				Critical (k_{cv} = 1.30, k_f = 1)				Flow Rate at a Pipe Design Pressure of 400 lbf/in² (gpm)		Critical (k_{cv} = 1.30, k_f = 1)				Flow Rate at a Pipe Design Pressure of 400 lbf/in² (gpm)		Liquid	Solids				Critical (k_{cv} = 1.30, k_f = 1)				Flow Rate at a Pipe Design Pressure of 400 lbf/in² (gpm)		Critical (k_{cv} = 1.30, k_f = 1)				Flow Rate at a Pipe Design Pressure of 400 lbf/in² (gpm)	
4	From Tank	To Tank		#	Dates (M/Y)		Design Pressure (lbf/in²)*	Carbon Steel Length (ft)	Stainless Steel Length (ft)		ρ_L Density (kg/L)	ρ_s Density (kg/L)	C_s Volume (%)	d_p Median Dia. (μm)	ρ_m Bulk Density (kg/L)	Velocity (ft/s)	Flow Rate (gpm)	Total Pressure Drop (lbf/in²)				Velocity (ft/s)	Flow Rate (gpm)	Total Pressure Drop (lbf/in²)				ρ_L Density (kg/L)	ρ_s Density (kg/L)	C_s Volume (%)	d_p Median Dia. (μm)	ρ_m Bulk Density (kg/L)	Velocity (ft/s)	Flow Rate (gpm)	Total Pressure Drop (lbf/in²)				Velocity (ft/s)	Flow Rate (gpm)	Total Pressure Drop (lbf/in²)			
5					Start	End												New	EOL	New	EOL			New	EOL	New	EOL								New	EOL	New	EOL			New	EOL	New	EOL
6	AN-101	AP-103	83-86	1	3/03	3/03	400	306	2,774	12	1.10	2.50	15	200	1.31	5.4	125	86	126	325	253	5.9	136	110	173	337	253	1.20	3.00	30	400	1.74	6.8	156	217	325	287	204	7.4	170	289		282	
7		AN-106	80-81	2	3/03	3/03		442	626	0	1.10	2.50	15	200	1.31	5.4	125	27	58	563	363	5.9	136	36	81	582	367	1.20	3.00	30	400	1.74	6.8	156	72	152	513	325	7.4	170	97	221	541	322
8		AN-107	80-81	3	9/05	8/12		557	626	0	1.10	2.50	15	200	1.31	5.4	125	30	67	534	336	5.9	136	39	94	553	339	1.20	3.00	30	400	1.74	6.8	156	80	177	488	298	7.4	170	107	258	514	289
9		BNFL		4	10/08	12/14	400	0	6,413	40	1.10	2.50	15	200	1.31	5.4	125	187	240	215	180	5.9	136	236	324	218	169	1.20	3.00	30	400	1.74	6.8	156					7.4	170				
10	AN-102	AN-106	80-81	1	8/06	8/06		319	626	0	1.10	2.50	15	200	1.31	5.4	125	24	47	598	401	5.9	136	31	67	618	406	1.20	3.00	30	400	1.74	6.8	156	64	125	545	361	7.4	170	86	182	576	363
11		AN-101	80-81	1	10/08	10/08		405	421	0	1.10	2.50	15	200	1.31	5.4	125	21	48	640	398	5.9	136	28	67	661	402	1.20	3.00	30	400	1.74	6.8	156	56	126	582	358	7.4	170	75	183	615	360
12		AN-105	80-81	1	12/12	12/12		329	626	0	1.10	2.50	15	200	1.31	5.4	125	24	48	595	397	5.9	136	32	68	615	402	1.20	3.00	30	400	1.74	6.8	156	64	128	542	358	7.4	170	87	185	573	360
13	AN-103	AN-105	80-81	1	10/11	10/11		300	626	0	1.10	2.50	15	200	1.31	5.4	125	24	46	604	408	5.9	136	31	64	624	413	1.20	3.00	30	400	1.74	6.8	156	63	121	551	368	7.4	170	84	176	581	371
14		BNFL		2	5/13	5/18		376	6,823	40	1.10	2.50	15	200	1.31	5.4	125	207		202	160	5.9	136	263		202	142	1.20	3.00	30	400	1.74	6.8	156					7.4	170				
15	AN-104	AN-101	80-81	4	9/05	5/15		526	626	0	1.10	2.50	15	200	1.31	5.4	125	29	64	541	342	5.9	136	38	91	560	346	1.20	3.00	30	400	1.74	6.8	156	78	170	494	305	7.4	170	104	248	521	298
16		BNFL		2	6/09	4/11	400	0	6,275	40	1.10	2.50	15	200	1.31	5.4	125	183	235	218	182	5.9	136	232	317	221	172	1.20	3.00	30	400	1.74	6.8	156					7.4	170				
17		AZ-101	71	1	6/09	6/09	400	562	1,560	5	1.10	2.50	15	200	1.31	5.4	125	57	102	396	277	5.9	136	74	142	411	278	1.20	3.00	30	400	1.74	6.8	156	147	266	359	236	7.4	170	196	383	369	193
18		AN-107	80-81	1	6/09	6/09		489	421	0	1.10	2.50	15	200	1.31	5.4	125	23	54	610	371	5.9	136	30	77	630	375	1.20	3.00	30	400	1.74	6.8	156	61	144	555	333	7.4	170	83	210	587	331
19		AN-102	80-81	1	4/11	4/11		439	626	0	1.10	2.50	15	200	1.31	5.4	125	27	57	563	364	5.9	136	35	81	583	368	1.20	3.00	30	400	1.74	6.8	156	72	151	514	326	7.4	170	97	220	542	323
20		AW-103	78-80	2	4/11	9/11		1,012	3,046	21	1.10	2.50	15	200	1.31	5.4	125	116	198	280	197	5.9	136	147	273	289	189	1.20	3.00	30	400	1.74	6.8	156			234		7.4	170			200	
21		AW-101	78-80	4	8/12	8/16		994	3,046	21	1.10	2.50	15	200	1.31	5.4	125	115	197	281	198	5.9	136	146	271	290	190	1.20	3.00	30	400	1.74	6.8	156			235		7.4	170			202	
22		AN-103	80-81	2	6/13	10/13		410	626	0	1.10	2.50	15	200	1.31	5.4	125	26	55	571	372	5.9	136	34	77	591	376	1.20	3.00	30	400	1.74	6.8	156	70	145	521	334	7.4	170	94	211	550	332
23		AN-106	80-81	2	1/14	5/14		374	421	0	1.10	2.50	15	200	1.31	5.4	125	20	45	653	409	5.9	136	26	63	673	414	1.20	3.00	30	400	1.74	6.8	156	54	119	593	369	7.4	170	72	173	627	371
24		AW-104	78-80	2	5/15	7/15		1,003	3,046	21	1.10	2.50	15	200	1.31	5.4	125	115	198	280	197	5.9	136	147	272	290	190	1.20	3.00	30	400	1.74	6.8	156			234		7.4	170			201	
25		AN-105	80-81	2	11/15	12/15		384	421	0	1.10	2.50	15	200	1.31	5.4	125	21	46	649	405	5.9	136	27	65	669	410	1.20	3.00	30	400	1.74	6.8	156	54	121	590	365	7.4	170	73	177	623	367
26		AP-101	83-86	2	2/17	2/17	400	419	2,636	12	1.10	2.50	15	200	1.31	5.4	125	85	131	327	247	5.9	136	109	180	339	247	1.20	3.00	30	400	1.74	6.8	156	216	337	289	196	7.4	170	286		284	
27		AP-105	83-86	1	12/17	12/17	400	302	2,636	12	1.10	2.50	15	200	1.31	5.4	125	82	121	333	259	5.9	136	105	166	346	259	1.20	3.00	30	400	1.74	6.8	156	208	312	296	211	7.4	170	276		293	
28		AW-105	78-80	1	3/18	3/18		1,125	3,046	21	1.10	2.50	15	200	1.31	5.4	125	119	208	276	191	5.9	136	151		285	183	1.20	3.00	30	400	1.74	6.8	156			229		7.4	170			185	
29		AP-102	83-86	1	4/19	4/19	400	431	2,636	12	1.10	2.50	15	200	1.31	5.4	125	85	132	326	246	5.9	136	109	181	338	246	1.20	3.00	30	400	1.74	6.8	156	216	340	288	195	7.4	170	287		283	
30		AW-106	78-80	1	10/19	10/19		1,114	3,046	21	1.10	2.50	15	200	1.31	5.4	125	118	207	276	192	5.9	136	150		285	183	1.20	3.00	30	400	1.74	6.8	156			229		7.4	170			187	
31	AN-105	AN-104	80-81	1	6/09	6/09		384	421	0	1.10	2.50	15	200	1.31	5.4	125	21	46	649	405	5.9	136	27	65	669	410	1.20	3.00	30	400	1.74	6.8	156	54	121	590	365	7.4	170	73	177	623	367
32		BNFL		3	10/11	11/15		452	7,028	40	1.10	2.50	15	200	1.31	5.4	125	214		197	155	5.9	136	272		197		1.20	3.00	30	400	1.74	6.8	156					7.4	170				
33	AN-106	AP-107	83-86	1	9/05	9/05		865	3,389	12	1.10	2.50	15	200	1.31	5.4	125	116	193	275	199	5.9	136	149	267	284	192	1.20	3.00	30	400	1.74	6.8	156			228		7.4	170			184	
34		BNFL		4	8/06	1/14		442	7,028	40	1.10	2.50	15	200	1.31	5.4	125	214		197	156	5.9	136	272		197		1.20	3.00	30	400	1.74	6.8	156					7.4	170				
35		AN-107	80-81	2	2/10	4/12		269	421	0	1.10	2.50	15	200	1.31	5.4	125	18	36	701	456	5.9	136	23	51	722	462	1.20	3.00	30	400	1.74	6.8	156	47	96	635	412	7.4	170	63	140	672	419
36	AN-107	AN-106	80-81	2	9/05	9/05		269	421	0	1.10	2.50	15	200	1.31	5.4	125	18	36	701	456	5.9	136	23	51	722	462	1.20	3.00	30	400	1.74	6.8	156	47	96	635	412	7.4	170	63	140	672	419
37		AW-102	78-80	1	10/10	10/10		1,357	3,006	21	1.10	2.50	15	200	1.31	5.4	125	124	225	269	182	5.9	136	157		278	171	1.20	3.00	30	400	1.74	6.8	156			220		7.4	170				
38	AP-101	AP-104	83-86	1	8/16	8/16	400	733	421	0	1.10	2.50	15	200	1.31	5.4	125	30	75	541	317	5.9	136	38	105	560	319	1.20	3.00	30	400	1.74	6.8	156	78	197	494	279	7.4	170	105	288	520	265
39		AP-102	83-86	1	2/17	2/17	400	850	421	0	1.10	2.50	15	200	1.31	5.4	125	32	84	515	298	5.9	136	42	119	534	299	1.20	3.00	30	400	1.74	6.8	156	86	222	471	260	7.4	170	115	325	495	238
40	AP-102	AN-106	80-81	1	2/10	2/10		883	3,389	-12	1.10	2.50	15	200	1.31	5.4	125	102	180	279	202	5.9	136	135	255	289	195	1.20	3.00	30	400	1.74	6.8	156			236		7.4	170			205	
41		AN-107	80-81	3	10/10	2/17		988	3,389	-12	1.10	2.50	15	200	1.31	5.4	125	105	189	276	197	5.9	136	139	267	285	189	1.20	3.00	30	400	1.74	6.8	156			232		7.4	170			194	
42		BNFL		5	6/15	4/19	400	431	5,370	28	1.10	2.50	15	200	1.31	5.4	125	164	233	230	181	5.9	136	209	318	235	170	1.20	3.00	30	400	1.74	6.8	156					7.4	170				
43	AP-104	AP-102	83-86	1	6/15	6/15	400	745	421	0	1.10	2.50	15	200	1.31	5.4	125	30	76	538	315	5.9	136	39	107	557	317	1.20	3.00	30	400	1.74	6.8	156	79	199	491	277	7.4	170	106	292	518	262
44		BNFL		3	8/16	10/18	400	314	5,370	28	1.10	2.50	15	200	1.31	5.4	125	161	223	232	186	5.9	136	205	304	237	177	1.20	3.00	30	400	1.74	6.8	156			150		7.4	170				
45	AP-105	AP-104	83-86	1	7/17	7/17	400	616	421	0	1.10	2.50	15	200	1.31	5.4	125	27	65	571	340	5.9	136	35	92	590	343	1.20	3.00	30	400	1.74	6.8	156	70	171	521	302	7.4	170	94	251	549	294
46		AP-102	83-86	1	12/17	12/17	400	733	421	0	1.10	2.50	15	200	1.31	5.4	125	30	75	541	317	5.9	136	38	105	560	319	1.20	3.00	30	400	1.74	6.8	156	78	197	494	279	7.4	170	105	288	520	265
47	AP-107	AW-102	78-80	10	9/00	9/05		1,223	421	9	1.10	2.50	15	200	1.31	5.4	125	47	120	449	253	5.9	136	60	168	466	251	1.20	3.00	30	400	1.74	6.8	156	118		409	207	7.4	170	156		427	
48	AP-108	AP-107	83-86	2	9/01	9/02	400	866	421	0	1.10	2.50	15	200	1.31	5.4	125	33	86	512	296	5.9	136	43	121	530	297	1.20	3.00	30	400	1.74	6.8	156	87	226	468	257	7.4	170	117	330	492	234
49	AW-101	AN-106	80-81	1	4/12	4/12		1,436	3,799	-21	1.10	2.50	15	200	1.31	5.4	125	122	235	252	173	5.9	136	162		259	161	1.20	3.00	30	400	1.74	6.8	156			200		7.4	170				
50		AN-101	80-81	1	8/12	8/12		994	3,184	-21	1.10	2.50	15	200	1.31	5.4	125	95	177	284	201	5.9	136	127	253	294	195	1.20	3.00	30	400	1.74	6.8	156	266		243		7.4	170			219	
51		AP-102	83-86	1	4/16	4/16		1,425	831	-9	1.10	2.50	15	200	1.31	5.4	125	53	140	388	227	5.9	136	70	200	402	223	1.20	3.00	30	400	1.74	6.8	156	146		352	170	7.4	170	198		361	
52	AW-103	AY-102	68-70	1	7/07	7/07		1,012	3,320	-10	1.10	2.50	15	200	1.31	5.4	125	105	190	277	196	5.9	136	139	268	286	189	1.20	3.00	30	400	1.74	6.8	156			233		7.4	170			197	
53		AY-101	68-70	1	3/08	3/08		1,012	3,695	-10	1.10	2.50	15	200	1.31	5.4	125	115	203	265	190	5.9	136	151		273	181	1.20	3.00	30	400	1.74	6.8	156			217		7.4	170				
54		AZ-101	71	1	10/10	10/10		1,012	2,942	-17	1.10	2.50	15	200	1.31	5.4	125	91	173	292	205	5.9	136	122	246	302	198	1.20	3.00	30	400	1.74	6.8	156	254		252		7.4	170			233	
55	AW-104	AP-102	83-86	1	10/10	10/10		1,434	831	-9	1.10	2.50	15	200	1.31	5.4	125	53	141	387	227	5.9	136	70	201	402	222	1.20	3.00	30	400	1.74	6.8	156	146		351	169	7.4	170	199		361	
56		AZ-102	77	1	5/13	5/13		1,003	3,327	-17	1.10	2.50	15	200	1.31	5.4	125	101	185	278	198	5.9	136	135	263	288	190	1.20	3.00	30	400	1.74	6.8	156			235		7.4	170			203	
57		AY-101	68-70	1	5/15	5/15		1,003	3,695	-10	1.10	2.50	15	200	1.31	5.4	125	114	202	265	190	5.9	136	151		273	182	1.20	3.00	30	400	1.74	6.8	156			218		7.4	170				
58	AW-105	AZ-101	71	1	10/16	10/16		1,125	2,942	-17	1.10	2.50	15	200	1.31	5.4	125	94	182	288	199	5.9	136	126	260	297	192	1.20	3.00	30	400	1.74	6.8	156	262		247		7.4	170			225	
59		AZ-102	77	1	3/18	3/18		1,125	3,327	-17	1.10	2.50	15	200	1.31	5.4	125	104	195	274	192	5.9	136	139		283	184	1.20	3.00	30	400	1.74	6.8	156			230		7.4	170			190	
60	AW-106	AP-107	83-86	1	9/05	9/05		1,537	831	-9	1.10	2.50	15	200	1.31	5.4	125	56	150	378	220	5.9	136	74	213	393	215	1.20	3.00	30	400	1.74	6.8	156	153		343	155	7.4	170	208		351	
61		AN-102	80-81	1	12/12	12/12		1,519	3,594	-21	1.10	2.50	15	200	1.31	5.4	125	119	235	256	173	5.9	136	158		263	161	1.20	3.00	30	400	1.74	6.8	156			205		7.4	170				
62		AW-102	78-80	2	9/00	10/10		314	421	0	1.10	2.50	15	200	1.31	5.4	125	19	40	679	434	5.9	136	24	56	700	439	1.20	3.00	30	400	1.74	6.8	156	50	106	616	392	7.4	170	67	154	652	397
63		AW-104	78-80	1	10/00	10/00		341	421	0	1.10	2.50	15	200	1.31	5.4	125	19	42	667	422	5.9	136	25	60	688	427	1.20	3.00	30	400	1.74	6.8	156	51	112	605	381	7.4	170	69	163	640	385
64		AP-101	83-86	2	10/00	8/01		1,533	831	-9	1.10	2.50	15	200	1.31	5.4	125	55	149	378	220	5.9	136	74	213	393	215	1.20	3.00	30	400	1.74	6.8	156	153		343	156	7.4	170	208		351	
65		AP-104	83-86	1	10/01	10/01		1,428	831	-9	1.10	2.50	15	200	1.31	5.4	125	53	141	387	227	5.9	136	70	201	402	222	1.20	3.00	30	400	1.74	6.8	156	146		352	170	7.4	170	198		361	
66		AW-105	78-80	2	10/01	1/02		2,239	1,241	0	1.10	2.50	15	200	1.31	5.4	125	89	226	308	178	5.9	136	116		319	166	1.20	3.00	30	400	1.74	6.8	156	235		269		7.4	170			259	
67		AP-108	83-86	1	2/05	2/05		1,557	831	-9	1.10	2.50	15	200	1.31	5.4	125	56	151	376	219	5.9	136	75	216	391	213	1.20	3.00	30	400	1.74	6.8	156	155		341	152	7.4	170	210		349	
68	AY-101	AN-107	80-81	1	3/07	3/07		557	2,313	-11	1.10	2.50	15	200	1.31	5.4	125	67	118	343	250	5.9	136	89	167	356	250	1.20	3.00	30	400	1.74	6.8	156	185		308	203	7.4	170	252		309	
69		BNFL		16	11/09	1/18	400	0	6,924	30	1.10	2.50	15	200	1.31	5.4	125	194	251	208	174	5.9	136	247	342	210	161	1.20	3.00	30	400	1.74	6.8	156					7.4	170				
70	AY-102	BNFL		6	1/08	10/09	400	0	6,549	30	1.10	2.50	15	200	1.31	5.4	125	184	238	215	179	5.9	136	235	324	217	168	1.20	3.00	30	400	1.74	6.8	156					7.4	170				
71		AY-101	68-70	1	2/12	2/12	400	0	386	0	1.10	2.50	15	200	1.31	5.4	125	10	13	939	777	5.9	136	13	18	962	788	1.20	3.00	30	400	1.74	6.8	156	26	35	842	699	7.4	170	35	50	887	726
72		AZ-102	77	1	6/17	6/17	400	0	1,466	-8	1.10	2.50	15	200	1.31	5.4	125	33	45	482	402	5.9	136	45	64	500	410	1.20	3.00	30	400	1.74	6.8	156	93	126	441	366	7.4	170	127	182	462	370
73		AP-101	83-86	1	10/17	10/17	400	128	2,910	2	1.10	2.50	15	200	1.31	5.4	125	79	110	330	268	5.9	136	102	152	343	269	1.20	3.00	30	400	1.74	6.8	156	206	290	293	224	7.4	170	277		290	
74		AP-105	83-86	1	12/17	12/17	400	302	2,910	2	1.10	2.50	15	200	1.31	5.4	125	83	124	321	250	5.9	136	108	173	333	250	1.20	3.00	30	400	1.74	6.8	156	218	328	283	201	7.4	170	293		277	
75		AN-103	80-81	1	6/18	6/18		376	1,733	-11	1.10	2.50	15	200	1.31	5.4	125	48	83	402	296	5.9	136	64	119	417	299	1.20	3.00	30	400	1.74	6.8	156	134	229	366	258	7.4	170	183		378	235
76		AP-104	83-86	1	10/18	10/18	400	314	2,910	2	1.10	2.50	15	200	1.31	5.4	125	83	125	320	249	5.9	136	108	174	332	249	1.20	3.00	30	400	1.74	6.8	156	219	331	282	199	7.4	170	294		277	
77		AN-107	80-81	1	10/19	10/19		557	1,733	-11	1.10	2.50	15	200	1.31	5.4	125	52	98	385	273	5.9	136	70	140	400	274	1.20	3.00	30	400	1.74	6.8	156	146	268	350	232	7.4	170	199		359	184
78		AW-102	78-80	1	10/19	10/19		761	2,910	10	1.10	2.50	15	200	1.31	5.4	125	100	167	297	215	5.9	136	128	231	308	210	1.20	3.00	30	400	1.74	6.8	156	256		256		7.4	170			240	
79	AZ-101	BNFL		18	10/04	4/19	400	0	6,171	36	1.10	2.50	15	200	1.31	5.4	125	178	229	221	185	5.9	136	226	310	224	175	1.20	3.00	30	400	1.74	6.8	156					7.4	170				
80	AZ-102	BNFL		18	11/06	11/91	400	0	6,556	36	1.10	2.50	15	200	1.31	5.4	125	188	242	213	178	5.9	136	239	328	216	167	1.20	3.00	30	400	1.74	6.8	156					7.4	170				
81	BNFL internal equivalent pipe length and elevation								884	45	included in BNFL routes						Exceeds 275 lbf/in²						Exceeds 400 lbf/in²										Supernate liquid only transfer					Less than 140 gpm						

Notes

New = new or like new pipeline with maximum expected pipe roughness of 2 mils (0.002 inches).

EOL = pipeline at end of life (50 years for carbon steel line, 40 years for stainless steel line) with pipe roughness due to corrosion estimated at 150 mils for carbon steel and 10 mils for stainless steel.

***Design Pressure** = All stainless steel pipelines have a design pressure of 400 lbf/in². The design pressure of carbon steel pipelines are either 275 or 400 lbf/in² as indicated. The predicted flow rate at design pressure given in this table assumes that all pipelines are or can be qualified to the higher 400 lbf/in² design pressure.

Table D-12. 3S4 Case 3c.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL	AM	AN	AO	AP	AQ	AR
1	CASE 3S4 Transfer List - Tank-to-Tank										Case 3c	Critical velocity by Oroskar and Turian (1980) empirical correlation (β_{cv} = 1.2). Pressure drop by Wasp et al. (1977) method with lognormal particle size distribution.																																
2												Group 1 Properties				Temperature = 10 °C						Temperature = 60 °C						Group 2 Properties					Temperature = 10 °C						Temperature = 60 °C					
3	Transfer		Tank Farm Built (Yr)	Transfer				3-in. Schedule-40 Pipe (3.068 in. inside dia.)		Total Change in Elevation (ft)	Liquid	Solids			ρ_m Bulk Density (kg/L)	Critical (κ_{cv} = 1.30, κ_f = 1)		Total Pressure Drop (lbf/in²)		Flow Rate at a Pipe Design Pressure of 400 lbf/in² (gpm)		Critical (κ_{cv} = 1.30, κ_f = 1)		Total Pressure Drop (lbf/in²)		Flow Rate at a Pipe Design Pressure of 400 lbf/in² (gpm)		Liquid	Solids			ρ_m Bulk Density (kg/L)	Critical (κ_{cv} = 1.30, κ_f = 1)		Total Pressure Drop (lbf/in²)		Flow Rate at a Pipe Design Pressure of 400 lbf/in² (gpm)		Critical (κ_{cv} = 1.30, κ_f = 1)		Total Pressure Drop (lbf/in²)		Flow Rate at a Pipe Design Pressure of 400 lbf/in² (gpm)	
4	From Tank	To Tank		#	Dates (M/Yr)		Design Pressure (lbf/in²)*	Carbon Steel Length (ft)	Stainless Steel Length (ft)		ρ_L Density (kg/L)	ρ_s Density (kg/L)	C_s Volume (%) times	d_p Median Dia. (μm)		Velocity (ft/s)	Flow Rate (gpm)					Velocity (ft/s)	Flow Rate (gpm)					ρ_L Density (kg/L)	ρ_s Density (kg/L)	C_s Volume (%) times	d_p Median Dia. (μm)		Velocity (ft/s)	Flow Rate (gpm)					Velocity (ft/s)	Flow Rate (gpm)				
5					Start	End							1.5					New	EOL	New	EOL			New	EOL	New	EOL			2.0					New	EOL	New	EOL			New	EOL	New	EOL
6	AN-101	AP-103	83-86	1	3/03	3/03	400	306	2,774	12	1.21	2.50	0.00	200	1.21	0.3	7	7	7	328	257	0.1	3	6	6	338	260	1.46	3.00	0.00	400	1.46	1.0	22	12	13	275	227	0.4	10	9	9	292	232
7		AN-106	80-81	2	3/03	3/03		442	626	0	1.21	2.50	0.00	200	1.21	0.3	7	0	0	573	370	0.1	3	0	0	584	371	1.46	3.00	0.00	400	1.46	1.0	22	2	2	492	333	0.4	10	0	0	513	336
8		AN-107	80-81	3	9/05	8/12		557	626	0	1.21	2.50	0.03	200	1.21	2.0	45	4	7	543	342	2.1	49	4	9	554	343	1.46	3.00	0.04	400	1.46	2.1	47	7	11	465	308	2.2	51	6	12	487	311
9		BNFL		4	10/08	12/14	400	0	6,413	40	1.21	2.50	0.29	200	1.21	2.8	64	61	70	219	187	3.0	70	63	77	227	189	1.46	3.00	0.38	400	1.47	2.9	67	92	101	179	161	3.1	72	90	104	192	167
10	AN-102	AN-106	80-81	1	8/06	8/06		319	626	0	1.21	2.50	0.24	200	1.21	2.7	62	6	10	609	409	2.9	68	6	12	621	410	1.46	3.00	0.32	400	1.46	2.8	65	9	14	524	367	3.0	70	9	16	546	371
11		AN-101	80-81	1	10/08	10/08		405	421	0	1.21	2.50	0.24	200	1.21	2.7	62	5	10	653	406	2.9	68	5	12	664	407	1.46	3.00	0.32	400	1.46	2.8	65	8	14	563	366	3.0	70	8	16	586	369
12		AN-105	80-81	1	12/12	12/12		329	626	0	1.21	2.50	1.26	200	1.23	3.5	80	9	17	603	403	3.8	87	10	21	615	405	1.46	3.00	1.68	400	1.49	3.6	84	15	24	518	362	3.9	90	15	28	541	366
13	AN-103	AN-105	80-81	1	10/11	10/11		300	626	0	1.21	2.50	0.20	200	1.21	2.6	60	5	9	616	416	2.9	66	5	11	627	417	1.46	3.00	0.26	400	1.46	2.7	63	9	13	530	373	3.0	68	8	14	552	377
14		BNFL		2	5/13	5/18		376	6,823	40	1.21	2.50	1.10	200	1.22	3.4	78	88	111	205	169	3.7	86	94	129	213	170	1.46	3.00	1.46	400	1.48	3.6	82	135	160	167	145	3.8	88	137	173	180	150
15	AN-104	AN-101	80-81	4	9/05	5/15		526	626	0	1.21	2.50	1.29	200	1.23	3.5	80	11	23	548	347	3.8	88	12	29	559	349	1.46	3.00	1.72	400	1.49	3.6	84	18	33	468	312	3.9	91	19	38	491	315
16		BNFL		2	6/09	4/11	400	0	6,275	40	1.21	2.50	0.71	200	1.22	3.2	73	72	85	221	188	3.5	80	76	96	230	191	1.46	3.00	0.94	400	1.47	3.3	77	110	122	181	162	3.6	83	110	129	194	168
17		AZ-101	71	1	6/09	6/09	400	562	1,560	5	1.21	2.50	4.01	200	1.26	4.1	95	32	55	394	278	4.5	103	37	69	405	279	1.46	3.00	5.34	400	1.54	4.3	99	52	77	331	246	4.6	106	55	91	351	250
18		AN-107	80-81	1	6/09	6/09		489	421	0	1.21	2.50	0.66	200	1.22	3.2	73	7	16	620	378	3.4	79	8	19	632	379	1.46	3.00	0.88	400	1.47	3.3	76	12	22	533	341	3.6	82	12	25	556	344
19		AN-102	80-81	1	4/11	4/11		439	626	0	1.21	2.50	7.32	200	1.30	4.5	103	18	37	555	360	4.9	112	22	49	570	363	1.46	3.00	9.76	400	1.61	4.6	106	29	52	469	321	5.0	115	32	64	496	326
20		AW-103	78-80	2	4/11	9/11		1,012	3,046	21	1.21	2.50	7.26	200	1.30	4.4	103	81	133	274	196	4.9	112	95	170	284	196	1.46	3.00	9.68	400	1.61	4.6	106	127	185	224	171	5.0	115	137	223	240	172
21		AW-101	78-80	4	8/12	8/16		994	3,046	21	1.21	2.50	2.78	200	1.25	3.9	90	61	98	280	201	4.3	98	68	119	290	202	1.46	3.00	3.70	400	1.52	4.1	94	95	137	232	177	4.4	101	99	157	247	180
22		AN-103	80-81	2	6/13	10/13		410	626	0	1.21	2.50	1.20	200	1.23	3.5	80	10	19	579	377	3.8	87	11	24	590	379	1.46	3.00	1.60	400	1.48	3.6	83	16	27	496	339	3.9	90	16	31	519	342
23		AN-106	80-81	2	1/14	5/14		374	421	0	1.21	2.50	1.17	200	1.23	3.4	79	7	16	663	416	3.7	86	8	19	675	417	1.46	3.00	1.56	400	1.48	3.6	83	12	22	571	375	3.9	89	13	26	595	378
24		AW-104	78-80	2	5/15	7/15		1,003	3,046	21	1.21	2.50	1.29	200	1.23	3.5	80	50	78	281	202	3.8	88	54	93	291	203	1.46	3.00	1.72	400	1.49	3.6	84	78	110	234	178	3.9	91	79	123	249	181
25		AN-105	80-81	2	11/15	12/15		384	421	0	1.21	2.50	1.29	200	1.23	3.5	80	8	17	658	412	3.8	88	9	20	671	413	1.46	3.00	1.72	400	1.49	3.6	84	13	23	567	371	3.9	91	13	27	591	374
26		AP-101	83-86	2	2/17	2/17	400	419	2,636	12	1.21	2.50	3.15	200	1.25	4.0	92	46	67	325	249	4.3	100	52	82	336	251	1.46	3.00	4.20	400	1.52	4.1	95	72	95	271	219	4.5	103	76	109	289	224
27		AP-105	83-86	1	12/17	12/17	400	302	2,636	12	1.21	2.50	4.77	200	1.27	4.2	97	50	71	330	258	4.6	106	58	88	341	260	1.46	3.00	6.36	400	1.56	4.4	101	79	101	274	226	4.7	109	84	117	292	231
28		AW-105	78-80	1	3/18	3/18		1,125	3,046	21	1.21	2.50	4.77	200	1.27	4.2	97	73	121	273	194	4.6	106	84	152	283	194	1.46	3.00	6.36	400	1.56	4.4	101	114	169	225	170	4.7	109	122	200	240	171
29		AP-102	83-86	1	4/19	4/19	400	431	2,636	12	1.21	2.50	3.36	200	1.25	4.0	92	47	69	324	248	4.4	101	53	84	335	250	1.46	3.00	4.48	400	1.53	4.2	96	74	98	270	218	4.5	104	78	112	288	222
30		AW-106	78-80	1	10/19	10/19		1,114	3,046	21	1.21	2.50	2.87	200	1.25	3.9	90	63	103	276	196	4.3	99	71	126	285	196	1.46	3.00	3.82	400	1.52	4.1	94	99	144	228	172	4.4	102	103	166	243	175
31	AN-105	AN-104	80-81	1	6/09	6/09		384	421	0	1.21	2.50	0.18	200	1.21	2.6	60	4	9	662	414	2.8	65	4	10	673	415	1.46	3.00	0.24	400	1.46	2.7	62	7	12	571	373	2.9	67	7	14	594	376
32		BNFL		3	10/11	11/15		452	7,028	40	1.21	2.50	1.22	200	1.23	3.5	80	93	119	201	164	3.8	87	100	138	209	166	1.46	3.00	1.62	400	1.48	3.6	83	143	171	164	141	3.9	90	145	186	176	145
33	AN-106	AP-107	83-86	1	9/05	9/05		865	3,389	12	1.21	2.50	0.00	200	1.21	0.3	7	7	7	278	205	0.1	3	7	7	287	206	1.46	3.00	0.00	400	1.46	1.0	22	14	16	231	181	0.4	10	9	9	246	185
34		BNFL		4	8/06	1/14		442	7,028	40	1.21	2.50	0.56	200	1.22	3.1	71	77	97	202	165	3.4	77	81	110	210	167	1.46	3.00	0.74	400	1.47	3.2	74	119	139	165	142	3.5	80	118	148	177	147
35		AN-107	80-81	2	2/10	4/12		269	421	0	1.21	2.50	0.05	200	1.21	2.1	48	2	5	717	466	2.3	53	3	5	728	468	1.46	3.00	0.06	400	1.46	2.2	50	4	7	620	420	2.4	54	4	7	644	423
36	AN-107	AN-106	80-81	2	9/05	9/05		269	421	0	1.21	2.50	0.33	200	1.21	2.8	65	4	8	716	466	3.1	71	5	10	728	467	1.46	3.00	0.44	400	1.47	3.0	68	7	12	619	419	3.2	74	7	14	643	423
37		AW-102	78-80	1	10/10	10/10		1,357	3,006	21	1.21	2.50	0.11	200	1.21	2.4	55	31	46	272	189	2.6	60	32	52	281	190	1.46	3.00	0.14	400	1.46	2.5	57	47	64	226	167	2.7	62	46	69	241	170
38	AP-101	AP-104	83-86	1	8/16	8/16	400	733	421	0	1.21	2.50	0.00	200	1.21	0.3	7	0	0	551	323	0.1	3	0	0	561	324	1.46	3.00	0.00	400	1.46	1.0	22	2	3	472	292	0.4	10	0	1	493	294
39		AP-102	83-86	1	2/17	2/17	400	850	421	0	1.21	2.50	0.00	200	1.21	0.3	7	0	0	524	304	0.1	3	0	0	535	305	1.46	3.00	0.00	400	1.46	1.0	22	2	3	448	274	0.4	10	0	1	469	276
40	AP-102	AN-106	80-81	1	2/10	2/10		883	3,389	-12	1.21	2.50	0.00	200	1.21	0.3	7	-6	-6	282	207	0.1	3	-6	-6	291	209	1.46	3.00	0.00	400	1.46	1.0	22	-1	0	235	184	0.4	10	-7	-6	251	188
41		AN-107	80-81	3	10/10	2/17		988	3,389	-12	1.21	2.50	0.05	200	1.21	2.1	48	9	18	278	202	2.3	53	10	22	287	204	1.46	3.00	0.06	400	1.46	2.2	50	19	29	232	179	2.4	54	18	32	247	183
42		BNFL		5	6/15	4/19	400	431	5,370	28	1.21	2.50	0.29	200	1.21	2.8	64	50	64	233	188	3.0	70	52	71	242	190	1.46	3.00	0.38	400	1.47	2.9	67	78	91	192	163	3.1	72	76	96	205	168
43	AP-104	AP-102	83-86	1	6/15	6/15	400	745	421	0	1.21	2.50	0.00	200	1.21	0.3	7	0	0	548	321	0.1	3	0	0	559	322	1.46	3.00	0.00	400	1.46	1.0	22	2	3	469	290	0.4	10	0	1	490	292
44		BNFL		3	8/16	10/18	400	314	5,370	28	1.21	2.50	0.24	200	1.21	2.7	62	48	59	236	192	2.9	68	50	66	244	194	1.46	3.00	0.32	400	1.46	2.8	65	74	85	194	167	3.0	70	72	89	208	172
45	AP-105	AP-104	83-86	1	7/17	7/17	400	616	421	0	1.21	2.50	0.24	200	1.21	2.7	62	6	14	581	347	2.9	68	6	16	592	347	1.46	3.00	0.32	400	1.46	2.8	65	10	19	499	313	3.0	70	10	22	521	315
46		AP-102	83-86	1	12/17	12/17	400	733	421	0	1.21	2.50	0.24	200	1.21	2.7	62	7	16	550	323	2.9	68	7	19	561	324	1.46	3.00	0.32	400	1.46	2.8	65	11	22	471	291	3.0	70	11	25	493	293
47	AP-107	AW-102	78-80	10	9/00	9/05		1,223	421	9	1.21	2.50	0.00	200	1.21	0.3	7	5	5	456	258	0.1	3	5	5	466	259	1.46	3.00	0.00	400	1.46	1.0	22	8	10	387	233	0.4	10	6	6	407	234
48	AP-108	AP-107	83-86	2	9/01	9/02	400	866	421	0	1.21	2.50	0.00	200	1.21	0.3	7	0	0	520	302	0.1	3	0	0	531	302	1.46	3.00	0.00	400	1.46	1.0	22	2	3	445	272	0.4	10	0	1	466	274
49	AW-101	AN-106	80-81	1	4/12	4/12		1,436	3,799	-21	1.21	2.50	0.23	200	1.21	2.7	62	19	40	254	181	2.9	67	20	49	263	182	1.46	3.00	0.30	400	1.46	2.8	65	37	61	212	160	3.0	70	36	68	226	164
50		AN-101	80-81	1	8/12	8/12		994	3,184	-21	1.21	2.50	0.29	200	1.21	2.8	64	15	31	286	207	3.0	70	16	39	295	208	1.46	3.00	0.38	400	1.47	2.9	67	30	48	240	184	3.1	72	29	54	255	187
51		AP-102	83-86	1	4/16	4/16		1,425	831	-9	1.21	2.50	0.29	200	1.21	2.8	64	9	28	391	232	3.0	70	10	34	401	233	1.46	3.00	0.38	400	1.47	2.9	67	18	39	331	209	3.1	72	17	45	349	211
52	AW-103	AY-102	68-70	1	7/07	7/07		1,012	3,320	-10	1.21	2.50	7.44	200	1.31	4.5	103	69	122	271	196	4.9	112	84	162	281	196	1.46	3.00	9.92	400	1.61	4.6	107	114	174	223	171	5.0	115	125	213	239	172
53		AY-101	68-70	1	3/08	3/08		1,012	3,695	-10	1.21	2.50	7.44	200	1.31	4.5	103	75	131	259	190	4.9	112	92	173	269	189	1.46	3.00	9.92	400	1.61	4.6	107	124	186	213	165	5.0	115	136	228	228	166
54		AZ-101	71	4	10/10	10/10		1,012	2,942	-17	1.21	2.50	7.44	200	1.31	4.5	103	58	110	285	204	4.9	112	72	147	296	204	1.46	3.00	9.92	400	1.61	4.6	107	96	157	236	179	5.0	115	109	194	253	180
55	AW-104	AP-102	83-86	1	10/10	10/10		1,434	831	-9	1.21	2.50	0.24	200	1.21	2.7	62	9	26	391	232	2.9	68	9	32	401	233	1.46	3.00	0.32	400	1.46	2.8	65	17	37	331	209	3.0	70	16	43	349	211
56		AZ-102	77	1	5/13	5/13		1,003	3,327	-17	1.21	2.50	4.55	200	1.27	4.2	96	54	98	275	200	4.6	105	64	128	285	200	1.46	3.00	6.06	400	1.55	4.4	100	91	141	228	176	4.7	108	98	170	244	178
57		AY-101	68-70	1	5/15	5/15		1,003	3,695	-10	1.21	2.50	4.55	200	1.27	4.2	96	63	109	263	192	4.6	105	74	140	272	193	1.46	3.00	6.06	400	1.55	4.4	100	104	156	217	169	4.7	108	112	187	232	171
58	AW-105	AZ-101	71	1	10/16	10/16		1,125	2,942	-17	1.21	2.50	2.96	200	1.25	3.9	91	42	82	286	202	4.3	99	49	106	296	203	1.46	3.00	3.94	400	1.52	4.1	95	73	118	239	179	4.4	102	77	141	255	182
59		AZ-102	77	1	3/18	3/18		1,125	3,327	-17	1.21	2.50	2.96	200	1.25	3.9	91	47	88	273	196	4.3	99	55	113	283	196	1.46	3.00	3.94	400	1.52	4.1	95	81	128	227	173	4.4	102	85	151	242	175
60	AW-106	AP-107	83-86	1	9/05	9/05		1,537	831	-9	1.21	2.50	0.00	200	1.21	0.3	7	-4	-4	382	225	0.1	3	-5	-5	392	226	1.46	3.00	0.00	400	1.46	1.0	22	-2	0	323	203	0.4	10	-5	-5	341	205
61		AN-102	80-81	1	12/12	12/12		1,519	3,594	-21	1.21	2.50	0.00	200	1.21	0.3	7	-10	-10	258	181	0.1	3	-11	-11	267	182	1.46	3.00	0.00	400	1.46	1.0	22	-8	-3	215	161	0.4	10	-12	-11	229	164
62		AW-102	78-80	2	9/00	10/10		314	421	0	1.21	2.50	0.00	200	1.21	0.3	7	0	0	694	444	0.1	3	0	0	706	445	1.46	3.00	0.00	400	1.46	1.0	22	1	2	600	400	0.4	10	0	0	623	403
63		AW-104	78-80	1	10/00	10/00		341	421	0	1.21	2.50	0.00	200	1.21	0.3	7	0	0	681	432	0.1	3	0	0	693	433	1.46	3.00	0.00	400	1.46	1.0	22	1	2	588	389	0.4	10	0	0	612	392
64		AP-101	83-86	2	10/00	8/01		1,533	831	-9	1.21	2.50	0.00	200	1.21	0.3	7	-4	-4	382	226	0.1	3	-5	-5	392	226	1.46	3.00	0.00	400	1.46	1.0	22	-2	0	323	203	0.4	10	-5	-5	341	205
65		AP-104	83-86	1	10/01	10/01		1,428	831	-9	1.21	2.50	0.00	200	1.21	0.3	7	-4	-4	391	232	0.1	3	-5	-5	402	233	1.46	3.00	0.00	400	1.46	1.0	22	-2	0	332	209	0.4	10	-5	-5	350	211
66		AW-105	78-80	2	10/01	1/02		2,239	1,241	0	1.21	2.50	0.00	200	1.21	0.3	7	0	1	311	185	0.1	3	0	0	320	186	1.46	3.00	0.00	400	1.46	1.0	22	5	8	260	166	0.4	10	1	2	276	168
67		AP-108	83-86	1	2/05	2/05		1,557	831	-9	1.21	2.50	0.00	200	1.21	0.3	7	-4	-4	380	224	0.1	3	-5	-5	390	225	1.46	3.00	0.00	400	1.46	1.0	22	-2	0	322	202	0.4	10	-5	-5	340	204
68	AY-101	AN-107	80-81	1	3/07	3/07		557	2,313	-11	1.21	2.50	0.00	200	1.21	0.3	7	-6	-5	346	255	0.1	3	-6	-6	356	257	1.46	3.00	0.00	400	1.46	1.0	22	-3	-2	292	227	0.4	10	-6	-6	309	231
69		BNFL		16	11/09	1/18	400	0	6,924	30	1.21	2.50	8.34	200	1.32	4.5	104	141	177	204	174	4.9	114	167	224	211	173	1.46	3.00	11.12	400	1.63	4.7	108	221	255	163	146	5.0	116	241	299	173	147
70	AY-102	BNFL		6	1/08	10/09	400	0	6,549	30	1.21	2.50	5.43	200	1.28	4.3	99	118	146	213	182	4.7	108	136	181	221	182	1.46	3.00	7.24	400	1.57	4.5	103	184	212	172	155	4.8	111	197	243	184	158
71		AY-101	68-70	1	2/12	2/12	400	0	386	0	1.21	2.50	10.61	200	1.35	4.7	107	8	10	916	760	5.1	117	9	13	935	768	1.46	3.00	14.14	400	1.68	4.8	111	12	14	781	870	5.2	119	14	17	818	686
72		AZ-102	77	1	6/17	6/17	400	0	1,466	-8	1.21	2.50	5.84	200	1.29	4.3	100	19	26	477	399	4.7	109	23	34	490	404	1.46	3.00	7.78	400	1.58	4.5	104	32	39	403	352	4.8	112	35	46	427	361
73		AP-101	83-86	1	10/17	10/17	400	128	2,910	2	1.21	2.50	1.44	200	1.23	3.5	82	31	42	331	270	3.9	89	35	50	341	273	1.46	3.00	1.92	400	1.49	3.7	85	51	62	278	238	4.0	92	52	68	295	244
74		AP-105	83-86	1	12/17	12/17	400	302	2,910	2	1.21	2.50	1.44	200	1.23	3.5	82	33	47	322	263	3.9	89	36	57	332	256	1.46	3.00	1.92	400	1.49	3.7	85	54	69	269	223	4.0	92	55	77	286	228
75		AN-103	80-81	1	6/18	6/18		376	1,733	-11	1.21	2.50	0.14	200	1.21	2.5	57	5	10	406	301	2.7	62	5	12	416	303	1.46	3.00	0.18	400	1.46	2.6	60	11	17	344	268	2.8	64	10	18	363	273
76		AP-104	83-86	1	10/18	10/18	400	314	2,910	2	1.21	2.50	0.14	200	1.21	2.5	57	17	23	323	254	2.7	62	17	26	332	256	1.46	3.00	0.18	400	1.46	2.6	60	28	34	271	224	2.8	64	27	36	287	229
77		AN-107	80-81	1	10/19	10/19		557	1,733	-11	1.21	2.50	0.09	200	1.21	2.3	54	4	11	389	278	2.5	58	4	13	399	279	1.46	3.00	0.12	400	1.46	2.4	56	10	17	330	248	2.6	60	9	19	348	252
78		AW-102	78-80	1	10/19	10/19		761	2,910	10	1.21	2.50	0.09	200	1.21	2.3	54	22	31	300	220	2.5	58	22	34	309	222	1.46	3.00	0.12	400	1.46	2.4	56	34	44	250	195	2.6	60	33	47	266	199
79	AZ-101	BNFL		18	10/04	4/19	400	0	6,171	36	1.21	2.50	5.96	200	1.29	4.3	100	119	147	218	186	4.7	109	137	181	226	187	1.46	3.00	7.94	400	1.58	4.5	104	184	211	176	158	4.9	112	197	242	189	161
80	AZ-102	BNFL		18	11/06	11/91	400	0	6,556	36	1.21	2.50	7.86	200	1.31	4.5	104	136	169	209	178	4.9	113	159	212	217	178	1.46	3.00	10.48	400	1.62	4.7	107	211	243	168	151	5.0	116	229	283	179	152
81	BNFL internal equivalent pipe length and elevation								884	45	included in BNFL routes						Exceeds 275 lbf/in²						Exceeds 400 lbf/in²					Supernate liquid only transfer												Less than 140 gpm				

Notes:

New = new or like new pipeline with maximum expected pipe roughness of 2 mils (0.002 inches).

EOL = pipeline at end of life (50 years for carbon steel line, 40 years for stainless steel line) with pipe roughness due to corrosion estimated at 150 mils for carbon steel and 10 mils for stainless steel.

***Design Pressure** = All stainless steel pipelines have a design pressure of 400 lbf/in². The design pressure of carbon steel pipelines are either 275 or 400 lbf/in² as indicated. The predicted flow rate at design pressure given in this table assumes that all pipelines are or can be qualified to the higher 400 lbf/in² design pressure.

Table D-14. 3S4 Case 4.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL	AM	AN	AO	AP	AQ	AR
1	CASE 3S4 Transfer List - Tank-to-Tank										Case 4					Critical velocity by Oroskar and Turian (1980) empirical correlation (β_{cv} = 1.2). Pressure drop by Wasp et al. (1977) method with lognormal particle size distribution.																																
2												Group 1 Properties					Temperature = 10 °C						Temperature = 60 °C						Group 2 Properties					Temperature = 10 °C						Temperature = 60 °C					
3	Transfer		Tank Farm Built (Yr)		Transfer			3-in. Schedule-40 Pipe (3.068 in. inside dia.)		Total Change in Elevation (ft)	Liquid	Solids				Critical (k_{cv} = 1.30, x_f = 1)		Total Pressure Drop (lbf/in^2)		Flow Rate at a Pipe Design Pressure of 400 lbf/in^2 (gpm)		Critical (k_{cv} = 1.30, x_f = 1)		Total Pressure Drop (lbf/in^2)		Flow Rate at a Pipe Design Pressure of 400 lbf/in^2 (gpm)		Liquid	Solids				Critical (k_{cv} = 1.30, x_f = 1)		Total Pressure Drop (lbf/in^2)		Flow Rate at a Pipe Design Pressure of 400 lbf/in^2 (gpm)		Critical (k_{cv} = 1.30, x_f = 1)		Total Pressure Drop (lbf/in^2)		Flow Rate at a Pipe Design Pressure of 400 lbf/in^2 (gpm)	
4	From Tank	To Tank		#	Dates (M/Yr)		Design Pressure (lbf/in^2)*	Carbon Steel Length (ft)	Stainless Steel Length (ft)		ρ_L Density (kg/L)	ρ_s Density (kg/L)	C_s Volume (%)	d_p Median Dia. (μm)	ρ_m Bulk Density (kg/L)	Velocity (ft/s)	Flow Rate (gpm)					Velocity (ft/s)	Flow Rate (gpm)					ρ_L Density (kg/L)	ρ_s Density (kg/L)	C_s Volume (%)	d_p Median Dia. (μm)	ρ_m Bulk Density (kg/L)	Velocity (ft/s)	Flow Rate (gpm)					Velocity (ft/s)	Flow Rate (gpm)				
5					Start	End												New	EOL	New	EOL			New	EOL	New	EOL								New	EOL	New	EOL			New	EOL	New	EOL
6	AN-101	AP-103	83-86	1	3/03	3/03	400	306	2,774	12	1.20	3.00	10	400	1.38	6.3	144	130	194	317	242	6.8	157	160	256	323	235	1.20	3.00	15	400	1.47	6.5	151	155	232	310	234	7.1	164	196	315	314	218
7		AN-106	80-81	2	3/03	3/03		442	626	0	1.20	3.00	10	400	1.38	6.3	144	43	91	556	357	6.8	157	53	123	572	356	1.20	3.00	15	400	1.47	6.5	151	51	110	546	349	7.1	164	65	151	565	347
8		AN-107	80-81	3	9/05	8/12		557	626	0	1.20	3.00	10	400	1.38	6.3	144	47	106	528	328	6.8	157	59	144	543	327	1.20	3.00	15	400	1.47	6.5	151	57	128	519	322	7.1	164	72	177	536	318
9		BNFL		4	10/08	12/14	400	0	6,413	40	1.20	3.00	10	400	1.38	6.3	144	279	363	199	159	6.8	157	341		191		1.20	3.00	15	400	1.47	6.5	151	332		185		7.1	164			145	
10	AN-102	AN-106	80-81	1	8/06	8/06		319	626	0	1.20	3.00	10	400	1.38	6.3	144	38	75	592	395	6.8	157	47	101	609	395	1.20	3.00	15	400	1.47	6.5	151	45	90	581	387	7.1	164	58	124	601	389
11		AN-101	80-81	1	10/08	10/08		405	421	0	1.20	3.00	10	400	1.38	6.3	144	33	75	634	392	6.8	157	41	102	651	392	1.20	3.00	15	400	1.47	6.5	151	39	91	622	384	7.1	164	50	126	643	385
12		AN-105	80-81	1	12/12	12/12		329	626	0	1.20	3.00	10	400	1.38	6.3	144	38	76	589	391	6.8	157	47	103	605	392	1.20	3.00	15	400	1.47	6.5	151	46	92	578	383	7.1	164	58	127	597	385
13	AN-103	AN-105	80-81	1	10/11	10/11		300	626	0	1.20	3.00	10	400	1.38	6.3	144	37	72	598	402	6.8	157	46	98	615	403	1.20	3.00	15	400	1.47	6.5	151	44	87	587	393	7.1	164	56	120	607	396
14		BNFL		2	5/13	5/18		376	6,823	40	1.20	3.00	10	400	1.38	6.3	144			183		6.8	157			169		1.20	3.00	15	400	1.47	6.5	151			166		7.1	164				
15	AN-104	AN-101	80-81	4	9/05	5/15		526	626	0	1.20	3.00	10	400	1.38	6.3	144	46	102	535	334	6.8	157	57	138	550	334	1.20	3.00	15	400	1.47	6.5	151	55	123	526	328	7.1	164	70	170	543	325
16		BNFL		2	6/09	4/11	400	0	6,275	40	1.20	3.00	10	400	1.38	6.3	144	274	356	202	162	6.8	157	335		194		1.20	3.00	15	400	1.47	6.5	151	326		189		7.1	164			156	
17		AZ-101	71	1	6/09	6/09	400	562	1,560	5	1.20	3.00	10	400	1.38	6.3	144	88	159	389	268	6.8	157	108	213	399	263	1.20	3.00	15	400	1.47	6.5	151	105	191	382	261	7.1	164	133	262	392	250
18		AN-107	80-81	1	6/09	6/09		489	421	0	1.20	3.00	10	400	1.38	6.3	144	36	86	603	365	6.8	157	45	117	620	364	1.20	3.00	15	400	1.47	6.5	151	43	104	592	357	7.1	164	55	144	612	357
19		AN-102	80-81	1	4/11	4/11		439	626	0	1.20	3.00	10	400	1.38	6.3	144	42	91	557	357	6.8	157	53	122	573	357	1.20	3.00	15	400	1.47	6.5	151	51	109	547	350	7.1	164	65	151	565	348
20		AW-103	78-80	2	4/11	9/11		1,012	3,046	21	1.20	3.00	10	400	1.38	6.3	144	174		269	180	6.8	157	213		272	154	1.20	3.00	15	400	1.47	6.5	151	207		261	165	7.1	164	261		260	
21		AW-101	78-80	4	8/12	8/16		994	3,046	21	1.20	3.00	10	400	1.38	6.3	144	173		270	181	6.8	157	212		273	155	1.20	3.00	15	400	1.47	6.5	151	206		262	166	7.1	164	260		260	
22		AN-103	80-81	2	6/13	10/13		410	626	0	1.20	3.00	10	400	1.38	6.3	144	41	87	565	366	6.8	157	51	117	581	365	1.20	3.00	15	400	1.47	6.5	151	49	105	555	358	7.1	164	63	144	573	358
23		AN-106	80-81	2	1/14	5/14		374	421	0	1.20	3.00	10	400	1.38	6.3	144	32	71	646	403	6.8	157	39	96	664	404	1.20	3.00	15	400	1.47	6.5	151	38	86	634	395	7.1	164	48	119	655	397
24		AW-104	78-80	2	5/15	7/15		1,003	3,046	21	1.20	3.00	10	400	1.38	6.3	144	174		270	181	6.8	157	213		272	155	1.20	3.00	15	400	1.47	6.5	151	207		262	166	7.1	164	260		260	
25		AN-105	80-81	2	11/15	12/15		384	421	0	1.20	3.00	10	400	1.38	6.3	144	32	73	642	399	6.8	157	40	98	660	400	1.20	3.00	15	400	1.47	6.5	151	38	87	630	391	7.1	164	49	121	651	393
26		AP-101	83-86	2	2/17	2/17	400	419	2,636	12	1.20	3.00	10	400	1.38	6.3	144	129	202	318	237	6.8	157	158	267	325	228	1.20	3.00	15	400	1.47	6.5	151	154	242	311	228	7.1	164	194	328	316	210
27		AP-105	83-86	1	12/17	12/17	400	302	2,636	12	1.20	3.00	10	400	1.38	6.3	144	124	186	325	248	6.8	157	153	246	332	241	1.20	3.00	15	400	1.47	6.5	151	148	223	318	240	7.1	164	187	302	323	226
28		AW-105	78-80	1	3/18	3/18		1,125	3,046	21	1.20	3.00	10	400	1.38	6.3	144	179		265	174	6.8	157	219		267	141	1.20	3.00	15	400	1.47	6.5	151	213		257	157	7.1	164	268		255	
29		AP-102	83-86	1	4/19	4/19	400	431	2,636	12	1.20	3.00	10	400	1.38	6.3	144	129	203	317	235	6.8	157	159	269	324	227	1.20	3.00	15	400	1.47	6.5	151	154	243	310	227	7.1	164	195	330	315	208
30		AW-106	78-80	1	10/19	10/19		1,114	3,046	21	1.20	3.00	10	400	1.38	6.3	144	178		266	175	6.8	157	218		268	143	1.20	3.00	15	400	1.47	6.5	151	212		257	158	7.1	164	267		255	
31	AN-105	AN-104	80-81	1	6/09	6/09		384	421	0	1.20	3.00	10	400	1.38	6.3	144	32	73	642	399	6.8	157	40	98	660	400	1.20	3.00	15	400	1.47	6.5	151	38	87	630	391	7.1	164	49	121	651	393
32		BNFL		3	10/11	11/15		452	7,028	40	1.20	3.00	10	400	1.38	6.3	144			178		6.8	157			161		1.20	3.00	15	400	1.47	6.5	151			159		7.1	164				
33	AN-106	AP-107	83-86	1	9/05	9/05		865	3,389	12	1.20	3.00	10	400	1.38	6.3	144	177		264	183	6.8	157	218		266	158	1.20	3.00	15	400	1.47	6.5	151	211		256	168	7.1	164	267		254	
34		BNFL		4	8/06	1/14		442	7,028	40	1.20	3.00	10	400	1.38	6.3	144			178		6.8	157			161		1.20	3.00	15	400	1.47	6.5	151			160		7.1	164				
35		AN-107	80-81	2	2/10	4/12		269	421	0	1.20	3.00	10	400	1.38	6.3	144	27	58	694	450	6.8	157	34	78	713	452	1.20	3.00	15	400	1.47	6.5	151	33	69	680	441	7.1	164	42	96	703	445
36	AN-107	AN-106	80-81	2	9/05	9/05		269	421	0	1.20	3.00	10	400	1.38	6.3	144	27	58	694	450	6.8	157	34	78	713	452	1.20	3.00	15	400	1.47	6.5	151	33	69	680	441	7.1	164	42	96	703	445
37		AW-102	78-80	1	10/10	10/10		1,357	3,006	21	1.20	3.00	10	400	1.38	6.3	144	186		258	163	6.8	157	228		260		1.20	3.00	15	400	1.47	6.5	151	222		250	142	7.1	164			246	
38	AP-101	AP-104	83-86	1	8/16	8/16	400	733	421	0	1.20	3.00	10	400	1.38	6.3	144	46	118	535	308	6.8	157	57	161	550	307	1.20	3.00	15	400	1.47	6.5	151	55	142	525	303	7.1	164	70	198	543	296
39		AP-102	83-86	1	2/17	2/17	400	850	421	0	1.20	3.00	10	400	1.38	6.3	144	51	134	509	289	6.8	157	63	182	523	286	1.20	3.00	15	400	1.47	6.5	151	61	161	500	283	7.1	164	77	224	516	275
40	AP-102	AN-106	80-81	1	2/10	2/10		883	3,389	-12	1.20	3.00	10	400	1.38	6.3	144	163		269	186	6.8	157	204		272	164	1.20	3.00	15	400	1.47	6.5	151	196		262	173	7.1	164	253		260	
41		AN-107	80-81	3	10/10	2/17		988	3,389	-12	1.20	3.00	10	400	1.38	6.3	144	167		265	181	6.8	157	209		268	154	1.20	3.00	15	400	1.47	6.5	151	201		258	166	7.1	164	259		256	
42		BNFL		5	6/15	4/19	400	431	5,370	28	1.20	3.00	10	400	1.38	6.3	144	248	357	216	161	6.8	157	304		211		1.20	3.00	15	400	1.47	6.5	151	295		204		7.1	164	371		186	
43	AP-104	AP-102	83-86	1	6/15	6/15	400	745	421	0	1.20	3.00	10	400	1.38	6.3	144	46	120	532	306	6.8	157	58	163	547	304	1.20	3.00	15	400	1.47	6.5	151	56	144	523	300	7.1	164	71	200	540	294
44		BNFL		3	8/16	10/18	400	314	5,370	28	1.20	3.00	10	400	1.38	6.3	144	243	342	218	167	6.8	157	298		214		1.20	3.00	15	400	1.47	6.5	151	289		207	146	7.1	164	364		191	
45	AP-105	AP-104	83-86	1	7/17	7/17	400	616	421	0	1.20	3.00	10	400	1.38	6.3	144	41	103	565	332	6.8	157	51	140	581	331	1.20	3.00	15	400	1.47	6.5	151	50	124	554	326	7.1	164	63	172	573	322
46		AP-102	83-86	1	12/17	12/17	400	733	421	0	1.20	3.00	10	400	1.38	6.3	144	46	118	535	308	6.8	157	57	161	550	307	1.20	3.00	15	400	1.47	6.5	151	55	142	525	303	7.1	164	70	198	543	296
47	AP-107	AW-102	78-80	10	9/00	9/05		1,223	421	9	1.20	3.00	10	400	1.38	6.3	144	71	188	443	242	6.8	157	87	254	455	234	1.20	3.00	15	400	1.47	6.5	151	84	225	435	235	7.1	164	106		448	217
48	AP-108	AP-107	83-86	2	9/01	9/02	400	866	421	0	1.20	3.00	10	400	1.38	6.3	144	51	136	506	287	6.8	157	64	185	520	283	1.20	3.00	15	400	1.47	6.5	151	61	163	497	281	7.1	164	78	227	513	272
49	AW-101	AN-106	80-81	1	4/12	4/12		1,436	3,799	-21	1.20	3.00	10	400	1.38	6.3	144	196		241	152	6.8	157	246		240		1.20	3.00	15	400	1.47	6.5	151	237		232		7.1	164			224	
50		AN-101	80-81	1	8/12	8/12		994	3,184	-21	1.20	3.00	10	400	1.38	6.3	144	154		275	186	6.8	157	194		278	163	1.20	3.00	15	400	1.47	6.5	151	186		268	173	7.1	164	241		267	
51		AP-102	83-86	1	4/16	4/16		1,425	831	-9	1.20	3.00	10	400	1.38	6.3	144	85	226	381	215	6.8	157	106		390	202	1.20	3.00	15	400	1.47	6.5	151	102	272	374	205	7.1	164	132		384	177
52	AW-103	AY-102	68-70	1	7/07	7/07		1,012	3,320	-10	1.20	3.00	10	400	1.38	6.3	144	167		266	180	6.8	157	208		269	153	1.20	3.00	15	400	1.47	6.5	151	201		259	165	7.1	164	258		257	
53		AY-101	68-70	1	3/08	3/08		1,012	3,695	-10	1.20	3.00	10	400	1.38	6.3	144	181		254	172	6.8	157	227		255		1.20	3.00	15	400	1.47	6.5	151	219		246	155	7.1	164			241	
54		AZ-101	71	1	10/10	10/10		1,012	2,942	-17	1.20	3.00	10	400	1.38	6.3	144	147		282	190	6.8	157	185		286	169	1.20	3.00	15	400	1.47	6.5	151	178		275	177	7.1	164	230		276	
55	AW-104	AP-102	83-86	1	10/10	10/10		1,434	831	-9	1.20	3.00	10	400	1.38	6.3	144	85	227	380	215	6.8	157	107		390	201	1.20	3.00	15	400	1.47	6.5	151	103	274	373	205	7.1	164	132		383	176
56		AZ-102	77	1	5/13	5/13		1,003	3,327	-17	1.20	3.00	10	400	1.38	6.3	144	162		268	182	6.8	157	204		271	156	1.20	3.00	15	400	1.47	6.5	151	196		261	168	7.1	164	253		259	
57		AY-101	68-70	1	5/15	5/15		1,003	3,695	-10	1.20	3.00	10	400	1.38	6.3	144	181		254	173	6.8	157	226		255		1.20	3.00	15	400	1.47	6.5	151	218		246	156	7.1	164			242	
58	AW-105	AZ-101	71	1	10/16	10/16		1,125	2,942	-17	1.20	3.00	10	400	1.38	6.3	144	152		278	184	6.8	157	191		281	159	1.20	3.00	15	400	1.47	6.5	151	183		271	170	7.1	164	237		271	
59		AZ-102	77	1	3/18	3/18		1,125	3,327	-17	1.20	3.00	10	400	1.38	6.3	144	167		264	175	6.8	157	210		266	144	1.20	3.00	15	400	1.47	6.5	151	202		256	160	7.1	164	260		254	
60	AW-106	AP-107	83-86	1	9/05	9/05		1,537	831	-9	1.20	3.00	10	400	1.38	6.3	144	89	240	371	207	6.8	157	112		380	192	1.20	3.00	15	400	1.47	6.5	151	108		364	197	7.1	164	139		373	161
61		AN-102	80-81	1	12/12	12/12		1,519	3,594	-21	1.20	3.00	10	400	1.38	6.3	144	191		244	152	6.8	157	240		244		1.20	3.00	15	400	1.47	6.5	151	231		236		7.1	164			229	
62		AW-102	78-80	2	9/00	10/10		314	421	0	1.20	3.00	10	400	1.38	6.3	144	29	63	672	428	6.8	157	36	86	690	429	1.20	3.00	15	400	1.47	6.5	151	35	76	659	419	7.1	164	45	106	681	423
63		AW-104	78-80	1	10/00	10/00		341	421	0	1.20	3.00	10	400	1.38	6.3	144	30	67	660	416	6.8	157	38	91	678	417	1.20	3.00	15	400	1.47	6.5	151	36	81	647	408	7.1	164	46	111	669	411
64		AP-101	83-86	2	10/00	8/01		1,533	831	-9	1.20	3.00	10	400	1.38	6.3	144	89	240	371	208	6.8	157	112		381	192	1.20	3.00	15	400	1.47	6.5	151	107		365	197	7.1	164	138		374	162
65		AP-104	83-86	1	10/01	10/01		1,428	831	-9	1.20	3.00	10	400	1.38	6.3	144	85	226	380	215	6.8	157	106		390	202	1.20	3.00	15	400	1.47	6.5	151	102	273	374	205	7.1	164	132		383	177
66		AW-105	78-80	2	10/01	1/02		2,239	1,241	0	1.20	3.00	10	400	1.38	6.3	144	139		299	158	6.8	157	172		304		1.20	3.00	15	400	1.47	6.5	151	166		292		7.1	164	212		295	
67		AP-108	83-86	1	2/05	2/05		1,557	831	-9	1.20	3.00	10	400	1.38	6.3	144	90	243	369	206	6.8	157	113		379	190	1.20	3.00	15	400	1.47	6.5	151	108		363	195	7.1	164	140		372	158
68	AY-101	AN-107	80-81	1	3/07	3/07		557	2,313	-11	1.20	3.00	10	400	1.38	6.3	144	108	189	335	240	6.8	157	135	255	343	232	1.20	3.00	15	400	1.47	6.5	151	130	228	329	232	7.1	164	168		335	215
69		BNFL		16	11/09	1/18	400	0	6,924	30	1.20	3.00	10	400	1.38	6.3	144	293	384	191	151	6.8	157	360		180		1.20	3.00	15	400	1.47	6.5	151	350		176		7.1	164				
70	AY-102	BNFL		6	1/08	10/09	400	0	6,549	30	1.20	3.00	10	400	1.38	6.3	144	278	364	198	158	6.8	157	342		190		1.20	3.00	15	400	1.47	6.5	151	332		185		7.1	164			142	
71		AY-101	68-70	1	2/12	2/12	400	0	388	0	1.20	3.00	10	400	1.38	6.3	144	15	20	928	768	6.8	157	19	27	951	779	1.20	3.00	15	400	1.47	6.5	151	18	25	908	752	7.1	164	24	33	936	766
72		AZ-102	77	1	6/17	6/17	400	0	1,468	-8	1.20	3.00	10	400	1.38	6.3	144	54	73	476	397	6.8	157	68	98	489	400	1.20	3.00	15	400	1.47	6.5	151	65	88	468	389	7.1	164	85	122	483	393
73		AP-101	83-86	1	10/17	10/17	400	128	2,910	2	1.20	3.00	10	400	1.38	6.3	144	122	172	322	258	6.8	157	151	228	329	253	1.20	3.00	15	400	1.47	6.5	151	146	206	315	251	7.1	164	186	280	320	239
74		AP-105	83-86	1	12/17	12/17	400	302	2,910	2	1.20	3.00	10	400	1.38	6.3	144	129	194	312	240	6.8	157	180	259	318	232	1.20	3.00	15	400	1.47	6.5	151	154	234	305	232	7.1	164	197	319	309	215
75		AN-103	80-81	1	6/18	6/18		376	1,733	-11	1.20	3.00	10	400	1.38	6.3	144	77	134	395	288	6.8	157	98	182	406	285	1.20	3.00	15	400	1.47	6.5	151	94	162	388	281	7.1	164	121	225	399	274
76		AP-104	83-86	1	10/18	10/18	400	314	2,910	2	1.20	3.00	10	400	1.38	6.3	144	129	196	312	239	6.8	157	160	261	318	230	1.20	3.00	15	400	1.47	6.5	151	155	236	305	230	7.1	164	197	321	309	213
77		AN-107	80-81	1	10/19	10/19		557	1,733	-11	1.20	3.00	10	400	1.38	6.3	144	84	158	378	264	6.8	157	107	214	388	258	1.20	3.00	15	400	1.47	6.5	151	102	191	372	257	7.1	164	132	265	381	246
78		AW-102	78-80	1	10/19	10/19		761	2,910	10	1.20	3.00	10	400	1.38	6.3	144	152	260	288	201	6.8	157	188		292	185	1.20	3.00	15	400	1.47	6.5	151	182		280	190	7.1	164	230		282	141
79	AZ-101	BNFL		18	10/04	4/19	400	0	6,171	36	1.20	3.00	10	400	1.38	6.3	144	267	348	205	165	6.8	157	327		198		1.20	3.00	15	400	1.47	6.5	151	318		193	143	7.1	164	399		165	
80	AZ-102	BNFL		18	11/06	11/91	400	0	6,556	36	1.20	3.00	10	400	1.38	6.3	144	283	368	197	157	6.8	157	346		188		1.20	3.00	15	400	1.47	6.5	151	336		183		7.1	164				
81	BNFL internal equivalent pipe length and elevation								884	45	Included in BNFL routes							Exceeds 275 lbf/in^2						Exceeds 400 lbf/in^2							Supernate liquid only transfer							Less than 140 gpm							

Notes (column AS):

New = new or like new pipeline with maximum expected pipe roughness of 2 mils (0.002 inches).

EOL = pipeline at end of life (50 years for carbon steel line, 40 years for stainless steel line) with pipe roughness due to corrosion estimated at 150 mils for carbon steel and 10 mils for stainless steel.

***Design Pressure** = All stainless steel pipelines have a design pressure of 400 lbf/in^2. The design pressure of carbon steel pipelines are either 275 or 400 lbf/in^2 as indicated. The predicted flow rate at design pressure given in this table assumes that all pipelines are or can be qualified to the higher 400 lbf/in^2 design pressure.

Table D-15. 3S6 Case Summary.

Case	Group 1 Properties					Results		Group 2 Properties					Results		Table
	Liquid	Solids				Critical Velocity (ft/s)		Liquid	Solids				Critical Velocity (ft/s)		
	ρ_L Density (kg/L)	ρ_s Density (kg/L)	C_s Volume (%)	d_p Median Dia. (µm)	ρ_m Bulk Density (kg/L)	Temperature (°C)		ρ_L Density (kg/L)	ρ_s Density (kg/L)	C_s Volume (%)	d_p Median Dia. (µm)	ρ_m Bulk Density (kg/L)	Temperature (°C)		
						10	60						10	60	
1a	1.21	2.5	15	5	1.4	2.6	2.8	1.46	3	30	10	1.92	2.7	2.9	D-16
1b	1.1				1.31	2.9	3.2	1.2				1.74	3.7	4	D-17
1c	1.21		1.5 x HTWOS		1.21-1.29	0.3-2.5	0.1-2.7	1.46		2.0 x HTWOS		1.46-1.66	1.0-2.6	0.4-2.8	D-18
1d	1.1				1.1-1.24	0.2-2.8	0.1-3.0	1.2				1.2-1.43	0.3-3.5	0.1-3.8	D-19
2a	1.21	2.5	15	40	1.4	3.7	4	1.46	3	30	100	1.92	4	4.3	D-20
2b	1.1				1.31	4.1	4.5	1.2				1.74	5.4	5.9	D-21
2c	1.21		1.5 x HTWOS		1.21-1.33	0.3-3.5	0.1-3.8	1.46		2.0 x HTWOS		1.46-1.66	1.0-3.8	0.4-4.1	D-22
2d	1.1				1.1-1.24	0.2-3.9	0.1-4.3	1.2				1.2-1.43	0.3-5.1	0.1-5.6	D-23
3a	1.21	2.5	15	200	1.4	4.8	5.3	1.46	3	30	400	1.92	5	5.4	D-24
3b	1.1				1.31	5.4	5.9	1.2				1.74	6.8	7.4	D-25
3c	1.21		1.5 x HTWOS		1.21-1.33	0.3-4.6	0.1-5.0	1.46		2.0 x HTWOS		1.46-1.66	1.0-4.8	0.4-5.1	D-26
3d	1.1				1.1-1.24	0.2-5.2	0.1-5.6	1.2				1.2-1.43	0.3-6.4	0.1-7.0	D-27
4	1.2	3	10	400	1.38	6.3	6.8	1.2	3	15	400	1.47	6.5	7.1	D-28
4-st															D-29
	3S6 HTWOS		0.0-6.45			1 ft/s = 0.3048 m/s									

Case 4-st assumes a pump lift station in AP Farms located at the AP "new" valve pit.
Selected long intermediate tank-to-tank transfers and all transfers to BNFL would go through the pump lift station.

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Table D-16. 3S6 Case 1a.

CASE 3S6 Transfer List - Tank-to-Tank

Row	Transfer: From Tank (A)	Transfer: To Tank (B)	Tank Farm Built (Yr) (C)	# (D)	Transfer Dates (M/Yr) Start (E)	Transfer Dates (M/Yr) End (F)	Design Pressure (lbf/in²)* (G)	3-in. Schedule-40 Pipe (3.068 in. inside dia.): Carbon Steel Length (ft) (H)	3-in. Schedule-40 Pipe: Stainless Steel Length (ft) (I)	Total Change in Elevation (ft) (J)
6	AN-101	AN-106	80-81	1	12/00	12/00	■	442	626	0
7		AP-103	83-86	1	7/03	7/03	400	306	2,774	12
8		AP-107	83-86	1	6/05	6/05	400	423	2,774	12
9		BNFL		7	2/11	12/19	400	0	6,413	40
10	AN-102	AP-107	83-86	1	3/10	3/10	■	828	3,184	12
11		BNFL		5	12/08	4/16	■	405	6,823	40
12	AN-103	AN-102	80-81	1	4/12	4/12	■	253	421	0
13		BNFL		9	4/14	6/19	■	376	6,823	40
14	AN-104	AN-101	80-81	3	6/05	2/16	■	562	626	0
15		AN-102	80-81	2	4/16	6/16	■	439	626	0
16		AN-103	80-81	2	4/14	8/14	■	410	626	0
17		AN-105	80-81	5	10/14	11/17	■	384	421	0
18		AN-106	80-81	2	8/13	10/13	■	374	421	0
19		AN-107	80-81	1	3/19	3/19	■	489	421	0
20		AP-101	83-86	4	10/13	2/17	400	419	2,636	12
21		AP-102	83-86	1	8/13	8/13	400	431	2,636	12
22		AP-104	83-86	1	11/17	11/17	400	314	2,636	12
23		AP-106	83-86	2	8/16	12/16	400	430	2,636	12
24		AP-108	83-86	1	7/18	7/18	400	443	2,636	12
25		AW-101	78-80	2	3/15	3/15	■	994	3,046	-21
26		AW-103	78-80	2	11/15	11/15	■	1,012	3,046	21
27		AW-104	78-80	1	1/19	1/19	■	1,003	3,046	21
28		AW-105	78-80	1	7/18	7/18	■	1,125	3,046	21
29		AZ-101	71	1	10/10	10/10	400	562	1,560	5
30		BNFL		1	9/10	9/10	400	0	6,275	40
31	AN-105	AN-102	80-81	1	3/10	3/10	■	329	626	0
32		BNFL		3	8/12	5/17	■	452	7,028	40
33	AN-106	AW-102	78-80	6	11/04	1/06	■	1,242	3,389	21
34		BNFL		7	12/18	3/19	■	442	7,028	40
35	AN-107	BNFL		1	7/11	7/11	■	557	7,028	40
36	AP-101	BNFL		2	4/06	12/16	400	419	5,370	28
37	AP-102	BNFL		9	7/18	12/18	400	431	5,370	28
38	AP-104	AP-107	83-86	1	1/13	1/13	400	737	421	0
39		BNFL		3	1/13	10/17	400	314	5,370	28
40	AP-105	AP-104	83-86	1	9/15	9/15	400	616	421	0
41		BNFL		1	2/18	2/18	400	302	5,370	28
42	AP-106	AN-102	80-81	1	10/13	10/13	■	745	3,184	-12
43		BNFL		1	8/16	8/16	400	340	5,370	28
44	AP-107	AW-102	78-80	16	8/00	7/18	■	1,223	421	9
45	AP-108	BNFL		1	7/18	7/18	400	443	5,370	28
46	AW-101	AN-105	80-81	1	8/12	8/12	■	1,446	3,799	-21
47		BNFL		9	3/15	8/19	■	994	5,780	19
48	AW-103	AW-104	78-80	1	10/15	11/15	■	2,015	1,241	0
49		AY-102	68-70	1	12/13	12/13	■	1,012	3,320	-10
50		BNFL		8	8/19	10/19	■	1,012	5,780	19
51	AW-104	AP-104	83-86	1	1/13	1/13	■	1,317	831	-9
52		AW-102	78-80	3	6/01	1/02	■	203	421	0
53		BNFL		6	4/18	1/19	■	1,003	5,780	19
54	AW-105	BNFL		7	1/18	7/18	■	1,125	5,780	19
55	AW-106	AP-105	83-86	2	10/04	6/05	■	1,416	831	-9
56		AP-106	83-86	2	4/01	1/02	■	1,454	831	-9
57		AP-108	83-86	1	3/09	3/09	■	1,557	831	-9
58		AW-102	78-80	13	12/01	7/18	■	314	421	0
59		AW-103	78-80	1	10/04	10/04	■	2,126	1,241	0
60		AW-104	78-80	2	1/02	8/02	■	341	421	0
61		AW-105	78-80	1	6/05	6/05	■	2,239	1,241	0
62	AY-101	BNFL		12	1/11	10/13	400	0	6,924	30
63	AY-102	AN-103	80-81	1	11/19	11/19	■	376	1,733	-11
64		AN-106	80-81	2	5/19	11/19	■	142	1,938	-11
65		AP-102	83-86	1	12/18	12/18	400	431	2,910	2
66		BNFL		16	1/09	2/18	400	0	6,549	30
67	AZ-101	BNFL		10	10/06	8/15	400	0	6,171	36
68	AZ-102	BNFL		6	7/07	3/08	400	0	6,556	36
69	BNFL internal equivalent pipe length and elevation								884	45

Case 1a. Critical velocity by Oroskar and Turian (1980) empirical correlation (β_{cv} = 1.2). Pressure drop by Wasp et al. (1977) method with lognormal particle size distribution.

Group 1 Properties; Critical (κ_{cv} = 1.30, κ_f = 1)

Row	Liquid ρ_L Density (kg/L) (K)	Solids ρ_s Density (kg/L) (L)	Solids C_s Volume (%) (M)	Solids d_p Median Dia. (μm) (N)	ρ_m Bulk Density (kg/L) (O)	10 °C Velocity (ft/s) (P)	10 °C Flow Rate (gpm) (Q)	10 °C Total Pressure Drop (lbf/in²) New (R)	10 °C Total Pressure Drop (lbf/in²) EOL (S)	10 °C Flow Rate at a Pipe Design Pressure of 400 lbf/in² (gpm) New (T)	10 °C Flow Rate at 400 lbf/in² (gpm) EOL (U)	60 °C Velocity (ft/s) (V)	60 °C Flow Rate (gpm) (W)	60 °C Total Pressure Drop (lbf/in²) New (X)	60 °C Total Pressure Drop (lbf/in²) EOL (Y)	60 °C Flow Rate at a Pipe Design Pressure of 400 lbf/in² (gpm) New (Z)	60 °C Flow Rate at 400 lbf/in² (gpm) EOL (AA)
6	1.21	2.50	15	5	1.40	2.6	60	7	13	525	343	2.8	65	7	15	539	345
7	1.21	2.50	15	5	1.40	2.6	60	27	35	299	237	2.8	65	27	38	311	240
8	1.21	2.50	15	5	1.40	2.6	60	28	37	293	228	2.8	65	28	40	305	231
9	1.21	2.50	15	5	1.40	2.6	60	66	75	198	171	2.8	65	66	79	208	175
10	1.21	2.50	15	5	1.40	2.6	60	33	47	260	194	2.8	65	33	52	271	196
11	1.21	2.50	15	5	1.40	2.6	60	71	85	186	155	2.8	65	71	91	195	158
12	1.21	2.50	15	5	1.40	2.6	60	4	8	666	440	2.8	65	4	9	681	442
13	1.21	2.50	15	5	1.40	2.6	60	71	85	186	155	2.8	65	71	91	196	158
14	1.21	2.50	15	5	1.40	2.6	60	8	15	497	316	2.8	65	8	17	510	318
15	1.21	2.50	15	5	1.40	2.6	60	7	13	526	344	2.8	65	7	15	540	345
16	1.21	2.50	15	5	1.40	2.6	60	7	12	533	351	2.8	65	7	14	547	353
17	1.21	2.50	15	5	1.40	2.6	60	5	10	608	384	2.8	65	5	12	622	385
18	1.21	2.50	15	5	1.40	2.6	60	5	10	611	387	2.8	65	5	12	626	389
19	1.21	2.50	15	5	1.40	2.6	60	6	12	570	352	2.8	65	6	14	585	353
20	1.21	2.50	15	5	1.40	2.6	60	27	36	300	232	2.8	65	27	39	312	235
21	1.21	2.50	15	5	1.40	2.6	60	27	36	299	231	2.8	65	27	39	311	234
22	1.21	2.50	15	5	1.40	2.6	60	27	34	306	241	2.8	65	27	37	318	244
23	1.21	2.50	15	5	1.40	2.6	60	27	36	300	232	2.8	65	27	39	311	234
24	1.21	2.50	15	5	1.40	2.6	60	27	36	299	231	2.8	65	27	39	311	233
25	1.21	2.50	15	5	1.40	2.6	60	39	55	257	188	2.8	65	39	60	268	190
26	1.21	2.50	15	5	1.40	2.6	60	39	55	256	187	2.8	65	39	60	268	189
27	1.21	2.50	15	5	1.40	2.6	60	39	55	257	187	2.8	65	39	60	268	189
28	1.21	2.50	15	5	1.40	2.6	60	40	57	253	182	2.8	65	40	63	264	184
29	1.21	2.50	15	5	1.40	2.6	60	17	25	365	261	2.8	65	17	28	378	263
30	1.21	2.50	15	5	1.40	2.6	60	65	74	200	173	2.8	65	65	78	210	177
31	1.21	2.50	15	5	1.40	2.6	60	6	11	556	375	2.8	65	6	12	570	377
32	1.21	2.50	15	5	1.40	2.6	60	73	88	182	151	2.8	65	73	94	192	154
33	1.21	2.50	15	5	1.40	2.6	60	43	62	239	173	2.8	65	43	68	250	175
34	1.21	2.50	15	5	1.40	2.6	60	73	88	182	152	2.8	65	73	94	192	155
35	1.21	2.50	15	5	1.40	2.6	60	74	90	181	149	2.8	65	74	96	191	152
36	1.21	2.50	15	5	1.40	2.6	60	55	67	211	173	2.8	65	55	72	222	176
37	1.21	2.50	15	5	1.40	2.6	60	55	67	211	173	2.8	65	55	72	221	175
38	1.21	2.50	15	5	1.40	2.6	60	8	17	503	299	2.8	65	7	19	517	300
39	1.21	2.50	15	5	1.40	2.6	60	54	65	213	177	2.8	65	54	69	224	180
40	1.21	2.50	15	5	1.40	2.6	60	7	14	533	322	2.8	65	7	17	547	323
41	1.21	2.50	15	5	1.40	2.6	60	54	65	214	177	2.8	65	54	69	224	180
42	1.21	2.50	15	5	1.40	2.6	60	18	31	268	202	2.8	65	18	36	279	204
43	1.21	2.50	15	5	1.40	2.6	60	54	65	213	176	2.8	65	54	70	223	179
44	1.21	2.50	15	5	1.40	2.6	60	16	31	416	239	2.8	65	16	35	429	240
45	1.21	2.50	15	5	1.40	2.6	60	55	67	211	172	2.8	65	55	72	221	175
46	1.21	2.50	15	5	1.40	2.6	60	21	43	232	167	2.8	65	21	50	242	169
47	1.21	2.50	15	5	1.40	2.6	60	56	75	196	153	2.8	65	56	82	206	156
48	1.21	2.50	15	5	1.40	2.6	60	21	46	293	179	2.8	65	21	53	305	180
49	1.21	2.50	15	5	1.40	2.6	60	22	38	254	187	2.8	65	22	44	265	189
50	1.21	2.50	15	5	1.40	2.6	60	56	75	195	153	2.8	65	56	82	205	155
51	1.21	2.50	15	5	1.40	2.6	60	9	25	367	223	2.8	65	9	30	380	224
52	1.21	2.50	15	5	1.40	2.6	60	4	7	693	470	2.8	65	4	8	708	472
53	1.21	2.50	15	5	1.40	2.6	60	56	75	196	153	2.8	65	56	82	206	155
54	1.21	2.50	15	5	1.40	2.6	60	57	77	194	150	2.8	65	56	85	204	153
55	1.21	2.50	15	5	1.40	2.6	60	9	27	359	216	2.8	65	9	32	371	217
56	1.21	2.50	15	5	1.40	2.6	60	9	27	355	214	2.8	65	9	33	368	215
57	1.21	2.50	15	5	1.40	2.6	60	10	29	347	208	2.8	65	10	35	360	209
58	1.21	2.50	15	5	1.40	2.6	60	5	9	637	411	2.8	65	5	10	652	413
59	1.21	2.50	15	5	1.40	2.6	60	22	48	288	175	2.8	65	22	56	300	176
60	1.21	2.50	15	5	1.40	2.6	60	5	9	625	400	2.8	65	5	11	640	402
61	1.21	2.50	15	5	1.40	2.6	60	23	50	283	171	2.8	65	22	58	295	172
62	1.21	2.50	15	5	1.40	2.6	60	63	72	192	166	2.8	65	63	77	202	169
63	1.21	2.50	15	5	1.40	2.6	60	7	14	371	278	2.8	65	7	16	384	281
64	1.21	2.50	15	5	1.40	2.6	60	7	11	374	301	2.8	65	7	13	387	305
65	1.21	2.50	15	5	1.40	2.6	60	23	32	289	225	2.8	65	23	35	300	228
66	1.21	2.50	15	5	1.40	2.6	60	61	69	198	171	2.8	65	60	74	208	174
67	1.21	2.50	15	5	1.40	2.6	60	62	70	203	175	2.8	65	62	75	213	179
68	1.21	2.50	15	5	1.40	2.6	60	65	73	196	170	2.8	65	64	78	206	173

Group 2 Properties; Critical (κ_{cv} = 1.30, κ_f = 1)

Row	Liquid ρ_L Density (kg/L) (AB)	Solids ρ_s Density (kg/L) (AC)	Solids C_s Volume (%) (AD)	Solids d_p Median Dia. (μm) (AE)	ρ_m Bulk Density (kg/L) (AF)	10 °C Velocity (ft/s) (AG)	10 °C Flow Rate (gpm) (AH)	10 °C Total Pressure Drop (lbf/in²) New (AI)	10 °C Total Pressure Drop (lbf/in²) EOL (AJ)	10 °C Flow Rate at a Pipe Design Pressure of 400 lbf/in² (gpm) New (AK)	10 °C Flow Rate at 400 lbf/in² (gpm) EOL (AL)	60 °C Velocity (ft/s) (AM)	60 °C Flow Rate (gpm) (AN)	60 °C Total Pressure Drop (lbf/in²) New (AO)	60 °C Total Pressure Drop (lbf/in²) EOL (AP)	60 °C Flow Rate at a Pipe Design Pressure of 400 lbf/in² (gpm) New (AQ)	60 °C Flow Rate at 400 lbf/in² (gpm) EOL (AR)
6	1.46	3.00	30	10	1.92	2.7	62	15	22	395	284	2.9	67	14	23	425	290
7	1.46	3.00	30	10	1.92	2.7	62	54	62	216	188	2.9	67	50	61	237	196
8	1.46	3.00	30	10	1.92	2.7	62	56	65	212	181	2.9	67	52	65	232	189
9	1.46	3.00	30	10	1.92	2.7	62	126	133	■	■	2.9	67	117	129	153	■
10	1.46	3.00	30	10	1.92	2.7	62	68	83	186	154	2.9	67	62	83	205	161
11	1.46	3.00	30	10	1.92	2.7	62	137	151	■	■	2.9	67	128	148	143	■
12	1.46	3.00	30	10	1.92	2.7	62	10	14	508	366	2.9	67	9	14	543	373
13	1.46	3.00	30	10	1.92	2.7	62	137	150	■	■	2.9	67	127	147	144	■
14	1.46	3.00	30	10	1.92	2.7	62	17	26	372	262	2.9	67	15	27	401	267
15	1.46	3.00	30	10	1.92	2.7	62	15	22	396	285	2.9	67	14	23	425	290
16	1.46	3.00	30	10	1.92	2.7	62	15	21	402	291	2.9	67	13	22	432	297
17	1.46	3.00	30	10	1.92	2.7	62	12	18	461	320	2.9	67	10	18	494	325
18	1.46	3.00	30	10	1.92	2.7	62	11	17	465	323	2.9	67	10	18	497	328
19	1.46	3.00	30	10	1.92	2.7	62	13	21	431	293	2.9	67	12	22	463	298
20	1.46	3.00	30	10	1.92	2.7	62	54	63	217	185	2.9	67	50	63	238	193
21	1.46	3.00	30	10	1.92	2.7	62	54	63	217	184	2.9	67	50	63	237	192
22	1.46	3.00	30	10	1.92	2.7	62	53	60	221	191	2.9	67	49	59	242	200
23	1.46	3.00	30	10	1.92	2.7	62	54	63	217	184	2.9	67	50	63	237	192
24	1.46	3.00	30	10	1.92	2.7	62	54	64	216	183	2.9	67	50	63	237	191
25	1.46	3.00	30	10	1.92	2.7	62	75	93	184	149	2.9	67	70	94	202	155
26	1.46	3.00	30	10	1.92	2.7	62	76	94	183	149	2.9	67	70	95	201	155
27	1.46	3.00	30	10	1.92	2.7	62	76	93	183	149	2.9	67	70	95	202	155
28	1.46	3.00	30	10	1.92	2.7	62	77	97	180	145	2.9	67	72	98	198	151
29	1.46	3.00	30	10	1.92	2.7	62	35	45	268	211	2.9	67	32	45	292	218
30	1.46	3.00	30	10	1.92	2.7	62	124	131	■	■	2.9	67	115	127	155	■
31	1.46	3.00	30	10	1.92	2.7	62	14	19	420	310	2.9	67	12	20	451	317
32	1.46	3.00	30	10	1.92	2.7	62	141	155	■	■	2.9	67	131	152	141	■
33	1.46	3.00	30	10	1.92	2.7	62	84	105	170	■	2.9	67	78	107	187	143
34	1.46	3.00	30	10	1.92	2.7	62	141	155	■	■	2.9	67	131	152	141	■
35	1.46	3.00	30	10	1.92	2.7	62	142	158	■	■	2.9	67	132	156	■	■
36	1.46	3.00	30	10	1.92	2.7	62	106	118	149	■	2.9	67	99	116	164	141
37	1.46	3.00	30	10	1.92	2.7	62	107	119	148	■	2.9	67	99	117	164	141
38	1.46	3.00	30	10	1.92	2.7	62	17	28	378	250	2.9	67	15	30	407	253
39	1.46	3.00	30	10	1.92	2.7	62	105	115	150	■	2.9	67	97	113	166	144
40	1.46	3.00	30	10	1.92	2.7	62	15	24	401	268	2.9	67	13	26	431	272
41	1.46	3.00	30	10	1.92	2.7	62	105	115	150	■	2.9	67	97	113	166	144
42	1.46	3.00	30	10	1.92	2.7	62	46	61	194	161	2.9	67	41	61	213	169
43	1.46	3.00	30	10	1.92	2.7	62	105	116	150	■	2.9	67	98	114	166	143
44	1.46	3.00	30	10	1.92	2.7	62	31	49	308	199	2.9	67	29	52	334	202
45	1.46	3.00	30	10	1.92	2.7	62	107	119	148	■	2.9	67	99	117	164	141
46	1.46	3.00	30	10	1.92	2.7	62	58	83	166	■	2.9	67	51	85	184	140
47	1.46	3.00	30	10	1.92	2.7	62	113	134	■	■	2.9	67	104	133	152	■
48	1.46	3.00	30	10	1.92	2.7	62	47	77	213	148	2.9	67	42	82	233	151
49	1.46	3.00	30	10	1.92	2.7	62	54	72	183	150	2.9	67	48	73	201	156
50	1.46	3.00	30	10	1.92	2.7	62	113	134	■	■	2.9	67	104	134	152	■
51	1.46	3.00	30	10	1.92	2.7	62	23	43	271	185	2.9	67	21	47	295	189
52	1.46	3.00	30	10	1.92	2.7	62	9	12	530	390	2.9	67	8	13	565	397
53	1.46	3.00	30	10	1.92	2.7	62	113	134	■	■	2.9	67	104	134	152	■
54	1.46	3.00	30	10	1.92	2.7	62	115	138	■	■	2.9	67	106	137	151	■
55	1.46	3.00	30	10	1.92	2.7	62	25	46	264	180	2.9	67	22	50	287	183
56	1.46	3.00	30	10	1.92	2.7	62	25	47	262	178	2.9	67	22	51	285	181
57	1.46	3.00	30	10	1.92	2.7	62	27	50	255	173	2.9	67	24	54	278	176
58	1.46	3.00	30	10	1.92	2.7	62	11	15	485	342	2.9	67	10	16	518	348
59	1.46	3.00	30	10	1.92	2.7	62	48	80	209	144	2.9	67	44	86	229	148
60	1.46	3.00	30	10	1.92	2.7	62	11	16	475	333	2.9	67	10	17	508	339
61	1.46	3.00	30	10	1.92	2.7	62	50	83	205	141	2.9	67	45	89	224	145
62	1.46	3.00	30	10	1.92	2.7	62	124	132	■	■	2.9	67	115	127	149	■
63	1.46	3.00	30	10	1.92	2.7	62	21	28	274	225	2.9	67	18	28	298	234
64	1.46	3.00	30	10	1.92	2.7	62	21	25	277	242	2.9	67	18	24	301	252
65	1.46	3.00	30	10	1.92	2.7	62	49	59	209	179	2.9	67	45	58	229	187
66	1.46	3.00	30	10	1.92	2.7	62	119	126	■	■	2.9	67	110	122	153	■
67	1.46	3.00	30	10	1.92	2.7	62	119	126	142	■	2.9	67	111	122	157	142
68	1.46	3.00	30	10	1.92	2.7	62	124	132	■	■	2.9	67	116	128	152	■

Row 69 legend: Included in BNFL routes ■ Exceeds 275 lbf/in² ■ Exceeds 400 lbf/in² — Supernate liquid only transfer ■ Less than 140 gpm

Notes

New = new or like new pipeline with maximum expected pipe roughness of 2 mils (0.002 inches).

EOL = pipeline at end of life (50 years for carbon steel line, 40 years for stainless steel line) with pipe roughness due to corrosion estimated at 150 mils for carbon steel and 10 mils for stainless steel.

***Design Pressure** = All stainless steel pipelines have a design pressure of 400 lbf/in². The design pressure of carbon steel pipelines are either 275 or 400 lbf/in² as indicated. The predicted flow rate at design pressure given in this table assumes that all pipelines are or can be qualified to the higher 400 lbf/in² design pressure.

Table D-17. 3S6 Case 1b.

CASE 3S6 Transfer List - Tank-to-Tank

Case 1b. Critical velocity by Oroskar and Turian (1980) empirical correlation (β_{cv} = 1.2). Pressure drop by Wasp et al. (1977) method with lognormal particle size distribution.

Group 1 Properties; Temperature = 10 °C and Temperature = 60 °C (Critical: κ_{cv} = 1.30, κ_f = 1)

Row	A: Transfer From Tank	B: Transfer To Tank	C: Tank Farm Built (Yr)	D: #	E: Transfer Dates (M/Yr) Start	F: Transfer Dates (M/Yr) End	G: Design Pressure (lbf/in²)	H: 3-in. Schedule-40 Pipe (3.068 in. inside dia.) Carbon Steel Length (ft)	I: 3-in. Schedule-40 Pipe (3.068 in. inside dia.) Stainless Steel Length (ft)	J: Total Change in Elevation (ft)	K: Liquid ρ_L Density (kg/L)	L: Solids ρ_s Density (kg/L)	M: Solids C_s Volume (%)	N: Solids d_p Median Dia. (μm)	O: ρ_m Bulk Density (kg/L)	P: 10 °C Critical Velocity (ft/s)	Q: 10 °C Critical Flow Rate (gpm)	R: 10 °C Total Pressure Drop (lbf/in²) New	S: 10 °C Total Pressure Drop (lbf/in²) EOL	T: 10 °C Flow Rate at a Pipe Design Pressure of 400 lbf/in² (gpm) New	U: 10 °C Flow Rate at a Pipe Design Pressure of 400 lbf/in² (gpm) EOL	V: 60 °C Critical Velocity (ft/s)	W: 60 °C Critical Flow Rate (gpm)	X: 60 °C Total Pressure Drop (lbf/in²) New	Y: 60 °C Total Pressure Drop (lbf/in²) EOL	Z: 60 °C Flow Rate at a Pipe Design Pressure of 400 lbf/in² (gpm) New	AA: 60 °C Flow Rate at a Pipe Design Pressure of 400 lbf/in² (gpm) EOL
6	AN-101	AN-106	80-81	1	12/00	12/00		442	626	0	1.10	2.50	15	5	1.31	2.9	67	8	15	548	356	3.2	74	8	17	560	357
7		AP-103	83-86	1	7/03	7/03	400	306	2,774	12	1.10	2.50	15	5	1.31	2.9	67	29	38	314	247	3.2	74	29	42	324	249
8		AP-107	83-86	1	6/05	6/05	400	423	2,774	12	1.10	2.50	15	5	1.31	2.9	67	30	40	308	237	3.2	74	30	45	318	239
9		BNFL		7	2/11	12/19	400	0	6,413	40	1.10	2.50	15	5	1.31	2.9	67	69	80	209	179	3.2	74	70	86	218	182
10	AN-102	AP-107	83-86	1	3/10	3/10		828	3,184	12	1.10	2.50	15	5	1.31	2.9	67	35	52	273	202	3.2	74	36	59	283	204
11		BNFL		5	12/08	4/16		405	6,823	40	1.10	2.50	15	5	1.31	2.9	67	74	92	196	161	3.2	74	76	100	205	164
12	AN-103	AN-102	80-81	1	4/12	4/12		253	421	0	1.10	2.50	15	5	1.31	2.9	67	5	9	694	457	3.2	74	5	10	708	458
13		BNFL		9	4/14	6/19		376	6,823	40	1.10	2.50	15	5	1.31	2.9	67	74	91	196	162	3.2	74	75	99	205	165
14	AN-104	AN-101	80-81	3	6/05	2/16		562	626	0	1.10	2.50	15	5	1.31	2.9	67	8	17	519	328	3.2	74	9	20	531	329
15		AN-102	80-81	2	4/16	6/16		439	626	0	1.10	2.50	15	5	1.31	2.9	67	8	15	549	356	3.2	74	8	17	561	358
16		AN-103	80-81	2	4/14	8/14		410	626	0	1.10	2.50	15	5	1.31	2.9	67	7	14	557	364	3.2	74	8	16	569	366
17		AN-105	80-81	5	10/14	11/17		384	421	0	1.10	2.50	15	5	1.31	2.9	67	6	12	634	398	3.2	74	6	14	647	399
18		AN-106	80-81	2	8/13	10/13		374	421	0	1.10	2.50	15	5	1.31	2.9	67	6	12	638	402	3.2	74	6	13	651	403
19		AN-107	80-81	1	3/19	3/19		489	421	0	1.10	2.50	15	5	1.31	2.9	67	6	14	595	364	3.2	74	7	16	608	366
20		AP-101	83-86	4	10/13	2/17	400	419	2,636	12	1.10	2.50	15	5	1.31	2.9	67	29	39	315	242	3.2	74	29	43	325	244
21		AP-102	83-86	1	8/13	8/13	400	431	2,636	12	1.10	2.50	15	5	1.31	2.9	67	29	39	314	241	3.2	74	29	44	325	243
22		AP-104	83-86	1	11/17	11/17	400	314	2,636	12	1.10	2.50	15	5	1.31	2.9	67	28	37	321	251	3.2	74	28	41	331	254
23		AP-106	83-86	2	8/16	12/16	400	430	2,636	12	1.10	2.50	15	5	1.31	2.9	67	29	39	314	241	3.2	74	29	44	325	243
24		AP-108	83-86	1	7/18	7/18	400	443	2,636	12	1.10	2.50	15	5	1.31	2.9	67	29	40	314	240	3.2	74	29	44	324	242
25		AW-101	78-80	2	3/15	3/15		994	3,046	21	1.10	2.50	15	5	1.31	2.9	67	41	60	270	195	3.2	74	41	67	280	197
26		AW-103	78-80	2	11/15	11/15		1,012	3,046	21	1.10	2.50	15	5	1.31	2.9	67	41	60	270	194	3.2	74	42	67	280	196
27		AW-104	78-80	1	1/19	1/19		1,003	3,046	21	1.10	2.50	15	5	1.31	2.9	67	41	60	270	195	3.2	74	41	67	280	197
28		AW-105	78-80	1	7/18	7/18		1,125	3,046	21	1.10	2.50	15	5	1.31	2.9	67	42	63	266	190	3.2	74	42	70	276	191
29		AZ-101	71	1	10/10	10/10	400	562	1,560	5	1.10	2.50	15	5	1.31	2.9	67	18	29	383	271	3.2	74	18	32	394	273
30		BNFL		1	9/10	9/10	400	0	6,275	40	1.10	2.50	15	5	1.31	2.9	67	68	78	211	181	3.2	74	69	85	220	184
31	AN-105	AN-102	80-81	1	3/10	3/10		329	626	0	1.10	2.50	15	5	1.31	2.9	67	7	12	581	389	3.2	74	7	14	593	391
32		BNFL		3	8/12	5/17		452	7,028	40	1.10	2.50	15	5	1.31	2.9	67	76	95	192	158	3.2	74	77	103	201	161
33	AN-106	AW-102	78-80	6	11/04	1/06		1,242	3,389	21	1.10	2.50	15	5	1.31	2.9	67	45	68	252	180	3.2	74	46	76	261	182
34		BNFL		7	12/18	3/19		442	7,028	40	1.10	2.50	15	5	1.31	2.9	67	76	94	193	158	3.2	74	77	103	201	161
35	AN-107	BNFL		1	7/11	7/11		557	7,028	40	1.10	2.50	15	5	1.31	2.9	67	77	97	191	156	3.2	74	78	106	200	158
36	AP-101	BNFL		2	4/06	12/16	400	419	5,370	28	1.10	2.50	15	5	1.31	2.9	67	57	72	222	180	3.2	74	58	79	232	183
37	AP-102	BNFL		9	7/18	12/18	400	431	5,370	28	1.10	2.50	15	5	1.31	2.9	67	57	73	222	180	3.2	74	58	79	232	183
38	AP-104	AP-107	83-86	1	1/13	1/13	400	737	421	0	1.10	2.50	15	5	1.31	2.9	67	8	19	526	310	3.2	74	8	23	538	311
39		BNFL		3	1/13	10/17	400	314	5,370	28	1.10	2.50	15	5	1.31	2.9	67	57	70	225	184	3.2	74	57	77	234	187
40	AP-105	AP-104	83-86	1	9/15	9/15	400	616	421	0	1.10	2.50	15	5	1.31	2.9	67	7	17	556	333	3.2	74	8	19	569	334
41		BNFL		1	2/18	2/18	400	302	5,370	28	1.10	2.50	15	5	1.31	2.9	67	56	70	225	185	3.2	74	57	76	234	187
42	AP-106	AN-102	80-81	1	10/13	10/13		745	3,184	-12	1.10	2.50	15	5	1.31	2.9	67	21	37	281	210	3.2	74	22	43	291	212
43		BNFL		1	8/16	8/16	400	340	5,370	28	1.10	2.50	15	5	1.31	2.9	67	57	71	224	183	3.2	74	58	77	233	186
44	AP-107	AW-102	78-80	16	8/00	7/18		1,223	421	9	1.10	2.50	15	5	1.31	2.9	67	17	35	436	248	3.2	74	17	40	447	249
45	AP-108	BNFL		1	7/18	7/18	400	443	5,370	28	1.10	2.50	15	5	1.31	2.9	67	57	73	222	180	3.2	74	58	80	231	182
46	AW-101	AN-105	80-81	1	8/12	8/12		1,446	3,799	-21	1.10	2.50	15	5	1.31	2.9	67	25	52	243	174	3.2	74	26	61	253	175
47		BNFL		9	3/15	8/19		994	5,780	19	1.10	2.50	15	5	1.31	2.9	67	59	83	206	160	3.2	74	60	93	215	162
48	AW-103	AW-104	78-80	1	10/15	11/15		2,015	1,241	0	1.10	2.50	15	5	1.31	2.9	67	23	53	307	186	3.2	74	24	62	318	187
49		AY-102	68-70	1	12/13	12/13		1,012	3,320	-10	1.10	2.50	15	5	1.31	2.9	67	25	45	267	194	3.2	74	26	52	277	196
50		BNFL		8	8/19	10/19		1,012	5,780	19	1.10	2.50	15	5	1.31	2.9	67	59	83	206	159	3.2	74	60	93	215	161
51	AW-104	AP-104	83-86	1	1/13	1/13		1,317	831	-9	1.10	2.50	15	5	1.31	2.9	67	10	30	384	231	3.2	74	11	36	395	232
52		AW-102	78-80	3	6/01	1/02		203	421	0	1.10	2.50	15	5	1.31	2.9	67	4	8	723	487	3.2	74	5	9	736	489
53		BNFL		6	4/18	1/19		1,003	5,780	19	1.10	2.50	15	5	1.31	2.9	67	59	83	206	159	3.2	74	60	93	215	161
54	AW-105	BNFL		7	1/18	7/18		1,125	5,780	19	1.10	2.50	15	5	1.31	2.9	67	60	86	204	156	3.2	74	61	96	213	159
55	AW-106	AP-105	83-86	2	10/04	6/05		1,416	831	-9	1.10	2.50	15	5	1.31	2.9	67	11	32	375	224	3.2	74	11	38	386	225
56		AP-106	83-86	2	4/01	1/02		1,454	831	-9	1.10	2.50	15	5	1.31	2.9	67	11	33	372	222	3.2	74	12	39	383	223
57		AP-108	83-86	1	3/09	3/09		1,557	831	-9	1.10	2.50	15	5	1.31	2.9	67	12	35	364	216	3.2	74	12	42	375	216
58		AW-102	78-80	13	12/01	7/18		314	421	0	1.10	2.50	15	5	1.31	2.9	67	5	10	664	426	3.2	74	5	12	677	428
59		AW-103	78-80	1	10/04	10/04		2,126	1,241	0	1.10	2.50	15	5	1.31	2.9	67	24	56	302	182	3.2	74	25	65	312	183
60		AW-104	78-80	2	1/02	8/02		341	421	0	1.10	2.50	15	5	1.31	2.9	67	5	11	652	415	3.2	74	6	13	665	416
61		AW-105	78-80	1	6/05	6/05		2,239	1,241	0	1.10	2.50	15	5	1.31	2.9	67	25	58	297	178	3.2	74	25	68	307	179
62	AY-101	BNFL		12	1/11	10/13	400	0	6,924	30	1.10	2.50	15	5	1.31	2.9	67	66	78	202	173	3.2	74	67	85	211	176
63	AY-102	AN-103	80-81	1	11/19	11/19		376	1,733	-11	1.10	2.50	15	5	1.31	2.9	67	9	17	389	289	3.2	74	9	20	400	291
64		AN-106	80-81	2	5/19	11/19		142	1,938	-11	1.10	2.50	15	5	1.31	2.9	67	8	14	391	313	3.2	74	9	16	403	316
65		AP-102	83-86	1	12/18	12/18	400	431	2,910	2	1.10	2.50	15	5	1.31	2.9	67	25	36	303	234	3.2	74	25	40	313	236
66		BNFL		16	1/09	2/18	400	0	6,549	30	1.10	2.50	15	5	1.31	2.9	67	64	75	208	178	3.2	74	65	81	217	181
67	AZ-101	BNFL		10	10/06	8/15	400	0	6,171	36	1.10	2.50	15	5	1.31	2.9	67	65	75	214	183	3.2	74	66	81	223	186
68	AZ-102	BNFL		6	7/07	3/08	400	0	6,556	36	1.10	2.50	15	5	1.31	2.9	67	67	79	207	177	3.2	74	68	85	216	180
69	BNFL internal equivalent pipe length and elevation								884	45	Included in BNFL routes							Exceeds 275 lbf/in²						Exceeds 400 lbf/in²			

Group 2 Properties; Temperature = 10 °C and Temperature = 60 °C (Critical: κ_{cv} = 1.30, κ_f = 1)

Row	AB: Liquid ρ_L Density (kg/L)	AC: Solids ρ_s Density (kg/L)	AD: Solids C_s Volume (%)	AE: Solids d_p Median Dia. (μm)	AF: ρ_m Bulk Density (kg/L)	AG: 10 °C Critical Velocity (ft/s)	AH: 10 °C Critical Flow Rate (gpm)	AI: 10 °C Total Pressure Drop (lbf/in²) New	AJ: 10 °C Total Pressure Drop (lbf/in²) EOL	AK: 10 °C Flow Rate at a Pipe Design Pressure of 400 lbf/in² (gpm) New	AL: 10 °C Flow Rate at a Pipe Design Pressure of 400 lbf/in² (gpm) EOL	AM: 60 °C Critical Velocity (ft/s)	AN: 60 °C Critical Flow Rate (gpm)	AO: 60 °C Total Pressure Drop (lbf/in²) New	AP: 60 °C Total Pressure Drop (lbf/in²) EOL	AQ: 60 °C Flow Rate at a Pipe Design Pressure of 400 lbf/in² (gpm) New	AR: 60 °C Flow Rate at a Pipe Design Pressure of 400 lbf/in² (gpm) EOL
6	1.20	3.00	30	10	1.74	3.7	84	17	31	462	307	4.0	92	17	36	479	309
7	1.20	3.00	30	10	1.74	3.7	84	58	76	261	211	4.0	92	58	83	274	215
8	1.20	3.00	30	10	1.74	3.7	84	59	81	255	202	4.0	92	59	89	269	206
9	1.20	3.00	30	10	1.74	3.7	84	132	153	171	150	4.0	92	131	163	182	155
10	1.20	3.00	30	10	1.74	3.7	84	72	106	226	172	4.0	92	72	118	239	176
11	1.20	3.00	30	10	1.74	3.7	84	144	178	160		4.0	92	144	193	171	
12	1.20	3.00	30	10	1.74	3.7	84	11	19	587	394	4.0	92	11	22	606	397
13	1.20	3.00	30	10	1.74	3.7	84	144	177	160		4.0	92	144	191	171	140
14	1.20	3.00	30	10	1.74	3.7	84	19	37	437	283	4.0	92	19	42	454	285
15	1.20	3.00	30	10	1.74	3.7	84	17	31	462	308	4.0	92	17	36	480	310
16	1.20	3.00	30	10	1.74	3.7	84	16	30	469	314	4.0	92	16	34	487	317
17	1.20	3.00	30	10	1.74	3.7	84	13	25	535	344	4.0	92	13	29	554	346
18	1.20	3.00	30	10	1.74	3.7	84	13	25	539	347	4.0	92	13	28	557	349
19	1.20	3.00	30	10	1.74	3.7	84	14	30	502	315	4.0	92	14	34	520	317
20	1.20	3.00	30	10	1.74	3.7	84	57	78	262	207	4.0	92	57	86	276	210
21	1.20	3.00	30	10	1.74	3.7	84	58	79	261	206	4.0	92	58	86	275	209
22	1.20	3.00	30	10	1.74	3.7	84	56	73	267	214	4.0	92	56	80	281	218
23	1.20	3.00	30	10	1.74	3.7	84	58	78	261	206	4.0	92	58	86	275	209
24	1.20	3.00	30	10	1.74	3.7	84	58	79	261	205	4.0	92	58	87	275	208
25	1.20	3.00	30	10	1.74	3.7	84	80	118	223	167	4.0	92	80	131	236	169
26	1.20	3.00	30	10	1.74	3.7	84	80	119	223	166	4.0	92	80	132	236	169
27	1.20	3.00	30	10	1.74	3.7	84	80	118	223	166	4.0	92	80	131	236	169
28	1.20	3.00	30	10	1.74	3.7	84	82	124	220	162	4.0	92	82	138	232	165
29	1.20	3.00	30	10	1.74	3.7	84	37	58	320	233	4.0	92	37	65	335	235
30	1.20	3.00	30	10	1.74	3.7	84	129	150	173	152	4.0	92	129	161	184	157
31	1.20	3.00	30	10	1.74	3.7	84	15	26	489	336	4.0	92	15	30	508	338
32	1.20	3.00	30	10	1.74	3.7	84	148	184	157		4.0	92	148	200	168	
33	1.20	3.00	30	10	1.74	3.7	84	89	135	208	154	4.0	92	89	151	220	156
34	1.20	3.00	30	10	1.74	3.7	84	148	184	157		4.0	92	148	199	168	
35	1.20	3.00	30	10	1.74	3.7	84	150	189	156		4.0	92	150	205	167	
36	1.20	3.00	30	10	1.74	3.7	84	113	142	183	153	4.0	92	112	154	195	157
37	1.20	3.00	30	10	1.74	3.7	84	113	143	183	152	4.0	92	113	155	194	156
38	1.20	3.00	30	10	1.74	3.7	84	18	41	443	268	4.0	92	18	47	460	269
39	1.20	3.00	30	10	1.74	3.7	84	111	137	185	156	4.0	92	111	149	196	160
40	1.20	3.00	30	10	1.74	3.7	84	16	35	469	288	4.0	92	16	41	487	290
41	1.20	3.00	30	10	1.74	3.7	84	111	137	185	156	4.0	92	111	148	197	160
42	1.20	3.00	30	10	1.74	3.7	84	53	85	234	180	4.0	92	53	96	248	183
43	1.20	3.00	30	10	1.74	3.7	84	111	138	184	155	4.0	92	111	150	196	159
44	1.20	3.00	30	10	1.74	3.7	84	33	69	365	214	4.0	92	33	79	381	215
45	1.20	3.00	30	10	1.74	3.7	84	113	143	182	152	4.0	92	113	156	194	156
46	1.20	3.00	30	10	1.74	3.7	84	67	120	203	150	4.0	92	67	138	215	152
47	1.20	3.00	30	10	1.74	3.7	84	121	169	170		4.0	92	121	186	181	
48	1.20	3.00	30	10	1.74	3.7	84	51	113	256	160	4.0	92	51	130	270	162
49	1.20	3.00	30	10	1.74	3.7	84	61	101	222	167	4.0	92	61	114	235	170
50	1.20	3.00	30	10	1.74	3.7	84	122	169	169		4.0	92	122	187	181	
51	1.20	3.00	30	10	1.74	3.7	84	27	67	322	200	4.0	92	27	79	338	201
52	1.20	3.00	30	10	1.74	3.7	84	10	17	611	420	4.0	92	10	19	631	423
53	1.20	3.00	30	10	1.74	3.7	84	122	169	169		4.0	92	121	186	181	
54	1.20	3.00	30	10	1.74	3.7	84	123	174	168		4.0	92	123	193	179	
55	1.20	3.00	30	10	1.74	3.7	84	29	72	315	194	4.0	92	29	84	330	195
56	1.20	3.00	30	10	1.74	3.7	84	29	74	312	192	4.0	92	29	86	327	193
57	1.20	3.00	30	10	1.74	3.7	84	31	78	305	187	4.0	92	31	91	320	188
58	1.20	3.00	30	10	1.74	3.7	84	12	22	561	368	4.0	92	12	25	580	370
59	1.20	3.00	30	10	1.74	3.7	84	53	118	252	157	4.0	92	53	136	265	158
60	1.20	3.00	30	10	1.74	3.7	84	12	23	551	358	4.0	92	12	26	570	360
61	1.20	3.00	30	10	1.74	3.7	84	55	123	247	153	4.0	92	55	142	261	155
62	1.20	3.00	30	10	1.74	3.7	84	132	154	166	146	4.0	92	131	166	177	151
63	1.20	3.00	30	10	1.74	3.7	84	25	41	326	249	4.0	92	25	47	342	252
64	1.20	3.00	30	10	1.74	3.7	84	24	35	329	269	4.0	92	24	39	344	273
65	1.20	3.00	30	10	1.74	3.7	84	54	76	252	200	4.0	92	54	84	266	204
66	1.20	3.00	30	10	1.74	3.7	84	126	147	171	151	4.0	92	126	158	182	155
67	1.20	3.00	30	10	1.74	3.7	84	125	145	175	154	4.0	92	125	155	187	159
68	1.20	3.00	30	10	1.74	3.7	84	131	152	169	149	4.0	92	131	163	181	154
69		Supernate liquid only transfer										Less than 140 gpm					

AS: Notes

New = new or like new pipeline with maximum expected pipe roughness of 2 mils (0.002 inches).

EOL = pipeline at end of life (50 years for carbon steel line, 40 years for stainless steel line) with pipe roughness due to corrosion estimated at 150 mils for carbon steel and 10 mils for stainless steel.

Design Pressure = All stainless steel pipelines have a design pressure of 400 lbf/in². The design pressure of carbon steel pipelines are either 275 or 400 lbf/in² as indicated. The predicted flow rate at design pressure given in this table assumes that all pipelines are or can be qualified to the higher 400 lbf/in² design pressure.

Table D-18. 3S6 Case 1c.

CASE 3S6 Transfer List - Tank-to-Tank — Case 1c

Critical velocity by Oroskar and Turian (1980) empirical correlation (β_{cv} = 1.2). Pressure drop by Wasp et al. (1977) method with lognormal particle size distribution.

Group 1 Properties; Temperature = 10 °C and 60 °C (Critical $(\kappa_{cv} = 1.30, \kappa_f = 1)$); 3-in. Schedule-40 Pipe (3.068 in. inside dia.)

Row	From Tank (A)	To Tank (B)	Tank Farm Built (Yr) (C)	# (D)	Dates (M/Yr) Start (E)	Dates (M/Yr) End (F)	Design Pressure (lbf/in²) (G)	Carbon Steel Length (ft) (H)	Stainless Steel Length (ft) (I)	Total Change in Elevation (ft) (J)	Liquid ρ_L Density (kg/L) (K)	Solids ρ_s Density (kg/L) (L)	C_s Volume (%) times 1.5 (M)	d_p Median Dia. (µm) (N)	ρ_m Bulk Density (kg/L) (O)	10 °C Velocity (ft/s) (P)	10 °C Flow Rate (gpm) (Q)	10 °C Total Pressure Drop (lbf/in²) New (R)	10 °C Total Pressure Drop (lbf/in²) EOL (S)	10 °C Flow Rate at a Pipe Design Pressure of 400 lbf/in² (gpm) New (T)	10 °C Flow Rate at 400 lbf/in² EOL (U)	60 °C Velocity (ft/s) (V)	60 °C Flow Rate (gpm) (W)	60 °C Total Pressure Drop New (X)	60 °C Total Pressure Drop EOL (Y)	60 °C Flow Rate at 400 lbf/in² New (Z)	60 °C Flow Rate at 400 lbf/in² EOL (AA)
6	AN-101	AN-106	80-81	1	12/00	12/00		442	626	0	1.21	2.50	**0.00**	5	1.21	0.3	7	0	0	573	370	0.1	3	0	0	584	371
7		AP-103	83-86	1	7/03	7/03	400	306	2,774	12	1.21	2.50	**0.00**	5	1.21	0.3	7	7	7	328	257	0.1	3	6	6	338	260
8		AP-107	83-86	1	6/05	6/05	400	423	2,774	12	1.21	2.50	**0.00**	5	1.21	0.3	7	7	7	322	247	0.1	3	6	6	332	249
9		**BNFL**		7	2/11	12/19	400	0	6,413	40	1.21	2.50	0.50	5	1.22	1.6	38	36	39	219	186	1.8	41	36	40	227	189
10	AN-102	AP-107	83-86	1	3/10	3/10		828	3,184	12	1.21	2.50	0.06	5	1.21	1.2	27	11	14	286	210	1.3	29	11	14	295	212
11		**BNFL**		5	12/08	4/16		405	6,823	40	1.21	2.50	0.82	5	1.22	1.8	41	40	46	205	168	1.9	44	40	48	213	170
12	AN-103	AN-102	80-81	1	4/12	4/12		253	421	0	1.21	2.50	0.23	5	1.21	1.5	33	1	2	724	475	1.6	37	1	2	736	476
13		**BNFL**		9	4/14	6/19		376	6,823	40	1.21	2.50	0.82	5	1.22	1.8	41	40	46	205	169	1.9	44	40	48	214	171
14	AN-104	AN-101	80-81	3	6/05	2/16		562	626	0	1.21	2.50	0.50	5	1.22	1.6	38	3	5	541	340	1.8	41	3	6	552	342
15		AN-102	80-81	2	4/16	6/16		439	626	0	1.21	2.50	0.59	5	1.22	1.7	39	3	5	572	370	1.8	42	3	5	583	371
16		AN-103	80-81	2	4/14	8/14		410	626	0	1.21	2.50	0.98	5	1.22	1.8	42	3	5	579	377	2.0	45	3	6	590	379
17		AN-105	80-81	5	10/14	11/17		384	421	0	1.21	2.50	4.76	5	1.27	2.3	52	4	7	644	404	2.5	57	4	8	657	405
18		AN-106	80-81	2	8/13	10/13		374	421	0	1.21	2.50	5.05	5	1.28	2.3	53	4	7	647	407	2.5	58	4	8	660	408
19		AN-107	80-81	1	3/19	3/19		489	421	0	1.21	2.50	1.65	5	1.23	2.0	45	3	6	616	376	2.1	49	3	7	628	377
20		AP-101	83-86	4	10/13	2/17	400	419	2,636	12	1.21	2.50	3.27	5	1.25	2.2	50	19	24	323	248	2.4	54	19	26	333	250
21		AP-102	83-86	1	8/13	8/13	400	431	2,636	12	1.21	2.50	5.05	5	1.28	2.3	53	21	27	319	244	2.5	58	21	29	329	246
22		AP-104	83-86	1	11/17	11/17	400	314	2,636	12	1.21	2.50	4.75	5	1.27	2.3	52	20	25	326	255	2.5	57	20	27	336	257
23		AP-106	83-86	2	8/16	12/16	400	430	2,636	12	1.21	2.50	2.02	5	1.24	2.0	46	17	22	325	248	2.2	51	17	23	335	250
24		AP-108	83-86	1	7/18	7/18	400	443	2,636	12	1.21	2.50	1.86	5	1.23	2.0	46	17	21	325	247	2.2	50	17	23	334	249
25		AW-101	78-80	2	3/15	3/15		994	3,046	21	1.21	2.50	0.63	5	1.22	1.7	39	21	27	282	203	1.8	42	21	28	291	205
26		AW-103	78-80	2	11/15	11/15		1,012	3,046	21	1.21	2.50	0.63	5	1.22	1.7	39	21	27	282	202	1.8	42	21	29	291	204
27		AW-104	78-80	1	1/19	1/19		1,003	3,046	21	1.21	2.50	1.65	5	1.23	2.0	45	24	32	280	201	2.1	49	24	35	289	203
28		AW-105	78-80	1	7/18	7/18		1,125	3,046	21	1.21	2.50	1.86	5	1.23	2.0	46	25	34	275	196	2.2	50	25	37	285	197
29		AZ-101	71	1	10/10	10/10	400	562	1,560	5	1.21	2.50	4.24	5	1.26	2.2	52	12	18	390	276	2.4	56	12	20	401	277
30		**BNFL**		1	9/10	9/10	400	0	6,275	40	1.21	2.50	1.27	5	1.23	1.9	43	40	44	220	188	2.1	47	40	46	229	190
31	AN-105	AN-102	80-81	1	3/10	3/10		329	626	0	1.21	2.50	0.24	5	1.21	1.5	34	2	3	606	405	1.6	37	2	3	617	406
32		**BNFL**		3	8/12	5/17		452	7,028	40	1.21	2.50	1.26	5	1.23	1.9	43	44	50	201	164	2.0	47	44	53	209	166
33	AN-106	AW-102	78-80	6	11/04	1/06		1,242	3,389	21	1.21	2.50	**0.00**	5	1.21	0.3	7	12	12	264	188	0.1	3	11	11	273	189
34		**BNFL**		7	12/18	3/19		442	7,028	40	1.21	2.50	4.83	5	1.27	2.3	52	55	66	196	161	2.5	57	55	70	204	163
35	AN-107	**BNFL**		1	7/11	7/11		557	7,028	40	1.21	2.50	0.34	5	1.21	1.5	36	37	42	200	162	1.7	39	37	43	208	164
36	AP-101	**BNFL**		2	4/06	12/16	400	419	5,370	28	1.21	2.50	1.14	5	1.22	1.8	43	32	37	232	187	2.0	46	32	39	240	189
37	AP-102	**BNFL**		9	7/18	12/18	400	431	5,370	28	1.21	2.50	0.23	5	1.21	1.4	33	25	28	233	188	1.6	36	25	30	242	190
38	AP-104	AP-107	83-86	1	1/13	1/13	400	737	421	0	1.21	2.50	**0.00**	5	1.21	0.3	7	0	0	550	323	0.1	3	0	0	561	323
39		**BNFL**		3	1/13	10/17	400	314	5,370	28	1.21	2.50	0.28	5	1.21	1.5	34	26	29	235	192	1.6	38	26	30	244	194
40	AP-105	AP-104	83-86	1	9/15	9/15	400	616	421	0	1.21	2.50	0.12	5	1.21	1.3	30	2	3	581	347	1.4	33	2	4	592	348
41		**BNFL**		1	2/18	2/18	400	302	5,370	28	1.21	2.50	0.12	5	1.21	1.3	30	24	26	236	193	1.4	33	23	27	244	195
42	AP-106	AN-102	80-81	1	10/13	10/13		745	3,184	-12	1.21	2.50	**0.00**	5	1.21	0.3	7	-6	-6	294	218	0.1	3	-6	-6	303	220
43		**BNFL**		1	8/16	8/16	400	340	5,370	28	1.21	2.50	**0.00**	5	1.21	0.3	7	15	15	235	191	0.1	3	15	15	244	194
44	AP-107	AW-102	78-80	16	8/00	7/18		1,223	421	9	1.21	2.50	**0.00**	5	1.21	0.3	7	5	5	456	258	0.1	3	5	5	466	259
45	AP-108	**BNFL**		1	7/18	7/18	400	443	5,370	28	1.21	2.50	**0.00**	5	1.21	0.3	7	15	15	233	187	0.1	3	15	15	242	190
46	AW-101	AN-105	80-81	1	8/12	8/12		1,446	3,799	-21	1.21	2.50	0.19	5	1.21	1.4	32	-2	3	254	180	1.5	35	-2	5	263	182
47		**BNFL**		9	3/15	8/19		994	5,780	19	1.21	2.50	0.60	5	1.22	1.7	39	27	33	215	166	1.8	42	26	36	224	168
48	AW-103	AW-104	78-80	1	10/15	11/15		2,015	1,241	0	1.21	2.50	5.99	5	1.29	2.3	54	15	34	310	187	2.6	59	15	40	320	188
49		AY-102	68-70	1	12/13	12/13		1,012	3,320	-10	1.21	2.50	5.99	5	1.29	2.3	54	15	27	269	196	2.6	59	15	31	279	198
50		**BNFL**		8	8/19	10/19		1,012	5,780	19	1.21	2.50	3.13	5	1.25	2.1	49	37	49	212	163	2.3	54	37	53	220	165
51	AW-104	AP-104	83-86	1	1/13	1/13		1,317	831	-9	1.21	2.50	0.29	5	1.21	1.5	35	0	4	401	240	1.6	38	0	6	411	241
52		AW-102	78-80	3	6/01	1/02		203	421	0	1.21	2.50	**0.00**	5	1.21	0.3	7	0	0	755	507	0.1	3	0	0	766	509
53		**BNFL**		6	4/18	1/19		1,003	5,780	19	1.21	2.50	2.46	5	1.24	2.1	48	35	46	213	164	2.3	52	35	50	221	166
54	AW-105	**BNFL**		7	1/18	7/18		1,125	5,780	19	1.21	2.50	2.40	5	1.24	2.1	48	35	47	211	161	2.3	52	35	51	219	163
55	AW-106	AP-105	83-86	2	10/04	6/05		1,416	831	-9	1.21	2.50	**0.00**	5	1.21	0.3	7	-4	-4	393	233	0.1	3	-5	-5	403	234
56		AP-106	83-86	2	4/01	1/02		1,454	831	-9	1.21	2.50	**0.00**	5	1.21	0.3	7	-4	-4	389	231	0.1	3	-5	-5	399	231
57		AP-108	83-86	1	3/09	3/09		1,557	831	-9	1.21	2.50	**0.00**	5	1.21	0.3	7	-4	-4	380	224	0.1	3	-5	-5	390	225
58		AW-102	78-80	13	12/01	7/18		314	421	0	1.21	2.50	**0.00**	5	1.21	0.3	7	0	0	694	444	0.1	3	0	0	706	445
59		AW-103	78-80	1	10/04	10/04		2,126	1,241	0	1.21	2.50	**0.00**	5	1.21	0.3	7	0	1	316	189	0.1	3	0	0	326	190
60		AW-104	78-80	2	1/02	8/02		341	421	0	1.21	2.50	**0.00**	5	1.21	0.3	7	0	0	681	432	0.1	3	0	0	693	433
61		AW-105	78-80	1	6/05	6/05		2,239	1,241	0	1.21	2.50	**0.00**	5	1.21	0.3	7	0	1	311	185	0.1	3	0	0	320	186
62	AY-101	**BNFL**		12	1/11	10/13	400	0	6,924	30	1.21	2.50	9.68	5	1.33	2.5	57	56	64	199	171	2.7	63	56	68	208	174
63	AY-102	AN-103	80-81	1	11/19	11/19		376	1,733	-11	1.21	2.50	1.31	5	1.23	1.9	44	0	3	403	299	2.1	47	0	5	413	301
64		AN-106	80-81	2	5/19	11/19		142	1,938	-11	1.21	2.50	1.33	5	1.23	1.9	44	0	2	406	324	2.1	48	0	3	416	326
65		AP-102	83-86	1	12/18	12/18	400	431	2,910	2	1.21	2.50	1.96	5	1.24	2.0	46	12	17	313	241	2.2	50	12	19	323	243
66		**BNFL**		16	1/09	2/18	400	0	6,549	30	1.21	2.50	9.18	5	1.33	2.5	57	53	60	206	177	2.7	62	53	64	215	180
67	AZ-101	**BNFL**		10	10/06	8/15	400	0	6,171	36	1.21	2.50	4.11	5	1.26	2.2	51	46	51	218	187	2.4	56	46	54	227	189
68	AZ-102	**BNFL**		6	7/07	3/08	400	0	6,556	36	1.21	2.50	2.65	5	1.24	2.1	48	44	49	214	183	2.3	53	44	52	222	185
69	BNFL internal equivalent pipe length and elevation								884	45	included in BNFL routes							Exceeds 275 lbf/in²					Exceeds 400 lbf/in²				

Group 2 Properties; Temperature = 10 °C and 60 °C (Critical $(\kappa_{cv} = 1.30, \kappa_f = 1)$)

Row	Liquid ρ_L Density (kg/L) (AB)	Solids ρ_s Density (kg/L) (AC)	C_s Volume (%) times 2.0 (AD)	d_p Median Dia. (µm) (AE)	ρ_m Bulk Density (kg/L) (AF)	10 °C Velocity (ft/s) (AG)	10 °C Flow Rate (gpm) (AH)	10 °C Total Pressure Drop (lbf/in²) New (AI)	10 °C Total Pressure Drop EOL (AJ)	10 °C Flow Rate at a Pipe Design Pressure of 400 lbf/in² (gpm) New (AK)	10 °C Flow Rate at 400 lbf/in² EOL (AL)	60 °C Velocity (ft/s) (AM)	60 °C Flow Rate (gpm) (AN)	60 °C Total Pressure Drop New (AO)	60 °C Total Pressure Drop EOL (AP)	60 °C Flow Rate at 400 lbf/in² New (AQ)	60 °C Flow Rate at 400 lbf/in² EOL (AR)
6	1.46	3.00	**0.00**	10	1.46	1.0	22	2	2	492	333	0.4	10	0	0	513	336
7	1.46	3.00	**0.00**	10	1.46	1.0	22	12	13	275	227	0.4	10	9	9	292	232
8	1.46	3.00	**0.00**	10	1.46	1.0	22	12	13	270	218	0.4	10	9	9	286	223
9	1.46	3.00	0.67	10	1.47	1.7	39	51	54	179	161	1.8	42	50	54	192	167
10	1.46	3.00	0.08	10	1.46	1.2	28	17	19	238	186	1.3	31	16	19	254	190
11	1.46	3.00	1.09	10	1.48	1.8	42	59	64	167	145	2.0	46	57	64	180	150
12	1.46	3.00	0.31	10	1.46	1.5	35	2	3	626	427	1.6	38	2	3	650	431
13	1.46	3.00	1.10	10	1.48	1.8	42	59	64	167	145	2.0	46	57	64	180	151
14	1.46	3.00	0.67	10	1.47	1.7	39	5	8	462	306	1.8	42	4	8	484	309
15	1.46	3.00	0.79	10	1.47	1.8	40	4	7	490	332	1.9	44	4	7	512	335
16	1.46	3.00	1.30	10	1.48	1.9	44	5	8	495	339	2.0	47	5	8	517	342
17	1.46	3.00	6.34	10	1.56	2.4	54	6	10	548	361	2.5	59	6	11	572	364
18	1.46	3.00	6.73	10	1.56	2.4	55	6	10	550	363	2.6	59	6	11	575	367
19	1.46	3.00	2.20	10	1.49	2.0	47	5	9	528	338	2.2	51	5	9	550	341
20	1.46	3.00	4.36	10	1.53	2.2	52	29	34	268	217	2.4	56	28	35	285	222
21	1.46	3.00	6.74	10	1.56	2.4	55	32	39	263	213	2.6	59	31	40	280	218
22	1.46	3.00	6.34	10	1.56	2.4	54	31	36	269	222	2.5	59	29	37	286	228
23	1.46	3.00	2.69	10	1.50	2.1	48	26	31	271	218	2.3	52	25	32	287	223
24	1.46	3.00	2.48	10	1.50	2.1	48	26	30	270	218	2.2	52	25	31	287	222
25	1.46	3.00	0.84	10	1.47	1.8	41	31	37	234	179	1.9	44	29	38	249	183
26	1.46	3.00	0.84	10	1.47	1.8	41	31	37	234	178	1.9	44	30	38	249	182
27	1.46	3.00	2.20	10	1.49	2.0	47	36	45	232	177	2.2	51	35	46	247	181
28	1.46	3.00	2.48	10	1.50	2.1	48	38	47	227	172	2.2	52	36	49	243	176
29	1.46	3.00	5.65	10	1.55	2.3	54	19	25	326	243	2.5	58	18	27	345	248
30	1.46	3.00	1.70	10	1.49	2.0	45	58	62	180	161	2.1	49	56	62	193	167
31	1.46	3.00	0.32	10	1.46	1.5	35	3	4	521	364	1.6	38	3	5	543	367
32	1.46	3.00	1.68	10	1.49	2.0	45	65	71	163	141	2.1	49	62	72	176	146
33	1.46	3.00	**0.00**	10	1.46	1.0	22	20	22	219	166	0.4	10	15	15	233	169
34	1.46	3.00	6.44	10	1.56	2.4	55	84	95	157		2.6	59	81	96	170	142
35	1.46	3.00	0.46	10	1.47	1.6	37	53	58	163	140	1.7	40	51	58	176	145
36	1.46	3.00	1.52	10	1.48	1.9	45	47	52	190	162	2.1	48	45	53	204	168
37	1.46	3.00	0.30	10	1.46	1.5	35	37	40	192	163	1.6	38	35	40	205	168
38	1.46	3.00	**0.00**	10	1.46	1.0	22	2	3	471	291	0.4	10	0	1	492	293
39	1.46	3.00	0.37	10	1.47	1.6	36	37	40	194	167	1.7	39	36	40	207	172
40	1.46	3.00	0.17	10	1.46	1.4	32	3	5	499	313	1.5	34	3	5	521	315
41	1.46	3.00	0.17	10	1.46	1.4	32	33	36	194	168	1.5	34	32	35	208	173
42	1.46	3.00	**0.00**	10	1.46	1.0	22	-2	0	246	193	0.4	10	-6	-6	262	198
43	1.46	3.00	**0.00**	10	1.46	1.0	22	26	27	194	167	0.4	10	19	20	207	172
44	1.46	3.00	**0.00**	10	1.46	1.0	22	8	10	387	233	0.4	10	6	6	407	234
45	1.46	3.00	**0.00**	10	1.46	1.0	22	27	28	192	163	0.4	10	19	20	206	168
46	1.46	3.00	0.25	10	1.46	1.5	34	3	9	212	160	1.6	37	1	9	226	163
47	1.46	3.00	0.80	10	1.47	1.8	40	41	48	177	145	1.9	44	39	49	190	149
48	1.46	3.00	7.98	10	1.58	2.4	56	27	49	255	166	2.6	60	25	53	272	168
49	1.46	3.00	7.98	10	1.58	2.4	56	29	42	220	171	2.6	60	27	45	236	175
50	1.46	3.00	4.17	10	1.52	2.2	52	58	71	172	141	2.4	56	55	73	185	146
51	1.46	3.00	0.39	10	1.47	1.6	36	2	7	340	216	1.7	39	1	8	358	218
52	1.46	3.00	**0.00**	10	1.46	1.0	22	1	1	654	456	0.4	10	0	0	678	460
53	1.46	3.00	3.28	10	1.51	2.2	50	55	67	173	142	2.3	54	52	68	186	147
54	1.46	3.00	3.20	10	1.51	2.2	50	55	68	172		2.3	54	53	70	185	144
55	1.46	3.00	**0.00**	10	1.46	1.0	22	-2	0	332	210	0.4	10	-5	-5	351	212
56	1.46	3.00	**0.00**	10	1.46	1.0	22	-2	0	329	208	0.4	10	-5	-5	348	210
57	1.46	3.00	**0.00**	10	1.46	1.0	22	-2	0	322	202	0.4	10	-5	-5	340	204
58	1.46	3.00	**0.00**	10	1.46	1.0	22	1	2	600	400	0.4	10	0	0	623	403
59	1.46	3.00	**0.00**	10	1.46	1.0	22	5	8	265	170	0.4	10	1	1	281	172
60	1.46	3.00	**0.00**	10	1.46	1.0	22	1	2	588	389	0.4	10	0	0	612	392
61	1.46	3.00	**0.00**	10	1.46	1.0	22	5	8	260	166	0.4	10	1	2	276	168
62	1.46	3.00	12.90	10	1.66	2.6	59	89	96	157	143	2.8	64	84	96	170	150
63	1.46	3.00	1.75	10	1.49	2.0	45	4	7	341	265	2.1	49	3	8	359	270
64	1.46	3.00	1.77	10	1.49	2.0	46	4	6	343	286	2.1	49	3	6	362	292
65	1.46	3.00	2.61	10	1.50	2.1	48	21	25	261	212	2.3	52	19	26	277	217
66	1.46	3.00	12.24	10	1.65	2.6	59	84	91	163	148	2.8	63	80	90	176	155
67	1.46	3.00	5.48	10	1.54	2.3	53	69	74	177	159	2.5	58	66	74	190	166
68	1.46	3.00	3.53	10	1.51	2.2	50	66	70	173	156	2.4	54	63	70	187	162
69	Supernate liquid only transfer										Less than 140 gpm						

Notes (AS):

New = new or like new pipeline with maximum expected pipe roughness of 2 mils (0.002 inches).

EOL = pipeline at end of life (50 years for carbon steel line, 40 years for stainless steel line) with pipe roughness due to corrosion estimated at 150 mils for carbon steel and 10 mils for stainless steel.

Design Pressure = All stainless steel pipelines have a design pressure of 400 lbf/in². The design pressure of carbon steel pipelines are either 275 or 400 lbf/in² as indicated. The predicted flow rate at design pressure given in this table assumes that all pipelines are or can be qualified to the higher 400 lbf/in² design pressure.

Table D-19. 3S6 Case 1d.

CASE 3S6 Transfer List - Tank-to-Tank — Case 1d. Critical velocity by Oroskar and Turian (1980) empirical correlation (β_{cv} = 1.2). Pressure drop by Wasp et al. (1977) method with lognormal particle size distribution.

Columns A–U: Transfer; 3-in. Schedule-40 Pipe (3.068 in. inside dia.); Group 1 Properties (Liquid, Solids); Temperature = 10 °C, Critical (κ_{cv} = 1.30, κ_f = 1)

Row	A From Tank	B To Tank	C Tank Farm Built (Yr)	D #	E Transfer Dates (M/Yr) Start	F End	G Design Pressure (lbf/in²)*	H Carbon Steel Length (ft)	I Stainless Steel Length (ft)	J Total Change in Elevation (ft)	K ρ_L Density (kg/L)	L ρ_s Density (kg/L)	M C_s Volume (%) times 1.5	N d_p Median Dia. (μm)	O ρ_m Bulk Density (kg/L)	P Velocity (ft/s)	Q Flow Rate (gpm)	R Total Pressure Drop (lbf/in²) New	S Total Pressure Drop (lbf/in²) EOL	T Flow Rate at a Pipe Design Pressure of 400 lbf/in² (gpm) New	U Flow Rate at Design Pressure (gpm) EOL
6	AN-101	AN-106	80-81	1	12/00	12/00		442	626	0	1.10	2.50	0.00	5	1.10	0.2	6	0	0	605	389
7		AP-103	83-86	1	7/03	7/03	400	306	2,774	12	1.10	2.50	0.00	5	1.10	0.2	6	6	6	348	271
8		AP-107	83-86	1	6/05	6/05	400	423	2,774	12	1.10	2.50	0.00	5	1.10	0.2	6	6	6	341	260
9		BNFL		7	2/11	12/19	400	0	6,413	40	1.10	2.50	0.50	5	1.11	1.8	42	35	39	233	197
10	AN-102	AP-107	83-86	1	3/10	3/10		828	3,184	12	1.10	2.50	0.06	5	1.10	1.3	30	11	14	303	221
11		BNFL		5	12/08	4/16		405	6,823	40	1.10	2.50	0.82	5	1.11	2.0	45	40	47	218	177
12	AN-103	AN-102	80-81	1	4/12	4/12		253	421	0	1.10	2.50	0.23	5	1.10	1.6	38	1	2	764	498
13		BNFL		9	4/14	6/19		376	6,823	40	1.10	2.50	0.82	5	1.11	2.0	46	40	46	218	178
14	AN-104	AN-101	80-81	3	6/05	2/16		562	626	0	1.10	2.50	0.50	5	1.11	1.8	42	3	6	571	357
15		AN-102	80-81	2	4/16	6/16		439	626	0	1.10	2.50	0.59	5	1.11	1.9	43	3	5	603	388
16		AN-103	80-81	2	4/14	8/14		410	626	0	1.10	2.50	0.98	5	1.11	2.0	47	3	6	610	396
17		AN-105	80-81	5	10/14	11/17		384	421	0	1.10	2.50	4.76	5	1.17	2.5	59	4	8	677	422
18		AN-106	80-81	2	8/13	10/13		374	421	0	1.10	2.50	5.05	5	1.17	2.6	59	4	8	680	425
19		AN-107	80-81	1	3/19	3/19		489	421	0	1.10	2.50	1.65	5	1.12	2.2	50	3	7	649	394
20		AP-101	83-86	4	10/13	2/17	400	419	2,636	12	1.10	2.50	3.27	5	1.15	2.4	56	19	25	341	260
21		AP-102	83-86	1	8/13	8/13	400	431	2,636	12	1.10	2.50	5.05	5	1.17	2.6	59	21	29	337	256
22		AP-104	83-86	1	11/17	11/17	400	314	2,636	12	1.10	2.50	4.75	5	1.17	2.5	59	20	26	344	267
23		AP-106	83-86	2	8/16	12/16	400	430	2,636	12	1.10	2.50	2.02	5	1.13	2.3	52	17	23	344	261
24		AP-108	83-86	1	7/18	7/18	400	443	2,636	12	1.10	2.50	1.86	5	1.13	2.2	51	17	22	343	260
25		AW-101	78-80	2	3/15	3/15		994	3,046	21	1.10	2.50	0.63	5	1.11	1.9	44	21	27	299	214
26		AW-103	78-80	2	11/15	11/15		1,012	3,046	21	1.10	2.50	0.63	5	1.11	1.9	44	21	28	299	213
27		AW-104	78-80	1	1/19	1/19		1,003	3,046	21	1.10	2.50	1.65	5	1.12	2.2	50	24	34	297	212
28		AW-105	78-80	1	7/18	7/18		1,125	3,046	21	1.10	2.50	1.86	5	1.13	2.2	51	25	36	292	206
29		AZ-101	71	1	10/10	10/10	400	562	1,560	5	1.10	2.50	4.24	5	1.16	2.5	58	12	19	411	289
30		BNFL		1	9/10	9/10	400	0	6,275	40	1.10	2.50	1.27	5	1.12	2.1	49	40	44	234	198
31	AN-105	AN-102	80-81	1	3/10	3/10		329	626	0	1.10	2.50	0.24	5	1.10	1.6	38	2	3	639	425
32		BNFL		3	8/12	5/17		452	7,028	40	1.10	2.50	1.26	5	1.12	2.1	49	44	52	213	173
33	AN-106	AW-102	78-80	6	11/04	1/06		1,242	3,389	21	1.10	2.50	0.00	5	1.10	0.2	6	10	10	280	198
34		BNFL		7	12/18	3/19		442	7,028	40	1.10	2.50	4.83	5	1.17	2.6	59	56	69	208	169
35	AN-107	BNFL		1	7/11	7/11		557	7,028	40	1.10	2.50	0.34	5	1.10	1.7	40	36	42	213	171
36	AP-101	BNFL		2	4/06	12/16	400	419	5,370	28	1.10	2.50	1.14	5	1.12	2.1	48	32	38	246	197
37	AP-102	BNFL		9	7/18	12/18	400	431	5,370	28	1.10	2.50	0.23	5	1.10	1.6	37	25	29	247	198
38	AP-104	AP-107	83-86	1	1/13	1/13	400	737	421	0	1.10	2.50	0.00	5	1.10	0.2	6	0	0	580	339
39		BNFL		3	1/13	10/17	400	314	5,370	28	1.10	2.50	0.28	5	1.10	1.7	39	25	29	250	203
40	AP-105	AP-104	83-86	1	9/15	9/15	400	616	421	0	1.10	2.50	0.12	5	1.10	1.5	34	2	4	613	364
41		BNFL		1	2/18	2/18	400	302	5,370	28	1.10	2.50	0.12	5	1.10	1.5	34	23	26	251	203
42	AP-106	AN-102	80-81	1	10/13	10/13		745	3,184	-12	1.10	2.50	0.00	5	1.10	0.2	6	-5	-5	311	229
43		BNFL		1	8/16	8/16	400	340	5,370	28	1.10	2.50	0.00	5	1.10	0.2	6	14	14	250	202
44	AP-107	AW-102	78-80	16	8/00	7/18		1,223	421	9	1.10	2.50	0.00	5	1.10	0.2	6	4	4	482	271
45	AP-108	BNFL		1	7/18	7/18	400	443	5,370	28	1.10	2.50	0.00	5	1.10	0.2	6	14	14	248	198
46	AW-101	AN-105	80-81	1	8/12	8/12		1,446	3,799	-21	1.10	2.50	0.19	5	1.10	1.6	36	0	6	269	189
47		BNFL		9	3/15	8/19		994	5,780	19	1.10	2.50	0.60	5	1.11	1.9	43	27	35	229	175
48	AW-103	AW-104	78-80	1	10/15	11/15		2,015	1,241	0	1.10	2.50	5.99	5	1.18	2.6	61	17	39	327	196
49		AY-102	68-70	1	12/13	12/13		1,012	3,320	-10	1.10	2.50	5.99	5	1.18	2.6	61	17	32	284	205
50		BNFL		8	8/19	10/19		1,012	5,780	19	1.10	2.50	3.13	5	1.14	2.4	55	38	52	224	171
51	AW-104	AP-104	83-86	1	1/13	1/13		1,317	831	-9	1.10	2.50	0.29	5	1.10	1.7	39	0	6	424	252
52		AW-102	78-80	3	6/01	1/02		203	421	0	1.10	2.50	0.00	5	1.10	0.2	6	0	0	796	532
53		BNFL		6	4/18	1/19		1,003	5,780	19	1.10	2.50	2.46	5	1.13	2.3	53	36	49	226	172
54	AW-105	BNFL		7	1/18	7/18		1,125	5,780	19	1.10	2.50	2.40	5	1.13	2.3	53	36	50	224	169
55	AW-106	AP-105	83-86	2	10/04	6/05		1,416	831	-9	1.10	2.50	0.00	5	1.10	0.2	6	-4	-4	415	245
56		AP-106	83-86	2	4/01	1/02		1,454	831	-9	1.10	2.50	0.00	5	1.10	0.2	6	-4	-4	411	242
57		AP-108	83-86	1	3/09	3/09		1,557	831	-9	1.10	2.50	0.00	5	1.10	0.2	6	-4	-4	402	235
58		AW-102	78-80	13	12/01	7/18		314	421	0	1.10	2.50	0.00	5	1.10	0.2	6	0	0	732	466
59		AW-103	78-80	1	10/04	10/04		2,126	1,241	0	1.10	2.50	0.00	5	1.10	0.2	6	0	0	335	199
60		AW-104	78-80	2	1/02	8/02		341	421	0	1.10	2.50	0.00	5	1.10	0.2	6	0	0	718	453
61		AW-105	78-80	1	6/05	6/05		2,239	1,241	0	1.10	2.50	0.00	5	1.10	0.2	6	0	0	329	194
62	AY-101	BNFL		12	1/11	10/13	400	0	6,924	30	1.10	2.50	9.68	5	1.24	2.8	64	58	68	210	179
63	AY-102	AN-103	80-81	1	11/19	11/19		376	1,733	-11	1.10	2.50	1.31	5	1.12	2.1	49	1	5	425	313
64		AN-106	80-81	2	5/19	11/19		142	1,938	-11	1.10	2.50	1.33	5	1.12	2.1	49	1	4	428	340
65		AP-102	83-86	1	12/18	12/18	400	431	2,910	2	1.10	2.50	1.96	5	1.13	2.2	52	13	19	331	253
66		BNFL		16	1/09	2/18	400	0	6,549	30	1.10	2.50	9.18	5	1.23	2.8	64	55	64	217	185
67	AZ-101	BNFL		10	10/06	8/15	400	0	6,171	36	1.10	2.50	4.11	5	1.16	2.5	58	46	53	232	196
68	AZ-102	BNFL		6	7/07	3/08	400	0	6,556	36	1.10	2.50	2.65	5	1.14	2.3	54	44	50	227	192
69	BNFL internal equivalent pipe length and elevation								884	45	included in BNFL routes						Exceeds 275 lbf/in²				

Columns V–AR: Temperature = 60 °C (Group 1); Group 2 Properties; Temperature = 10 °C and 60 °C (Group 2). Critical (κ_{cv} = 1.30, κ_f = 1)

Row	V Velocity (ft/s)	W Flow Rate (gpm)	X Total Pressure Drop (lbf/in²) New	Y EOL	Z Flow Rate at a Pipe Design Pressure of 400 lbf/in² (gpm) New	AA EOL	AB ρ_L Density (kg/L)	AC ρ_s Density (kg/L)	AD C_s Volume (%) times 2.0	AE d_p Median Dia. (μm)	AF ρ_m Bulk Density (kg/L)	AG Velocity (ft/s)	AH Flow Rate (gpm)	AI Total Pressure Drop (lbf/in²) New	AJ EOL	AK Flow Rate at a Pipe Design Pressure of 400 lbf/in² (gpm) New	AL EOL	AM Velocity (ft/s)	AN Flow Rate (gpm)	AO Total Pressure Drop (lbf/in²) New	AP EOL	AQ Flow Rate at a Pipe Design Pressure of 400 lbf/in² (gpm) New	AR EOL
6	0.1	2	0	0	614	390	1.20	3.00	0.00	10	1.20	0.3	7	0	0	576	372	0.1	2	0	0	587	373
7	0.1	2	6	6	357	273	1.20	3.00	0.00	10	1.20	0.3	7	7	7	330	259	0.1	2	6	6	340	261
8	0.1	2	6	6	350	262	1.20	3.00	0.00	10	1.20	0.3	7	7	7	324	248	0.1	2	6	6	333	250
9	2.0	46	35	41	240	199	1.20	3.00	0.67	10	1.21	2.3	53	49	55	219	187	2.5	58	49	58	228	190
10	1.4	33	11	15	312	223	1.20	3.00	0.08	10	1.20	1.7	38	16	20	288	211	1.8	42	16	22	297	213
11	2.2	50	40	50	225	179	1.20	3.00	1.09	10	1.22	2.5	57	57	68	205	168	2.7	63	57	74	213	170
12	1.8	41	1	3	774	500	1.20	3.00	0.31	10	1.21	2.1	47	2	4	727	476	2.2	52	2	5	739	478
13	2.2	50	40	49	226	180	1.20	3.00	1.10	10	1.22	2.5	57	57	68	206	169	2.7	63	57	74	214	171
14	2.0	46	3	7	580	358	1.20	3.00	0.67	10	1.21	2.3	53	5	10	542	341	2.5	58	5	12	553	342
15	2.1	47	3	6	613	389	1.20	3.00	0.79	10	1.21	2.4	55	5	9	573	370	2.6	60	5	10	584	372
16	2.2	51	3	7	620	397	1.20	3.00	1.30	10	1.22	2.6	59	5	10	579	377	2.8	64	5	12	590	378
17	2.8	64	4	9	688	423	1.20	3.00	6.34	10	1.31	3.2	74	7	14	634	397	3.5	80	7	16	646	399
18	2.8	65	4	9	691	426	1.20	3.00	6.73	10	1.32	3.2	74	7	14	636	400	3.5	81	7	17	648	401
19	2.4	55	3	8	659	395	1.20	3.00	2.20	10	1.24	2.8	64	5	12	614	375	3.0	69	6	14	626	376
20	2.6	61	19	28	350	262	1.20	3.00	4.36	10	1.28	3.0	70	30	41	320	245	3.3	77	30	45	330	247
21	2.8	65	22	32	346	258	1.20	3.00	6.74	10	1.32	3.2	74	33	47	313	240	3.5	81	34	52	323	242
22	2.8	64	21	29	353	269	1.20	3.00	6.34	10	1.31	3.2	74	32	43	321	251	3.5	80	33	47	331	253
23	2.5	57	18	25	353	263	1.20	3.00	2.69	10	1.25	2.8	66	26	36	324	247	3.1	71	27	40	333	249
24	2.4	56	17	25	352	262	1.20	3.00	2.48	10	1.24	2.8	65	26	35	324	246	3.1	71	26	39	333	248
25	2.1	48	21	30	308	215	1.20	3.00	0.84	10	1.22	2.4	55	29	41	283	203	2.6	60	30	45	292	205
26	2.1	48	21	30	307	214	1.20	3.00	0.84	10	1.22	2.4	55	30	41	282	202	2.6	60	30	46	291	204
27	2.4	55	25	37	305	213	1.20	3.00	2.20	10	1.24	2.8	64	36	52	279	201	3.0	69	36	58	289	202
28	2.4	56	26	40	300	207	1.20	3.00	2.48	10	1.24	2.8	65	37	56	274	195	3.1	71	38	62	284	196
29	2.7	63	13	22	421	290	1.20	3.00	5.65	10	1.30	3.2	73	20	32	385	272	3.4	79	21	37	395	273
30	2.3	53	40	47	242	200	1.20	3.00	1.70	10	1.23	2.7	61	57	65	220	187	2.9	67	57	70	228	190
31	1.8	41	2	4	649	426	1.20	3.00	0.32	10	1.21	2.1	48	3	6	608	406	2.3	52	3	7	619	408
32	2.3	53	44	56	221	175	1.20	3.00	1.68	10	1.23	2.7	61	63	77	200	164	2.9	67	64	84	209	166
33	0.1	2	10	10	288	199	1.20	3.00	0.00	10	1.20	0.3	7	11	12	265	189	0.1	2	11	11	274	190
34	2.8	64	57	75	216	171	1.20	3.00	6.44	10	1.32	3.2	74	86	109	193	158	3.5	81	88	120	201	161
35	1.9	44	36	44	221	173	1.20	3.00	0.46	10	1.21	2.2	50	50	60	201	163	2.4	55	50	64	209	165
36	2.3	52	32	41	254	199	1.20	3.00	1.52	10	1.23	2.6	60	46	57	232	187	2.9	66	47	63	240	189
37	1.8	41	25	30	255	200	1.20	3.00	0.30	10	1.21	2.0	47	34	41	234	188	2.2	51	35	44	243	191
38	0.1	2	0	0	590	339	1.20	3.00	0.00	10	1.20	0.3	7	0	0	552	324	0.1	2	0	0	563	325
39	1.8	42	25	31	258	205	1.20	3.00	0.37	10	1.21	2.1	49	35	42	236	193	2.3	53	35	44	245	195
40	1.6	37	2	4	623	365	1.20	3.00	0.17	10	1.20	1.9	43	3	6	584	348	2.0	47	3	7	595	349
41	1.6	37	23	27	258	205	1.20	3.00	0.17	10	1.20	1.9	43	31	36	237	194	2.0	47	31	38	246	196
42	0.1	2	-6	-6	320	231	1.20	3.00	0.00	10	1.20	0.3	7	-6	-6	296	219	0.1	2	-6	-6	305	221
43	0.1	2	13	13	258	204	1.20	3.00	0.00	10	1.20	0.3	7	15	15	237	192	0.1	2	15	15	245	195
44	0.1	2	4	4	491	272	1.20	3.00	0.00	10	1.20	0.3	7	5	5	458	259	0.1	2	5	5	469	260
45	0.1	2	13	13	256	200	1.20	3.00	0.00	10	1.20	0.3	7	15	15	234	188	0.1	2	15	15	243	191
46	1.7	40	0	8	277	191	1.20	3.00	0.25	10	1.20	2.0	46	6	17	255	181	2.2	50	6	21	264	182
47	2.1	47	27	38	237	176	1.20	3.00	0.80	10	1.21	2.4	55	40	55	216	166	2.6	60	41	61	224	168
48	2.9	66	17	46	336	196	1.20	3.00	7.98	10	1.34	3.3	76	30	70	304	183	3.6	83	31	81	314	184
49	2.9	66	18	37	292	206	1.20	3.00	7.98	10	1.34	3.3	76	34	60	263	192	3.6	83	35	69	273	194
50	2.6	61	39	58	232	173	1.20	3.00	4.17	10	1.28	3.0	70	61	86	210	162	3.3	76	62	96	218	164
51	1.8	42	0	7	433	252	1.20	3.00	0.39	10	1.21	2.1	49	3	13	403	241	2.3	54	3	16	413	241
52	0.1	2	0	0	806	534	1.20	3.00	0.00	10	1.20	0.3	7	0	0	758	509	0.1	2	0	0	770	511
53	2.5	58	37	54	234	174	1.20	3.00	3.28	10	1.26	2.9	67	57	80	212	163	3.2	74	58	89	220	165
54	2.5	58	37	56	231	171	1.20	3.00	3.20	10	1.26	2.9	67	57	82	210	160	3.2	73	58	92	218	162
55	0.1	2	-4	-4	424	245	1.20	3.00	0.00	10	1.20	0.3	7	-4	-4	395	234	0.1	2	-5	-5	405	235
56	0.1	2	-4	-4	420	243	1.20	3.00	0.00	10	1.20	0.3	7	-4	-4	391	232	0.1	2	-5	-5	401	232
57	0.1	2	-4	-4	411	236	1.20	3.00	0.00	10	1.20	0.3	7	-4	-4	382	225	0.1	2	-5	-5	392	226
58	0.1	2	0	0	742	467	1.20	3.00	0.00	10	1.20	0.3	7	0	0	697	446	0.1	2	0	0	709	447
59	0.1	2	0	0	343	199	1.20	3.00	0.00	10	1.20	0.3	7	0	1	318	190	0.1	2	0	0	327	191
60	0.1	2	0	0	729	454	1.20	3.00	0.00	10	1.20	0.3	7	0	0	685	434	0.1	2	0	0	696	435
61	0.1	2	0	0	338	195	1.20	3.00	0.00	10	1.20	0.3	7	0	1	313	186	0.1	2	0	0	322	187
62	3.0	70	59	74	219	182	1.20	3.00	12.90	10	1.43	3.5	80	94	113	191	165	3.8	87	96	123	201	168
63	2.3	53	2	7	435	315	1.20	3.00	1.75	10	1.23	2.7	62	6	12	403	298	2.9	67	6	15	413	300
64	2.3	53	2	5	438	342	1.20	3.00	1.77	10	1.23	2.7	62	6	10	406	323	2.9	67	6	12	416	326
65	2.5	57	13	21	340	255	1.20	3.00	2.61	10	1.25	2.8	65	22	32	312	240	3.1	71	23	36	322	242
66	3.0	70	56	70	226	188	1.20	3.00	12.24	10	1.42	3.5	80	88	106	198	171	3.8	87	90	116	207	174
67	2.7	63	47	58	240	199	1.20	3.00	5.48	10	1.30	3.1	72	70	82	215	184	3.4	79	71	90	224	187
68	2.6	59	45	54	235	195	1.20	3.00	3.53	10	1.26	3.0	68	66	77	212	181	3.2	74	67	83	221	184
69		Exceeds 400 lbf/in²									Supernate liquid only transfer						Less than 140 gpm						

Notes (column AS):

New = new or like new pipeline with maximum expected pipe roughness of 2 mils (0.002 inches).

EOL = pipeline at end of life (50 years for carbon steel line, 40 years for stainless steel line) with pipe roughness due to corrosion estimated at 150 mils for carbon steel and 10 mils for stainless steel.

*Design Pressure = All stainless steel pipelines have a design pressure of 400 lbf/in². The design pressure of carbon steel pipelines are either 275 or 400 lbf/in² as indicated. The predicted flow rate at design pressure given in this table assumes that all pipelines are or can be qualified to the higher 400 lbf/in² design pressure.

Table D-20. 3S6 Case 2a.

CASE 3S6 Transfer List - Tank-to-Tank — **Case 2a** — Critical velocity by Oroskar and Turian (1980) empirical correlation (β_{cv} = 1.2). Pressure drop by Wasp et al. (1977) method with lognormal particle size distribution.

Column groups: Transfer (A–B); Tank Farm Built (C); Transfer (D–F); 3-in. Schedule-40 Pipe (3.068 in. inside dia.) (G–I); Total Change in Elevation (J); Group 1 Properties: Liquid (K), Solids (L–N), Bulk (O); Group 1, Temperature = 10 °C: Critical (κ_{cv} = 1.30, κ_f = 1) (P–Q), Total Pressure Drop (R–S), Flow Rate at a Pipe Design Pressure of 400 lbf/in² (T–U); Group 1, Temperature = 60 °C: Critical (κ_{cv} = 1.30, κ_f = 1) (V–W), Total Pressure Drop (X–Y), Flow Rate at a Pipe Design Pressure of 400 lbf/in² (Z–AA); Group 2 Properties: Liquid (AB), Solids (AC–AE), Bulk (AF); Group 2, Temperature = 10 °C: Critical (AG–AH), Total Pressure Drop (AI–AJ), Flow Rate at a Pipe Design Pressure of 400 lbf/in² (AK–AL); Group 2, Temperature = 60 °C: Critical (AM–AN), Total Pressure Drop (AO–AP), Flow Rate at a Pipe Design Pressure of 400 lbf/in² (AQ–AR); Notes (AS).

Row	A From Tank	B To Tank	C Tank Farm Built (Yr)	D #	E Dates (M/Yr) Start	F Dates (M/Yr) End	G Design Pressure (lbf/in²)*	H Carbon Steel Length (ft)	I Stainless Steel Length (ft)	J Total Change in Elevation (ft)	K ρ_L Density (kg/L)	L ρ_s Density (kg/L)	M C_s Volume (%)	N d_p Median Dia. (μm)	O ρ_m Bulk Density (kg/L)	P Velocity (ft/s)	Q Flow Rate (gpm)	R Total Pressure Drop (lbf/in²) New	S Total Pressure Drop (lbf/in²) EOL	T Flow Rate at 400 lbf/in² (gpm) New	U Flow Rate at 400 lbf/in² (gpm) EOL	V Velocity (ft/s)	W Flow Rate (gpm)	X Total Pressure Drop (lbf/in²) New	Y Total Pressure Drop (lbf/in²) EOL	Z Flow Rate at 400 lbf/in² (gpm) New	AA Flow Rate at 400 lbf/in² (gpm) EOL	AB ρ_L Density (kg/L)	AC ρ_s Density (kg/L)	AD C_s Volume (%)	AE d_p Median Dia. (μm)	AF ρ_m Bulk Density (kg/L)	AG Velocity (ft/s)	AH Flow Rate (gpm)	AI Total Pressure Drop (lbf/in²) New	AJ Total Pressure Drop (lbf/in²) EOL	AK Flow Rate at 400 lbf/in² (gpm) New	AL Flow Rate at 400 lbf/in² (gpm) EOL	AM Velocity (ft/s)	AN Flow Rate (gpm)	AO Total Pressure Drop (lbf/in²) New	AP Total Pressure Drop (lbf/in²) EOL	AQ Flow Rate at 400 lbf/in² (gpm) New	AR Flow Rate at 400 lbf/in² (gpm) EOL
6	AN-101	AN-106	80-81	1	12/00	12/00		442	626	0	1.21	2.50	15	40	1.40	3.7	85	13	25	525	343	4.0	93	13	29	540	345	1.46	3.00	30	100	1.92	4.0	92	29	45	397	285	4.3	99	27	49	428	291
7		AP-103	83-86	1	7/03	7/03	400	306	2,774	12	1.21	2.50	15	40	1.40	3.7	85	45	60	299	238	4.0	93	46	67	312	241	1.46	3.00	30	100	1.92	4.0	92	93	112	218	189	4.3	99	87	114	240	198
8		AP-107	83-86	1	6/05	6/05	400	423	2,774	12	1.21	2.50	15	40	1.40	3.7	85	46	64	294	228	4.0	93	47	72	306	232	1.46	3.00	30	100	1.92	4.0	92	96	118	214	182	4.3	99	90	121	235	191
9		BNFL		7	2/11	12/19	400	0	6,413	40	1.21	2.50	15	40	1.40	3.7	85	102	121	199	172	4.0	93	105	133	209	176	1.46	3.00	30	100	1.92	4.0	92	207	225			4.3	99	194	225	156	140
10	AN-102	AP-107	83-86	1	3/10	3/10		828	3,184	12	1.21	2.50	15	40	1.40	3.7	85	56	85	261	194	4.0	93	57	96	272	197	1.46	3.00	30	100	1.92	4.0	92	118	155	188	155	4.3	99	111	161	208	162
11		BNFL		5	12/08	4/16		405	6,823	40	1.21	2.50	15	40	1.40	3.7	85	112	142	186	155	4.0	93	115	157	197	158	1.46	3.00	30	100	1.92	4.0	92	229	262			4.3	99	215	264	146	
12	AN-103	AN-102	80-81	1	4/12	4/12		253	421	0	1.21	2.50	15	40	1.40	3.7	85	8	15	666	441	4.0	93	8	18	682	443	1.46	3.00	30	100	1.92	4.0	92	18	28	510	367	4.3	99	17	30	545	374
13		BNFL		9	4/14	6/19		376	6,823	40	1.21	2.50	15	40	1.40	3.7	85	111	141	187	156	4.0	93	114	156	197	159	1.46	3.00	30	100	1.92	4.0	92	228	260			4.3	99	214	262	147	
14	AN-104	AN-101	80-81	3	6/05	2/16		562	626	0	1.21	2.50	15	40	1.40	3.7	85	14	30	497	317	4.0	93	15	35	512	318	1.46	3.00	30	100	1.92	4.0	92	32	52	374	263	4.3	99	30	57	404	268
15		AN-102	80-81	2	4/16	6/16		439	626	0	1.21	2.50	15	40	1.40	3.7	85	13	25	526	344	4.0	93	13	29	541	346	1.46	3.00	30	100	1.92	4.0	92	29	45	398	285	4.3	99	27	48	428	291
16		AN-103	80-81	2	4/14	8/14		410	626	0	1.21	2.50	15	40	1.40	3.7	85	13	24	534	352	4.0	93	13	28	548	354	1.46	3.00	30	100	1.92	4.0	92	28	43	404	291	4.3	99	26	46	435	298
17		AN-105	80-81	5	10/14	11/17		384	421	0	1.21	2.50	15	40	1.40	3.7	85	10	20	608	384	4.0	93	10	23	623	386	1.46	3.00	30	100	1.92	4.0	92	22	36	463	320	4.3	99	20	39	497	326
18		AN-106	80-81	2	8/13	10/13		374	421	0	1.21	2.50	15	40	1.40	3.7	85	10	20	612	388	4.0	93	10	23	627	390	1.46	3.00	30	100	1.92	4.0	92	21	35	466	323	4.3	99	20	38	500	329
19		AN-107	80-81	1	3/19	3/19		489	421	0	1.21	2.50	15	40	1.40	3.7	85	11	24	571	352	4.0	93	11	28	586	354	1.46	3.00	30	100	1.92	4.0	92	25	42	433	294	4.3	99	23	46	465	299
20		AP-101	83-86	4	10/13	2/17	400	419	2,636	12	1.21	2.50	15	40	1.40	3.7	85	44	62	301	233	4.0	93	46	70	313	236	1.46	3.00	30	100	1.92	4.0	92	93	114	219	186	4.3	99	87	117	241	194
21		AP-102	83-86	1	8/13	8/13	400	431	2,636	12	1.21	2.50	15	40	1.40	3.7	85	45	63	300	232	4.0	93	46	70	312	235	1.46	3.00	30	100	1.92	4.0	92	93	115	219	185	4.3	99	87	118	240	194
22		AP-104	83-86	1	11/17	11/17	400	314	2,636	12	1.21	2.50	15	40	1.40	3.7	85	43	58	306	242	4.0	93	44	65	319	245	1.46	3.00	30	100	1.92	4.0	92	90	108	223	192	4.3	99	84	110	245	202
23		AP-106	83-86	2	8/16	12/16	400	430	2,636	12	1.21	2.50	15	40	1.40	3.7	85	44	63	300	232	4.0	93	46	70	313	235	1.46	3.00	30	100	1.92	4.0	92	93	115	219	185	4.3	99	87	118	240	194
24		AP-108	83-86	1	7/18	7/18	400	443	2,636	12	1.21	2.50	15	40	1.40	3.7	85	45	63	300	231	4.0	93	46	71	312	234	1.46	3.00	30	100	1.92	4.0	92	93	116	218	184	4.3	99	87	119	240	193
25		AW-101	78-80	2	3/15	3/15		994	3,046	21	1.21	2.50	15	40	1.40	3.7	85	62	94	258	188	4.0	93	63	107	269	191	1.46	3.00	30	100	1.92	4.0	92	127	168	186	150	4.3	99	119	176	205	157
26		AW-103	78-80	2	11/15	11/15		1,012	3,046	21	1.21	2.50	15	40	1.40	3.7	85	62	95	257	187	4.0	93	63	107	269	190	1.46	3.00	30	100	1.92	4.0	92	127	169	185	150	4.3	99	119	177	205	156
27		AW-104	78-80	1	1/19	1/19		1,003	3,046	21	1.21	2.50	15	40	1.40	3.7	85	62	95	257	188	4.0	93	63	107	269	190	1.46	3.00	30	100	1.92	4.0	92	127	169	185	150	4.3	99	119	176	205	157
28		AW-105	78-80	1	7/18	7/18		1,125	3,046	21	1.21	2.50	15	40	1.40	3.7	85	63	99	253	183	4.0	93	65	112	265	185	1.46	3.00	30	100	1.92	4.0	92	130	176	182	146	4.3	99	122	184	202	152
29		AZ-101	71	1	10/10	10/10	400	562	1,560	5	1.21	2.50	15	40	1.40	3.7	85	29	47	366	261	4.0	93	30	53	379	264	1.46	3.00	30	100	1.92	4.0	92	62	85	270	212	4.3	99	57	89	295	220
30		BNFL		1	9/10	9/10	400	0	6,275	40	1.21	2.50	15	40	1.40	3.7	85	100	119	201	174	4.0	93	103	130	212	177	1.46	3.00	30	100	1.92	4.0	92	203	221	142		4.3	99	191	221	158	142
31	AN-105	AN-102	80-81	1	3/10	3/10		329	626	0	1.21	2.50	15	40	1.40	3.7	85	12	21	557	376	4.0	93	12	25	572	378	1.46	3.00	30	100	1.92	4.0	92	26	38	422	311	4.3	99	24	41	454	318
32		BNFL		3	8/12	5/17		452	7,028	40	1.21	2.50	15	40	1.40	3.7	85	115	146	183	152	4.0	93	118	162	193	155	1.46	3.00	30	100	1.92	4.0	92	236	271			4.3	99	221	274	143	
33	AN-106	AW-102	78-80	6	11/04	1/06		1,242	3,389	21	1.21	2.50	15	40	1.40	3.7	85	69	108	240	173	4.0	93	71	123	251	176	1.46	3.00	30	100	1.92	4.0	92	143	193	172		4.3	99	134	203	190	145
34		BNFL		7	12/18	3/19		442	7,028	40	1.21	2.50	15	40	1.40	3.7	85	115	146	183	152	4.0	93	118	162	193	155	1.46	3.00	30	100	1.92	4.0	92	235	270			4.3	99	221	273	144	
35	AN-107	BNFL		1	7/11	7/11		557	7,028	40	1.21	2.50	15	40	1.40	3.7	85	116	150	182	149	4.0	93	119	167	192	153	1.46	3.00	30	100	1.92	4.0	92	238				4.3	99	224		142	
36	AP-101	BNFL		2	4/06	12/16	400	419	5,370	28	1.21	2.50	15	40	1.40	3.7	85	87	113	212	173	4.0	93	89	126	223	177	1.46	3.00	30	100	1.92	4.0	92	180	209	150		4.3	99	168	212	167	143
37	AP-102	BNFL		9	7/18	12/18	400	431	5,370	28	1.21	2.50	15	40	1.40	3.7	85	87	113	212	173	4.0	93	89	126	222	176	1.46	3.00	30	100	1.92	4.0	92	180	210	150		4.3	99	169	213	167	143
38	AP-104	AP-107	83-86	1	1/13	1/13	400	737	421	0	1.21	2.50	15	40	1.40	3.7	85	14	33	504	299	4.0	93	14	39	518	301	1.46	3.00	30	100	1.92	4.0	92	31	57	380	250	4.3	99	29	62	410	254
39		BNFL		3	1/13	10/17	400	314	5,370	28	1.21	2.50	15	40	1.40	3.7	85	86	109	214	177	4.0	93	88	121	225	181	1.46	3.00	30	100	1.92	4.0	92	177	203	152		4.3	99	166	205	169	146
40	AP-105	AP-104	83-86	1	9/15	9/15	400	616	421	0	1.21	2.50	15	40	1.40	3.7	85	13	28	533	322	4.0	93	13	33	548	323	1.46	3.00	30	100	1.92	4.0	92	28	50	403	269	4.3	99	26	54	434	273
41		BNFL		1	2/18	2/18	400	302	5,370	28	1.21	2.50	15	40	1.40	3.7	85	86	109	214	178	4.0	93	88	121	225	181	1.46	3.00	30	100	1.92	4.0	92	177	202	152		4.3	99	166	204	169	146
42	AP-106	AN-102	80-81	1	10/13	10/13		745	3,184	-12	1.21	2.50	15	40	1.40	3.7	85	40	67	269	202	4.0	93	42	78	281	205	1.46	3.00	30	100	1.92	4.0	92	96	130	196	163	4.3	99	88	135	216	170
43		BNFL		1	8/16	8/16	400	340	5,370	28	1.21	2.50	15	40	1.40	3.7	85	86	110	213	176	4.0	93	88	122	224	180	1.46	3.00	30	100	1.92	4.0	92	178	204	152		4.3	99	166	206	169	145
44	AP-107	AW-102	78-80	16	8/00	7/18		1,223	421	9	1.21	2.50	15	40	1.40	3.7	85	25	56	417	240	4.0	93	26	65	431	241	1.46	3.00	30	100	1.92	4.0	92	52	93	310	200	4.3	99	49	103	337	203
45	AP-108	BNFL		1	7/18	7/18	400	443	5,370	28	1.21	2.50	15	40	1.40	3.7	85	87	114	211	173	4.0	93	90	127	222	176	1.46	3.00	30	100	1.92	4.0	92	180	211	150		4.3	99	169	213	167	142
46	AW-101	AN-105	80-81	1	8/12	8/12		1,446	3,799	-21	1.21	2.50	15	40	1.40	3.7	85	51	96	232	167	4.0	93	53	113	244	170	1.46	3.00	30	100	1.92	4.0	92	124	183	168		4.3	99	114	193	187	141
47		BNFL		9	3/15	8/19		994	5,780	19	1.21	2.50	15	40	1.40	3.7	85	94	134	196	154	4.0	93	96	152	207	156	1.46	3.00	30	100	1.92	4.0	92	199	249			4.3	99	186	256	155	
48	AW-103	AW-104	78-80	1	10/15	11/15		2,015	1,241	0	1.21	2.50	15	40	1.40	3.7	85	39	91	294	179	4.0	93	41	107	306	181	1.46	3.00	30	100	1.92	4.0	92	88	158	214	148	4.3	99	82	173	236	152
49		AY-102	68-70	1	12/13	12/13		1,012	3,320	-10	1.21	2.50	15	40	1.40	3.7	85	46	80	255	187	4.0	93	48	93	266	190	1.46	3.00	30	100	1.92	4.0	92	109	152	185	151	4.3	99	100	159	205	158
50		BNFL		8	8/19	10/19		1,012	5,780	19	1.21	2.50	15	40	1.40	3.7	85	94	135	196	153	4.0	93	96	152	207	156	1.46	3.00	30	100	1.92	4.0	92	199	250			4.3	99	186	257	155	
51	AW-104	AP-104	83-86	1	1/13	1/13		1,317	831	-9	1.21	2.50	15	40	1.40	3.7	85	21	54	368	223	4.0	93	21	65	381	224	1.46	3.00	30	100	1.92	4.0	92	51	97	273	186	4.3	99	46	107	298	190
52		AW-102	78-80	3	6/01	1/02		203	421	0	1.21	2.50	15	40	1.40	3.7	85	8	14	693	470	4.0	93	8	16	709	473	1.46	3.00	30	100	1.92	4.0	92	17	25	532	391	4.3	99	16	26	568	398
53		BNFL		6	4/18	1/19		1,003	5,780	19	1.21	2.50	15	40	1.40	3.7	85	94	135	196	153	4.0	93	96	152	207	156	1.46	3.00	30	100	1.92	4.0	92	199	249			4.3	99	186	256	155	
54	AW-105	BNFL		7	1/18	7/18		1,125	5,780	19	1.21	2.50	15	40	1.40	3.7	85	95	139	194	151	4.0	93	98	157	205	153	1.46	3.00	30	100	1.92	4.0	92	203	256			4.3	99	189	264	154	
55	AW-106	AP-105	83-86	2	10/04	6/05		1,416	831	-9	1.21	2.50	15	40	1.40	3.7	85	22	58	359	217	4.0	93	23	69	372	218	1.46	3.00	30	100	1.92	4.0	92	53	102	266	180	4.3	99	49	113	291	184
56		AP-106	83-86	2	4/01	1/02		1,454	831	-9	1.21	2.50	15	40	1.40	3.7	85	22	59	356	214	4.0	93	23	71	369	216	1.46	3.00	30	100	1.92	4.0	92	54	105	264	178	4.3	99	50	116	288	182
57		AP-108	83-86	1	3/09	3/09		1,557	831	-9	1.21	2.50	15	40	1.40	3.7	85	23	63	348	208	4.0	93	24	75	361	210	1.46	3.00	30	100	1.92	4.0	92	57	111	257	174	4.3	99	52	123	281	177
58		AW-102	78-80	13	12/01	7/18		314	421	0	1.21	2.50	15	40	1.40	3.7	85	9	18	637	412	4.0	93	9	20	653	414	1.46	3.00	30	100	1.92	4.0	92	20	31	487	343	4.3	99	18	34	521	349
59		AW-103	78-80	1	10/04	10/04		2,126	1,241	0	1.21	2.50	15	40	1.40	3.7	85	41	95	289	175	4.0	93	42	112	301	177	1.46	3.00	30	100	1.92	4.0	92	91	165	211	145	4.3	99	84	181	232	149
60		AW-104	78-80	2	1/02	8/02		341	421	0	1.21	2.50	15	40	1.40	3.7	85	9	19	626	400	4.0	93	10	22	641	402	1.46	3.00	30	100	1.92	4.0	92	21	33	477	334	4.3	99	19	36	511	340
61		AW-105	78-80	1	6/05	6/05		2,239	1,241	0	1.21	2.50	15	40	1.40	3.7	85	42	99	284	172	4.0	93	43	116	296	173	1.46	3.00	30	100	1.92	4.0	92	94	171	207	142	4.3	99	87	188	228	145
62	AY-101	BNFL		12	1/11	10/13	400	0	6,924	30	1.21	2.50	15	40	1.40	3.7	85	102	122	192	167	4.0	93	104	135	203	170	1.46	3.00	30	100	1.92	4.0	92	212	232			4.3	99	198	231	152	
63	AY-102	AN-103	80-81	1	11/19	11/19		376	1,733	-11	1.21	2.50	15	40	1.40	3.7	85	19	33	372	279	4.0	93	20	38	385	282	1.46	3.00	30	100	1.92	4.0	92	48	65	276	227	4.3	99	44	68	301	235
64		AN-106	80-81	2	5/19	11/19		142	1,936	-11	1.21	2.50	15	40	1.40	3.7	85	18	27	375	302	4.0	93	19	32	388	306	1.46	3.00	30	100	1.92	4.0	92	47	57	279	243	4.3	99	43	58	304	254
65		AP-102	83-86	1	12/18	12/18	400	431	2,910	2	1.21	2.50	15	40	1.40	3.7	85	41	60	289	226	4.0	93	43	68	302	229	1.46	3.00	30	100	1.92	4.0	92	92	114	211	180	4.3	99	85	117	232	189
66		BNFL		16	1/09	2/18	400	0	6,549	30	1.21	2.50	15	40	1.40	3.7	85	97	116	198	171	4.0	93	100	129	209	175	1.46	3.00	30	100	1.92	4.0	92	202	221	140		4.3	99	189	220	156	140
67	AZ-101	BNFL		10	10/06	8/15	400	0	6,171	36	1.21	2.50	15	40	1.40	3.7	85	97	115	203	176	4.0	93	99	126	214	180	1.46	3.00	30	100	1.92	4.0	92	197	215	144		4.3	99	185	214	160	144
68	AZ-102	BNFL		6	7/07	3/08	400	0	6,556	36	1.21	2.50	15	40	1.40	3.7	85	101	121	197	170	4.0	93	104	133	208	174	1.46	3.00	30	100	1.92	4.0	92	207	226			4.3	99	194	226	155	
69	BNFL internal equivalent pipe length and elevation								884	45	included in BNFL routes							Exceeds 275 lbf/in²						Exceeds 400 lbf/in²								Supernate liquid only transfer							Less than 140 gpm						

Notes:

New = new or like new pipeline with *maximum expected* pipe roughness of 2 mils (0.002 inches).

EOL = pipeline at end of life (50 years for carbon steel line, 40 years for stainless steel line) with pipe roughness due to corrosion estimated at 150 mils for carbon steel and 10 mils for stainless steel.

***Design Pressure** = All stainless steel pipelines have a design pressure of 400 lbf/in². The design pressure of carbon steel pipelines are either 275 or 400 lbf/in² as indicated. The predicted flow rate at design pressure given in this table assumes that all pipelines are or can be qualified to the higher 400 lbf/in² design pressure.

Table D-21. 3S6 Case 2b.

CASE 3S6 Transfer List - Tank-to-Tank

Case 2b. Critical velocity by Oroskar and Turian (1980) empirical correlation (β_{cv} = 1.2). Pressure drop by Wasp et al. (1977) method with lognormal particle size distribution.

Transfer (columns A–J; 3-in. Schedule-40 Pipe (3.068 in. inside dia.))

Row	From Tank	To Tank	Tank Farm Built (Yr)	#	Dates (M/Yr) Start	Dates (M/Yr) End	Design Pressure (lbf/in²)*	Carbon Steel Length (ft)	Stainless Steel Length (ft)	Total Change in Elevation (ft)
6	AN-101	AN-106	80-81	1	12/00	12/00		442	626	0
7		AP-103	83-86	1	7/03	7/03	400	306	2,774	12
8		AP-107	83-86	1	6/05	6/05	400	423	2,774	12
9		**BNFL**		7	2/11	12/19	400	0	6,413	40
10	AN-102	AP-107	83-86	1	3/10	3/10		828	3,184	12
11		**BNFL**		5	12/08	4/16		405	6,823	40
12	AN-103	AN-102	80-81	1	4/12	4/12		253	421	0
13		**BNFL**		9	4/14	6/19		376	6,823	40
14	AN-104	AN-101	80-81	3	6/05	2/16		562	626	0
15		AN-102	80-81	2	4/16	6/16		439	626	0
16		AN-103	80-81	2	4/14	8/14		410	626	0
17		AN-105	80-81	5	10/14	11/17		384	421	0
18		AN-106	80-81	2	8/13	10/13		374	421	0
19		AN-107	80-81	1	3/19	3/19		489	421	0
20		AP-101	83-86	4	10/13	2/17	400	419	2,636	12
21		AP-102	83-86	1	8/13	8/13	400	431	2,636	12
22		AP-104	83-86	1	11/17	11/17	400	314	2,636	12
23		AP-106	83-86	2	8/16	12/16	400	430	2,636	12
24		AP-108	83-86	1	7/18	7/18	400	443	2,636	12
25		AW-101	78-80	2	3/15	3/15		994	3,046	21
26		AW-103	78-80	2	11/15	11/15		1,012	3,046	21
27		AW-104	78-80	1	1/19	1/19		1,003	3,046	21
28		AW-105	78-80	1	7/18	7/18		1,125	3,046	21
29		AZ-101	71	1	10/10	10/10	400	562	1,560	5
30		**BNFL**		1	9/10	9/10	400	0	6,275	40
31	AN-105	AN-102	80-81	1	3/10	3/10		329	626	0
32		**BNFL**		3	8/12	5/17		452	7,028	40
33	AN-106	AW-102	78-80	6	11/04	1/06		1,242	3,389	21
34		**BNFL**		7	12/18	3/19		442	7,028	40
35	AN-107	**BNFL**		1	7/11	7/11		557	7,028	40
36	AP-101	**BNFL**		2	4/06	12/16	400	419	5,370	28
37	AP-102	**BNFL**		9	7/18	12/18	400	431	5,370	28
38	AP-104	AP-107	83-86	1	1/13	1/13	400	737	421	0
39		**BNFL**		3	1/13	10/17	400	314	5,370	28
40	AP-105	AP-104	83-86	1	9/15	9/15	400	616	421	0
41		**BNFL**		1	2/18	2/18	400	302	5,370	28
42	AP-106	AN-102	80-81	1	10/13	10/13		745	3,184	-12
43		**BNFL**		1	8/16	8/16	400	340	5,370	28
44	AP-107	AW-102	78-80	16	8/00	7/18		1,223	421	9
45	AP-108	**BNFL**		1	7/18	7/18	400	443	5,370	28
46	AW-101	AN-105	80-81	1	8/12	8/12		1,446	3,799	-21
47		**BNFL**		9	3/15	8/19		994	5,780	19
48	AW-103	AW-104	78-80	1	10/15	11/15		2,015	1,241	0
49		AY-102	68-70	1	12/13	12/13		1,012	3,320	-10
50		**BNFL**		8	8/19	10/19		1,012	5,780	19
51	AW-104	AP-104	83-86	1	1/13	1/13		1,317	831	-9
52		AW-102	78-80	3	6/01	1/02		203	421	0
53		**BNFL**		6	4/18	1/19		1,003	5,780	19
54	AW-105	**BNFL**		7	1/18	7/18		1,125	5,780	19
55	AW-106	AP-105	83-86	2	10/04	6/05		1,416	831	-9
56		AP-106	83-86	2	4/01	1/02		1,454	831	-9
57		AP-108	83-86	1	3/09	3/09		1,557	831	-9
58		AW-102	78-80	13	12/01	7/18		314	421	0
59		AW-103	78-80	1	10/04	10/04		2,126	1,241	0
60		AW-104	78-80	2	1/02	8/02		341	421	0
61		AW-105	78-80	1	6/05	6/05		2,239	1,241	0
62	AY-101	**BNFL**		12	1/11	10/13	400	0	6,924	30
63	AY-102	AN-103	80-81	1	11/19	11/19		376	1,733	-11
64		AN-106	80-81	2	5/19	11/19		142	1,938	-11
65		AP-102	83-86	1	12/18	12/18	400	431	2,910	2
66		**BNFL**		16	1/09	2/18	400	0	6,549	30
67	AZ-101	**BNFL**		10	10/06	8/15	400	0	6,171	36
68	AZ-102	**BNFL**		6	7/07	3/08	400	0	6,556	36
69	BNFL internal equivalent pipe length and elevation								884	45

Group 1 Properties (columns K–AA). Critical (κ_{cv} = 1.30, κ_f = 1)

Row	ρ_L Density (kg/L)	ρ_s Density (kg/L)	C_v Volume (%)	d_p Median Dia. (μm)	ρ_m Bulk Density (kg/L)	10 °C Velocity (ft/s)	10 °C Flow Rate (gpm)	10 °C Total Pressure Drop (lbf/in²) New	10 °C Total Pressure Drop (lbf/in²) EOL	10 °C Flow Rate at a Pipe Design Pressure of 400 lbf/in² (gpm) New	10 °C Flow Rate at 400 lbf/in² (gpm) EOL	60 °C Velocity (ft/s)	60 °C Flow Rate (gpm)	60 °C Total Pressure Drop (lbf/in²) New	60 °C Total Pressure Drop (lbf/in²) EOL	60 °C Flow Rate at a Pipe Design Pressure of 400 lbf/in² (gpm) New	60 °C Flow Rate at 400 lbf/in² (gpm) EOL
6	1.10	2.50	15	40	1.31	4.1	95	14	29	549	356	4.5	104	15	35	562	358
7	1.10	2.50	15	40	1.31	4.1	95	48	67	314	248	4.5	104	51	77	326	251
8	1.10	2.50	15	40	1.31	4.1	95	50	72	308	238	4.5	104	52	83	320	241
9	1.10	2.50	15	40	1.31	4.1	95	109	133	210	180	4.5	104	114	149	220	183
10	1.10	2.50	15	40	1.31	4.1	95	60	96	274	202	4.5	104	64	111	285	205
11	1.10	2.50	15	40	1.31	4.1	95	120	157	197	162	4.5	104	126	178	207	165
12	1.10	2.50	15	40	1.31	4.1	95	9	18	695	457	4.5	104	10	21	709	459
13	1.10	2.50	15	40	1.31	4.1	95	119	155	197	163	4.5	104	125	176	207	166
14	1.10	2.50	15	40	1.31	4.1	95	16	34	520	328	4.5	104	17	41	533	330
15	1.10	2.50	15	40	1.31	4.1	95	14	29	550	357	4.5	104	15	34	563	359
16	1.10	2.50	15	40	1.31	4.1	95	14	28	558	365	4.5	104	15	33	571	367
17	1.10	2.50	15	40	1.31	4.1	95	11	23	635	398	4.5	104	11	28	649	400
18	1.10	2.50	15	40	1.31	4.1	95	11	23	639	402	4.5	104	11	27	653	404
19	1.10	2.50	15	40	1.31	4.1	95	12	28	596	365	4.5	104	13	33	610	367
20	1.10	2.50	15	40	1.31	4.1	95	48	70	316	242	4.5	104	50	80	327	245
21	1.10	2.50	15	40	1.31	4.1	95	48	70	315	241	4.5	104	51	81	327	244
22	1.10	2.50	15	40	1.31	4.1	95	46	65	322	252	4.5	104	49	75	333	255
23	1.10	2.50	15	40	1.31	4.1	95	48	70	315	242	4.5	104	51	81	327	244
24	1.10	2.50	15	40	1.31	4.1	95	48	71	315	240	4.5	104	51	81	326	243
25	1.10	2.50	15	40	1.31	4.1	95	66	106	271	196	4.5	104	69	122	282	198
26	1.10	2.50	15	40	1.31	4.1	95	66	107	271	195	4.5	104	70	123	281	197
27	1.10	2.50	15	40	1.31	4.1	95	66	106	271	195	4.5	104	70	123	282	198
28	1.10	2.50	15	40	1.31	4.1	95	68	111	267	190	4.5	104	71	129	278	192
29	1.10	2.50	15	40	1.31	4.1	95	31	53	384	271	4.5	104	33	62	396	274
30	1.10	2.50	15	40	1.31	4.1	95	107	130	212	182	4.5	104	112	147	222	185
31	1.10	2.50	15	40	1.31	4.1	95	13	25	582	390	4.5	104	14	29	595	392
32	1.10	2.50	15	40	1.31	4.1	95	123	162	193	159	4.5	104	129	184	203	162
33	1.10	2.50	15	40	1.31	4.1	95	74	122	253	181	4.5	104	78	141	263	183
34	1.10	2.50	15	40	1.31	4.1	95	123	162	194	159	4.5	104	129	184	203	162
35	1.10	2.50	15	40	1.31	4.1	95	124	167	192	156	4.5	104	131	190	202	159
36	1.10	2.50	15	40	1.31	4.1	95	93	125	223	181	4.5	104	98	143	234	184
37	1.10	2.50	15	40	1.31	4.1	95	93	126	223	181	4.5	104	99	144	233	184
38	1.10	2.50	15	40	1.31	4.1	95	15	38	527	310	4.5	104	16	45	540	312
39	1.10	2.50	15	40	1.31	4.1	95	92	121	226	185	4.5	104	97	138	236	188
40	1.10	2.50	15	40	1.31	4.1	95	14	33	557	334	4.5	104	15	39	571	335
41	1.10	2.50	15	40	1.31	4.1	95	92	121	226	185	4.5	104	97	137	236	189
42	1.10	2.50	15	40	1.31	4.1	95	46	79	282	210	4.5	104	49	94	293	213
43	1.10	2.50	15	40	1.31	4.1	95	92	122	225	184	4.5	104	97	139	235	187
44	1.10	2.50	15	40	1.31	4.1	95	27	64	437	249	4.5	104	28	75	449	250
45	1.10	2.50	15	40	1.31	4.1	95	94	126	223	180	4.5	104	99	144	233	183
46	1.10	2.50	15	40	1.31	4.1	95	58	114	244	174	4.5	104	63	136	255	176
47	1.10	2.50	15	40	1.31	4.1	95	101	152	207	160	4.5	104	107	175	217	163
48	1.10	2.50	15	40	1.31	4.1	95	44	106	308	186	4.5	104	46	126	320	187
49	1.10	2.50	15	40	1.31	4.1	95	52	94	268	195	4.5	104	56	111	278	197
50	1.10	2.50	15	40	1.31	4.1	95	102	152	207	160	4.5	104	108	176	217	162
51	1.10	2.50	15	40	1.31	4.1	95	24	64	385	231	4.5	104	26	78	397	233
52	1.10	2.50	15	40	1.31	4.1	95	8	16	723	488	4.5	104	9	19	738	490
53	1.10	2.50	15	40	1.31	4.1	95	102	152	207	160	4.5	104	108	175	217	162
54	1.10	2.50	15	40	1.31	4.1	95	103	157	205	157	4.5	104	109	182	215	159
55	1.10	2.50	15	40	1.31	4.1	95	25	69	376	225	4.5	104	27	83	388	226
56	1.10	2.50	15	40	1.31	4.1	95	26	70	373	222	4.5	104	28	85	385	224
57	1.10	2.50	15	40	1.31	4.1	95	27	75	365	216	4.5	104	29	90	377	217
58	1.10	2.50	15	40	1.31	4.1	95	10	20	665	427	4.5	104	10	24	679	429
59	1.10	2.50	15	40	1.31	4.1	95	45	110	303	182	4.5	104	48	132	314	183
60	1.10	2.50	15	40	1.31	4.1	95	10	22	653	415	4.5	104	11	25	667	417
61	1.10	2.50	15	40	1.31	4.1	95	47	115	298	178	4.5	104	50	137	309	179
62	1.10	2.50	15	40	1.31	4.1	95	109	135	203	174	4.5	104	115	153	213	178
63	1.10	2.50	15	40	1.31	4.1	95	22	39	390	290	4.5	104	24	47	402	293
64	1.10	2.50	15	40	1.31	4.1	95	21	33	392	314	4.5	104	23	39	405	317
65	1.10	2.50	15	40	1.31	4.1	95	46	89	304	235	4.5	104	48	80	315	238
66	1.10	2.50	15	40	1.31	4.1	95	104	129	209	179	4.5	104	110	146	219	183
67	1.10	2.50	15	40	1.31	4.1	95	103	126	215	184	4.5	104	108	142	225	187
68	1.10	2.50	15	40	1.31	4.1	95	108	133	208	178	4.5	104	114	150	218	182

Group 2 Properties (columns AB–AR). Critical (κ_{cv} = 1.30, κ_f = 1)

Row	ρ_L Density (kg/L)	ρ_s Density (kg/L)	C_v Volume (%)	d_p Median Dia. (μm)	ρ_m Bulk Density (kg/L)	10 °C Velocity (ft/s)	10 °C Flow Rate (gpm)	10 °C Total Pressure Drop (lbf/in²) New	10 °C Total Pressure Drop (lbf/in²) EOL	10 °C Flow Rate at a Pipe Design Pressure of 400 lbf/in² (gpm) New	10 °C Flow Rate at 400 lbf/in² (gpm) EOL	60 °C Velocity (ft/s)	60 °C Flow Rate (gpm)	60 °C Total Pressure Drop (lbf/in²) New	60 °C Total Pressure Drop (lbf/in²) EOL	60 °C Flow Rate at a Pipe Design Pressure of 400 lbf/in² (gpm) New	60 °C Flow Rate at 400 lbf/in² (gpm) EOL
6	1.20	3.00	30	100	1.74	5.4	124	33	67	467	310	5.9	135	39	86	490	315
7	1.20	3.00	30	100	1.74	5.4	124	105	149	266	214	5.9	135	122	186	284	219
8	1.20	3.00	30	100	1.74	5.4	124	109	160	261	206	5.9	135	126	201	278	209
9	1.20	3.00	30	100	1.74	5.4	124	231	285	175	153	5.9	135	265	352	185	150
10	1.20	3.00	30	100	1.74	5.4	124	134	215	232	175	5.9	135	156	271	248	175
11	1.20	3.00	30	100	1.74	5.4	124	256		164		5.9	135			172	
12	1.20	3.00	30	100	1.74	5.4	124	21	41	593	397	5.9	135	25	52	617	403
13	1.20	3.00	30	100	1.74	5.4	124	255		165		5.9	135			173	
14	1.20	3.00	30	100	1.74	5.4	124	37	79	442	286	5.9	135	43	101	464	290
15	1.20	3.00	30	100	1.74	5.4	124	33	67	468	310	5.9	135	39	86	490	315
16	1.20	3.00	30	100	1.74	5.4	124	32	64	475	317	5.9	135	38	82	497	322
17	1.20	3.00	30	100	1.74	5.4	124	25	54	541	347	5.9	135	29	69	564	351
18	1.20	3.00	30	100	1.74	5.4	124	25	53	544	350	5.9	135	29	67	568	355
19	1.20	3.00	30	100	1.74	5.4	124	28	64	508	318	5.9	135	33	82	531	322
20	1.20	3.00	30	100	1.74	5.4	124	105	154	267	210	5.9	135	121	193	285	214
21	1.20	3.00	30	100	1.74	5.4	124	105	155	267	209	5.9	135	121	195	284	213
22	1.20	3.00	30	100	1.74	5.4	124	101	144	272	218	5.9	135	117	180	290	222
23	1.20	3.00	30	100	1.74	5.4	124	105	155	267	209	5.9	135	121	195	284	213
24	1.20	3.00	30	100	1.74	5.4	124	105	156	266	208	5.9	135	122	196	284	212
25	1.20	3.00	30	100	1.74	5.4	124	142	232	229	169	5.9	135	163		244	168
26	1.20	3.00	30	100	1.74	5.4	124	143	234	228	168	5.9	135	164		244	167
27	1.20	3.00	30	100	1.74	5.4	124	142	233	229	168	5.9	135	164		244	168
28	1.20	3.00	30	100	1.74	5.4	124	146	245	225	164	5.9	135	168		240	162
29	1.20	3.00	30	100	1.74	5.4	124	70	120	326	236	5.9	135	81	152	345	240
30	1.20	3.00	30	100	1.74	5.4	124	226	279	177	154	5.9	135	260	345	188	152
31	1.20	3.00	30	100	1.74	5.4	124	30	56	495	339	5.9	135	35	72	518	344
32	1.20	3.00	30	100	1.74	5.4	124	264		161		5.9	135			169	
33	1.20	3.00	30	100	1.74	5.4	124	160	269	213	155	5.9	135	185		227	152
34	1.20	3.00	30	100	1.74	5.4	124	264		161		5.9	135			169	
35	1.20	3.00	30	100	1.74	5.4	124	267		160		5.9	135			167	
36	1.20	3.00	30	100	1.74	5.4	124	202	274	188	155	5.9	135	233	343	200	152
37	1.20	3.00	30	100	1.74	5.4	124	202	275	188	154	5.9	135	233	344	199	152
38	1.20	3.00	30	100	1.74	5.4	124	36	87	448	271	5.9	135	42	112	470	274
39	1.20	3.00	30	100	1.74	5.4	124	199	264	190	158	5.9	135	229	330	202	157
40	1.20	3.00	30	100	1.74	5.4	124	32	76	475	291	5.9	135	38	97	497	294
41	1.20	3.00	30	100	1.74	5.4	124	198	263	190	159	5.9	135	228	328	202	157
42	1.20	3.00	30	100	1.74	5.4	124	114	189	240	183	5.9	135	134	243	256	184
43	1.20	3.00	30	100	1.74	5.4	124	199	267	189	157	5.9	135	230	333	201	156
44	1.20	3.00	30	100	1.74	5.4	124	58	141	370	216	5.9	135	67	179	391	218
45	1.20	3.00	30	100	1.74	5.4	124	203	277	187	154	5.9	135	233	346	199	151
46	1.20	3.00	30	100	1.74	5.4	124	148	274	208	151	5.9	135	176		222	147
47	1.20	3.00	30	100	1.74	5.4	124	226		174		5.9	135	262		184	
48	1.20	3.00	30	100	1.74	5.4	124	102	243	262	162	5.9	135	119		279	159
49	1.20	3.00	30	100	1.74	5.4	124	128	221	228	169	5.9	135	151		243	168
50	1.20	3.00	30	100	1.74	5.4	124	226		174		5.9	135	263		184	
51	1.20	3.00	30	100	1.74	5.4	124	60	153	328	202	5.9	135	72	198	348	203
52	1.20	3.00	30	100	1.74	5.4	124	19	36	617	423	5.9	135	23	46	641	430
53	1.20	3.00	30	100	1.74	5.4	124	226		174		5.9	135	262		184	
54	1.20	3.00	30	100	1.74	5.4	124	230		172		5.9	135	267		182	
55	1.20	3.00	30	100	1.74	5.4	124	63	162	320	196	5.9	135	75	210	340	197
56	1.20	3.00	30	100	1.74	5.4	124	65	166	318	194	5.9	135	77	215	337	194
57	1.20	3.00	30	100	1.74	5.4	124	68	176	310	189	5.9	135	81	228	330	189
58	1.20	3.00	30	100	1.74	5.4	124	23	47	567	371	5.9	135	27	60	591	376
59	1.20	3.00	30	100	1.74	5.4	124	105	253	257	158	5.9	135	123		274	155
60	1.20	3.00	30	100	1.74	5.4	124	24	49	557	361	5.9	135	28	63	580	366
61	1.20	3.00	30	100	1.74	5.4	124	109	264	253	155	5.9	135	127		270	151
62	1.20	3.00	30	100	1.74	5.4	124	238	297	170	148	5.9	135	275	370	179	144
63	1.20	3.00	30	100	1.74	5.4	124	57	96	332	252	5.9	135	69	125	352	258
64	1.20	3.00	30	100	1.74	5.4	124	56	82	334	273	5.9	135	68	106	354	280
65	1.20	3.00	30	100	1.74	5.4	124	105	158	258	204	5.9	135	123	201	275	207
66	1.20	3.00	30	100	1.74	5.4	124	227	282	175	153	5.9	135	261	351	186	150
67	1.20	3.00	30	100	1.74	5.4	124	220	272	180	157	5.9	135	253	337	191	155
68	1.20	3.00	30	100	1.74	5.4	124	232	287	174	152	5.9	135	267	356	184	149

Row 69 legend (blank cells above correspond to black-filled cells): Included in BNFL routes; Exceeds 275 lbf/in²; Exceeds 400 lbf/in²; Supernate liquid only transfer; Less than 140 gpm.

Notes:

New = new or like new pipeline with maximum expected pipe roughness of 2 mils (0.002 inches).

EOL = pipeline at end of life (50 years for carbon steel line, 40 years for stainless steel line) with pipe roughness due to corrosion estimated at 150 mils for carbon steel and 10 mils for stainless steel.

***Design Pressure** = All stainless steel pipelines have a design pressure of 400 lbf/in². The design pressure of carbon steel pipelines are either 275 or 400 lbf/in² as indicated. The predicted flow rate at design pressure given in this table assumes that all pipelines are or can be qualified to the higher 400 lbf/in² design pressure.

Table D-22. 3S6 Case 2c.

CASE 3S6 Transfer List - Tank-to-Tank — Case 2c

Critical velocity by Oroskar and Turian (1980) empirical correlation (β_{cv} = 1.2). Pressure drop by Wasp et al. (1977) method with lognormal particle size distribution.

Row	A: From Tank	B: To Tank	C: Tank Farm Built (Yr)	D: #	E: Transfer Dates (M/Yr) Start	F: End	G: Design Pressure (lbf/in²)*	H: 3-in. Schedule-40 Pipe (3.068 in. inside dia.) Carbon Steel Length (ft)	I: Stainless Steel Length (ft)	J: Total Change in Elevation (ft)	K: Group 1 Liquid ρ_L Density (kg/L)	L: Solids ρ_s Density (kg/L)	M: C_s Volume (%) times 1.5	N: d_p Median Dia. (μm)	O: ρ_m Bulk Density (kg/L)	P: Temp. = 10 °C Velocity (ft/s)	Q: Critical (κ_{cv} = 1.30, κ_f = 1) Flow Rate (gpm)	R: Total Pressure Drop (lbf/in²) New	S: Total Pressure Drop EOL	T: Flow Rate at a Pipe Design Pressure of 400 lbf/in² (gpm) New	U: Flow Rate EOL	V: Temp. = 60 °C Velocity (ft/s)	W: Critical (κ_{cv} = 1.30, κ_f = 1) Flow Rate (gpm)	X: Total Pressure Drop (lbf/in²) New	Y: Total Pressure Drop EOL	Z: Flow Rate at a Pipe Design Pressure of 400 lbf/in² (gpm) New	AA: Flow Rate EOL
6	AN-101	AN-106	80-81	1	12/00	12/00		442	626	0	1.21	2.50	0.00	40	1.21	0.3	7	0	0	573	370	0.1	3	0	0	584	371
7		AP-103	83-86	1	7/03	7/03	400	306	2,774	12	1.21	2.50	0.00	40	1.21	0.3	7	7	7	328	257	0.1	3	6	6	338	260
8		AP-107	83-86	1	6/05	6/05	400	423	2,774	12	1.21	2.50	0.00	40	1.21	0.3	7	7	7	322	247	0.1	3	6	6	332	249
9		BNFL		7	2/11	12/19	400	0	6,413	40	1.21	2.50	0.50	40	1.22	2.3	53	49	55	219	186	2.5	58	49	59	227	189
10	AN-102	AP-107	83-86	1	3/10	3/10		828	3,184	12	1.21	2.50	0.06	40	1.21	1.7	38	16	20	286	210	1.8	42	16	22	295	212
11		BNFL		5	12/08	4/16		405	6,823	40	1.21	2.50	0.82	40	1.22	2.5	57	57	69	205	168	2.7	63	58	74	213	170
12	AN-103	AN-102	80-81	1	4/12	4/12		253	421	0	1.21	2.50	0.23	40	1.21	2.1	47	2	4	724	475	2.2	52	2	5	736	476
13		BNFL		9	4/14	6/19		376	6,823	40	1.21	2.50	0.82	40	1.22	2.5	57	57	68	205	169	2.7	63	58	74	214	171
14	AN-104	AN-101	80-81	3	6/05	2/16		562	626	0	1.21	2.50	0.50	40	1.22	2.3	53	5	10	541	340	2.5	58	5	12	552	342
15		AN-102	80-81	2	4/16	6/16		439	626	0	1.21	2.50	0.59	40	1.22	2.4	55	5	9	572	370	2.6	60	5	11	583	371
16		AN-103	80-81	2	4/14	8/14		410	626	0	1.21	2.50	0.98	40	1.22	2.6	59	5	10	579	377	2.8	64	6	12	590	379
17		AN-105	80-81	5	10/14	11/17		384	421	0	1.21	2.50	4.76	40	1.27	3.2	74	7	14	645	404	3.5	81	7	16	657	406
18		AN-106	80-81	2	8/13	10/13		374	421	0	1.21	2.50	5.05	40	1.28	3.2	75	7	14	648	407	3.5	81	7	16	660	409
19		AN-107	80-81	1	3/19	3/19		489	421	0	1.21	2.50	1.65	40	1.23	2.8	64	5	12	616	376	3.0	69	6	14	628	377
20		AP-101	83-86	4	10/13	2/17	400	419	2,636	12	1.21	2.50	3.27	40	1.25	3.1	70	29	40	323	248	3.3	77	30	45	334	250
21		AP-102	83-86	1	8/13	8/13	400	431	2,636	12	1.21	2.50	5.05	40	1.28	3.2	75	33	45	319	244	3.5	81	34	51	330	247
22		AP-104	83-86	1	11/17	11/17	400	314	2,636	12	1.21	2.50	4.75	40	1.27	3.2	74	31	42	326	255	3.5	81	32	47	337	258
23		AP-106	83-86	2	8/16	12/16	400	430	2,636	12	1.21	2.50	2.02	40	1.24	2.8	66	26	36	325	248	3.1	72	27	40	335	251
24		AP-108	83-86	1	7/18	7/18	400	443	2,636	12	1.21	2.50	1.86	40	1.23	2.8	65	26	35	325	248	3.1	71	26	39	335	250
25		AW-101	78-80	2	3/15	3/15		994	3,046	21	1.21	2.50	0.63	40	1.22	2.4	55	30	41	282	203	2.6	60	30	46	292	205
26		AW-103	78-80	2	11/15	11/15		1,012	3,046	21	1.21	2.50	0.63	40	1.22	2.4	55	30	42	282	202	2.6	60	30	46	291	204
27		AW-104	78-80	1	1/19	1/19		1,003	3,046	21	1.21	2.50	1.65	40	1.23	2.8	64	36	52	280	201	3.0	69	36	58	290	203
28		AW-105	78-80	1	7/18	7/18		1,125	3,046	21	1.21	2.50	1.86	40	1.23	2.8	65	37	56	275	196	3.1	71	38	63	285	197
29		AZ-101	71	1	10/10	10/10	400	562	1,560	5	1.21	2.50	4.24	40	1.26	3.2	73	20	32	391	276	3.5	80	20	36	402	278
30		BNFL		1	9/10	9/10	400	0	6,275	40	1.21	2.50	1.27	40	1.23	2.7	61	57	65	220	188	2.9	67	58	70	229	190
31	AN-105	AN-102	80-81	1	3/10	3/10		329	626	0	1.21	2.50	0.24	40	1.21	2.1	48	3	6	606	405	2.3	52	3	7	617	406
32		BNFL		3	8/12	5/17		452	7,028	40	1.21	2.50	1.26	40	1.23	2.7	61	63	77	201	164	2.9	67	64	85	209	166
33	AN-106	AW-102	78-80	6	11/04	1/06		1,242	3,389	21	1.21	2.50	0.00	40	1.21	0.3	7	12	12	264	188	0.1	3	11	11	273	189
34		BNFL		7	12/18	3/19		442	7,028	40	1.21	2.50	4.83	40	1.27	3.2	74	84	106	196	161	3.5	81	87	118	205	164
35	AN-107	BNFL		1	7/11	7/11		557	7,028	40	1.21	2.50	0.34	40	1.21	2.2	50	51	60	200	162	2.4	55	51	65	209	164
36	AP-101	BNFL		2	4/06	12/16	400	419	5,370	28	1.21	2.50	1.14	40	1.22	2.6	60	46	58	232	187	2.9	66	47	63	241	189
37	AP-102	BNFL		9	7/18	12/18	400	431	5,370	28	1.21	2.50	0.23	40	1.21	2.0	47	35	41	233	188	2.2	51	35	44	242	190
38	AP-104	AP-107	83-86	1	1/13	1/13	400	737	421	0	1.21	2.50	0.00	40	1.21	0.3	7	0	0	550	323	0.1	3	0	0	561	323
39		BNFL		3	1/13	10/17	400	314	5,370	28	1.21	2.50	0.28	40	1.21	2.1	49	36	42	235	192	2.3	53	36	45	244	195
40	AP-105	AP-104	83-86	1	9/15	9/15	400	616	421	0	1.21	2.50	0.12	40	1.21	1.9	43	3	6	581	347	2.0	47	3	7	592	348
41		BNFL		1	2/18	2/18	400	302	5,370	28	1.21	2.50	0.12	40	1.21	1.9	43	31	36	236	193	2.0	47	31	38	244	195
42	AP-106	AN-102	80-81	1	10/13	10/13		745	3,184	-12	1.21	2.50	0.00	40	1.21	0.3	7	-6	-6	294	218	0.1	3	-6	-6	303	220
43		BNFL		1	8/16	8/16	400	340	5,370	28	1.21	2.50	0.00	40	1.21	0.3	7	15	15	235	191	0.1	3	15	15	244	194
44	AP-107	AW-102	78-80	16	8/00	7/18		1,223	421	9	1.21	2.50	0.00	40	1.21	0.3	7	5	5	456	258	0.1	3	5	5	466	259
45	AP-108	BNFL		1	7/18	7/18	400	443	5,370	28	1.21	2.50	0.00	40	1.21	0.3	7	15	15	233	187	0.1	3	15	15	242	190
46	AW-101	AN-105	80-81	1	8/12	8/12		1,446	3,799	-21	1.21	2.50	0.19	40	1.21	2.0	46	6	17	254	180	2.2	50	6	21	263	182
47		BNFL		9	3/15	8/19		994	5,780	19	1.21	2.50	0.60	40	1.22	2.4	55	41	55	216	166	2.6	60	41	61	224	168
48	AW-103	AW-104	78-80	1	10/15	11/15		2,015	1,241	0	1.21	2.50	5.99	40	1.29	3.3	76	29	68	310	187	3.6	83	30	80	321	188
49		AY-102	68-70	1	12/13	12/13		1,012	3,320	-10	1.21	2.50	5.99	40	1.29	3.3	76	33	58	269	196	3.6	83	34	68	279	198
50		BNFL		8	8/19	10/19		1,012	5,780	19	1.21	2.50	3.13	40	1.25	3.0	70	60	85	212	163	3.3	76	62	96	221	165
51	AW-104	AP-104	83-86	1	1/13	1/13		1,317	831	-9	1.21	2.50	0.29	40	1.21	2.1	49	3	13	401	240	2.3	54	3	16	411	241
52		AW-102	78-80	3	6/01	1/02		203	421	0	1.21	2.50	0.00	40	1.21	0.3	7	0	0	755	507	0.1	3	0	0	766	509
53		BNFL		6	4/18	1/19		1,003	5,780	19	1.21	2.50	2.46	40	1.24	2.9	68	56	79	213	164	3.2	74	58	89	222	166
54	AW-105	BNFL		7	1/18	7/18		1,125	5,780	19	1.21	2.50	2.40	40	1.24	2.9	67	57	81	211	161	3.2	73	58	92	220	163
55	AW-106	AP-105	83-86	2	10/04	6/05		1,416	831	-9	1.21	2.50	0.00	40	1.21	0.3	7	-4	-4	393	233	0.1	3	-5	-5	403	234
56		AP-106	83-86	2	4/01	1/02		1,454	831	-9	1.21	2.50	0.00	40	1.21	0.3	7	-4	-4	389	231	0.1	3	-5	-5	399	231
57		AP-108	83-86	1	3/09	3/09		1,557	831	-9	1.21	2.50	0.00	40	1.21	0.3	7	-4	-4	380	224	0.1	3	-5	-5	390	225
58		AW-102	78-80	13	12/01	7/18		314	421	0	1.21	2.50	0.00	40	1.21	0.3	7	0	0	694	444	0.1	3	0	0	706	445
59		AW-103	78-80	1	10/04	10/04		2,126	1,241	0	1.21	2.50	0.00	40	1.21	0.3	7	0	1	316	189	0.1	3	0	0	326	190
60		AW-104	78-80	2	1/02	8/02		341	421	0	1.21	2.50	0.00	40	1.21	0.3	7	0	0	681	432	0.1	3	0	0	693	433
61		AW-105	78-80	1	6/05	6/05		2,239	1,241	0	1.21	2.50	0.00	40	1.21	0.3	7	0	1	311	185	0.1	3	0	0	320	186
62	AY-101	BNFL		12	1/11	10/13	400	0	6,924	30	1.21	2.50	9.68	40	1.33	3.5	81	89	107	199	172	3.8	88	92	119	209	175
63	AY-102	AN-103	80-81	1	11/19	11/19		376	1,733	-11	1.21	2.50	1.31	40	1.23	2.7	62	6	12	403	299	2.9	67	6	15	414	301
64		AN-106	80-81	2	5/19	11/19		142	1,938	-11	1.21	2.50	1.33	40	1.23	2.7	62	6	10	406	324	2.9	67	6	12	416	326
65		AP-102	83-86	1	12/18	12/18	400	431	2,910	2	1.21	2.50	1.96	40	1.24	2.8	65	22	32	313	241	3.1	71	23	36	323	244
66		BNFL		16	1/09	2/18	400	0	6,549	30	1.21	2.50	9.18	40	1.33	3.5	81	84	101	206	177	3.8	88	86	111	216	180
67	AZ-101	BNFL		10	10/06	8/15	400	0	6,171	36	1.21	2.50	4.11	40	1.26	3.2	73	69	81	219	187	3.4	79	71	89	228	190
68	AZ-102	BNFL		6	7/07	3/08	400	0	6,556	36	1.21	2.50	2.65	40	1.24	3.0	68	65	76	214	183	3.2	74	67	83	223	186
69	BNFL internal equivalent pipe length and elevation								884	45	Included in BNFL routes						Exceeds 275 lbf/in²						Exceeds 400 lbf/in²				

Row	AB: Group 2 Liquid ρ_L Density (kg/L)	AC: Solids ρ_s Density (kg/L)	AD: C_s Volume (%) times 2.0	AE: d_p Median Dia. (μm)	AF: ρ_m Bulk Density (kg/L)	AG: Temp. = 10 °C Velocity (ft/s)	AH: Critical (κ_{cv} = 1.30, κ_f = 1) Flow Rate (gpm)	AI: Total Pressure Drop (lbf/in²) New	AJ: Total Pressure Drop EOL	AK: Flow Rate at a Pipe Design Pressure of 400 lbf/in² (gpm) New	AL: Flow Rate EOL	AM: Temp. = 60 °C Velocity (ft/s)	AN: Critical (κ_{cv} = 1.30, κ_f = 1) Flow Rate (gpm)	AO: Total Pressure Drop (lbf/in²) New	AP: Total Pressure Drop EOL	AQ: Flow Rate at a Pipe Design Pressure of 400 lbf/in² (gpm) New	AR: Flow Rate EOL
6	1.46	3.00	0.00	100	1.46	1.0	22	2	2	492	333	0.4	10	0	0	513	336
7	1.46	3.00	0.00	100	1.46	1.0	22	12	13	275	227	0.4	10	9	9	292	232
8	1.46	3.00	0.00	100	1.46	1.0	22	12	13	270	218	0.4	10	9	9	286	223
9	1.46	3.00	0.67	100	1.47	2.5	58	76	82	179	161	2.7	62	74	83	192	167
10	1.46	3.00	0.08	100	1.46	1.8	42	25	31	238	186	1.9	45	24	32	254	190
11	1.46	3.00	1.09	100	1.48	2.7	62	90	103	167	145	2.9	67	88	106	180	150
12	1.46	3.00	0.31	100	1.46	2.2	51	4	7	626	427	2.4	55	4	7	650	431
13	1.46	3.00	1.10	100	1.48	2.7	62	90	103	167	146	2.9	67	88	106	180	151
14	1.46	3.00	0.67	100	1.47	2.5	58	9	16	463	306	2.7	62	9	17	484	309
15	1.46	3.00	0.79	100	1.47	2.6	59	9	14	490	332	2.8	64	8	15	512	335
16	1.46	3.00	1.30	100	1.48	2.8	64	10	16	496	339	3.0	69	9	17	518	342
17	1.46	3.00	6.34	100	1.56	3.5	80	12	21	549	361	3.7	86	12	23	574	365
18	1.46	3.00	6.73	100	1.56	3.5	81	12	21	551	364	3.8	87	12	23	576	367
19	1.46	3.00	2.20	100	1.49	3.0	69	10	18	528	338	3.2	74	10	20	551	341
20	1.46	3.00	4.36	100	1.53	3.3	76	49	62	268	217	3.6	82	47	65	286	223
21	1.46	3.00	6.74	100	1.56	3.5	81	55	70	263	213	3.8	87	53	74	281	219
22	1.46	3.00	6.34	100	1.56	3.5	80	52	64	270	223	3.7	86	51	68	288	229
23	1.46	3.00	2.69	100	1.50	3.1	71	43	54	271	219	3.3	77	42	57	288	224
24	1.46	3.00	2.48	100	1.50	3.1	70	43	54	271	218	3.3	76	41	57	288	223
25	1.46	3.00	0.84	100	1.47	2.6	60	47	61	234	179	2.8	65	46	65	250	183
26	1.46	3.00	0.84	100	1.47	2.6	60	47	62	234	178	2.8	64	46	65	249	182
27	1.46	3.00	2.20	100	1.49	3.0	69	58	77	232	177	3.2	74	56	83	247	181
28	1.46	3.00	2.48	100	1.50	3.1	70	61	83	228	172	3.3	76	59	89	243	176
29	1.46	3.00	5.65	100	1.55	3.4	79	34	49	326	244	3.7	85	33	53	346	248
30	1.46	3.00	1.70	100	1.49	2.9	67	89	98	180	162	3.1	72	87	100	193	168
31	1.46	3.00	0.32	100	1.46	2.2	52	6	9	521	364	2.4	56	6	10	543	367
32	1.46	3.00	1.68	100	1.49	2.9	66	101	117	163	141	3.1	72	99	121	176	147
33	1.46	3.00	0.00	100	1.46	1.0	22	20	22	219	166	0.4	10	15	15	233	169
34	1.46	3.00	6.44	100	1.56	3.5	80	139	163	158		3.8	86	135	171	171	143
35	1.46	3.00	0.46	100	1.47	2.4	55	79	90	163	140	2.6	59	76	92	176	145
36	1.46	3.00	1.52	100	1.48	2.8	65	75	87	190	163	3.1	70	73	91	204	168
37	1.46	3.00	0.30	100	1.46	2.2	51	54	62	192	163	2.4	55	52	63	205	168
38	1.46	3.00	0.00	100	1.46	1.0	22	2	3	471	291	0.4	10	0	1	492	293
39	1.46	3.00	0.37	100	1.47	2.3	53	56	63	194	167	2.5	57	54	64	208	172
40	1.46	3.00	0.17	100	1.46	2.0	47	6	10	499	313	2.2	50	5	11	521	315
41	1.46	3.00	0.17	100	1.46	2.0	47	48	53	194	168	2.2	50	46	54	208	173
42	1.46	3.00	0.00	100	1.46	1.0	22	-2	0	246	193	0.4	10	-6	-6	262	198
43	1.46	3.00	0.00	100	1.46	1.0	22	26	27	194	167	0.4	10	19	20	207	172
44	1.46	3.00	0.00	100	1.46	1.0	22	8	10	387	233	0.4	10	6	6	407	234
45	1.46	3.00	0.00	100	1.46	1.0	22	27	28	192	163	0.4	10	19	20	206	168
46	1.46	3.00	0.25	100	1.46	2.2	50	18	31	212	160	2.3	54	16	34	226	163
47	1.46	3.00	0.80	100	1.47	2.6	59	68	85	177	145	2.8	64	65	89	190	149
48	1.46	3.00	7.98	100	1.58	3.6	82	52	101	256	167	3.9	89	50	114	273	169
49	1.46	3.00	7.98	100	1.58	3.6	82	62	93	221	172	3.9	89	60	102	237	176
50	1.46	3.00	4.17	100	1.52	3.3	76	102	131	172	142	3.5	82	99	140	186	146
51	1.46	3.00	0.39	100	1.47	2.3	53	9	21	340	216	2.5	57	8	24	358	218
52	1.46	3.00	0.00	100	1.46	1.0	22	1	1	654	456	0.4	10	0	0	678	460
53	1.46	3.00	3.28	100	1.51	3.2	73	95	123	174	143	3.4	79	93	130	187	147
54	1.46	3.00	3.20	100	1.51	3.2	73	96	125	172	140	3.4	79	94	133	185	144
55	1.46	3.00	0.00	100	1.46	1.0	22	-2	0	332	210	0.4	10	-5	-5	351	212
56	1.46	3.00	0.00	100	1.46	1.0	22	-2	0	329	208	0.4	10	-5	-5	348	210
57	1.46	3.00	0.00	100	1.46	1.0	22	-2	0	322	202	0.4	10	-5	-5	340	204
58	1.46	3.00	0.00	100	1.46	1.0	22	1	2	600	400	0.4	10	0	0	623	403
59	1.46	3.00	0.00	100	1.46	1.0	22	5	8	265	170	0.4	10	1	1	281	172
60	1.46	3.00	0.00	100	1.46	1.0	22	1	2	588	389	0.4	10	0	0	612	392
61	1.46	3.00	0.00	100	1.46	1.0	22	5	8	260	166	0.4	10	1	2	276	168
62	1.46	3.00	12.90	100	1.66	3.8	87	152	170	158	144	4.1	94	147	175	172	151
63	1.46	3.00	1.75	100	1.49	2.9	67	14	22	341	266	3.1	72	13	24	360	270
64	1.46	3.00	1.77	100	1.49	2.9	67	14	19	343	287	3.1	72	13	20	362	293
65	1.46	3.00	2.61	100	1.50	3.1	71	39	51	261	212	3.3	76	38	54	278	218
66	1.46	3.00	12.24	100	1.65	3.8	87	142	159	164	149	4.0	93	138	164	178	156
67	1.46	3.00	5.48	100	1.54	3.4	79	112	124	177	160	3.7	85	109	129	191	166
68	1.46	3.00	3.53	100	1.51	3.2	74	105	117	174	157	3.5	80	103	121	187	163
69					Supernate liquid only transfer								Less than 140 gpm				

Notes (column AS):

New = new or like new pipeline with maximum expected pipe roughness of 2 mils (0.002 inches).

EOL = pipeline at end of life (50 years for carbon steel line, 40 years for stainless steel line) with pipe roughness due to corrosion estimated at 150 mils for carbon steel and 10 mils for stainless steel.

***Design Pressure** = All stainless steel pipelines have a design pressure of 400 lbf/in². The design pressure of carbon steel pipelines are either 275 or 400 lbf/in² as indicated. The predicted flow rate at design pressure given in this table assumes that all pipelines are or can be qualified to the higher 400 lbf/in² design pressure.

Table D-23. 3S6 Case 2d.

CASE 3S6 Transfer List - Tank-to-Tank

Case 2d — Critical velocity by Oroskar and Turian (1980) empirical correlation (β_{cv} = 1.2). Pressure drop by Wasp et al. (1977) method with lognormal particle size distribution.

Group 1 Properties (Liquid; Solids) — Temperature = 10 °C; Temperature = 60 °C. Critical (κ_{cv} = 1.30, κ_f = 1). 3-in. Schedule-40 Pipe (3.068 in. inside dia.)

Row	From Tank	To Tank	Tank Farm Built (Yr)	#	Transfer Dates (M/Yr) Start	Transfer Dates (M/Yr) End	Design Pressure* (lbf/in²)	Carbon Steel Length (ft)	Stainless Steel Length (ft)	Total Change in Elevation (ft)	ρ_L Density (kg/L)	ρ_s Density (kg/L)	C_v Volume (%) times 1.5	d_p Median Dia. (µm)	ρ_m Bulk Density (kg/L)	10 °C Critical Velocity (ft/s)	10 °C Critical Flow Rate (gpm)	10 °C Total Pressure Drop (lbf/in²) New	10 °C Total Pressure Drop (lbf/in²) EOL	10 °C Flow Rate at a Pipe Design Pressure of 400 lbf/in² (gpm) New	10 °C Flow Rate at 400 lbf/in² (gpm) EOL	60 °C Critical Velocity (ft/s)	60 °C Critical Flow Rate (gpm)	60 °C Total Pressure Drop (lbf/in²) New	60 °C Total Pressure Drop (lbf/in²) EOL	60 °C Flow Rate at a Pipe Design Pressure of 400 lbf/in² (gpm) New	60 °C Flow Rate at 400 lbf/in² (gpm) EOL
6	AN-101	AN-106	80-81	1	12/00	12/00		442	626	0	1.10	2.50	0.00	40	1.10	0.2	6	0	0	605	389	0.1	2	0	0	614	390
7		AP-103	83-86	1	7/03	7/03	400	306	2,774	12	1.10	2.50	0.00	40	1.10	0.2	6	6	6	348	271	0.1	2	6	6	357	273
8		AP-107	83-86	1	6/05	6/05	400	423	2,774	12	1.10	2.50	0.00	40	1.10	0.2	6	6	6	341	260	0.1	2	6	6	350	262
9		BNFL		7	2/11	12/19	400	0	6,413	40	1.10	2.50	0.50	40	1.11	2.6	60	49	57	233	197	2.8	65	51	62	240	199
10	AN-102	AP-107	83-86	1	3/10	3/10		828	3,184	12	1.10	2.50	0.06	40	1.10	1.9	43	16	22	303	221	2.0	47	16	24	312	223
11		BNFL		5	12/08	4/16		405	6,823	40	1.10	2.50	0.82	40	1.11	2.8	64	58	72	218	177	3.1	70	60	80	226	179
12	AN-103	AN-102	80-81	1	4/12	4/12		253	421	0	1.10	2.50	0.23	40	1.10	2.3	53	3	5	764	498	2.5	58	3	6	774	500
13		BNFL		9	4/14	6/19		376	6,823	40	1.10	2.50	0.82	40	1.11	2.8	64	58	72	218	178	3.1	70	60	79	226	180
14	AN-104	AN-101	80-81	3	6/05	2/16		562	626	0	1.10	2.50	0.50	40	1.11	2.6	60	6	12	571	357	2.8	65	6	14	580	358
15		AN-102	80-81	2	4/16	6/16		439	626	0	1.10	2.50	0.59	40	1.11	2.7	61	5	10	603	388	2.9	67	5	12	613	389
16		AN-103	80-81	2	4/14	8/14		410	626	0	1.10	2.50	0.98	40	1.11	2.9	66	6	12	610	396	3.1	72	6	14	620	397
17		AN-105	80-81	5	10/14	11/17		384	421	0	1.10	2.50	4.76	40	1.17	3.6	83	7	16	677	422	3.9	91	8	19	688	424
18		AN-106	80-81	2	8/13	10/13		374	421	0	1.10	2.50	5.05	40	1.17	3.6	84	7	16	680	426	4.0	92	8	19	692	427
19		AN-107	80-81	1	3/19	3/19		469	421	0	1.10	2.50	1.65	40	1.12	3.1	71	6	13	649	394	3.4	78	6	16	659	395
20		AP-101	83-86	4	10/13	2/17	400	419	2,636	12	1.10	2.50	3.27	40	1.15	3.4	79	31	44	342	260	3.7	86	32	50	351	262
21		AP-102	83-86	1	8/13	8/13	400	431	2,636	12	1.10	2.50	5.05	40	1.17	3.6	84	35	50	337	256	4.0	92	37	57	347	258
22		AP-104	83-86	1	11/17	11/17	400	314	2,636	12	1.10	2.50	4.75	40	1.17	3.6	83	33	46	345	268	3.9	91	35	52	354	270
23		AP-106	83-86	2	8/16	12/16	400	430	2,636	12	1.10	2.50	2.02	40	1.13	3.2	74	27	39	344	261	3.5	80	29	44	353	263
24		AP-108	83-86	1	7/18	7/18	400	443	2,636	12	1.10	2.50	1.86	40	1.13	3.2	73	27	38	344	260	3.4	79	28	43	353	262
25		AW-101	78-80	2	3/15	3/15		994	3,046	21	1.10	2.50	0.63	40	1.11	2.7	62	30	44	299	214	2.9	68	31	50	308	215
26		AW-103	78-80	2	11/15	11/15		1,012	3,046	21	1.10	2.50	0.63	40	1.11	2.7	62	30	44	299	213	2.9	68	31	50	307	214
27		AW-104	78-80	1	1/19	1/19		1,003	3,046	21	1.10	2.50	1.65	40	1.12	3.1	71	37	56	297	212	3.4	78	38	64	305	213
28		AW-105	78-80	1	7/18	7/18		1,125	3,046	21	1.10	2.50	1.86	40	1.13	3.2	73	39	61	292	206	3.5	79	40	69	301	207
29		AZ-101	71	1	10/10	10/10	400	562	1,560	5	1.10	2.50	4.24	40	1.16	3.5	82	21	36	412	289	3.9	89	22	41	422	291
30		BNFL		1	9/10	9/10	400	0	6,275	40	1.10	2.50	1.27	40	1.12	3.0	69	58	68	234	198	3.3	75	60	75	242	201
31	AN-105	AN-102	80-81	1	3/10	3/10		329	626	0	1.10	2.50	0.24	40	1.10	2.3	53	4	7	639	425	2.5	58	4	8	649	426
32		BNFL		3	8/12	5/17		452	7,028	40	1.10	2.50	1.26	40	1.12	3.0	69	65	82	213	173	3.3	75	67	92	221	175
33	AN-106	AW-102	78-80	6	11/04	1/06		1,242	3,389	21	1.10	2.50	0.00	40	1.10	0.2	6	10	10	280	198	0.1	2	10	10	288	199
34		BNFL		7	12/18	3/19		442	7,028	40	1.10	2.50	4.83	40	1.17	3.6	83	88	115	208	170	3.9	91	93	131	216	172
35	AN-107	BNFL		1	7/11	7/11		557	7,028	40	1.10	2.50	0.34	40	1.10	2.4	56	51	63	213	171	2.7	62	52	69	221	173
36	AP-101	BNFL		2	4/06	12/16	400	419	5,370	28	1.10	2.50	1.14	40	1.12	2.9	68	48	61	246	197	3.2	74	50	68	254	199
37	AP-102	BNFL		9	7/18	12/18	400	431	5,370	28	1.10	2.50	0.23	40	1.10	2.3	53	35	43	248	198	2.5	58	36	47	255	200
38	AP-104	AP-107	83-86	1	1/13	1/13	400	737	421	0	1.10	2.50	0.00	40	1.10	0.2	6	0	0	580	339	0.1	2	0	0	590	339
39		BNFL		3	1/13	10/17	400	314	5,370	28	1.10	2.50	0.28	40	1.10	2.4	55	36	44	250	203	2.6	60	37	48	258	205
40	AP-105	AP-104	83-86	1	9/15	9/15	400	616	421	0	1.10	2.50	0.12	40	1.10	2.1	48	3	7	613	364	2.3	53	3	9	623	365
41		BNFL		1	2/18	2/18	400	302	5,370	28	1.10	2.50	0.12	40	1.10	2.1	48	31	37	251	203	2.3	53	32	40	259	205
42	AP-106	AN-102	80-81	1	10/13	10/13		745	3,184	-12	1.10	2.50	0.00	40	1.10	0.2	6	-5	-5	311	229	0.1	2	-6	-6	320	231
43		BNFL		1	8/16	8/16	400	340	5,370	28	1.10	2.50	0.00	40	1.10	0.2	6	14	14	250	202	0.1	2	13	13	258	204
44	AP-107	AW-102	78-80	16	8/00	7/18		1,223	421	9	1.10	2.50	0.00	40	1.10	0.2	6	4	4	482	271	0.1	2	4	4	491	272
45	AP-108	BNFL		1	7/18	7/18	400	443	5,370	28	1.10	2.50	0.00	40	1.10	0.2	6	14	14	248	198	0.1	2	13	13	256	200
46	AW-101	AN-105	80-81	1	8/12	8/12		1,446	3,799	-21	1.10	2.50	0.19	40	1.10	2.2	51	8	22	269	189	2.4	56	9	26	277	191
47		BNFL		9	3/15	8/19		994	5,780	19	1.10	2.50	0.60	40	1.11	2.7	61	42	60	229	175	2.9	67	44	67	237	177
48	AW-103	AW-104	78-80	1	10/15	11/15		2,015	1,241	0	1.10	2.50	5.99	40	1.18	3.7	86	32	78	327	196	4.1	94	34	93	337	197
49		AY-102	68-70	1	12/13	12/13		1,012	3,320	-10	1.10	2.50	5.99	40	1.18	3.7	86	37	68	284	205	4.1	94	40	80	293	207
50		BNFL		8	8/19	10/19		1,012	5,780	19	1.10	2.50	3.13	40	1.14	3.4	78	64	94	225	172	3.7	86	67	108	233	173
51	AW-104	AP-104	83-86	1	1/13	1/13		1,317	831	-9	1.10	2.50	0.29	40	1.10	2.4	55	4	16	424	252	2.6	60	5	19	433	252
52		AW-102	78-80	3	6/01	1/02		203	421	0	1.10	2.50	0.00	40	1.10	0.2	6	0	0	796	532	0.1	2	0	0	806	534
53		BNFL		6	4/18	1/19		1,003	5,780	19	1.10	2.50	2.46	40	1.13	3.3	76	60	87	226	173	3.6	83	63	100	234	174
54	AW-105	BNFL		7	1/18	7/18		1,125	5,780	19	1.10	2.50	2.40	40	1.13	3.3	75	60	90	224	169	3.6	83	63	103	232	171
55	AW-106	AP-105	83-86	2	10/04	6/05		1,416	831	-9	1.10	2.50	0.00	40	1.10	0.2	6	-4	-4	415	245	0.1	2	-4	-4	424	245
56		AP-106	83-86	2	4/01	1/02		1,454	831	-9	1.10	2.50	0.00	40	1.10	0.2	6	-4	-4	411	242	0.1	2	-4	-4	420	243
57		AP-108	83-86	1	3/09	3/09		1,557	831	-9	1.10	2.50	0.00	40	1.10	0.2	6	-4	-4	402	235	0.1	2	-4	-4	411	236
58		AW-102	78-80	13	12/01	7/18		314	421	0	1.10	2.50	0.00	40	1.10	0.2	6	0	0	732	466	0.1	2	0	0	742	467
59		AW-103	78-80	1	10/04	10/04		2,126	1,241	0	1.10	2.50	0.00	40	1.10	0.2	6	0	0	335	199	0.1	2	0	0	343	199
60		AW-104	78-80	2	1/02	8/02		341	421	0	1.10	2.50	0.00	40	1.10	0.2	6	0	0	718	453	0.1	2	0	0	729	454
61		AW-105	78-80	1	6/05	6/05		2,239	1,241	0	1.10	2.50	0.00	40	1.10	0.2	6	0	0	329	194	0.1	2	0	0	338	195
62	AY-101	BNFL		12	1/11	10/13	400	0	6,924	30	1.10	2.50	9.68	40	1.24	3.9	91	95	118	211	180	4.3	99	101	134	220	183
63	AY-102	AN-103	80-81	1	11/19	11/19		376	1,733	-11	1.10	2.50	1.31	40	1.12	3.0	69	8	15	426	313	3.3	75	8	19	435	315
64		AN-106	80-81	2	5/19	11/19		142	1,938	-11	1.10	2.50	1.33	40	1.12	3.0	69	7	12	429	340	3.3	76	8	15	438	342
65		AP-102	83-86	1	12/18	12/18	400	431	2,910	2	1.10	2.50	1.96	40	1.13	3.2	73	24	36	331	254	3.5	80	25	41	340	256
66		BNFL		16	1/09	2/18	400	0	6,549	30	1.10	2.50	9.18	40	1.23	3.9	90	89	110	218	186	4.3	99	95	125	227	189
67	AZ-101	BNFL		10	10/06	8/15	400	0	6,171	36	1.10	2.50	4.11	40	1.16	3.5	81	72	87	232	197	3.9	89	75	97	240	199
68	AZ-102	BNFL		6	7/07	3/08	400	0	6,556	36	1.10	2.50	2.65	40	1.14	3.3	77	67	81	227	193	3.6	84	71	91	235	195
69	BNFL internal equivalent pipe length and elevation								884	45	included in BNFL routes																

Group 2 Properties — Temperature = 10 °C; Temperature = 60 °C. Critical (κ_{cv} = 1.30, κ_f = 1).

Row	ρ_L Density (kg/L)	ρ_s Density (kg/L)	C_v Volume (%) times 2.0	d_p Median Dia. (µm)	ρ_m Bulk Density (kg/L)	10 °C Critical Velocity (ft/s)	10 °C Critical Flow Rate (gpm)	10 °C Total Pressure Drop (lbf/in²) New	10 °C Total Pressure Drop (lbf/in²) EOL	10 °C Flow Rate at a Pipe Design Pressure of 400 lbf/in² (gpm) New	10 °C Flow Rate at 400 lbf/in² (gpm) EOL	60 °C Critical Velocity (ft/s)	60 °C Critical Flow Rate (gpm)	60 °C Total Pressure Drop (lbf/in²) New	60 °C Total Pressure Drop (lbf/in²) EOL	60 °C Flow Rate at a Pipe Design Pressure of 400 lbf/in² (gpm) New	60 °C Flow Rate at 400 lbf/in² (gpm) EOL
6	1.20	3.00	0.00	100	1.20	0.3	7	0	0	576	372	0.1	2	0	0	587	373
7	1.20	3.00	0.00	100	1.20	0.3	7	7	7	330	259	0.1	2	6	6	340	261
8	1.20	3.00	0.00	100	1.20	0.3	7	7	7	324	248	0.1	2	6	6	333	250
9	1.20	3.00	0.67	100	1.21	3.4	78	77	92	220	187	3.7	85	81	103	228	190
10	1.20	3.00	0.08	100	1.20	2.4	56	25	36	288	211	2.7	61	26	40	297	213
11	1.20	3.00	1.09	100	1.22	3.7	84	94	122	206	168	4.0	92	100	139	214	170
12	1.20	3.00	0.31	100	1.21	3.0	70	5	9	727	476	3.3	76	5	11	739	478
13	1.20	3.00	1.10	100	1.22	3.7	84	94	121	206	169	4.0	92	100	139	214	171
14	1.20	3.00	0.67	100	1.21	3.4	78	10	22	542	341	3.7	85	11	26	554	343
15	1.20	3.00	0.79	100	1.21	3.5	80	10	20	573	371	3.8	88	10	23	585	372
16	1.20	3.00	1.30	100	1.22	3.8	87	11	22	579	378	4.1	94	12	27	591	379
17	1.20	3.00	6.34	100	1.31	4.7	108	14	31	637	399	5.1	118	16	39	651	402
18	1.20	3.00	6.73	100	1.32	4.7	109	14	31	639	402	5.2	119	16	39	654	405
19	1.20	3.00	2.20	100	1.24	4.1	94	11	26	615	375	4.4	102	13	32	628	377
20	1.20	3.00	4.36	100	1.28	4.5	103	54	80	322	246	4.9	112	60	96	333	249
21	1.20	3.00	6.74	100	1.32	4.7	109	62	92	316	242	5.2	119	70	113	328	244
22	1.20	3.00	6.34	100	1.31	4.7	108	58	84	323	253	5.1	118	66	102	335	256
23	1.20	3.00	2.69	100	1.25	4.2	96	47	70	325	248	4.6	105	52	83	335	250
24	1.20	3.00	2.48	100	1.24	4.1	95	46	69	325	247	4.5	104	51	81	335	249
25	1.20	3.00	0.84	100	1.22	3.5	81	49	76	283	204	3.8	88	52	88	293	205
26	1.20	3.00	0.84	100	1.22	3.5	81	49	76	283	203	3.8	88	52	88	292	204
27	1.20	3.00	2.20	100	1.24	4.1	94	62	99	280	201	4.4	102	67	118	290	203
28	1.20	3.00	2.48	100	1.24	4.1	95	65	108	276	196	4.5	104	71	129	285	197
29	1.20	3.00	5.65	100	1.30	4.6	107	39	67	387	273	5.1	116	44	82	400	276
30	1.20	3.00	1.70	100	1.23	3.9	90	94	114	221	188	4.3	98	101	131	229	190
31	1.20	3.00	0.32	100	1.21	3.0	70	7	13	608	406	3.3	76	7	15	620	408
32	1.20	3.00	1.68	100	1.23	3.9	90	108	141	201	164	4.3	98	116	164	209	166
33	1.20	3.00	0.00	100	1.20	0.3	7	11	12	265	189	0.1	2	11	11	274	190
34	1.20	3.00	6.44	100	1.32	4.7	109	154	207	195	159	5.1	118	173	251	203	159
35	1.20	3.00	0.46	100	1.21	3.2	74	80	104	201	163	3.5	81	84	117	209	165
36	1.20	3.00	1.52	100	1.23	3.8	89	79	106	232	187	4.2	97	85	123	241	189
37	1.20	3.00	0.30	100	1.21	3.0	69	55	70	234	188	3.3	76	57	79	243	191
38	1.20	3.00	0.00	100	1.20	0.3	7	0	0	552	324	0.1	2	0	0	563	325
39	1.20	3.00	0.37	100	1.21	3.1	72	57	71	237	193	3.4	78	59	80	245	195
40	1.20	3.00	0.17	100	1.20	2.7	63	6	14	584	348	3.0	69	6	16	595	349
41	1.20	3.00	0.17	100	1.20	2.7	63	48	59	237	194	3.0	69	49	65	246	196
42	1.20	3.00	0.00	100	1.20	0.3	7	-6	-6	296	219	0.1	2	-6	-6	305	221
43	1.20	3.00	0.00	100	1.20	0.3	7	15	15	237	192	0.1	2	15	15	245	195
44	1.20	3.00	0.00	100	1.20	0.3	7	5	5	458	259	0.1	2	5	5	469	260
45	1.20	3.00	0.00	100	1.20	0.3	7	15	15	234	188	0.1	2	15	15	243	191
46	1.20	3.00	0.25	100	1.20	2.9	67	23	49	255	181	3.2	74	25	59	264	182
47	1.20	3.00	0.80	100	1.21	3.5	80	73	106	216	166	3.8	88	77	123	225	168
48	1.20	3.00	7.98	100	1.34	4.8	112	61	152	307	185	5.3	122	71	191	318	185
49	1.20	3.00	7.98	100	1.34	4.8	112	76	136	266	193	5.3	122	88	172	277	194
50	1.20	3.00	4.17	100	1.28	4.4	102	114	173	211	162	4.8	112	127	210	220	163
51	1.20	3.00	0.39	100	1.21	3.1	72	11	33	403	241	3.4	79	12	40	413	241
52	1.20	3.00	0.00	100	1.20	0.3	7	0	0	758	509	0.1	2	0	0	770	511
53	1.20	3.00	3.28	100	1.26	4.3	99	106	160	213	163	4.7	108	118	193	221	164
54	1.20	3.00	3.20	100	1.26	4.3	99	107	165	211	161	4.7	108	119	198	219	161
55	1.20	3.00	0.00	100	1.20	0.3	7	-4	-4	395	234	0.1	2	-5	-5	405	235
56	1.20	3.00	0.00	100	1.20	0.3	7	-4	-4	391	232	0.1	2	-5	-5	401	232
57	1.20	3.00	0.00	100	1.20	0.3	7	-4	-4	382	225	0.1	2	-5	-5	392	226
58	1.20	3.00	0.00	100	1.20	0.3	7	0	0	697	446	0.1	2	0	0	709	447
59	1.20	3.00	0.00	100	1.20	0.3	7	0	1	318	190	0.1	2	0	0	327	191
60	1.20	3.00	0.00	100	1.20	0.3	7	0	0	685	434	0.1	2	0	0	696	435
61	1.20	3.00	0.00	100	1.20	0.3	7	0	1	313	186	0.1	2	0	0	322	187
62	1.20	3.00	12.90	100	1.43	5.1	118	173	219	195	167	5.6	128	199	270	204	167
63	1.20	3.00	1.75	100	1.23	3.9	90	19	34	404	299	4.3	99	21	41	414	301
64	1.20	3.00	1.77	100	1.23	3.9	91	18	28	406	324	4.3	99	21	35	417	327
65	1.20	3.00	2.61	100	1.25	4.2	96	45	68	313	241	4.5	105	50	82	324	243
66	1.20	3.00	12.24	100	1.42	5.1	117	161	204	202	173	5.5	128	186	251	211	173
67	1.20	3.00	5.48	100	1.30	4.6	106	123	153	217	185	5.0	116	137	183	226	187
68	1.20	3.00	3.53	100	1.26	4.3	100	115	142	213	182	4.7	109	126	167	222	184

Legend (row 69): Exceeds 275 lbf/in² — Exceeds 400 lbf/in² — Supernate liquid only transfer — Less than 140 gpm

Notes

New = new or like new pipeline with maximum expected pipe roughness of 2 mils (0.002 inches).

EOL = pipeline at end of life (50 years for carbon steel line, 40 years for stainless steel line) with pipe roughness due to corrosion estimated at 150 mils for carbon steel and 10 mils for stainless steel.

*__Design Pressure__ = All stainless steel pipelines have a design pressure of 400 lbf/in². The design pressure of carbon steel pipelines are either 275 or 400 lbf/in² as indicated. The predicted flow rate at design pressure given in this table assumes that all pipelines are or can be qualified to the higher 400 lbf/in² design pressure.

Table D-24. 3S6 Case 3a.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL	AM	AN	AO	AP	AQ	AR	AS
1	CASE 3S6 Transfer List - Tank-to-Tank										Case 3a	Critical velocity by Oroskar and Turian (1980) empirical correlation (β_{cv} = 1.2). Pressure drop by Wasp et al. (1977) method with lognormal particle size distribution.																																		
2											Group 1 Properties					Temperature = 10 °C						Temperature = 60 °C						Group 2 Properties					Temperature = 10 °C						Temperature = 60 °C						
3	Transfer		Tank Farm Built (Yr)	#	Transfer		Design Pressure (lbf/in²)*	3-in. Schedule-40 Pipe (3.068 in. inside dia.)		Total Change in Elevation (ft)	Liquid	Solids			ρ_m Bulk Density (kg/L)	Critical (κ_{cv} = 1.30, κ_f = 1)				Flow Rate at a Pipe Design Pressure of 400 lbf/in² (gpm)		Critical (κ_{cv} = 1.30, κ_f = 1)				Flow Rate at a Pipe Design Pressure of 400 lbf/in² (gpm)		Liquid	Solids			ρ_m Bulk Density (kg/L)	Critical (κ_{cv} = 1.30, κ_f = 1)				Flow Rate at a Pipe Design Pressure of 400 lbf/in² (gpm)		Critical (κ_{cv} = 1.30, κ_f = 1)				Flow Rate at a Pipe Design Pressure of 400 lbf/in² (gpm)		Notes
4	From Tank	To Tank			Dates (M/Yr)			Carbon Steel Length (ft)	Stainless Steel Length (ft)		ρ_L Density (kg/L)	ρ_s Density (kg/L)	C_s Volume (%)	d_p Median Dia. (μm)		Velocity (ft/s)	Flow Rate (gpm)	Total Pressure Drop (lbf/in²)				Velocity (ft/s)	Flow Rate (gpm)	Total Pressure Drop (lbf/in²)				ρ_L Density (kg/L)	ρ_s Density (kg/L)	C_s Volume (%)	d_p Median Dia. (μm)		Velocity (ft/s)	Flow Rate (gpm)	Total Pressure Drop (lbf/in²)				Velocity (ft/s)	Flow Rate (gpm)	Total Pressure Drop (lbf/in²)				
5					Start	End												New	EOL	New	EOL			New	EOL	New	EOL								New	EOL	New	EOL			New	EOL	New	EOL	
6	AN-101	AN-106	80-81	1	12/00	12/00		442	626	0	1.21	2.50	15	200	1.40	4.8	111	24	48	534	347	5.3	121	30	66	552	351	1.46	3.00	30	400	1.92	5.0	115	44	76	412	292	5.4	124	52	101	452	301	**New** = new or like new pipeline with maximum expected pipe roughness of 2 mils (0.002 inches).
7		AP-103	83-86	1	7/03	7/03	400	306	2,774	12	1.21	2.50	15	200	1.40	4.8	111	75	107	307	242	5.3	121	93	144	320	244	1.46	3.00	30	400	1.92	5.0	115	138	176	232	196	5.4	124	160	223	257	202	
8		AP-107	83-86	1	6/05	6/05	400	423	2,774	12	1.21	2.50	15	200	1.40	4.8	111	78	115	301	232	5.3	121	96	155	314	233	1.46	3.00	30	400	1.92	5.0	115	143	188	228	189	5.4	124	165	239	252	193	
9		BNFL		7	2/11	12/19	400	0	6,413	40	1.21	2.50	15	200	1.40	4.8	111	166	207	203	173	5.3	121	203	271	210	169	1.46	3.00	30	400	1.92	5.0	115	300	343	147		5.4	124	345		151		
10	AN-102	AP-107	83-86	1	3/10	3/10		828	3,184	12	1.21	2.50	15	200	1.40	4.8	111	96	155	267	197	5.3	121	119	209	279	195	1.46	3.00	30	400	1.92	5.0	115	177	249	201	159	5.4	124	205		221	155	
11		BNFL		5	12/08	4/16		405	6,823	40	1.21	2.50	15	200	1.40	4.8	111	184	247	190	155	5.3	121	226		196	147	1.46	3.00	30	400	1.92	5.0	115					5.4	124					
12	AN-103	AN-102	80-81	1	4/12	4/12		253	421	0	1.21	2.50	15	200	1.40	4.8	111	15	29	675	445	5.3	121	19	40	695	451	1.46	3.00	30	400	1.92	5.0	115	28	47	526	374	5.4	124	33	62	570	386	**EOL** = pipeline at end of life (50 years for carbon steel line, 40 years for stainless steel line) with pipe roughness due to corrosion estimated at 150 mils for carbon steel and 10 mils for stainless steel.
13		BNFL		9	4/14	6/19		376	6,823	40	1.21	2.50	15	200	1.40	4.8	111	184	245	191	156	5.3	121	225		196	148	1.46	3.00	30	400	1.92	5.0	115					5.4	124					
14	AN-104	AN-101	80-81	3	6/05	2/16		562	626	0	1.21	2.50	15	200	1.40	4.8	111	26	56	505	321	5.3	121	33	78	524	324	1.46	3.00	30	400	1.92	5.0	115	49	88	390	269	5.4	124	58	118	428	277	
15		AN-102	80-81	2	4/16	6/16		439	626	0	1.21	2.50	15	200	1.40	4.8	111	24	48	534	348	5.3	121	30	66	553	352	1.46	3.00	30	400	1.92	5.0	115	44	76	413	292	5.4	124	52	100	452	301	
16		AN-103	80-81	2	4/14	8/14		410	626	0	1.21	2.50	15	200	1.40	4.8	111	23	46	542	356	5.3	121	29	63	561	360	1.46	3.00	30	400	1.92	5.0	115	43	73	419	299	5.4	124	50	96	459	308	
17		AN-105	80-81	5	10/14	11/17		384	421	0	1.21	2.50	15	200	1.40	4.8	111	18	38	616	389	5.3	121	22	53	636	393	1.46	3.00	30	400	1.92	5.0	115	33	60	479	327	5.4	124	39	80	521	337	
18		AN-106	80-81	2	8/13	10/13		374	421	0	1.21	2.50	15	200	1.40	4.8	111	18	38	620	392	5.3	121	22	52	640	396	1.46	3.00	30	400	1.92	5.0	115	33	59	482	330	5.4	124	39	79	524	340	
19		AN-107	80-81	1	3/19	3/19		489	421	0	1.21	2.50	15	200	1.40	4.8	111	20	45	579	356	5.3	121	25	63	598	359	1.46	3.00	30	400	1.92	5.0	115	38	71	449	300	5.4	124	44	95	490	308	
20		AP-101	83-86	4	10/13	2/17	400	419	2,636	12	1.21	2.50	15	200	1.40	4.8	111	75	111	308	237	5.3	121	92	149	322	238	1.46	3.00	30	400	1.92	5.0	115	137	181	233	193	5.4	124	158	230	258	197	
21		AP-102	83-86	1	8/13	8/13	400	431	2,636	12	1.21	2.50	15	200	1.40	4.8	111	75	112	307	236	5.3	121	93	150	321	237	1.46	3.00	30	400	1.92	5.0	115	138	182	233	192	5.4	124	159	232	258	196	
22		AP-104	83-86	1	11/17	11/17	400	314	2,636	12	1.21	2.50	15	200	1.40	4.8	111	73	104	314	246	5.3	121	90	139	327	248	1.46	3.00	30	400	1.92	5.0	115	133	170	238	200	5.4	124	153	216	263	206	
23		AP-106	83-86	2	8/16	12/16	400	430	2,636	12	1.21	2.50	15	200	1.40	4.8	111	75	112	307	236	5.3	121	93	150	321	237	1.46	3.00	30	400	1.92	5.0	115	138	182	233	192	5.4	124	159	232	258	196	***Design Pressure** = All stainless steel pipelines have a design pressure of 400 lbf/in². The design pressure of carbon steel pipelines are either 275 or 400 lbf/in² as indicated. The predicted flow rate at design pressure given in this table assumes that all pipelines are or can be qualified to the higher 400 lbf/in² design pressure.
24		AP-108	83-86	1	7/18	7/18	400	443	2,636	12	1.21	2.50	15	200	1.40	4.8	111	75	113	307	235	5.3	121	93	151	320	236	1.46	3.00	30	400	1.92	5.0	115	138	183	232	191	5.4	124	160	234	257	195	
25		AW-101	78-80	2	3/15	3/15		994	3,046	21	1.21	2.50	15	200	1.40	4.8	111	102	168	264	190	5.3	121	125	225	276	188	1.46	3.00	30	400	1.92	5.0	115	186	268	198	153	5.4	124	213		218	146	
26		AW-103	78-80	2	11/15	11/15		1,012	3,046	21	1.21	2.50	15	200	1.40	4.8	111	102	169	264	189	5.3	121	126	227	275	187	1.46	3.00	30	400	1.92	5.0	115	186	269	198	152	5.4	124	214		217	145	
27		AW-104	78-80	1	1/19	1/19		1,003	3,046	21	1.21	2.50	15	200	1.40	4.8	111	102	168	264	190	5.3	121	125	226	276	187	1.46	3.00	30	400	1.92	5.0	115	186	268	198	153	5.4	124	214		217	146	
28		AW-105	78-80	1	7/18	7/18		1,125	3,046	21	1.21	2.50	15	200	1.40	4.8	111	105	177	260	184	5.3	121	129	238	271	181	1.46	3.00	30	400	1.92	5.0	115	191		195	148	5.4	124	220		213		
29		AZ-101	71	1	10/10	10/10	400	562	1,560	5	1.21	2.50	15	200	1.40	4.8	111	50	86	374	265	5.3	121	62	117	390	267	1.46	3.00	30	400	1.92	5.0	115	93	138	286	219	5.4	124	107	179	316	226	
30		BNFL		1	9/10	9/10	400	0	6,275	40	1.21	2.50	15	200	1.40	4.8	111	163	203	206	175	5.3	121	199	266	213	172	1.46	3.00	30	400	1.92	5.0	115	295	337	149		5.4	124	338		154		
31	AN-105	AN-102	80-81	1	3/10	3/10		329	626	0	1.21	2.50	15	200	1.40	4.8	111	21	40	565	380	5.3	121	27	56	584	385	1.46	3.00	30	400	1.92	5.0	115	40	64	437	319	5.4	124	46	85	478	329	
32		BNFL		3	8/12	5/17		452	7,028	40	1.21	2.50	15	200	1.40	4.8	111	190	256	187	151	5.3	121	233		192	142	1.46	3.00	30	400	1.92	5.0	115					5.4	124					
33	AN-106	AW-102	78-80	6	11/04	1/06		1,242	3,389	21	1.21	2.50	15	200	1.40	4.8	111	115	194	246	174	5.3	121	142	262	257	170	1.46	3.00	30	400	1.92	5.0	115	210		183		5.4	124	242		200		
34		BNFL		7	12/18	3/19		442	7,028	40	1.21	2.50	15	200	1.40	4.8	111	190	255	187	152	5.3	121	232		192	143	1.46	3.00	30	400	1.92	5.0	115					5.4	124					
35	AN-107	BNFL		1	7/11	7/11		557	7,028	40	1.21	2.50	15	200	1.40	4.8	111	192	263	185	149	5.3	121	235		190		1.46	3.00	30	400	1.92	5.0	115					5.4	124					
36	AP-101	BNFL		2	4/06	12/16	400	419	5,370	28	1.21	2.50	15	200	1.40	4.8	111	145	199	217	175	5.3	121	178	264	225	171	1.46	3.00	30	400	1.92	5.0	115	264	326	159		5.4	124	304		169		
37	AP-102	BNFL		9	7/18	12/18	400	431	5,370	28	1.21	2.50	15	200	1.40	4.8	111	145	200	217	174	5.3	121	178	265	225	170	1.46	3.00	30	400	1.92	5.0	115	265	327	159		5.4	124	305		169		
38	AP-104	AP-107	83-86	1	1/13	1/13	400	737	421	0	1.21	2.50	15	200	1.40	4.8	111	26	62	512	303	5.3	121	32	87	530	305	1.46	3.00	30	400	1.92	5.0	115	48	97	395	256	5.4	124	56	130	434	261	
39		BNFL		3	1/13	10/17	400	314	5,370	28	1.21	2.50	15	200	1.40	4.8	111	143	192	219	179	5.3	121	175	254	228	176	1.46	3.00	30	400	1.92	5.0	115	260	315	161		5.4	124	299	396	171		
40	AP-105	AP-104	83-86	1	9/15	9/15	400	616	421	0	1.21	2.50	15	200	1.40	4.8	111	23	54	542	326	5.3	121	29	75	560	329	1.46	3.00	30	400	1.92	5.0	115	43	84	419	275	5.4	124	50	113	458	282	
41		BNFL		1	2/18	2/18	400	302	5,370	28	1.21	2.50	15	200	1.40	4.8	111	142	191	220	179	5.3	121	175	253	228	176	1.46	3.00	30	400	1.92	5.0	115	259	314	161		5.4	124	298	394	172		
42	AP-106	AN-102	80-81	1	10/13	10/13		745	3,184	-12	1.21	2.50	15	200	1.40	4.8	111	79	134	275	205	5.3	121	102	187	288	204	1.46	3.00	30	400	1.92	5.0	115	153	221	209	167	5.4	124	181		231	166	
43		BNFL		1	8/16	8/16	400	340	5,370	28	1.21	2.50	15	200	1.40	4.8	111	143	193	219	176	5.3	121	176	256	227	175	1.46	3.00	30	400	1.92	5.0	115	261	318	161		5.4	124	300	399	171		
44	AP-107	AW-102	78-80	16	8/00	7/18		1,223	421	9	1.21	2.50	15	200	1.40	4.8	111	42	101	425	242	5.3	121	51	139	442	243	1.46	3.00	30	400	1.92	5.0	115	76	154	325	204	5.4	124	87	206	359	205	
45	AP-108	BNFL		1	7/18	7/18	400	443	5,370	28	1.21	2.50	15	200	1.40	4.8	111	146	200	217	174	5.3	121	179	266	225	170	1.46	3.00	30	400	1.92	5.0	115	265	329	159		5.4	124	305		169		
46	AW-101	AN-105	80-81	1	8/12	8/12		1,446	3,799	-21	1.21	2.50	15	200	1.40	4.8	111	103	194	238	168	5.3	121	133	272	248	163	1.46	3.00	30	400	1.92	5.0	115	201		180		5.4	124	237		195		
47		BNFL		9	3/15	8/19		994	5,780	19	1.21	2.50	15	200	1.40	4.8	111	161	244	201	153	5.3	121	200		208	145	1.46	3.00	30	400	1.92	5.0	115			146		5.4	124			150		
48	AW-103	AW-104	78-80	1	10/15	11/15		2,015	1,241	0	1.21	2.50	15	200	1.40	4.8	111	72	173	301	180	5.3	121	91	240	314	176	1.46	3.00	30	400	1.92	5.0	115	135	268	229	149	5.4	124	158		253		
49		AY-102	68-70	1	12/13	12/13		1,012	3,320	-10	1.21	2.50	15	200	1.40	4.8	111	90	158	261	189	5.3	121	114	219	273	187	1.46	3.00	30	400	1.92	5.0	115	172	257	198	154	5.4	124	202		217	147	
50		BNFL		8	8/19	10/19		1,012	5,780	19	1.21	2.50	15	200	1.40	4.8	111	162	246	201	153	5.3	121	201		207	144	1.46	3.00	30	400	1.92	5.0	115			146		5.4	124			150		
51	AW-104	AP-104	83-86	1	1/13	1/13		1,317	831	-9	1.21	2.50	15	200	1.40	4.8	111	42	109	376	226	5.3	121	54	153	391	225	1.46	3.00	30	400	1.92	5.0	115	82	169	288	190	5.4	124	97	230	321	189	
52		AW-102	78-80	3	6/01	1/02		203	421	0	1.21	2.50	15	200	1.40	4.8	111	14	26	702	475	5.3	121	17	36	722	480	1.46	3.00	30	400	1.92	5.0	115	26	41	547	398	5.4	124	30	54	592	411	
53		BNFL		6	4/18	1/19		1,003	5,780	19	1.21	2.50	15	200	1.40	4.8	111	162	245	201	153	5.3	121	200		207	144	1.46	3.00	30	400	1.92	5.0	115			146		5.4	124			150		
54	AW-105	BNFL		7	1/18	7/18		1,125	5,780	19	1.21	2.50	15	200	1.40	4.8	111	164	253	199	150	5.3	121	204		205	140	1.46	3.00	30	400	1.92	5.0	115			144		5.4	124			147		
55	AW-106	AP-105	83-86	2	10/04	6/05		1,416	831	-9	1.21	2.50	15	200	1.40	4.8	111	44	115	367	219	5.3	121	57	162	383	218	1.46	3.00	30	400	1.92	5.0	115	86	179	281	184	5.4	124	102	244	312	182	
56		AP-106	83-86	2	4/01	1/02		1,454	831	-9	1.21	2.50	15	200	1.40	4.8	111	45	118	364	217	5.3	121	58	166	379	216	1.46	3.00	30	400	1.92	5.0	115	88	183	279	182	5.4	124	103	250	309	180	
57		AP-108	83-86	1	3/09	3/09		1,557	831	-9	1.21	2.50	15	200	1.40	4.8	111	47	125	356	210	5.3	121	61	176	371	209	1.46	3.00	30	400	1.92	5.0	115	92	194	272	177	5.4	124	108	264	302	174	
58		AW-102	78-80	13	12/01	7/18		314	421	0	1.21	2.50	15	200	1.40	4.8	111	16	34	646	416	5.3	121	20	46	666	421	1.46	3.00	30	400	1.92	5.0	115	31	53	502	350	5.4	124	36	70	545	360	
59		AW-103	78-80	1	10/04	10/04		2,126	1,241	0	1.21	2.50	15	200	1.40	4.8	111	74	181	296	176	5.3	121	94	251	309	172	1.46	3.00	30	400	1.92	5.0	115	140		224	145	5.4	124	163		248		
60		AW-104	78-80	2	1/02	8/02		341	421	0	1.21	2.50	15	200	1.40	4.8	111	17	35	634	405	5.3	121	21	49	654	409	1.46	3.00	30	400	1.92	5.0	115	32	56	493	341	5.4	124	37	74	536	351	
61		AW-105	78-80	1	6/05	6/05		2,239	1,241	0	1.21	2.50	15	200	1.40	4.8	111	77	189	291	172	5.3	121	97	262	304	167	1.46	3.00	30	400	1.92	5.0	115	145		220	142	5.4	124	169		244		
62	AY-101	BNFL		12	1/11	10/13	400	0	6,924	30	1.21	2.50	15	200	1.40	4.8	111	171	215	197	168	5.3	121	211	285	203	163	1.46	3.00	30	400	1.92	5.0	115	313	359	141		5.4	124	360		144		
63	AY-102	AN-103	80-81	1	11/19	11/19		376	1,733	-11	1.21	2.50	15	200	1.40	4.8	111	40	68	380	283	5.3	121	52	96	396	287	1.46	3.00	30	400	1.92	5.0	115	78	113	292	235	5.4	124	93	150	323	244	
64		AN-106	80-81	2	5/19	11/19		142	1,938	-11	1.21	2.50	15	200	1.40	4.8	111	39	58	383	307	5.3	121	51	81	398	312	1.46	3.00	30	400	1.92	5.0	115	77	99	294	253	5.4	124	92	129	325	265	
65		AP-102	83-86	1	12/18	12/18	400	431	2,910	2	1.21	2.50	15	200	1.40	4.8	111	75	113	297	229	5.3	121	94	154	310	231	1.46	3.00	30	400	1.92	5.0	115	140	186	225	187	5.4	124	163	240	249	190	
66		BNFL		16	1/09	2/18	400	0	6,549	30	1.21	2.50	15	200	1.40	4.8	111	163	205	203	173	5.3	121	200	270	210	169	1.46	3.00	30	400	1.92	5.0	115	297	341	147		5.4	124	342		152		
67	AZ-101	BNFL		10	10/06	8/15	400	0	6,171	36	1.21	2.50	15	200	1.40	4.8	111	158	198	208	178	5.3	121	194	260	216	174	1.46	3.00	30	400	1.92	5.0	115	287	328	151		5.4	124	329		158		
68	AZ-102	BNFL		6	7/07	3/08	400	0	6,556	36	1.21	2.50	15	200	1.40	4.8	111	167	209	202	172	5.3	121	204	274	208	168	1.46	3.00	30	400	1.92	5.0	115	303	347	145		5.4	124	348		150		
69	BNFL internal equivalent pipe length and elevation								884	45	included in BNFL routes						Exceeds 275 lbf/in²						Exceeds 400 lbf/in²					Supernate liquid only transfer											Less than 140 gpm						

Table D-25. 3S6 Case 3b.

CASE 3S6 Transfer List - Tank-to-Tank — Case 3b — Critical velocity by Oroskar and Turian (1980) empirical correlation (β_{cv} = 1.2). Pressure drop by Wasp et al. (1977) method with lognormal particle size distribution.

Group 1 Properties: Liquid ρ_L, Solids ρ_s, C_v, d_p; Group 1 at 10 °C (cols P–U) and 60 °C (cols V–AA). Group 2 Properties (cols AB–AF); Group 2 at 10 °C (cols AG–AL) and 60 °C (cols AM–AR). Critical (κ_{cv} = 1.30, κ_f = 1). Transfer pipe: 3-in. Schedule-40 Pipe (3.068 in. inside dia.).

Row	A: Transfer From Tank	B: Transfer To Tank	C: Tank Farm Built (Yr)	D: #	E: Dates (M/Yr) Start	F: Dates (M/Yr) End	G: Design Pressure (lbf/in²)	H: Carbon Steel Length (ft)	I: Stainless Steel Length (ft)	J: Total Change in Elevation (ft)	K: ρ_L Density (kg/L)	L: ρ_s Density (kg/L)	M: C_v Volume (%)	N: d_p Median Dia. (μm)	O: ρ_m Bulk Density (kg/L)	P: 10 °C Critical Velocity (ft/s)	Q: 10 °C Critical Flow Rate (gpm)	R: 10 °C Total Pressure Drop (lbf/in²) New	S: 10 °C Total Pressure Drop (lbf/in²) EOL	T: 10 °C Flow Rate at a Pipe Design Pressure of 400 lbf/in² (gpm) New	U: 10 °C Flow Rate at 400 lbf/in² (gpm) EOL	V: 60 °C Critical Velocity (ft/s)	W: 60 °C Critical Flow Rate (gpm)	X: 60 °C Total Pressure Drop (lbf/in²) New	Y: 60 °C Total Pressure Drop (lbf/in²) EOL	Z: 60 °C Flow Rate at 400 lbf/in² (gpm) New	AA: 60 °C Flow Rate at 400 lbf/in² (gpm) EOL	AB: ρ_L Density (kg/L)	AC: ρ_s Density (kg/L)	AD: C_v Volume (%)	AE: d_p Median Dia. (μm)	AF: ρ_m Bulk Density (kg/L)	AG: 10 °C Critical Velocity (ft/s)	AH: 10 °C Critical Flow Rate (gpm)	AI: 10 °C Total Pressure Drop (lbf/in²) New	AJ: 10 °C Total Pressure Drop (lbf/in²) EOL	AK: 10 °C Flow Rate at 400 lbf/in² (gpm) New	AL: 10 °C Flow Rate at 400 lbf/in² (gpm) EOL	AM: 60 °C Critical Velocity (ft/s)	AN: 60 °C Critical Flow Rate (gpm)	AO: 60 °C Total Pressure Drop (lbf/in²) New	AP: 60 °C Total Pressure Drop (lbf/in²) EOL	AQ: 60 °C Flow Rate at 400 lbf/in² (gpm) New	AR: 60 °C Flow Rate at 400 lbf/in² (gpm) EOL
6	AN-101	AN-106	80-81	1	12/00	12/00		442	626	0	1.10	2.50	15	200	1.31	5.4	125	27	58	563	363	5.9	136	36	81	582	367	1.20	3.00	30	400	1.74	6.8	156	72	152	513	325	7.4	170	97	221	541	322
7		AP-103	83-86	1	7/03	7/03	400	306	2,774	12	1.10	2.50	15	200	1.31	5.4	125	86	126	325	253	5.9	136	110	173	337	253	1.20	3.00	30	400	1.74	6.8	156	217	325	287	204	7.4	170	289		282	
8		AP-107	83-86	1	6/05	6/05	400	423	2,774	12	1.10	2.50	15	200	1.31	5.4	125	89	135	319	242	5.9	136	113	186	331	242	1.20	3.00	30	400	1.74	6.8	156	225	350	280	189	7.4	170	299		274	
9		BNFL		7	2/11	12/19	400	0	6,413	40	1.10	2.50	15	200	1.31	5.4	125	187	240	215	180	5.9	136	236	324	218	169	1.20	3.00	30	400	1.74	6.8	156					7.4	170				
10	AN-102	AP-107	83-86	1	3/10	3/10		828	3,184	12	1.10	2.50	15	200	1.31	5.4	125	109	183	284	205	5.9	136	140	253	293	199	1.20	3.00	30	400	1.74	6.8	156			239		7.4	170			211	
11		BNFL		5	12/08	4/16		405	6,823	40	1.10	2.50	15	200	1.31	5.4	125	208		201	159	5.9	136	264		202	140	1.20	3.00	30	400	1.74	6.8	156					7.4	170				
12	AN-103	AN-102	80-81	1	4/12	4/12		253	421	0	1.10	2.50	15	200	1.31	5.4	125	17	35	709	465	5.9	136	22	49	731	471	1.20	3.00	30	400	1.74	6.8	156	46	93	643	420	7.4	170	61	135	680	428
13		BNFL		9	4/14	6/19		376	6,823	40	1.10	2.50	15	200	1.31	5.4	125	207		202	160	5.9	136	263		202	142	1.20	3.00	30	400	1.74	6.8	156					7.4	170				
14	AN-104	AN-101	80-81	3	6/05	2/16		562	626	0	1.10	2.50	15	200	1.31	5.4	125	30	67	533	335	5.9	136	40	95	552	338	1.20	3.00	30	400	1.74	6.8	156	80	178	487	297	7.4	170	108	260	513	288
15		AN-102	80-81	2	4/16	6/16		439	626	0	1.10	2.50	15	200	1.31	5.4	125	27	57	563	364	5.9	136	35	81	583	368	1.20	3.00	30	400	1.74	6.8	156	72	151	514	326	7.4	170	97	220	542	323
16		AN-103	80-81	2	4/14	8/14		410	626	0	1.10	2.50	15	200	1.31	5.4	125	26	55	571	372	5.9	136	34	77	591	376	1.20	3.00	30	400	1.74	6.8	156	70	145	521	334	7.4	170	94	211	550	332
17		AN-105	80-81	5	10/14	11/17		384	421	0	1.10	2.50	15	200	1.31	5.4	125	21	46	649	405	5.9	136	27	65	669	410	1.20	3.00	30	400	1.74	6.8	156	54	121	590	365	7.4	170	73	177	623	367
18		AN-106	80-81	2	8/13	10/13		374	421	0	1.10	2.50	15	200	1.31	5.4	125	20	45	653	409	5.9	136	26	63	673	414	1.20	3.00	30	400	1.74	6.8	156	54	119	593	369	7.4	170	72	173	627	371
19		AN-107	80-81	1	3/19	3/19		489	421	0	1.10	2.50	15	200	1.31	5.4	125	23	54	610	371	5.9	136	30	77	630	375	1.20	3.00	30	400	1.74	6.8	156	61	144	555	333	7.4	170	83	210	587	331
20		AP-101	83-86	4	10/13	2/17	400	419	2,636	12	1.10	2.50	15	200	1.31	5.4	125	85	131	327	247	5.9	136	109	180	339	247	1.20	3.00	30	400	1.74	6.8	156	216	337	289	196	7.4	170	286		284	
21		AP-102	83-86	1	8/13	8/13	400	431	2,636	12	1.10	2.50	15	200	1.31	5.4	125	85	132	326	246	5.9	136	109	181	338	246	1.20	3.00	30	400	1.74	6.8	156	216	340	288	195	7.4	170	287		283	
22		AP-104	83-86	1	11/17	11/17	400	314	2,636	12	1.10	2.50	15	200	1.31	5.4	125	82	122	333	257	5.9	136	105	167	345	258	1.20	3.00	30	400	1.74	6.8	156	208	314	295	210	7.4	170	277		292	
23		AP-106	83-86	2	8/16	12/16	400	430	2,636	12	1.10	2.50	15	200	1.31	5.4	125	85	131	326	246	5.9	136	109	181	338	246	1.20	3.00	30	400	1.74	6.8	156	216	339	288	195	7.4	170	287		284	
24		AP-108	83-86	1	7/18	7/18	400	443	2,636	12	1.10	2.50	15	200	1.31	5.4	125	86	133	325	245	5.9	136	109	182	337	245	1.20	3.00	30	400	1.74	6.8	156	217	342	287	193	7.4	170	289		283	
25		AW-101	78-80	2	3/15	3/15		994	3,046	21	1.10	2.50	15	200	1.31	5.4	125	115	197	281	198	5.9	136	146	271	290	190	1.20	3.00	30	400	1.74	6.8	156			235		7.4	170			202	
26		AW-103	78-80	2	11/15	11/15		1,012	3,046	21	1.10	2.50	15	200	1.31	5.4	125	116	198	280	197	5.9	136	147	273	289	189	1.20	3.00	30	400	1.74	6.8	156			234		7.4	170			200	
27		AW-104	78-80	1	1/19	1/19		1,003	3,046	21	1.10	2.50	15	200	1.31	5.4	125	115	198	280	197	5.9	136	147	272	290	190	1.20	3.00	30	400	1.74	6.8	156			234		7.4	170			201	
28		AW-105	78-80	1	7/18	7/18		1,125	3,046	21	1.10	2.50	15	200	1.31	5.4	125	119	208	276	191	5.9	136	151		285	183	1.20	3.00	30	400	1.74	6.8	156			229		7.4	170			185	
29		AZ-101	71	1	10/10	10/10	400	562	1,560	5	1.10	2.50	15	200	1.31	5.4	125	57	102	396	277	5.9	136	74	142	411	278	1.20	3.00	30	400	1.74	6.8	156	147	266	359	236	7.4	170	196	383	369	193
30		BNFL		1	9/10	9/10	400	0	6,275	40	1.10	2.50	15	200	1.31	5.4	125	183	235	218	182	5.9	136	232	317	221	172	1.20	3.00	30	400	1.74	6.8	156					7.4	170				
31	AN-105	AN-102	80-81	1	3/10	3/10		329	626	0	1.10	2.50	15	200	1.31	5.4	125	24	48	595	397	5.9	136	32	68	615	402	1.20	3.00	30	400	1.74	6.8	156	64	128	542	358	7.4	170	87	185	573	360
32		BNFL		3	8/12	5/17		452	7,028	40	1.10	2.50	15	200	1.31	5.4	125	214		197	155	5.9	136	272		197		1.20	3.00	30	400	1.74	6.8	156					7.4	170				
33	AN-106	AW-102	78-80	6	11/04	1/06		1,242	3,389	21	1.10	2.50	15	200	1.31	5.4	125	130	229	261	181	5.9	136	166		269	170	1.20	3.00	30	400	1.74	6.8	156			209		7.4	170				
34		BNFL		7	12/18	3/19		442	7,028	40	1.10	2.50	15	200	1.31	5.4	125	214		197	156	5.9	136	272		197		1.20	3.00	30	400	1.74	6.8	156					7.4	170				
35	AN-107	BNFL		1	7/11	7/11		557	7,028	40	1.10	2.50	15	200	1.31	5.4	125	217		196	152	5.9	136			195		1.20	3.00	30	400	1.74	6.8	156					7.4	170				
36	AP-101	BNFL		2	4/06	12/16	400	419	5,370	28	1.10	2.50	15	200	1.31	5.4	125	164	232	230	181	5.9	136	209	317	235	171	1.20	3.00	30	400	1.74	6.8	156					7.4	170				
37	AP-102	BNFL		9	7/18	12/18	400	431	5,370	28	1.10	2.50	15	200	1.31	5.4	125	164	233	230	181	5.9	136	209	318	235	170	1.20	3.00	30	400	1.74	6.8	156					7.4	170				
38	AP-104	AP-107	83-86	1	1/13	1/13	400	737	421	0	1.10	2.50	15	200	1.31	5.4	125	30	75	540	316	5.9	136	39	106	559	318	1.20	3.00	30	400	1.74	6.8	156	78	198	493	279	7.4	170	105	289	519	264
39		BNFL		3	1/13	10/17	400	314	5,370	28	1.10	2.50	15	200	1.31	5.4	125	161	223	232	186	5.9	136	205	304	237	177	1.20	3.00	30	400	1.74	6.8	156			150		7.4	170				
40	AP-105	AP-104	83-86	1	9/15	9/15	400	616	421	0	1.10	2.50	15	200	1.31	5.4	125	27	65	571	340	5.9	136	35	92	590	343	1.20	3.00	30	400	1.74	6.8	156	70	171	521	302	7.4	170	94	251	549	294
41		BNFL		1	2/18	2/18	400	302	5,370	28	1.10	2.50	15	200	1.31	5.4	125	161	222	233	186	5.9	136	205	303	238	177	1.20	3.00	30	400	1.74	6.8	156			151		7.4	170				
42	AP-106	AN-102	80-81	1	10/13	10/13		745	3,184	-12	1.10	2.50	15	200	1.31	5.4	125	94	162	292	213	5.9	136	124	229	302	208	1.20	3.00	30	400	1.74	6.8	156	256		251		7.4	170			232	
43		BNFL		1	8/16	8/16	400	340	5,370	28	1.10	2.50	15	200	1.31	5.4	125	162	225	232	185	5.9	136	206	308	237	175	1.20	3.00	30	400	1.74	6.8	156			148		7.4	170				
44	AP-107	AW-102	78-80	16	8/00	7/18		1,223	421	9	1.10	2.50	15	200	1.31	5.4	125	47	120	449	253	5.9	136	60	168	466	251	1.20	3.00	30	400	1.74	6.8	156	118		409	207	7.4	170	156		427	
45	AP-108	BNFL		1	7/18	7/18	400	443	5,370	28	1.10	2.50	15	200	1.31	5.4	125	165	234	230	180	5.9	136	209	320	234	170	1.20	3.00	30	400	1.74	6.8	156					7.4	170				
46	AW-101	AN-105	80-81	1	8/12	8/12		1,446	3,799	-21	1.10	2.50	15	200	1.31	5.4	125	122	235	252	173	5.9	136	163		259	160	1.20	3.00	30	400	1.74	6.8	156			199		7.4	170				
47		BNFL		9	3/15	8/19		994	5,780	19	1.10	2.50	15	200	1.31	5.4	125	184		212	157	5.9	136	236		215		1.20	3.00	30	400	1.74	6.8	156					7.4	170				
48	AW-103	AW-104	78-80	1	10/15	11/15		2,015	1,241	0	1.10	2.50	15	200	1.31	5.4	125	83	208	319	187	5.9	136	108		331	177	1.20	3.00	30	400	1.74	6.8	156	220		281		7.4	170			275	
49		AY-102	68-70	1	12/13	12/13		1,012	3,320	-10	1.10	2.50	15	200	1.31	5.4	125	105	190	277	196	5.9	136	139	268	286	189	1.20	3.00	30	400	1.74	6.8	156			233		7.4	170			197	
50		BNFL		8	8/19	10/19		1,012	5,780	19	1.10	2.50	15	200	1.31	5.4	125	185		212	156	5.9	136	237		214		1.20	3.00	30	400	1.74	6.8	156					7.4	170				
51	AW-104	AP-104	83-86	1	1/13	1/13		1,317	831	-9	1.10	2.50	15	200	1.31	5.4	125	50	132	397	235	5.9	136	67	188	413	231	1.20	3.00	30	400	1.74	6.8	156	138		362	183	7.4	170	188		372	
52		AW-102	78-80	3	6/01	1/02		203	421	0	1.10	2.50	15	200	1.31	5.4	125	16	31	737	495	5.9	136	21	43	759	502	1.20	3.00	30	400	1.74	6.8	156	42	82	667	448	7.4	170	57	119	705	459
53		BNFL		6	4/18	1/19		1,003	5,780	19	1.10	2.50	15	200	1.31	5.4	125	184		212	157	5.9	136	237		215		1.20	3.00	30	400	1.74	6.8	156					7.4	170				
54	AW-105	BNFL		7	1/18	7/18		1,125	5,780	19	1.10	2.50	15	200	1.31	5.4	125	187		210	153	5.9	136	241		212		1.20	3.00	30	400	1.74	6.8	156					7.4	170				
55	AW-106	AP-105	83-86	2	10/04	6/05		1,416	831	-9	1.10	2.50	15	200	1.31	5.4	125	52	140	388	228	5.9	136	70	199	403	223	1.20	3.00	30	400	1.74	6.8	156	145		353	171	7.4	170	197		362	
56		AP-106	83-86	2	4/01	1/02		1,454	831	-9	1.10	2.50	15	200	1.31	5.4	125	53	143	385	225	5.9	136	71	204	400	221	1.20	3.00	30	400	1.74	6.8	156	148		350	166	7.4	170	201		359	
57		AP-108	83-86	1	3/09	3/09		1,557	831	-9	1.10	2.50	15	200	1.31	5.4	125	56	151	376	219	5.9	136	75	216	391	213	1.20	3.00	30	400	1.74	6.8	156	155		341	152	7.4	170	210		349	
58		AW-102	78-80	13	12/01	7/18		314	421	0	1.10	2.50	15	200	1.31	5.4	125	19	40	679	434	5.9	136	24	56	700	439	1.20	3.00	30	400	1.74	6.8	156	50	106	616	392	7.4	170	67	154	652	397
59		AW-103	78-80	1	10/04	10/04		2,126	1,241	0	1.10	2.50	15	200	1.31	5.4	125	86	217	313	182	5.9	136	112		325	171	1.20	3.00	30	400	1.74	6.8	156	227		275		7.4	170			267	
60		AW-104	78-80	2	1/02	8/02		341	421	0	1.10	2.50	15	200	1.31	5.4	125	19	42	667	422	5.9	136	25	60	688	427	1.20	3.00	30	400	1.74	6.8	156	51	112	605	381	7.4	170	69	163	640	385
61		AW-105	78-80	1	6/05	6/05		2,239	1,241	0	1.10	2.50	15	200	1.31	5.4	125	89	226	308	178	5.9	136	116		319	166	1.20	3.00	30	400	1.74	6.8	156	235		269		7.4	170			259	
62	AY-101	BNFL		12	1/11	10/13	400	0	6,924	30	1.10	2.50	15	200	1.31	5.4	125	194	251	208	174	5.9	136	247	342	210	161	1.20	3.00	30	400	1.74	6.8	156					7.4	170				
63	AY-102	AN-103	80-81	1	11/19	11/19		376	1,733	-11	1.10	2.50	15	200	1.31	5.4	125	48	83	402	296	5.9	136	64	119	417	299	1.20	3.00	30	400	1.74	6.8	156	134	229	366	258	7.4	170	183		378	235
64		AN-106	80-81	2	5/19	11/19		142	1,938	-11	1.10	2.50	15	200	1.31	5.4	125	47	71	405	321	5.9	136	63	101	420	325	1.20	3.00	30	400	1.74	6.8	156	132	198	369	286	7.4	170	180		381	272
65		AP-102	83-86	1	12/18	12/18	400	431	2,910	2	1.10	2.50	15	200	1.31	5.4	125	86	135	314	239	5.9	136	112	188	326	238	1.20	3.00	30	400	1.74	6.8	156	227	356	276	185	7.4	170	304		268	
66		BNFL		16	1/09	2/18	400	0	6,549	30	1.10	2.50	15	200	1.31	5.4	125	184	238	215	179	5.9	136	235	324	217	168	1.20	3.00	30	400	1.74	6.8	156					7.4	170				
67	AZ-101	BNFL		10	10/06	8/15	400	0	6,171	36	1.10	2.50	15	200	1.31	5.4	125	178	229	221	185	5.9	136	226	310	224	175	1.20	3.00	30	400	1.74	6.8	156					7.4	170				
68	AZ-102	BNFL		6	7/07	3/08	400	0	6,556	36	1.10	2.50	15	200	1.31	5.4	125	188	242	213	178	5.9	136	239	328	216	167	1.20	3.00	30	400	1.74	6.8	156					7.4	170				
69	BNFL internal equivalent pipe length and elevation								884	45	included in BNFL routes						Exceeds 275 lbf/in²						Exceeds 400 lbf/in²									Supernate liquid only transfer							Less than 140 gpm					

Legend (shaded cells): Exceeds 275 lbf/in²; Exceeds 400 lbf/in²; Supernate liquid only transfer; Less than 140 gpm.

Notes (AS):

New = new or like new pipeline with maximum expected pipe roughness of 2 mils (0.002 inches).

EOL = pipeline at end of life (50 years for carbon steel line, 40 years for stainless steel line) with pipe roughness due to corrosion estimated at 150 mils for carbon steel and 10 mils for stainless steel.

Design Pressure = All stainless steel pipelines have a design pressure of 400 lbf/in². The design pressure of carbon steel pipelines are either 275 or 400 lbf/in² as indicated. The predicted flow rate at design pressure given in this table assumes that all pipelines are or can be qualified to the higher 400 lbf/in² design pressure.

Table D-26. 3S6 Case 3c.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL	AM	AN	AO	AP	AQ	AR
1	CASE 3S6 Transfer List - Tank-to-Tank										Case 3c					Critical velocity by Oroskar and Turian (1980) empirical correlation (β_{cv} = 1.2). Pressure drop by Wasp et al. (1977) method with lognormal particle size distribution.																													
2											Group 1 Properties					Temperature = 10 °C						Temperature = 60 °C						Group 2 Properties					Temperature = 10 °C						Temperature = 60 °C					
3	Transfer		Tank Farm Built (Yr)		Transfer		3-in. Schedule-40 Pipe (3.068 in. inside dia.)			Total Change in Elevation (ft)	Liquid	Solids			ρ_m Bulk Density (kg/L)	Critical (κ_{cv} = 1.30, κ_f = 1)				Flow Rate at a Pipe Design Pressure of 400 lbf/in² (gpm)		Critical (κ_{cv} = 1.30, κ_f = 1)				Flow Rate at a Pipe Design Pressure of 400 lbf/in² (gpm)		Liquid	Solids			ρ_m Bulk Density (kg/L)	Critical (κ_{cv} = 1.30, κ_f = 1)				Flow Rate at a Pipe Design Pressure of 400 lbf/in² (gpm)		Critical (κ_{cv} = 1.30, κ_f = 1)				Flow Rate at a Pipe Design Pressure of 400 lbf/in² (gpm)	
4	From Tank	To Tank		#	Dates (M/Yr)		Design Pressure (lbf/in²)*	Carbon Steel Length (ft)	Stainless Steel Length (ft)		ρ_L Density (kg/L)	ρ_s Density (kg/L)	C_v Volume (%) times	d_p Median Dia. (μm)		Velocity (ft/s)	Flow Rate (gpm)	Total Pressure Drop (lbf/in²)				Velocity (ft/s)	Flow Rate (gpm)	Total Pressure Drop (lbf/in²)				ρ_L Density (kg/L)	ρ_s Density (kg/L)	C_v Volume (%) times	d_p Median Dia. (μm)		Velocity (ft/s)	Flow Rate (gpm)	Total Pressure Drop (lbf/in²)				Velocity (ft/s)	Flow Rate (gpm)	Total Pressure Drop (lbf/in²)			
5					Start	End							1.5					New	EOL	New	EOL			New	EOL	New	EOL			2.0					New	EOL	New	EOL			New	EOL	New	EOL
6	AN-101	AN-106	80-81	1	12/00	12/00		442	626	0	1.21	2.50	0.00	200	1.21	0.3	7	0	0	573	370	0.1	3	0	0	584	371	1.46	3.00	0.00	400	1.46	1.0	22	2	2	492	333	0.4	10	0	0	513	336
7		AP-103	83-86	1	7/03	7/03	400	306	2,774	12	1.21	2.50	0.00	200	1.21	0.3	7	7	7	328	257	0.1	3	6	6	338	260	1.46	3.00	0.00	400	1.46	1.0	22	12	13	275	227	0.4	10	9	9	292	232
8		AP-107	83-86	1	6/05	6/05	400	423	2,774	12	1.21	2.50	0.00	200	1.21	0.3	7	7	7	322	247	0.1	3	6	6	332	249	1.46	3.00	0.00	400	1.46	1.0	22	12	13	270	218	0.4	10	9	9	286	223
9		BNFL		7	2/11	12/19	400	0	6,413	40	1.21	2.50	0.50	200	1.22	3.0	70	66	80	219	187	3.3	76	71	89	227	189	1.46	3.00	0.67	400	1.47	3.2	73	103	114	179	161	3.4	79	103	120	192	166
10	AN-102	AP-107	83-86	1	3/10	3/10		828	3,184	12	1.21	2.50	0.06	200	1.21	2.2	50	22	30	286	210	2.4	55	22	34	295	212	1.46	3.00	0.08	400	1.46	2.3	52	34	43	238	186	2.5	56	33	46	254	190
11		BNFL		5	12/08	4/16		405	6,823	40	1.21	2.50	0.82	200	1.22	3.3	75	82	104	205	168	3.6	82	87	119	213	170	1.46	3.00	1.09	400	1.48	3.4	78	127	149	167	145	3.7	85	127	160	180	149
12	AN-103	AN-102	80-81	1	4/12	4/12		253	421	0	1.21	2.50	0.23	200	1.21	2.7	62	4	7	725	475	2.9	68	4	9	736	476	1.46	3.00	0.31	400	1.46	2.8	65	7	10	627	428	3.0	70	6	12	651	431
13		BNFL		9	4/14	6/19		376	6,823	40	1.21	2.50	0.82	200	1.22	3.3	75	82	104	206	169	3.6	82	87	118	214	171	1.46	3.00	1.10	400	1.48	3.4	79	127	148	168	146	3.7	85	127	160	180	150
14	AN-104	AN-101	80-81	3	6/05	2/16		562	626	0	1.21	2.50	0.50	200	1.22	3.0	70	9	18	541	341	3.3	76	9	22	552	342	1.46	3.00	0.67	400	1.47	3.2	73	14	25	463	306	3.4	79	14	29	485	309
15		AN-102	80-81	2	4/16	6/16		439	626	0	1.21	2.50	0.59	200	1.22	3.1	71	8	16	572	370	3.4	78	9	19	584	371	1.46	3.00	0.79	400	1.47	3.2	75	14	23	491	333	3.5	81	13	26	513	336
16		AN-103	80-81	2	4/14	8/14		410	626	0	1.21	2.50	0.98	200	1.22	3.3	77	9	18	579	378	3.6	84	10	22	591	379	1.46	3.00	1.30	400	1.48	3.5	81	15	26	497	339	3.8	87	15	29	519	343
17		AN-105	80-81	5	10/14	11/17		384	421	0	1.21	2.50	4.76	200	1.27	4.2	97	12	26	648	406	4.6	106	14	33	662	408	1.46	3.00	6.34	400	1.56	4.4	101	19	35	554	364	4.7	109	21	43	581	368
18		AN-106	80-81	2	8/13	10/13		374	421	0	1.21	2.50	5.05	200	1.28	4.2	98	12	26	651	409	4.6	107	14	33	665	412	1.46	3.00	6.73	400	1.56	4.4	102	19	36	556	367	4.8	110	21	43	584	371
19		AN-107	80-81	1	3/19	3/19		489	421	0	1.21	2.50	1.65	200	1.23	3.6	83	10	21	617	377	3.9	91	11	26	629	378	1.46	3.00	2.20	400	1.49	3.8	87	16	30	530	339	4.1	94	16	35	553	342
20		AP-101	83-86	4	10/13	2/17	400	419	2,636	12	1.21	2.50	3.27	200	1.25	4.0	92	47	68	325	249	4.4	100	52	83	336	251	1.46	3.00	4.36	400	1.53	4.2	96	73	96	271	219	4.5	103	77	110	289	223
21		AP-102	83-86	1	8/13	8/13	400	431	2,636	12	1.21	2.50	5.05	200	1.28	4.2	98	53	78	322	246	4.6	107	61	98	333	248	1.46	3.00	6.74	400	1.56	4.4	102	83	111	268	216	4.8	110	89	130	285	220
22		AP-104	83-86	1	11/17	11/17	400	314	2,636	12	1.21	2.50	4.75	200	1.27	4.2	97	50	71	329	257	4.6	106	58	88	340	259	1.46	3.00	6.34	400	1.56	4.4	101	79	101	274	225	4.7	109	84	118	292	230
23		AP-106	83-86	2	8/16	12/16	400	430	2,636	12	1.21	2.50	2.02	200	1.24	3.7	86	41	59	326	249	4.1	94	45	71	336	251	1.46	3.00	2.69	400	1.50	3.9	90	64	84	273	219	4.2	97	66	94	290	224
24		AP-108	83-86	1	7/18	7/18	400	443	2,636	12	1.21	2.50	1.86	200	1.23	3.7	85	40	58	326	248	4.0	93	44	69	336	250	1.46	3.00	2.48	400	1.50	3.8	89	63	82	272	219	4.1	96	65	93	289	223
25		AW-101	78-80	2	3/15	3/15		994	3,046	21	1.21	2.50	0.63	200	1.22	3.1	72	43	64	283	203	3.4	79	45	74	292	205	1.46	3.00	0.84	400	1.47	3.3	75	66	90	235	179	3.5	81	65	99	250	183
26		AW-103	78-80	2	11/15	11/15		1,012	3,046	21	1.21	2.50	0.63	200	1.22	3.1	72	43	65	282	202	3.4	79	45	75	291	204	1.46	3.00	0.84	400	1.47	3.3	75	66	91	234	179	3.5	81	66	99	249	182
27		AW-104	78-80	1	1/19	1/19		1,003	3,046	21	1.21	2.50	1.65	200	1.23	3.6	83	54	84	281	202	3.9	91	58	100	290	203	1.46	3.00	2.20	400	1.49	3.8	87	83	118	233	178	4.1	94	85	133	248	181
28		AW-105	78-80	1	7/18	7/18		1,125	3,046	21	1.21	2.50	1.86	200	1.23	3.7	85	57	91	276	196	4.0	93	62	110	286	197	1.46	3.00	2.48	400	1.50	3.8	89	88	127	229	173	4.1	96	90	145	244	176
29		AZ-101	71	1	10/10	10/10	400	562	1,560	5	1.21	2.50	4.24	200	1.26	4.1	95	33	56	393	277	4.5	104	38	71	405	279	1.46	3.00	5.65	400	1.55	4.3	99	52	79	330	246	4.6	107	56	93	350	250
30		BNFL		1	9/10	9/10	400	0	6,275	40	1.21	2.50	1.27	200	1.23	3.5	80	82	98	221	188	3.8	87	88	113	229	190	1.46	3.00	1.70	400	1.49	3.6	84	126	141	180	162	3.9	90	128	152	193	167
31	AN-105	AN-102	80-81	1	3/10	3/10		329	626	0	1.21	2.50	0.24	200	1.21	2.7	62	6	10	606	405	2.9	68	6	12	617	406	1.46	3.00	0.32	400	1.46	2.8	65	9	15	521	364	3.0	70	9	16	543	367
32		BNFL		3	8/12	5/17		452	7,028	40	1.21	2.50	1.26	200	1.23	3.5	80	93	120	201	164	3.8	87	101	140	209	166	1.46	3.00	1.68	400	1.49	3.6	84	145	173	163	141	3.9	90	147	188	176	145
33	AN-106	AW-102	78-80	6	11/04	1/06		1,242	3,389	21	1.21	2.50	0.00	200	1.21	0.3	7	12	12	264	188	0.1	3	11	11	273	189	1.46	3.00	0.00	400	1.46	1.0	22	20	22	219	166	0.4	10	15	15	233	169
34		BNFL		7	12/18	3/19		442	7,028	40	1.21	2.50	4.83	200	1.27	4.2	97	133	177	198	161	4.6	106	152	218	205	161	1.46	3.00	6.44	400	1.56	4.4	101	207	252	159		4.7	109	220		170	
35	AN-107	BNFL		1	7/11	7/11		557	7,028	40	1.21	2.50	0.34	200	1.21	2.9	66	70	89	200	162	3.1	72	73	99	208	164	1.46	3.00	0.46	400	1.47	3.0	69	108	127	163	140	3.2	74	107	134	176	145
36	AP-101	BNFL		2	4/06	12/16	400	419	5,370	28	1.21	2.50	1.14	200	1.22	3.4	79	69	90	232	187	3.7	86	74	105	241	189	1.46	3.00	1.52	400	1.48	3.6	82	107	129	191	163	3.9	89	108	141	204	167
37	AP-102	BNFL		9	7/18	12/18	400	431	5,370	28	1.21	2.50	0.23	200	1.21	2.7	62	48	60	233	188	2.9	67	50	67	242	190	1.46	3.00	0.30	400	1.46	2.8	65	74	86	192	163	3.0	70	72	90	205	168
38	AP-104	AP-107	83-86	1	1/13	1/13	400	737	421	0	1.21	2.50	0.00	200	1.21	0.3	7	0	0	550	323	0.1	3	0	0	561	323	1.46	3.00	0.00	400	1.46	1.0	22	2	3	471	291	0.4	10	0	1	492	293
39		BNFL		3	1/13	10/17	400	314	5,370	28	1.21	2.50	0.28	200	1.21	2.8	64	49	61	235	192	3.0	70	51	68	244	194	1.46	3.00	0.37	400	1.47	2.9	67	76	88	194	167	3.1	72	75	92	208	172
40	AP-105	AP-104	83-86	1	9/15	9/15	400	616	421	0	1.21	2.50	0.12	200	1.21	2.4	56	5	11	581	347	2.7	61	5	13	592	348	1.46	3.00	0.17	400	1.46	2.6	59	8	16	499	313	2.8	64	8	17	521	315
41		BNFL		1	2/18	2/18	400	302	5,370	28	1.21	2.50	0.12	200	1.21	2.4	56	42	51	236	193	2.7	61	43	56	245	195	1.46	3.00	0.17	400	1.46	2.6	59	64	73	194	168	2.8	64	62	75	208	173
42	AP-106	AN-102	80-81	1	10/13	10/13		745	3,184	-12	1.21	2.50	0.00	200	1.21	0.3	7	-6	-6	294	218	0.1	3	-6	-6	303	220	1.46	3.00	0.00	400	1.46	1.0	22	-2	0	246	193	0.4	10	-6	-6	262	198
43		BNFL		1	8/16	8/16	400	340	5,370	28	1.21	2.50	0.00	200	1.21	0.3	7	15	15	235	191	0.1	3	15	15	244	194	1.46	3.00	0.00	400	1.46	1.0	22	26	27	194	167	0.4	10	19	20	207	172
44	AP-107	AW-102	78-80	16	8/00	7/18		1,223	421	9	1.21	2.50	0.00	200	1.21	0.3	7	5	5	456	258	0.1	3	5	5	466	259	1.46	3.00	0.00	400	1.46	1.0	22	8	10	387	233	0.4	10	6	6	407	234
45	AP-108	BNFL		1	7/18	7/18	400	443	5,370	28	1.21	2.50	0.00	200	1.21	0.3	7	15	15	233	187	0.1	3	15	15	242	190	1.46	3.00	0.00	400	1.46	1.0	22	27	28	192	163	0.4	10	19	20	206	168
46	AW-101	AN-105	80-81	1	8/12	8/12		1,446	3,799	-21	1.21	2.50	0.19	200	1.21	2.6	60	17	37	254	180	2.8	65	19	45	263	182	1.46	3.00	0.25	400	1.46	2.7	63	35	57	212	160	2.9	68	33	64	226	163
47		BNFL		9	3/15	8/19		994	5,780	19	1.21	2.50	0.60	200	1.22	3.1	72	62	89	216	166	3.4	78	66	103	224	168	1.46	3.00	0.80	400	1.47	3.3	75	99	128	177	145	3.5	81	98	139	190	149
48	AW-103	AW-104	78-80	1	10/15	11/15		2,015	1,241	0	1.21	2.50	5.99	200	1.29	4.3	100	52	126	314	188	4.7	109	62	165	325	187	1.46	3.00	7.98	400	1.58	4.5	104	84	172	260	167	4.9	112	91	214	278	166
49		AY-102	68-70	1	12/13	12/13		1,012	3,320	-10	1.21	2.50	5.99	200	1.29	4.3	100	64	113	272	197	4.7	109	76	148	282	197	1.46	3.00	7.98	400	1.58	4.5	104	105	161	225	173	4.9	112	115	196	241	175
50		BNFL		8	8/19	10/19		1,012	5,780	19	1.21	2.50	3.13	200	1.25	4.0	91	98	146	213	163	4.3	100	110	179	221	163	1.46	3.00	4.17	400	1.52	4.1	95	155	208	174	141	4.5	103	163	239	186	143
51	AW-104	AP-104	83-86	1	1/13	1/13		1,317	831	-9	1.21	2.50	0.29	200	1.21	2.8	64	9	26	401	240	3.0	70	9	32	412	241	1.46	3.00	0.39	400	1.47	2.9	67	17	37	340	216	3.1	72	16	43	359	218
52		AW-102	78-80	3	6/01	1/02		203	421	0	1.21	2.50	0.00	200	1.21	0.3	7	0	0	755	507	0.1	3	0	0	766	509	1.46	3.00	0.00	400	1.46	1.0	22	1	1	654	456	0.4	10	0	0	678	460
53		BNFL		6	4/18	1/19		1,003	5,780	19	1.21	2.50	2.46	200	1.24	3.8	88	91	135	214	164	4.2	96	102	164	222	165	1.46	3.00	3.28	400	1.51	4.0	92	145	193	175	142	4.3	99	150	219	187	145
54	AW-105	BNFL		7	1/18	7/18		1,125	5,780	19	1.21	2.50	2.40	200	1.24	3.8	88	92	138	212	161	4.2	96	102	169	220	162	1.46	3.00	3.20	400	1.51	4.0	92	146	197	173		4.3	99	151	225	185	142
55	AW-106	AP-105	83-86	2	10/04	6/05		1,416	831	-9	1.21	2.50	0.00	200	1.21	0.3	7	-4	-4	393	233	0.1	3	-5	-5	403	234	1.46	3.00	0.00	400	1.46	1.0	22	-2	0	332	210	0.4	10	-5	-5	351	212
56		AP-106	83-86	2	4/01	1/02		1,454	831	-9	1.21	2.50	0.00	200	1.21	0.3	7	-4	-4	389	231	0.1	3	-5	-5	399	231	1.46	3.00	0.00	400	1.46	1.0	22	-2	0	329	208	0.4	10	-5	-5	348	210
57		AP-108	83-86	1	3/09	3/09		1,557	831	-9	1.21	2.50	0.00	200	1.21	0.3	7	-4	-4	380	224	0.1	3	-5	-5	390	225	1.46	3.00	0.00	400	1.46	1.0	22	-2	0	322	202	0.4	10	-5	-5	340	204
58		AW-102	78-80	13	12/01	7/18		314	421	0	1.21	2.50	0.00	200	1.21	0.3	7	0	0	694	444	0.1	3	0	0	706	445	1.46	3.00	0.00	400	1.46	1.0	22	1	2	600	400	0.4	10	0	0	623	403
59		AW-103	78-80	1	10/04	10/04		2,126	1,241	0	1.21	2.50	0.00	200	1.21	0.3	7	0	1	316	189	0.1	3	0	0	326	190	1.46	3.00	0.00	400	1.46	1.0	22	5	8	265	170	0.4	10	1	1	281	172
60		AW-104	78-80	2	1/02	8/02		341	421	0	1.21	2.50	0.00	200	1.21	0.3	7	0	0	681	432	0.1	3	0	0	693	433	1.46	3.00	0.00	400	1.46	1.0	22	1	2	588	389	0.4	10	0	0	612	392
61		AW-105	78-80	1	6/05	6/05		2,239	1,241	0	1.21	2.50	0.00	200	1.21	0.3	7	0	1	311	185	0.1	3	0	0	320	186	1.46	3.00	0.00	400	1.46	1.0	22	5	8	260	166	0.4	10	1	2	276	168
62	AY-101	BNFL		12	1/11	10/13	400	0	6,924	30	1.21	2.50	9.68	200	1.33	4.6	106	148	186	202	173	5.0	116	177	238	209	171	1.46	3.00	12.90	400	1.66	4.8	110	232	268	161	145	5.1	118	255	317	171	144
63	AY-102	AN-103	80-81	1	11/19	11/19		376	1,733	-11	1.21	2.50	1.31	200	1.23	3.5	81	15	27	404	299	3.8	88	17	34	415	301	1.46	3.00	1.75	400	1.49	3.7	84	27	40	342	266	3.9	91	27	46	361	271
64		AN-106	80-81	2	5/19	11/19		142	1,938	-11	1.21	2.50	1.33	200	1.23	3.5	81	14	22	407	324	3.8	88	16	28	418	327	1.46	3.00	1.77	400	1.49	3.7	84	26	35	345	287	3.9	91	27	39	364	294
65		AP-102	83-86	1	12/18	12/18	400	431	2,910	2	1.21	2.50	1.96	200	1.24	3.7	85	38	56	315	242	4.0	93	42	69	324	244	1.46	3.00	2.61	400	1.50	3.9	89	62	82	263	213	4.2	96	64	93	280	218
66		BNFL		16	1/09	2/18	400	0	6,549	30	1.21	2.50	9.18	200	1.33	4.6	105	138	173	209	178	5.0	115	165	221	217	177	1.46	3.00	12.24	400	1.65	4.7	109	217	250	167	150	5.1	118	238	295	178	151
67	AZ-101	BNFL		10	10/06	8/15	400	0	6,171	36	1.21	2.50	4.11	200	1.26	4.1	95	107	131	220	188	4.5	104	121	159	228	189	1.46	3.00	5.48	400	1.54	4.3	99	165	189	179	160	4.6	107	174	213	191	164
68	AZ-102	BNFL		6	7/07	3/08	400	0	6,556	36	1.21	2.50	2.65	200	1.24	3.9	89	99	121	215	183	4.2	97	110	144	223	185	1.46	3.00	3.53	400	1.51	4.0	93	154	175	175	157	4.4	100	160	194	187	181
69	BNFL internal equivalent pipe length and elevation								884	45	included in BNFL routes						Exceeds 275 lbf/in²						Exceeds 400 lbf/in²										Supernate liquid only transfer						Less than 140 gpm					

Notes (column AS):

New = new or like new pipeline with maximum expected pipe roughness of 2 mils (0.002 inches).

EOL = pipeline at end of life (50 years for carbon steel line, 40 years for stainless steel line) with pipe roughness due to corrosion estimated at 150 mils for carbon steel and 10 mils for stainless steel.

*Design Pressure = All stainless steel pipelines have a design pressure of 400 lbf/in². The design pressure of carbon steel pipelines are either 275 or 400 lbf/in² as indicated. The predicted flow rate at design pressure given in this table assumes that all pipelines are or can be qualified to the higher 400 lbf/in² design pressure.

Table D-27. 3S6 Case 3d.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL	AM	AN	AO	AP	AQ	AR
1	CASE 3S6 Transfer List - Tank-to-Tank										Case 3d					Critical velocity by Oroskar and Turian (1980) empirical correlation (β_{cv} = 1.2). Pressure drop by Wasp et al. (1977) method with lognormal particle size distribution.																													
2											Group 1 Properties					Temperature = 10 °C						Temperature = 60 °C						Group 2 Properties					Temperature = 10 °C						Temperature = 60 °C					
3	Transfer				Transfer			3-in. Schedule-40 Pipe (3.068 in. inside dia.)			Liquid	Solids				Critical (κ_{cv} = 1.30, κ_f = 1)				Flow Rate at a Pipe Design Pressure of 400 lbf/in² (gpm)		Critical (κ_{cv} = 1.30, κ_f = 1)				Flow Rate at a Pipe Design Pressure of 400 lbf/in² (gpm)		Liquid	Solids				Critical (κ_{cv} = 1.30, κ_f = 1)				Flow Rate at a Pipe Design Pressure of 400 lbf/in² (gpm)		Critical (κ_{cv} = 1.30, κ_f = 1)				Flow Rate at a Pipe Design Pressure of 400 lbf/in² (gpm)	
4	From Tank	To Tank	Tank Farm Built (Yr)	#	Dates (M/Yr)		Design Pressure (lbf/in²)*	Carbon Steel Length (ft)	Stainless Steel Length (ft)	Total Change in Elevation (ft)	ρ_L Density (kg/L)	ρ_s Density (kg/L)	C_s Volume (%) times	d_p Median Dia. (µm)	ρ_m Bulk Density (kg/L)	Velocity (ft/s)	Flow Rate (gpm)	Total Pressure Drop (lbf/in²)				Velocity (ft/s)	Flow Rate (gpm)	Total Pressure Drop (lbf/in²)				ρ_L Density (kg/L)	ρ_s Density (kg/L)	C_s Volume (%) times	d_p Median Dia. (µm)	ρ_m Bulk Density (kg/L)	Velocity (ft/s)	Flow Rate (gpm)	Total Pressure Drop (lbf/in²)				Velocity (ft/s)	Flow Rate (gpm)	Total Pressure Drop (lbf/in²)			
5					Start	End							1.5					New	EOL	New	EOL			New	EOL	New	EOL			2.0					New	EOL	New	EOL			New	EOL	New	EOL
6	AN-101	AN-106	80-81	1	12/00	12/00		442	626	0	1.10	2.50	0.00	200	1.10	0.2	6	0	0	605	389	0.1	2	0	0	614	390	1.20	3.00	0.00	400	1.20	0.3	7	0	0	576	372	0.1	2	0	0	587	373
7		AP-103	83-86	1	7/03	7/03	400	306	2,774	12	1.10	2.50	0.00	200	1.10	0.2	6	6	6	348	271	0.1	2	6	6	357	273	1.20	3.00	0.00	400	1.20	0.3	7	7	7	330	259	0.1	2	6	6	340	261
8		AP-107	83-86	1	6/05	6/05	400	423	2,774	12	1.10	2.50	0.00	200	1.10	0.2	6	6	6	341	260	0.1	2	6	6	350	262	1.20	3.00	0.00	400	1.20	0.3	7	7	7	324	248	0.1	2	6	6	333	250
9		BNFL		7	2/11	12/19	400	0	6,413	40	1.10	2.50	0.50	200	1.11	3.4	78	71	85	233	197	3.7	85	75	97	240	199	1.20	3.00	0.67	400	1.21	4.3	99	113	140	219	186	4.7	108	123	163	227	188
10	AN-102	AP-107	83-86	1	3/10	3/10		828	3,184	12	1.10	2.50	0.06	200	1.10	2.4	56	23	33	303	221	2.7	61	23	37	312	223	1.20	3.00	0.08	400	1.20	3.1	71	36	54	288	211	3.4	77	37	61	297	213
11		BNFL		5	12/08	4/16		405	6,823	40	1.10	2.50	0.82	200	1.11	3.7	84	87	113	218	177	4.0	92	94	132	226	179	1.20	3.00	1.09	400	1.22	4.6	106	144	194	205	166	5.0	116	159	230	212	166
12	AN-103	AN-102	80-81	1	4/12	4/12		253	421	0	1.10	2.50	0.23	200	1.10	3.0	70	4	8	764	498	3.3	76	5	10	774	500	1.20	3.00	0.31	400	1.21	3.8	88	8	15	728	477	4.2	96	8	18	740	478
13		BNFL		9	4/14	6/19		376	6,823	40	1.10	2.50	0.82	200	1.11	3.7	84	86	113	219	178	4.0	92	94	132	226	179	1.20	3.00	1.10	400	1.22	4.6	106	144	193	205	167	5.0	116	159	229	212	167
14	AN-104	AN-101	80-81	3	6/05	2/16		562	626	0	1.10	2.50	0.50	200	1.11	3.4	78	9	21	571	357	3.7	86	10	25	581	359	1.20	3.00	0.67	400	1.21	4.3	99	17	37	544	342	4.7	108	19	46	555	343
15		AN-102	80-81	2	4/16	6/16		439	626	0	1.10	2.50	0.59	200	1.11	3.5	80	9	16	604	388	3.8	88	10	22	614	390	1.20	3.00	0.79	400	1.21	4.4	101	16	34	575	371	4.8	110	18	41	586	373
16		AN-103	80-81	2	4/14	8/14		410	626	0	1.10	2.50	0.98	200	1.11	3.8	86	10	21	611	396	4.1	94	11	26	622	398	1.20	3.00	1.30	400	1.22	4.7	109	19	38	582	379	5.2	119	21	48	594	380
17		AN-105	80-81	5	10/14	11/17		384	421	0	1.10	2.50	4.76	200	1.17	4.7	109	13	30	683	424	5.2	119	16	39	696	427	1.20	3.00	6.34	400	1.31	5.9	137	26	60	651	404	6.5	149	32	79	666	406
18		AN-106	80-81	2	8/13	10/13		374	421	0	1.10	2.50	5.05	200	1.17	4.8	110	14	30	686	428	5.2	120	16	40	700	430	1.20	3.00	6.73	400	1.32	6.0	138	27	60	654	407	6.5	150	32	80	670	409
19		AN-107	80-81	1	3/19	3/19		489	421	0	1.10	2.50	1.65	200	1.12	4.1	93	11	25	651	395	4.4	102	12	31	662	396	1.20	3.00	2.20	400	1.24	5.1	118	20	46	620	377	5.6	129	23	59	633	378
20		AP-101	83-86	4	10/13	2/17	400	419	2,636	12	1.10	2.50	3.27	200	1.15	4.5	103	51	76	345	261	4.9	113	59	96	354	263	1.20	3.00	4.36	400	1.28	5.6	130	93	144	326	246	6.1	142	109	182	334	244
21		AP-102	83-86	1	8/13	8/13	400	431	2,636	12	1.10	2.50	5.05	200	1.17	4.8	110	58	89	341	258	5.2	120	69	114	351	259	1.20	3.00	6.74	400	1.32	6.0	138	110	172	322	241	6.5	150	132	223	329	237
22		AP-104	83-86	1	11/17	11/17	400	314	2,636	12	1.10	2.50	4.75	200	1.17	4.7	109	55	81	349	270	5.2	119	65	103	358	271	1.20	3.00	6.34	400	1.31	5.9	136	104	155	329	253	6.5	149	124	200	337	250
23		AP-106	83-86	2	8/16	12/16	400	430	2,636	12	1.10	2.50	2.02	200	1.13	4.2	96	44	66	346	262	4.6	105	50	81	355	263	1.20	3.00	2.69	400	1.25	5.3	121	79	121	327	248	5.7	132	90	150	336	248
24		AP-108	83-86	1	7/18	7/18	400	443	2,636	12	1.10	2.50	1.86	200	1.13	4.1	95	43	65	345	261	4.5	104	49	79	354	262	1.20	3.00	2.48	400	1.24	5.2	120	77	118	327	247	5.7	131	88	146	336	247
25		AW-101	78-80	2	3/15	3/15		994	3,046	21	1.10	2.50	0.63	200	1.11	3.5	81	45	70	300	214	3.8	88	48	83	308	215	1.20	3.00	0.84	400	1.22	4.4	102	74	121	284	203	4.8	111	81	145	292	203
26		AW-103	78-80	2	11/15	11/15		1,012	3,046	21	1.10	2.50	0.63	200	1.11	3.5	81	45	71	299	213	3.8	88	48	84	307	214	1.20	3.00	0.84	400	1.22	4.4	102	74	122	283	202	4.8	111	81	146	292	202
27		AW-104	78-80	1	1/19	1/19		1,003	3,046	21	1.10	2.50	1.65	200	1.12	4.1	93	57	94	298	212	4.4	102	64	115	307	213	1.20	3.00	2.20	400	1.24	5.1	118	100	169	281	200	5.6	129	113	209	289	198
28		AW-105	78-80	1	7/18	7/18		1,125	3,046	21	1.10	2.50	1.86	200	1.13	4.1	95	61	102	293	206	4.5	104	68	126	302	207	1.20	3.00	2.48	400	1.24	5.2	120	106	185	277	193	5.7	131	121	231	284	190
29		AZ-101	71	1	10/10	10/10	400	562	1,560	5	1.10	2.50	4.24	200	1.16	4.6	107	37	64	416	291	5.1	117	43	83	427	292	1.20	3.00	5.65	400	1.30	5.8	134	69	125	395	275	6.4	147	83	162	405	273
30		BNFL		1	9/10	9/10	400	0	6,275	40	1.10	2.50	1.27	200	1.12	3.9	90	87	107	235	198	4.3	98	95	126	242	200	1.20	3.00	1.70	400	1.23	4.9	113	146	184	220	186	5.4	124	163	220	226	185
31	AN-105	AN-102	80-81	1	3/10	3/10		329	626	0	1.10	2.50	0.24	200	1.10	3.0	70	6	12	639	425	3.3	76	7	14	650	426	1.20	3.00	0.32	400	1.21	3.8	88	11	21	609	407	4.2	96	12	25	620	408
32		BNFL		3	8/12	5/17		452	7,028	40	1.10	2.50	1.26	200	1.12	3.9	90	99	132	214	173	4.3	98	110	157	221	174	1.20	3.00	1.68	400	1.23	4.9	113	169	232	200	161	5.4	124	190		206	159
33	AN-106	AW-102	78-80	6	11/04	1/06		1,242	3,389	21	1.10	2.50	0.00	200	1.10	0.2	6	10	10	280	198	0.1	2	10	10	288	199	1.20	3.00	0.00	400	1.20	0.3	7	11	12	265	189	0.1	2	11	11	274	190
34		BNFL		7	12/18	3/19		442	7,028	40	1.10	2.50	4.83	200	1.17	4.7	109	146	199	210	169	5.2	119	171	252	215	166	1.20	3.00	6.44	400	1.32	5.9	137	270		188	144	6.5	149			185	
35	AN-107	BNFL		1	7/11	7/11		557	7,028	40	1.10	2.50	0.34	200	1.10	3.2	74	73	95	213	171	3.5	81	78	109	221	173	1.20	3.00	0.46	400	1.21	4.0	93	118	158	201	162	4.4	102	126	183	208	163
36	AP-101	BNFL		2	4/06	12/16	400	419	5,370	28	1.10	2.50	1.14	200	1.12	3.8	88	73	99	247	197	4.2	97	81	118	255	199	1.20	3.00	1.52	400	1.23	4.8	112	125	174	232	186	5.3	122	140	209	239	185
37	AP-102	BNFL		9	7/18	12/18	400	431	5,370	28	1.10	2.50	0.23	200	1.10	3.0	69	50	64	248	198	3.3	76	52	73	255	200	1.20	3.00	0.30	400	1.21	3.8	87	79	106	234	188	4.1	95	84	122	242	190
38	AP-104	AP-107	83-86	1	1/13	1/13	400	737	421	0	1.10	2.50	0.00	200	1.10	0.2	6	0	0	580	339	0.1	2	0	0	590	339	1.20	3.00	0.00	400	1.20	0.3	7	0	0	552	324	0.1	2	0	0	563	325
39		BNFL		3	1/13	10/17	400	314	5,370	28	1.10	2.50	0.28	200	1.10	3.1	72	51	66	250	203	3.4	78	54	75	258	205	1.20	3.00	0.37	400	1.21	3.9	90	82	108	236	193	4.3	99	88	125	245	194
40	AP-105	AP-104	83-86	1	9/15	9/15	400	616	421	0	1.10	2.50	0.12	200	1.10	2.7	63	5	13	613	364	3.0	69	6	15	623	365	1.20	3.00	0.17	400	1.20	3.5	80	10	22	584	348	3.8	87	10	27	595	349
41		BNFL		1	2/18	2/18	400	302	5,370	28	1.10	2.50	0.12	200	1.10	2.7	63	43	54	251	203	3.0	69	45	60	259	205	1.20	3.00	0.17	400	1.20	3.5	80	67	86	237	193	3.8	87	70	98	245	196
42	AP-106	AN-102	80-81	1	10/13	10/13		745	3,184	-12	1.10	2.50	0.00	200	1.10	0.2	6	-5	-5	311	229	0.1	2	-6	-6	320	231	1.20	3.00	0.00	400	1.20	0.3	7	-6	-6	296	219	0.1	2	-6	-6	305	221
43		BNFL		1	8/16	8/16	400	340	5,370	28	1.10	2.50	0.00	200	1.10	0.2	6	14	14	250	202	0.1	2	13	13	258	204	1.20	3.00	0.00	400	1.20	0.3	7	15	15	237	192	0.1	2	15	15	245	195
44	AP-107	AW-102	78-80	16	8/00	7/18		1,223	421	9	1.10	2.50	0.00	200	1.10	0.2	6	4	4	482	271	0.1	2	4	4	491	272	1.20	3.00	0.00	400	1.20	0.3	7	5	5	458	259	0.1	2	5	5	469	260
45	AP-108	BNFL		1	7/18	7/18	400	443	5,370	28	1.10	2.50	0.00	200	1.10	0.2	6	14	14	248	198	0.1	2	13	13	256	200	1.20	3.00	0.00	400	1.20	0.3	7	15	15	234	188	0.1	2	15	15	243	191
46	AW-101	AN-105	80-81	1	8/12	8/12		1,446	3,799	-21	1.10	2.50	0.19	200	1.10	2.9	67	21	45	269	189	3.2	73	23	55	277	191	1.20	3.00	0.25	400	1.20	3.7	85	44	87	255	181	4.0	93	48	105	264	182
47		BNFL		9	3/15	8/19		994	5,780	19	1.10	2.50	0.60	200	1.11	3.5	80	66	98	229	175	3.8	88	72	116	237	176	1.20	3.00	0.80	400	1.21	4.4	101	114	173	216	165	4.8	111	125	206	223	165
48	AW-103	AW-104	78-80	1	10/15	11/15		2,015	1,241	0	1.10	2.50	5.99	200	1.18	4.9	112	59	148	332	196	5.3	123	72	197	342	194	1.20	3.00	7.98	400	1.34	6.1	141	118		313	175	6.7	153	144		320	153
49		AY-102	68-70	1	12/13	12/13		1,012	3,320	-10	1.10	2.50	5.99	200	1.18	4.9	112	73	133	288	206	5.3	123	91	178	297	204	1.20	3.00	7.98	400	1.34	6.1	141	151	274	269	185	6.7	153	186		273	169
50		BNFL		8	8/19	10/19		1,012	5,780	19	1.10	2.50	3.13	200	1.14	4.5	103	107	166	226	171	4.9	112	125	209	233	170	1.20	3.00	4.17	400	1.28	5.6	129	199		209	154	6.1	141	234		212	141
51	AW-104	AP-104	83-86	1	1/13	1/13		1,317	831	-9	1.10	2.50	0.29	200	1.10	3.1	72	10	31	424	252	3.4	79	11	38	433	252	1.20	3.00	0.39	400	1.21	3.9	91	21	58	403	241	4.3	99	24	71	413	241
52		AW-102	78-80	3	6/01	1/02		203	421	0	1.10	2.50	0.00	200	1.10	0.2	6	0	0	796	532	0.1	2	0	0	806	534	1.20	3.00	0.00	400	1.20	0.3	7	0	0	758	509	0.1	2	0	0	770	511
53		BNFL		6	4/18	1/19		1,003	5,780	19	1.10	2.50	2.46	200	1.13	4.3	99	100	153	227	172	4.7	108	114	190	234	172	1.20	3.00	3.28	400	1.26	5.4	125	182		211	157	5.9	136	211		215	149
54	AW-105	BNFL		7	1/18	7/18		1,125	5,780	19	1.10	2.50	2.40	200	1.13	4.3	99	101	157	225	169	4.7	108	115	195	232	168	1.20	3.00	3.20	400	1.26	5.4	124	183		209	154	5.9	136	213		213	145
55	AW-106	AP-105	83-86	2	10/04	6/05		1,416	831	-9	1.10	2.50	0.00	200	1.10	0.2	6	-4	-4	415	245	0.1	2	-4	-4	424	245	1.20	3.00	0.00	400	1.20	0.3	7	-4	-4	395	234	0.1	2	-5	-5	405	235
56		AP-106	83-86	2	4/01	1/02		1,454	831	-9	1.10	2.50	0.00	200	1.10	0.2	6	-4	-4	411	242	0.1	2	-4	-4	420	243	1.20	3.00	0.00	400	1.20	0.3	7	-4	-4	391	232	0.1	2	-5	-5	401	232
57		AP-108	83-86	1	3/09	3/09		1,557	831	-9	1.10	2.50	0.00	200	1.10	0.2	6	-4	-4	402	235	0.1	2	-4	-4	411	236	1.20	3.00	0.00	400	1.20	0.3	7	-4	-4	382	225	0.1	2	-5	-5	392	226
58		AW-102	78-80	13	12/01	7/18		314	421	0	1.10	2.50	0.00	200	1.10	0.2	6	0	0	732	466	0.1	2	0	0	742	467	1.20	3.00	0.00	400	1.20	0.3	7	0	0	697	446	0.1	2	0	0	709	447
59		AW-103	78-80	1	10/04	10/04		2,126	1,241	0	1.10	2.50	0.00	200	1.10	0.2	6	0	0	335	199	0.1	2	0	0	343	199	1.20	3.00	0.00	400	1.20	0.3	7	0	1	318	190	0.1	2	0	0	327	191
60		AW-104	78-80	2	1/02	8/02		341	421	0	1.10	2.50	0.00	200	1.10	0.2	6	0	0	718	453	0.1	2	0	0	729	454	1.20	3.00	0.00	400	1.20	0.3	7	0	0	685	434	0.1	2	0	0	696	435
61		AW-105	78-80	1	6/05	6/05		2,239	1,241	0	1.10	2.50	0.00	200	1.10	0.2	6	0	0	329	194	0.1	2	0	0	338	195	1.20	3.00	0.00	400	1.20	0.3	7	0	1	313	186	0.1	2	0	0	322	187
62	AY-101	BNFL		12	1/11	10/13	400	0	6,924	30	1.10	2.50	9.68	200	1.24	5.2	119	165	214	215	180	5.6	130	204	281	219	174	1.20	3.00	12.90	400	1.43	6.4	148	327		183		7.0	162			155	
63	AY-102	AN-103	80-81	1	11/19	11/19		376	1,733	-11	1.10	2.50	1.31	200	1.12	3.9	90	17	32	427	314	4.3	99	20	41	437	316	1.20	3.00	1.75	400	1.23	4.9	114	36	64	406	300	5.4	124	42	80	416	301
64		AN-106	80-81	2	5/19	11/19		142	1,938	-11	1.10	2.50	1.33	200	1.12	3.9	91	17	27	430	341	4.3	99	20	34	440	343	1.20	3.00	1.77	400	1.23	5.0	114	36	54	409	325	5.4	125	42	68	419	327
65		AP-102	83-86	1	12/18	12/18	400	431	2,910	2	1.10	2.50	1.96	200	1.13	4.2	96	42	65	333	254	4.5	105	48	80	342	256	1.20	3.00	2.61	400	1.25	5.2	121	78	122	315	241	5.7	132	91	152	324	240
66		BNFL		16	1/09	2/18	400	0	6,549	30	1.10	2.50	9.18	200	1.23	5.1	118	155	199	222	186	5.6	129	190	261	227	182	1.20	3.00	12.24	400	1.42	6.4	148	303	397	193	149	7.0	161	377		176	
67	AZ-101	BNFL		10	10/06	8/15	400	0	6,171	36	1.10	2.50	4.11	200	1.16	4.6	107	116	147	234	197	5.1	116	135	182	241	197	1.20	3.00	5.48	400	1.30	5.8	134	211	273	215	179	6.3	146	250	344	217	169
68	AZ-102	BNFL		6	7/07	3/08	400	0	6,556	36	1.10	2.50	2.65	200	1.14	4.3	100	107	135	228	193	4.8	109	122	164	235	193	1.20	3.00	3.53	400	1.26	5.5	126	190	244	212	177	6.0	138	220	302	216	172
69	BNFL internal equivalent pipe length and elevation								884	45	included in BNFL routes						Exceeds 275 lbf/in²						Exceeds 400 lbf/in²						Supernate liquid only transfer							Less than 140 gpm							

Notes (column AS):

New = new or like new pipeline with maximum expected pipe roughness of 2 mils (0.002 inches).

EOL = pipeline at end of life (50 years for carbon steel line, 40 years for stainless steel line) with pipe roughness due to corrosion estimated at 150 mils for carbon steel and 10 mils for stainless steel.

***Design Pressure** = All stainless steel pipelines have a design pressure of 400 lbf/in². The design pressure of carbon steel pipelines are either 275 or 400 lbf/in² as indicated. The predicted flow rate at design pressure given in this table assumes that all pipelines are or can be qualified to the higher 400 lbf/in² design pressure.

Table D-28. 3S6 Case 4.

CASE 3S6 Transfer List - Tank-to-Tank

Row	Transfer From Tank	Transfer To Tank	Tank Farm Built (Yr)	Transfer #	Dates (M/Yr) Start	Dates (M/Yr) End	Design Pressure (lbf/in²)	3-in. Schedule-40 Pipe (3.068 in. inside dia.) Carbon Steel Length (ft)	Stainless Steel Length (ft)	Total Change in Elevation (ft)
6	AN-101	AN-106	80-81	1	12/00	12/00		442	626	0
7		AP-103	83-86	1	7/03	7/03	400	306	2,774	12
8		AP-107	83-86	1	6/05	6/05	400	423	2,774	12
9		BNFL		7	2/11	12/19	400	0	6,413	40
10	AN-102	AP-107	83-86	1	3/10	3/10		828	3,184	12
11		BNFL		5	12/08	4/16		405	6,823	40
12	AN-103	AN-102	80-81	1	4/12	4/12		253	421	0
13		BNFL		9	4/14	6/19		376	6,823	40
14	AN-104	AN-101	80-81	3	6/05	2/16		562	626	0
15		AN-102	80-81	2	4/16	6/16		439	626	0
16		AN-103	80-81	2	4/14	8/14		410	626	0
17		AN-105	80-81	5	10/14	11/17		384	421	0
18		AN-106	80-81	2	8/13	10/13		374	421	0
19		AN-107	80-81	1	3/19	3/19		489	421	0
20		AP-101	83-86	4	10/13	2/17	400	419	2,636	12
21		AP-102	83-86	1	8/13	8/13	400	431	2,636	12
22		AP-104	83-86	1	11/17	11/17	400	314	2,636	12
23		AP-106	83-86	2	8/16	12/16	400	430	2,636	12
24		AP-108	83-86	1	7/18	7/18	400	443	2,636	12
25		AW-101	78-80	2	3/15	3/15		994	3,046	21
26		AW-103	78-80	2	11/15	11/15		1,012	3,046	21
27		AW-104	78-80	1	1/19	1/19		1,003	3,046	21
28		AW-105	78-80	1	7/18	7/18		1,125	3,046	21
29		AZ-101	71	1	10/10	10/10	400	562	1,560	5
30		BNFL		1	9/10	9/10	400	0	6,275	40
31	AN-105	AN-102	80-81	1	3/10	3/10		329	626	0
32		BNFL		3	8/12	5/17		452	7,028	40
33	AN-106	AW-102	78-80	6	11/04	1/06		1,242	3,389	21
34		BNFL		7	12/18	3/19		442	7,028	40
35	AN-107	BNFL		1	7/11	7/11		557	7,028	40
36	AP-101	BNFL		2	4/06	12/16	400	419	5,370	28
37	AP-102	BNFL		9	7/18	12/18	400	431	5,370	28
38	AP-104	AP-107	83-86	1	1/13	1/13	400	737	421	0
39		BNFL		3	1/13	10/17	400	314	5,370	28
40	AP-105	AP-104	83-86	1	9/15	9/15	400	616	421	0
41		BNFL		1	2/18	2/18	400	302	5,370	28
42	AP-106	AN-102	80-81	1	10/13	10/13		745	3,184	-12
43		BNFL		1	8/16	8/16	400	340	5,370	28
44	AP-107	AW-102	78-80	16	8/00	7/18		1,223	421	9
45	AP-108	BNFL		1	7/18	7/18	400	443	5,370	28
46	AW-101	AN-105	80-81	1	8/12	8/12		1,446	3,799	-21
47		BNFL		9	3/15	8/19		994	5,780	19
48	AW-103	AW-104	78-80	1	10/15	11/15		2,015	1,241	0
49		AY-102	68-70	1	12/13	12/13		1,012	3,320	-10
50		BNFL		8	8/19	10/19		1,012	5,780	19
51	AW-104	AP-104	83-86	1	1/13	1/13		1,317	831	-9
52		AW-102	78-80	3	6/01	1/02		203	421	0
53		BNFL		6	4/18	1/19		1,003	5,780	19
54	AW-105	BNFL		7	1/18	7/18		1,125	5,780	19
55	AW-106	AP-105	83-86	2	10/04	6/05		1,416	831	-9
56		AP-106	83-86	2	4/01	1/02		1,454	831	-9
57		AP-108	83-86	1	3/09	3/09		1,557	831	-9
58		AW-102	78-80	13	12/01	7/18		314	421	0
59		AW-103	78-80	1	10/04	10/04		2,126	1,241	0
60		AW-104	78-80	2	1/02	8/02		341	421	0
61		AW-105	78-80	1	6/05	6/05		2,239	1,241	0
62	AY-101	BNFL		12	1/11	10/13	400	0	6,924	30
63	AY-102	AN-103	80-81	1	11/19	11/19		376	1,733	-11
64		AN-106	80-81	2	5/19	11/19		142	1,938	-11
65		AP-102	83-86	1	12/18	12/18	400	431	2,910	2
66		BNFL		16	1/09	2/18	400	0	6,549	30
67	AZ-101	BNFL		10	10/06	8/15	400	0	6,171	36
68	AZ-102	BNFL		6	7/07	3/08	400	0	6,556	36
69	BNFL internal equivalent pipe length and elevation								884	45

Case 4 — Critical velocity by Oroskar and Turian (1980) empirical correlation (β_{cv} = 1.2). Pressure drop by Wasp et al. (1977) method with lognormal particle size distribution.

Group 1 Properties

Row	Liquid ρ_L Density (kg/L)	Solids ρ_s Density (kg/L)	C_v Volume (%)	d_p Median Dia. (μm)	ρ_m Bulk Density (kg/L)	10 °C Critical (κ_{cv} = 1.30, κ_f = 1) Velocity (ft/s)	10 °C Flow Rate (gpm)	10 °C Total Pressure Drop (lbf/in²) New	10 °C Total Pressure Drop EOL	10 °C Flow Rate at a Pipe Design Pressure of 400 lbf/in² (gpm) New	10 °C Flow Rate EOL	60 °C Critical (κ_{cv} = 1.30, κ_f = 1) Velocity (ft/s)	60 °C Flow Rate (gpm)	60 °C Total Pressure Drop (lbf/in²) New	60 °C Total Pressure Drop EOL	60 °C Flow Rate at a Pipe Design Pressure of 400 lbf/in² (gpm) New	60 °C Flow Rate EOL
6	1.20	3.00	10	400	1.38	6.3	144	43	91	556	357	6.8	157	53	123	572	356
7	1.20	3.00	10	400	1.38	6.3	144	130	194	317	242	6.8	157	160	256	323	235
8	1.20	3.00	10	400	1.38	6.3	144	134	209	310	231	6.8	157	165	277	316	222
9	1.20	3.00	10	400	1.38	6.3	144	279	363	199	159	6.8	157	341		191	
10	1.20	3.00	10	400	1.38	6.3	144	167		273	190	6.8	157	206		276	169
11	1.20	3.00	10	400	1.38	6.3	144			183		6.8	157			168	
12	1.20	3.00	10	400	1.38	6.3	144	27	55	702	459	6.8	157	33	75	721	461
13	1.20	3.00	10	400	1.38	6.3	144			183		6.8	157			169	
14	1.20	3.00	10	400	1.38	6.3	144	47	107	527	327	6.8	157	59	144	542	326
15	1.20	3.00	10	400	1.38	6.3	144	42	91	557	357	6.8	157	53	122	573	357
16	1.20	3.00	10	400	1.38	6.3	144	41	87	565	366	6.8	157	51	117	581	365
17	1.20	3.00	10	400	1.38	6.3	144	32	73	642	399	6.8	157	40	98	660	400
18	1.20	3.00	10	400	1.38	6.3	144	32	71	646	403	6.8	157	39	96	664	404
19	1.20	3.00	10	400	1.38	6.3	144	36	86	603	365	6.8	157	45	117	620	364
20	1.20	3.00	10	400	1.38	6.3	144	129	202	318	237	6.8	157	158	267	325	228
21	1.20	3.00	10	400	1.38	6.3	144	129	203	317	235	6.8	157	159	269	324	227
22	1.20	3.00	10	400	1.38	6.3	144	125	188	324	247	6.8	157	153	248	331	240
23	1.20	3.00	10	400	1.38	6.3	144	129	203	317	236	6.8	157	159	269	324	227
24	1.20	3.00	10	400	1.38	6.3	144	130	205	317	234	6.8	157	160	271	323	225
25	1.20	3.00	10	400	1.38	6.3	144	173		270	181	6.8	157	212		273	155
26	1.20	3.00	10	400	1.38	6.3	144	174		269	180	6.8	157	213		272	154
27	1.20	3.00	10	400	1.38	6.3	144	174		270	181	6.8	157	213		272	155
28	1.20	3.00	10	400	1.38	6.3	144	179		265	174	6.8	157	219		267	141
29	1.20	3.00	10	400	1.38	6.3	144	88	159	389	268	6.8	157	108	213	399	263
30	1.20	3.00	10	400	1.38	6.3	144	274	356	202	162	6.8	157	335		194	
31	1.20	3.00	10	400	1.38	6.3	144	38	76	589	391	6.8	157	47	103	605	392
32	1.20	3.00	10	400	1.38	6.3	144			178		6.8	157			161	
33	1.20	3.00	10	400	1.38	6.3	144	197		249	161	6.8	157	242		250	
34	1.20	3.00	10	400	1.38	6.3	144			178		6.8	157			161	
35	1.20	3.00	10	400	1.38	6.3	144			176		6.8	157			158	
36	1.20	3.00	10	400	1.38	6.3	144	247	356	216	161	6.8	157	303		211	
37	1.20	3.00	10	400	1.38	6.3	144	248	357	216	161	6.8	157	304		211	
38	1.20	3.00	10	400	1.38	6.3	144	46	119	534	308	6.8	157	57	161	549	306
39	1.20	3.00	10	400	1.38	6.3	144	243	342	218	167	6.8	157	298		214	
40	1.20	3.00	10	400	1.38	6.3	144	41	103	565	332	6.8	157	51	140	581	331
41	1.20	3.00	10	400	1.38	6.3	144	243	340	219	167	6.8	157	297		215	
42	1.20	3.00	10	400	1.38	6.3	144	149	259	282	200	6.8	157	187		286	182
43	1.20	3.00	10	400	1.38	6.3	144	244	345	218	165	6.8	157	299		214	
44	1.20	3.00	10	400	1.38	6.3	144	71	188	443	242	6.8	157	87	254	455	234
45	1.20	3.00	10	400	1.38	6.3	144	248	359	215	160	6.8	157	304		211	
46	1.20	3.00	10	400	1.38	6.3	144	196		240	152	6.8	157	247		240	
47	1.20	3.00	10	400	1.38	6.3	144			196		6.8	157			187	
48	1.20	3.00	10	400	1.38	6.3	144	130		310	169	6.8	157	161		316	
49	1.20	3.00	10	400	1.38	6.3	144	167		266	180	6.8	157	208		269	153
50	1.20	3.00	10	400	1.38	6.3	144			196		6.8	157			186	
51	1.20	3.00	10	400	1.38	6.3	144	80	212	391	224	6.8	157	101		401	212
52	1.20	3.00	10	400	1.38	6.3	144	25	49	730	489	6.8	157	31	66	749	492
53	1.20	3.00	10	400	1.38	6.3	144			196		6.8	157			187	
54	1.20	3.00	10	400	1.38	6.3	144			193		6.8	157			183	
55	1.20	3.00	10	400	1.38	6.3	144	84	225	381	216	6.8	157	106		391	203
56	1.20	3.00	10	400	1.38	6.3	144	86	230	378	213	6.8	157	108		388	199
57	1.20	3.00	10	400	1.38	6.3	144	90	243	369	206	6.8	157	113		379	190
58	1.20	3.00	10	400	1.38	6.3	144	29	63	672	428	6.8	157	36	86	690	429
59	1.20	3.00	10	400	1.38	6.3	144	134		305	164	6.8	157	167		310	
60	1.20	3.00	10	400	1.38	6.3	144	30	67	660	416	6.8	157	38	91	678	417
61	1.20	3.00	10	400	1.38	6.3	144	139		299	158	6.8	157	172		304	
62	1.20	3.00	10	400	1.38	6.3	144	293	384	191	151	6.8	157	360		180	
63	1.20	3.00	10	400	1.38	6.3	144	77	134	395	288	6.8	157	98	182	406	285
64	1.20	3.00	10	400	1.38	6.3	144	76	114	398	314	6.8	157	96	154	409	313
65	1.20	3.00	10	400	1.38	6.3	144	134	211	306	228	6.8	157	166	282	311	218
66	1.20	3.00	10	400	1.38	6.3	144	278	364	198	158	6.8	157	342		190	
67	1.20	3.00	10	400	1.38	6.3	144	267	348	205	165	6.8	157	327		198	
68	1.20	3.00	10	400	1.38	6.3	144	283	368	197	157	6.8	157	346		188	

Group 2 Properties

Row	Liquid ρ_L Density (kg/L)	Solids ρ_s Density (kg/L)	C_v Volume (%)	d_p Median Dia. (μm)	ρ_m Bulk Density (kg/L)	10 °C Critical (κ_{cv} = 1.30, κ_f = 1) Velocity (ft/s)	10 °C Flow Rate (gpm)	10 °C Total Pressure Drop (lbf/in²) New	10 °C Total Pressure Drop EOL	10 °C Flow Rate at a Pipe Design Pressure of 400 lbf/in² (gpm) New	10 °C Flow Rate EOL	60 °C Critical (κ_{cv} = 1.30, κ_f = 1) Velocity (ft/s)	60 °C Flow Rate (gpm)	60 °C Total Pressure Drop (lbf/in²) New	60 °C Total Pressure Drop EOL	60 °C Flow Rate at a Pipe Design Pressure of 400 lbf/in² (gpm) New	60 °C Flow Rate EOL
6	1.20	3.00	15	400	1.47	6.5	151	51	110	546	349	7.1	164	65	151	565	347
7	1.20	3.00	15	400	1.47	6.5	151	155	232	310	234	7.1	164	196	315	314	218
8	1.20	3.00	15	400	1.47	6.5	151	160	251	303	222	7.1	164	202	340	307	202
9	1.20	3.00	15	400	1.47	6.5	151	332		185		7.1	164			145	
10	1.20	3.00	15	400	1.47	6.5	151	199		266	176	7.1	164	252		265	
11	1.20	3.00	15	400	1.47	6.5	151			166		7.1	164				
12	1.20	3.00	15	400	1.47	6.5	151	32	67	688	449	7.1	164	41	92	711	454
13	1.20	3.00	15	400	1.47	6.5	151			166		7.1	164				
14	1.20	3.00	15	400	1.47	6.5	151	57	128	518	321	7.1	164	72	178	535	316
15	1.20	3.00	15	400	1.47	6.5	151	51	109	547	350	7.1	164	65	151	565	348
16	1.20	3.00	15	400	1.47	6.5	151	49	105	555	358	7.1	164	63	144	573	358
17	1.20	3.00	15	400	1.47	6.5	151	38	87	630	391	7.1	164	49	121	651	393
18	1.20	3.00	15	400	1.47	6.5	151	38	86	634	395	7.1	164	48	119	655	397
19	1.20	3.00	15	400	1.47	6.5	151	43	104	592	357	7.1	164	55	144	612	357
20	1.20	3.00	15	400	1.47	6.5	151	154	242	311	228	7.1	164	194	328	316	210
21	1.20	3.00	15	400	1.47	6.5	151	154	243	310	227	7.1	164	195	330	315	208
22	1.20	3.00	15	400	1.47	6.5	151	149	225	317	239	7.1	164	188	304	322	224
23	1.20	3.00	15	400	1.47	6.5	151	154	243	310	227	7.1	164	195	330	315	208
24	1.20	3.00	15	400	1.47	6.5	151	155	245	310	226	7.1	164	195	333	314	207
25	1.20	3.00	15	400	1.47	6.5	151	206		262	166	7.1	164	260		260	
26	1.20	3.00	15	400	1.47	6.5	151	207		261	165	7.1	164	261		260	
27	1.20	3.00	15	400	1.47	6.5	151	207		262	166	7.1	164	260		260	
28	1.20	3.00	15	400	1.47	6.5	151	213		257	157	7.1	164	268		255	
29	1.20	3.00	15	400	1.47	6.5	151	105	191	382	261	7.1	164	133	262	392	250
30	1.20	3.00	15	400	1.47	6.5	151	326		189		7.1	164			156	
31	1.20	3.00	15	400	1.47	6.5	151	46	92	578	383	7.1	164	58	127	597	385
32	1.20	3.00	15	400	1.47	6.5	151			159		7.1	164				
33	1.20	3.00	15	400	1.47	6.5	151	235		241		7.1	164			235	
34	1.20	3.00	15	400	1.47	6.5	151			160		7.1	164				
35	1.20	3.00	15	400	1.47	6.5	151			157		7.1	164				
36	1.20	3.00	15	400	1.47	6.5	151	294		205		7.1	164	371		186	
37	1.20	3.00	15	400	1.47	6.5	151	295		204		7.1	164	371		186	
38	1.20	3.00	15	400	1.47	6.5	151	55	143	524	302	7.1	164	71	199	542	296
39	1.20	3.00	15	400	1.47	6.5	151	289		207	146	7.1	164	364		191	
40	1.20	3.00	15	400	1.47	6.5	151	50	124	554	326	7.1	164	63	172	573	322
41	1.20	3.00	15	400	1.47	6.5	151	289		208	147	7.1	164	364		191	
42	1.20	3.00	15	400	1.47	6.5	151	180		275	188	7.1	164	232		276	
43	1.20	3.00	15	400	1.47	6.5	151	291		207	144	7.1	164	366		190	
44	1.20	3.00	15	400	1.47	6.5	151	84	225	435	235	7.1	164	106		448	217
45	1.20	3.00	15	400	1.47	6.5	151	296		204		7.1	164	372		185	
46	1.20	3.00	15	400	1.47	6.5	151	237		232		7.1	164			224	
47	1.20	3.00	15	400	1.47	6.5	151			182		7.1	164				
48	1.20	3.00	15	400	1.47	6.5	151	156		303	152	7.1	164	198		307	
49	1.20	3.00	15	400	1.47	6.5	151	201		259	165	7.1	164	258		257	
50	1.20	3.00	15	400	1.47	6.5	151			182		7.1	164				
51	1.20	3.00	15	400	1.47	6.5	151	97	255	384	214	7.1	164	125		394	191
52	1.20	3.00	15	400	1.47	6.5	151	30	59	715	479	7.1	164	38	81	739	485
53	1.20	3.00	15	400	1.47	6.5	151			182		7.1	164				
54	1.20	3.00	15	400	1.47	6.5	151			179		7.1	164				
55	1.20	3.00	15	400	1.47	6.5	151	102	271	375	206	7.1	164	131		384	178
56	1.20	3.00	15	400	1.47	6.5	151	104		371	203	7.1	164	134		381	173
57	1.20	3.00	15	400	1.47	6.5	151	108		363	195	7.1	164	140		372	158
58	1.20	3.00	15	400	1.47	6.5	151	35	76	659	419	7.1	164	45	106	681	423
59	1.20	3.00	15	400	1.47	6.5	151	161		298	145	7.1	164	205		301	
60	1.20	3.00	15	400	1.47	6.5	151	36	81	647	408	7.1	164	46	111	669	411
61	1.20	3.00	15	400	1.47	6.5	151	166		292		7.1	164	212		295	
62	1.20	3.00	15	400	1.47	6.5	151	350		176		7.1	164				
63	1.20	3.00	15	400	1.47	6.5	151	94	162	388	281	7.1	164	121	225	399	274
64	1.20	3.00	15	400	1.47	6.5	151	92	139	391	307	7.1	164	120	191	402	304
65	1.20	3.00	15	400	1.47	6.5	151	161	254	299	219	7.1	164	205	347	302	198
66	1.20	3.00	15	400	1.47	6.5	151	332		185		7.1	164			142	
67	1.20	3.00	15	400	1.47	6.5	151	318		193	143	7.1	164	399		165	
68	1.20	3.00	15	400	1.47	6.5	151	336		183		7.1	164				

Legend (row 69): Included in BNFL routes | Exceeds 275 lbf/in² | Exceeds 400 lbf/in² | Supernate liquid only transfer | Less than 140 gpm

Notes:

New = new or like new pipeline with maximum expected pipe roughness of 2 mils (0.002 inches).

EOL = pipeline at end of life (50 years for carbon steel line, 40 years for stainless steel line) with pipe roughness due to corrosion estimated at 150 mils for carbon steel and 10 mils for stainless steel.

Design Pressure = All stainless steel pipelines have a design pressure of 400 lbf/in². The design pressure of carbon steel pipelines are either 275 or 400 lbf/in² as indicated.

The predicted flow rate at design pressure given in this table assumes that all pipelines are or can be qualified to the higher 400 lbf/in² design pressure.

Table D-29. 3S6 Case 4-st. (Sheet 1 of 2)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL	AM	AN	AO	AP	AQ	AR
1	CASE 3S6 Transfer List - Tank-to-Tank										Case 4-st	Critical velocity by Oroskar and Turian (1980) empirical correlation (β_{cv} = 1.2). Pressure drop by Wasp et al. (1977) method with lognormal particle size distribution.																																
2											Group 1 Properties					Temperature = 10 °C						Temperature = 60 °C						Group 2 Properties					Temperature = 10 °C						Temperature = 60 °C					
3	Transfer		Tank Farm Built (Yr)	Transfer				3-in. Schedule-40 Pipe (3.068 in. inside dia.)		Total Change in Elevation (ft)	Liquid	Solids			ρ_m Bulk Density (kg/L)	Critical (κ_{cv} = 1.30, κ_f = 1)				Flow Rate at a Pipe Design Pressure of 400 lbf/in² (gpm)		Critical (κ_{cv} = 1.30, κ_f = 1)				Flow Rate at a Pipe Design Pressure of 400 lbf/in² (gpm)		Liquid	Solids			ρ_m Bulk Density (kg/L)	Critical (κ_{cv} = 1.30, κ_f = 1)				Flow Rate at a Pipe Design Pressure of 400 lbf/in² (gpm)		Critical (κ_{cv} = 1.30, κ_f = 1)				Flow Rate at a Pipe Design Pressure of 400 lbf/in² (gpm)	
4	From Tank	To Tank		#	Dates (M/Yr)		Design Pressure* (lbf/in²)	Carbon Steel Length (ft)	Stainless Steel Length (ft)		ρ_L Density (kg/L)	ρ_s Density (kg/L)	C_v Volume (%)	d_p Median Dia. (μm)		Velocity (ft/s)	Flow Rate (gpm)	Total Pressure Drop (lbf/in²)				Velocity (ft/s)	Flow Rate (gpm)	Total Pressure Drop (lbf/in²)				ρ_L Density (kg/L)	ρ_s Density (kg/L)	C_v Volume (%)	d_p Median Dia. (μm)		Velocity (ft/s)	Flow Rate (gpm)	Total Pressure Drop (lbf/in²)				Velocity (ft/s)	Flow Rate (gpm)	Total Pressure Drop (lbf/in²)			
5					Start	End												New	EOL	New	EOL			New	EOL	New	EOL								New	EOL	New	EOL			New	EOL	New	EOL
6	AN-101	AN-106	80-81	1	12/00	12/00		442	626	0	1.20	3.00	10	400	1.38	6.3	144	43	91	556	357	6.8	157	53	123	572	356	1.20	3.00	15	400	1.47	6.5	151	51	110	546	349	7.1	164	65	151	565	347
7	AN-101	AP-PIT					400	0	1,914	10	1.20	3.00	10	400	1.38	6.3	144	82	107	409	341	6.8	157	101	140	420	342	1.20	3.00	15	400	1.47	6.5	151	98	128	401	334	7.1	164	123	172	413	333
8	AP-PIT	AP-103	83-86	1	7/03	7/03	400	306	1,076	2	1.20	3.00	10	400	1.38	6.3	144	56	98	487	347	6.8	157	70	131	501	346	1.20	3.00	15	400	1.47	6.5	151	67	118	478	339	7.1	164	85	162	494	338
9	AN-101	AP-PIT					400	0	1,914	10	1.20	3.00	10	400	1.38	6.3	144	82	107	409	341	6.8	157	101	140	420	342	1.20	3.00	15	400	1.47	6.5	151	98	128	401	334	7.1	164	123	172	413	333
10	AP-PIT	AP-107	83-86	1	6/05	6/05	400	423	1,076	2	1.20	3.00	10	400	1.38	6.3	144	61	114	467	320	6.8	157	75	152	480	319	1.20	3.00	15	400	1.47	6.5	151	73	136	459	313	7.1	164	93	187	473	309
11	AN-101	AP-PIT					400	0	1,914	10	1.20	3.00	10	400	1.38	6.3	144	82	107	409	341	6.8	157	101	140	420	342	1.20	3.00	15	400	1.47	6.5	151	98	128	401	334	7.1	164	123	172	413	333
12	AP-PIT	BNFL		7	2/11	12/19	400	0	4,402	38	1.20	3.00	10	400	1.38	6.3	144	198	255	253	208	6.8	157	241	331	254	195	1.20	3.00	15	400	1.47	6.5	151	235	304	244	197	7.1	164	292		239	161
13	AN-102	AP-PIT						405	2,324	10	1.20	3.00	10	400	1.38	6.3	144	115	182	339	251	6.8	157	141	241	347	244	1.20	3.00	15	400	1.47	6.5	151	137	218	332	243	7.1	164	173		338	229
14	AP-PIT	AP-107	83-86	1	3/10	3/10		423	1,076	2	1.20	3.00	10	400	1.38	6.3	144	61	114	467	320	6.8	157	75	152	480	319	1.20	3.00	15	400	1.47	6.5	151	73	136	459	313	7.1	164	93	187	473	309
15	AN-102	AP-PIT						405	2,324	10	1.20	3.00	10	400	1.38	6.3	144	115	182	339	251	6.8	157	141	241	347	244	1.20	3.00	15	400	1.47	6.5	151	137	218	332	243	7.1	164	173		338	229
16	AP-PIT	BNFL		5	12/08	4/16	400	0	4,402	38	1.20	3.00	10	400	1.38	6.3	144	198	255	253	208	6.8	157	241	331	254	195	1.20	3.00	15	400	1.47	6.5	151	235	304	244	197	7.1	164	292		239	161
17	AN-103	AN-102	80-81	1	4/12	4/12		253	421	0	1.20	3.00	10	400	1.38	6.3	144	27	55	702	459	6.8	157	33	75	721	461	1.20	3.00	15	400	1.47	6.5	151	32	67	688	449	7.1	164	41	92	711	454
18	AN-103	AP-PIT						376	1,916	10	1.20	3.00	10	400	1.38	6.3	144	97	157	372	273	6.8	157	119	207	381	269	1.20	3.00	15	400	1.47	6.5	151	116	188	365	266	7.1	164	146	255	374	257
19	AP-PIT	BNFL		9	4/14	6/19	400	0	4,402	38	1.20	3.00	10	400	1.38	6.3	144	198	255	253	208	6.8	157	241	331	254	195	1.20	3.00	15	400	1.47	6.5	151	235	304	244	197	7.1	164	292		239	161
20	AN-104	AN-101	80-81	3	6/05	2/16		562	626	0	1.20	3.00	10	400	1.38	6.3	144	47	107	527	327	6.8	157	59	144	542	326	1.20	3.00	15	400	1.47	6.5	151	57	128	518	321	7.1	164	72	178	535	316
21	AN-104	AN-102	80-81	2	4/16	6/16		439	626	0	1.20	3.00	10	400	1.38	6.3	144	42	91	557	357	6.8	157	53	122	573	357	1.20	3.00	15	400	1.47	6.5	151	51	109	547	350	7.1	164	65	151	565	348
22	AN-104	AN-103	80-81	2	4/14	8/14		410	626	0	1.20	3.00	10	400	1.38	6.3	144	41	87	565	366	6.8	157	51	117	581	365	1.20	3.00	15	400	1.47	6.5	151	49	105	555	358	7.1	164	63	144	573	358
23	AN-104	AN-105	80-81	5	10/14	11/17		384	421	0	1.20	3.00	10	400	1.38	6.3	144	32	73	642	399	6.8	157	40	98	660	400	1.20	3.00	15	400	1.47	6.5	151	38	87	630	391	7.1	164	49	121	651	393
24	AN-104	AN-106	80-81	2	8/13	10/13		374	421	0	1.20	3.00	10	400	1.38	6.3	144	32	71	646	403	6.8	157	39	96	664	404	1.20	3.00	15	400	1.47	6.5	151	38	86	634	395	7.1	164	48	119	655	397
25	AN-104	AN-107	80-81	1	3/19	3/19		489	421	0	1.20	3.00	10	400	1.38	6.3	144	36	86	603	365	6.8	157	45	117	620	364	1.20	3.00	15	400	1.47	6.5	151	43	104	592	357	7.1	164	55	144	612	357
26	AN-104	AP-PIT					400	0	1,776	10	1.20	3.00	10	400	1.38	6.3	144	77	100	425	355	6.8	157	94	130	437	356	1.20	3.00	15	400	1.47	6.5	151	91	119	417	347	7.1	164	115	160	430	348
27	AP-PIT	AP-101	83-86	4	10/13	2/17	400	419	1,076	2	1.20	3.00	10	400	1.38	6.3	144	61	113	468	320	6.8	157	75	152	481	320	1.20	3.00	15	400	1.47	6.5	151	73	136	459	314	7.1	164	92	186	474	310
28	AN-104	AP-PIT					400	0	1,776	10	1.20	3.00	10	400	1.38	6.3	144	77	100	425	355	6.8	157	94	130	437	356	1.20	3.00	15	400	1.47	6.5	151	91	119	417	347	7.1	164	115	160	430	348
29	AP-PIT	AP-102	83-86	1	8/13	8/13	400	431	1,076	2	1.20	3.00	10	400	1.38	6.3	144	61	115	466	318	6.8	157	76	154	479	317	1.20	3.00	15	400	1.47	6.5	151	73	138	458	312	7.1	164	93	189	472	307
30	AN-104	AP-PIT					400	0	1,776	10	1.20	3.00	10	400	1.38	6.3	144	77	100	425	355	6.8	157	94	130	437	356	1.20	3.00	15	400	1.47	6.5	151	91	119	417	347	7.1	164	115	160	430	348
31	AP-PIT	AP-104	83-86	1	11/17	11/17	400	314	1,076	2	1.20	3.00	10	400	1.38	6.3	144	57	99	486	345	6.8	157	70	133	499	344	1.20	3.00	15	400	1.47	6.5	151	68	119	477	337	7.1	164	86	163	492	335
32	AN-104	AP-PIT					400	0	1,776	10	1.20	3.00	10	400	1.38	6.3	144	77	100	425	355	6.8	157	94	130	437	356	1.20	3.00	15	400	1.47	6.5	151	91	119	417	347	7.1	164	115	160	430	348
33	AP-PIT	AP-106	83-86	2	8/16	12/16	400	349	1,076	2	1.20	3.00	10	400	1.38	6.3	144	58	104	479	335	6.8	157	72	139	493	335	1.20	3.00	15	400	1.47	6.5	151	69	125	471	329	7.1	164	88	171	486	326
34	AN-104	AP-PIT					400	0	1,776	10	1.20	3.00	10	400	1.38	6.3	144	77	100	425	355	6.8	157	94	130	437	356	1.20	3.00	15	400	1.47	6.5	151	91	119	417	347	7.1	164	115	160	430	348
35	AP-PIT	AP-108	83-86	1	7/18	7/18	400	443	1,076	2	1.20	3.00	10	400	1.38	6.3	144	62	116	464	316	6.8	157	76	156	477	314	1.20	3.00	15	400	1.47	6.5	151	74	140	456	309	7.1	164	94	192	470	305
36	AN-104	AP-PIT					400	0	1,776	10	1.20	3.00	10	400	1.38	6.3	144	77	100	425	355	6.8	157	94	130	437	356	1.20	3.00	15	400	1.47	6.5	151	91	119	417	347	7.1	164	115	160	430	348
37	AP-PIT	AW-101	78-80	2	3/15	3/15		994	1,272	11	1.20	3.00	10	400	1.38	6.3	144	97	204	374	233	6.8	157	119	274	383	223	1.20	3.00	15	400	1.47	6.5	151	115	245	367	224	7.1	164	145		376	204
38	AN-104	AP-PIT					400	0	1,776	10	1.20	3.00	10	400	1.38	6.3	144	77	100	425	355	6.8	157	94	130	437	356	1.20	3.00	15	400	1.47	6.5	151	91	119	417	347	7.1	164	115	160	430	348
39	AP-PIT	AW-103	78-80	2	11/15	11/15		1,012	1,283	11	1.20	3.00	10	400	1.38	6.3	144	98	207	371	231	6.8	157	120		381	220	1.20	3.00	15	400	1.47	6.5	151	117	248	364	221	7.1	164	147		373	201
40	AN-104	AP-PIT					400	0	1,776	10	1.20	3.00	10	400	1.38	6.3	144	77	100	425	355	6.8	157	94	130	437	356	1.20	3.00	15	400	1.47	6.5	151	91	119	417	347	7.1	164	115	160	430	348
41	AP-PIT	AW-104	78-80	1	1/19	1/19		1,000	1,271	11	1.20	3.00	10	400	1.38	6.3	144	97	205	373	232	6.8	157	119	275	383	222	1.20	3.00	15	400	1.47	6.5	151	116	246	366	224	7.1	164	145		376	203
42	AN-104	AP-PIT					400	0	1,776	10	1.20	3.00	10	400	1.38	6.3	144	77	100	425	355	6.8	157	94	130	437	356	1.20	3.00	15	400	1.47	6.5	151	91	119	417	347	7.1	164	115	160	430	348
43	AP-PIT	AW-105	78-80	1	7/18	7/18		1,125	1,395	11	1.20	3.00	10	400	1.38	6.3	144	107	228	353	218	6.8	157	131		362	205	1.20	3.00	15	400	1.47	6.5	151	127	273	346	207	7.1	164	161		354	180
44	AN-104	AZ-101	71	1	10/10	10/10	400	562	1,560	4	1.20	3.00	10	400	1.38	6.3	144	87	159	389	268	6.8	157	107	212	399	263	1.20	3.00	15	400	1.47	6.5	151	104	190	382	261	7.1	164	132	261	392	250
45	AN-104	AP-PIT					400	0	1,776	10	1.20	3.00	10	400	1.38	6.3	144	77	100	425	355	6.8	157	94	130	437	356	1.20	3.00	15	400	1.47	6.5	151	91	119	417	347	7.1	164	115	160	430	348
46	AP-PIT	BNFL		1	9/10	9/10	400	0	4,402	38	1.20	3.00	10	400	1.38	6.3	144	198	255	253	208	6.8	157	241	331	254	195	1.20	3.00	15	400	1.47	6.5	151	235	304	244	197	7.1	164	292		239	161
47	AN-105	AN-102	80-81	1	3/10	3/10		329	626	0	1.20	3.00	10	400	1.38	6.3	144	38	76	589	391	6.8	157	47	103	605	392	1.20	3.00	15	400	1.47	6.5	151	46	92	578	383	7.1	164	58	127	597	385
48	AN-105	AP-PIT						384	2,197	10	1.20	3.00	10	400	1.38	6.3	144	109	173	349	259	6.8	157	134	229	357	253	1.20	3.00	15	400	1.47	6.5	151	130	207	342	251	7.1	164	164		350	239
49	AP-PIT	BNFL		3	8/12	5/17	400	0	4,402	38	1.20	3.00	10	400	1.38	6.3	144	198	255	253	208	6.8	157	241	331	254	195	1.20	3.00	15	400	1.47	6.5	151	235	304	244	197	7.1	164	292		239	161
50	AN-106	AP-PIT						442	2,529	10	1.20	3.00	10	400	1.38	6.3	144	124	198	324	239	6.8	157	153	262	330	231	1.20	3.00	15	400	1.47	6.5	151	148	237	317	230	7.1	164	187		322	213
51	AP-PIT	AW-102	78-80	6	11/04	1/06		761	968	11	1.20	3.00	10	400	1.38	6.3	144	75	158	431	270	6.8	157	92	211	443	265	1.20	3.00	15	400	1.47	6.5	151	90	189	423	263	7.1	164	112	258	436	252
52	AN-106	AP-PIT						442	2,529	10	1.20	3.00	10	400	1.38	6.3	144	124	198	324	239	6.8	157	153	262	330	231	1.20	3.00	15	400	1.47	6.5	151	148	237	317	230	7.1	164	187		322	213
53	AP-PIT	BNFL		7	12/18	3/19	400	0	4,402	38	1.20	3.00	10	400	1.38	6.3	144	198	255	253	208	6.8	157	241	331	254	195	1.20	3.00	15	400	1.47	6.5	151	235	304	244	197	7.1	164	292		239	161
54	AN-107	AP-PIT						557	2,529	10	1.20	3.00	10	400	1.38	6.3	144	129	213	317	228	6.8	157	159		323	218	1.20	3.00	15	400	1.47	6.5	151	154	255	310	219	7.1	164	194		314	198
55	AP-PIT	BNFL		1	7/11	7/11	400	0	4,402	38	1.20	3.00	10	400	1.38	6.3	144	198	255	253	208	6.8	157	241	331	254	195	1.20	3.00	15	400	1.47	6.5	151	235	304	244	197	7.1	164	292		239	161
56	AP-101	AP-PIT					400	419	1,076	-2	1.20	3.00	10	400	1.38	6.3	144	58	111	469	321	6.8	157	73	149	482	321	1.20	3.00	15	400	1.47	6.5	151	70	133	461	315	7.1	164	90	184	476	311
57	AP-PIT	BNFL		2	4/06	12/16	400	0	4,402	38	1.20	3.00	10	400	1.38	6.3	144	198	255	253	208	6.8	157	241	331	254	195	1.20	3.00	15	400	1.47	6.5	151	235	304	244	197	7.1	164	292		239	161
58	AP-102	AP-PIT					400	431	1,076	-2	1.20	3.00	10	400	1.38	6.3	144	59	112	467	319	6.8	157	73	151	480	318	1.20	3.00	15	400	1.47	6.5	151	71	135	459	313	7.1	164	91	187	474	309
59	AP-PIT	BNFL		9	7/18	12/18	400	0	4,402	38	1.20	3.00	10	400	1.38	6.3	144	198	255	253	208	6.8	157	241	331	254	195	1.20	3.00	15	400	1.47	6.5	151	235	304	244	197	7.1	164	292		239	161
60	AP-104	AP-107	83-86	1	1/13	1/13	400	737	421	0	1.20	3.00	10	400	1.38	6.3	144	46	119	534	308	6.8	157	57	161	549	306	1.20	3.00	15	400	1.47	6.5	151	55	143	524	302	7.1	164	71	199	542	296
61	AP-104	AP-PIT					400	314	1,076	-2	1.20	3.00	10	400	1.38	6.3	144	54	97	487	346	6.8	157	68	130	501	345	1.20	3.00	15	400	1.47	6.5	151	65	117	479	339	7.1	164	83	161	494	337
62	AP-PIT	BNFL		3	1/13	10/17	400	0	4,402	38	1.20	3.00	10	400	1.38	6.3	144	198	255	253	208	6.8	157	241	331	254	195	1.20	3.00	15	400	1.47	6.5	151	235	304	244	197	7.1	164	292		239	161
63	AP-105	AP-104	83-86	1	9/15	9/15	400	616	421	0	1.20	3.00	10	400	1.38	6.3	144	41	103	565	332	6.8	157	51	140	581	331	1.20	3.00	15	400	1.47	6.5	151	50	124	554	326	7.1	164	63	172	573	322
64	AP-105	AP-PIT					400	302	1,076	-2	1.20	3.00	10	400	1.38	6.3	144	54	95	489	349	6.8	157	67	128	503	349	1.20	3.00	15	400	1.47	6.5	151	65	115	481	342	7.1	164	83	158	496	340
65	AP-PIT	BNFL		1	2/18	2/18	400	0	4,402	38	1.20	3.00	10	400	1.38	6.3	144	198	255	253	208	6.8	157	241	331	254	195	1.20	3.00	15	400	1.47	6.5	151	235	304	244	197	7.1	164	292		239	161
66	AP-106	AP-PIT					400	349	1,076	-2	1.20	3.00	10	400	1.38	6.3	144	56	101	481	336	6.8	157	69	137	494	337	1.20	3.00	15	400	1.47	6.5	151	67	122	472	330	7.1	164	86	168	488	328
67	AP-PIT	AN-102	80-81	1	10/13	10/13		405	2,324	-10	1.20	3.00	10	400	1.38	6.3	144	103	170	344	255	6.8	157	129	229	352	249	1.20	3.00	15	400	1.47	6.5	151	124	205	338	248	7.1	164	160		345	235
68	AP-106	AP-PIT					400	349	1,076	-2	1.20	3.00	10	400	1.38	6.3	144	56	101	481	336	6.8	157	69	137	494	337	1.20	3.00	15	400	1.47	6.5	151	67	122	472	330	7.1	164	86	168	488	328
69	AP-PIT	BNFL		1	8/16	8/16	400	0	4,402	38	1.20	3.00	10	400	1.38	6.3	144	198	255	253	208	6.8	157	241	331	254	195	1.20	3.00	15	400	1.47	6.5	151	235	304	244	197	7.1	164	292		239	161
70	AP-107	AW-102	78-80	16	8/00	7/18		1,223	421	8	1.20	3.00	10	400	1.38	6.3	144	70	188	443	243	6.8	157	86	253	455	234	1.20	3.00	15	400	1.47	6.5	151	84	225	435	235	7.1	164	105		449	218
71	AP-108	AP-PIT					400	443	1,076	-2	1.20	3.00	10	400	1.38	6.3	144	59	114	465	317	6.8	157	74	153	478	316	1.20	3.00	15	400	1.47	6.5	151	71	137	457	310	7.1	164	91	189	472	306
72	AP-PIT	BNFL		1	7/18	7/18	400	0	4,402	38	1.20	3.00	10	400	1.38	6.3	144	198	255	253	208	6.8	157	241	331	254	195	1.20	3.00	15	400	1.47	6.5	151	235	304	244	197	7.1	164	292		239	161
73	AW-101	AP-PIT						233	2,042	-11	1.20	3.00	10	400	1.38	6.3	144	84	132	380	292	6.8	157	106	178	389	289	1.20	3.00	15	400	1.47	6.5	151	102	160	373	285	7.1	164	132	221	383	279
74	AP-PIT	AN-105	80-81	1	8/12	8/12		384	2,186	-10	1.20	3.00	10	400	1.38	6.3	144	96	160	356	263	6.8	157	121	216	364	258	1.20	3.00	15	400	1.47	6.5	151	116	193	349	256	7.1	164	150	267	357	245
75	AW-101	AP-PIT						1,033	1,486	-11	1.20	3.00	10	400	1.38	6.3	144	94	208	360	226	6.8	157	118		368	216	1.20	3.00	15	400	1.47	6.5	151	113	250	353	217	7.1	164	146		361	195
76	AP-PIT	BNFL		9	3/15	8/19	400	0	4,402	38	1.20	3.00	10	400	1.38	6.3	144	198	255	253	208	6.8	157	241	331	254	195	1.20	3.00	15	400	1.47	6.5	151	235	304	244	197	7.1	164	292		239	161
77	AW-103	AW-104	78-80	1	10/15	11/15		455	831	0	1.20	3.00	10	400	1.38	6.3	144	51	104	506	333	6.8	157	64	140	520	333	1.20	3.00	15	400	1.47	6.5	151	61	125	497	327	7.1	164	78	172	513	324
78	AW-103	AP-PIT						1,012	1,281	-11	1.20	3.00	10	400	1.38	6.3	144	85	194	378	235	6.8	157	107	264	388	226	1.20	3.00	15	400	1.47	6.5	151	103	234	371	227	7.1	164	133		381	208
79	AP-PIT	AY-102	68-70	1	12/13	12/13	400	0	2,050	1	1.20	3.00	10	400	1.38	6.3	144	82	109	397	331	6.8	157	102	144	408	331	1.20	3.00	15	400	1.47	6.5	151	99	131	390	324	7.1	164	126	178	401	323
80	AW-103	AP-PIT						1,012	1,281	-11	1.20	3.00	10	400	1.38	6.3	144	85	194	378	235	6.8	157	107	264	388	226	1.20	3.00	15	400	1.47	6.5	151	103	234	371	227	7.1	164	133		381	208
81	AP-PIT	BNFL		8	8/19	10/19	400	0	4,402	38	1.20	3.00	10	400	1.38	6.3	144	198	255	253	208	6.8	157	241	331	254	195	1.20	3.00	15	400	1.47	6.5	151	235	304	244	197	7.1	164	292		239	161
82	AW-104	AP-104	83-86	1	1/13	1/13		1,317	831	-9	1.20	3.00	10	400	1.38	6.3	144	80	212	391	224	6.8	157	101		401	212	1.20	3.00	15	400	1.47	6.5	151	97	255	384	214	7.1	164	125		394	191

AS – Notes

New = new or like new pipeline with maximum expected pipe roughness of 2 mils (0.002 inches).

EOL = pipeline at end of life (50 years for carbon steel line, 40 years for stainless steel line) with pipe roughness due to corrosion estimated at 150 mils for carbon steel and 10 mils for stainless steel.

***Design Pressure** = All stainless steel pipelines have a design pressure of 400 lbf/in². The design pressure of carbon steel pipelines are either 275 or 400 lbf/in² as indicated. The predicted flow rate at design pressure given in this table assumes that all pipelines are or can be qualified to the higher 400 lbf/in² design pressure.

Table D-29. 3S6 Case 4-st. (Sheet 2 of 2)

CASE 3S6 Transfer List - Tank-to-Tank — Case 4-st

Critical velocity by Oroskar and Turian (1980) empirical correlation (β_{cv} = 1.2). Pressure drop by Wasp et al. (1977) method with lognormal particle size distribution.

Row	A: Transfer From Tank	B: Transfer To Tank	C: Tank Farm Built (Yr)	D: Transfer #	E: Dates (M/Yr) Start	F: Dates (M/Yr) End	G: Design Pressure (lbf/in²)	H: 3-in. Schedule-40 Pipe (3.068 in. inside dia.) Carbon Steel Length (ft)	I: Stainless Steel Length (ft)	J: Total Change in Elevation (ft)	K: Group 1 Liquid ρ_L Density (kg/L)	L: Solids ρ_s Density (kg/L)	M: C_v Volume (%)	N: d_p Median Dia. (μm)	O: ρ_m Bulk Density (kg/L)	P: Temperature = 10 °C Critical (k_{cv} = 1.30, k_f = 1) Velocity (ft/s)	Q: Flow Rate (gpm)	R: Total Pressure Drop (lbf/in²) New	S: Total Pressure Drop (lbf/in²) EOL	T: Flow Rate at a Pipe Design Pressure of 400 lbf/in² (gpm) New	U: Flow Rate at 400 lbf/in² (gpm) EOL	V: Temperature = 60 °C Critical (k_{cv} = 1.30, k_f = 1) Velocity (ft/s)	W: Flow Rate (gpm)	X: Total Pressure Drop (lbf/in²) New	Y: Total Pressure Drop (lbf/in²) EOL	Z: Flow Rate at 400 lbf/in² (gpm) New	AA: Flow Rate at 400 lbf/in² (gpm) EOL	AB: Group 2 Liquid ρ_L Density (kg/L)	AC: Solids ρ_s Density (kg/L)	AD: C_v Volume (%)	AE: d_p Median Dia. (μm)	AF: ρ_m Bulk Density (kg/L)	AG: Temperature = 10 °C Critical (k_{cv} = 1.30, k_f = 1) Velocity (ft/s)	AH: Flow Rate (gpm)	AI: Total Pressure Drop (lbf/in²) New	AJ: Total Pressure Drop (lbf/in²) EOL	AK: Flow Rate at 400 lbf/in² (gpm) New	AL: Flow Rate at 400 lbf/in² (gpm) EOL	AM: Temperature = 60 °C Critical (k_{cv} = 1.30, k_f = 1) Velocity (ft/s)	AN: Flow Rate (gpm)	AO: Total Pressure Drop (lbf/in²) New	AP: Total Pressure Drop (lbf/in²) EOL	AQ: Flow Rate at 400 lbf/in² (gpm) New	AR: Flow Rate at 400 lbf/in² (gpm) EOL	AS: Notes
83	AW-104	AW-102	78-80	3	6/01	1/02		203	421	0	1.20	3.00	10	400	1.38	6.3	144	25	49	730	489	6.8	157	31	66	749	492	1.20	3.00	15	400	1.47	6.5	151	30	59	715	479	7.1	164	38	81	739	485	
84	AW-104	**AP-PIT**						1,000	1,281	-11	1.20	3.00	10	400	1.38	6.3	144	84	192	379	236	6.8	157	106	262	389	227	1.20	3.00	15	400	1.47	6.5	151	102	232	372	228	7.1	164	132		382	209	
85	**AP-PIT**	**BNFL**		6	4/18	1/19	400	0	4,402	38	1.20	3.00	10	400	1.38	6.3	144	198	255	253	208	6.8	157	241	331	254	195	1.20	3.00	15	400	1.47	6.5	151	235	304	244	197	7.1	164	292		239	161	
86	AW-105	**AP-PIT**						1,125	1,281	-11	1.20	3.00	10	400	1.38	6.3	144	89	209	369	225	6.8	157	112		378	214	1.20	3.00	15	400	1.47	6.5	151	108	252	362	216	7.1	164	140		371	194	
87	**AP-PIT**	**BNFL**		7	1/18	7/18	400	0	4,402	38	1.20	3.00	10	400	1.38	6.3	144	198	255	253	208	6.8	157	241	331	254	195	1.20	3.00	15	400	1.47	6.5	151	235	304	244	197	7.1	164	292		239	161	
88	AW-106	AP-105	83-86	2	10/04	6/05		1,416	831	-9	1.20	3.00	10	400	1.38	6.3	144	84	225	381	216	6.8	157	106		391	203	1.20	3.00	15	400	1.47	6.5	151	102	271	375	206	7.1	164	131		384	178	
89	AW-106	AP-106	83-86	2	4/01	1/02		1,454	831	-9	1.20	3.00	10	400	1.38	6.3	144	86	230	378	213	6.8	157	108		388	199	1.20	3.00	15	400	1.47	6.5	151	104		371	203	7.1	164	134		381	173	
90	AW-106	AP-108	83-86	1	3/09	3/09		1,557	831	-9	1.20	3.00	10	400	1.38	6.3	144	90	243	369	206	6.8	157	113		379	190	1.20	3.00	15	400	1.47	6.5	151	108		363	195	7.1	164	140		372	158	
91	AW-106	AW-102	78-80	13	12/01	7/18		314	421	0	1.20	3.00	10	400	1.38	6.3	144	29	63	672	428	6.8	157	36	86	690	429	1.20	3.00	15	400	1.47	6.5	151	35	76	659	419	7.1	164	45	106	681	423	
92	AW-106	AW-103	78-80	1	10/04	10/04		566	831	0	1.20	3.00	10	400	1.38	6.3	144	56	118	485	311	6.8	157	69	160	499	309	1.20	3.00	15	400	1.47	6.5	151	67	142	477	304	7.1	164	85	196	492	299	
93	AW-106	AW-104	78-80	2	1/02	8/02		341	421	0	1.20	3.00	10	400	1.38	6.3	144	30	67	660	416	6.8	157	38	91	678	417	1.20	3.00	15	400	1.47	6.5	151	36	81	647	408	7.1	164	46	111	669	411	
94	AW-106	AW-105	78-80	1	6/05	6/05		679	831	0	1.20	3.00	10	400	1.38	6.3	144	60	133	466	291	6.8	157	75	180	479	288	1.20	3.00	15	400	1.47	6.5	151	72	160	458	285	7.1	164	92	221	472	278	
95	AY-101	**AP-PIT**					400	0	2,240	0	1.20	3.00	10	400	1.38	6.3	144	89	118	379	316	6.8	157	111	157	389	316	1.20	3.00	15	400	1.47	6.5	151	107	142	373	310	7.1	164	137	193	382	307	
96	**AP-PIT**	**BNFL**		12	1/11	10/13	400	0	4,402	38	1.20	3.00	10	400	1.38	6.3	144	198	255	253	208	6.8	157	241	331	254	195	1.20	3.00	15	400	1.47	6.5	151	235	304	244	197	7.1	164	292		239	161	
97	AY-102	AN-103	80-81	1	11/19	11/19		376	1,733	-10	1.20	3.00	10	400	1.38	6.3	144	78	135	395	288	6.8	157	98	183	405	284	1.20	3.00	15	400	1.47	6.5	151	94	163	388	281	7.1	164	122	226	399	274	
98	AY-102	AN-106	80-81	2	5/19	11/19		142	1,938	-10	1.20	3.00	10	400	1.38	6.3	144	77	115	398	314	6.8	157	97	155	408	313	1.20	3.00	15	400	1.47	6.5	151	93	139	391	307	7.1	164	120	192	402	303	
99	AY-102	**AP-PIT**					400	0	2,050	0	1.20	3.00	10	400	1.38	6.3	144	82	108	398	332	6.8	157	101	143	408	332	1.20	3.00	15	400	1.47	6.5	151	98	130	390	325	7.1	164	125	177	401	323	
100	***AP-PIT***	*AP-102*	*83-86*	*1*	*12/18*	*12/18*	*400*	*431*	*763*	*2*	*1.20*	*3.00*	*10*	*400*	*1.38*	*6.3*	144	48	98	525	346	6.8	157	60	132	540	345	1.20	3.00	15	400	1.47	6.5	151	58	118	516	338	7.1	164	74	162	533	335	
101	AY-102	**AP-PIT**					400	0	2,039	0	1.20	3.00	10	400	1.38	6.3	144	81	108	399	332	6.8	157	101	143	409	333	1.20	3.00	15	400	1.47	6.5	151	97	130	392	326	7.1	164	124	176	402	324	
102	**AP-PIT**	**BNFL**		16	1/09	2/18	400	0	4,402	38	1.20	3.00	10	400	1.38	6.3	144	198	255	253	208	6.8	157	241	331	254	195	1.20	3.00	15	400	1.47	6.5	151	235	304	244	197	7.1	164	292		239	161	
103	AZ-101	**AP-PIT**					400	0	1,564	6	1.20	3.00	10	400	1.38	6.3	144	66	86	456	380	6.8	157	81	113	468	382	1.20	3.00	15	400	1.47	6.5	151	79	103	447	372	7.1	164	99	139	461	375	
104	**AP-PIT**	**BNFL**		10	10/06	8/15	400	0	4,402	38	1.20	3.00	10	400	1.38	6.3	144	198	255	253	208	6.8	157	241	331	254	195	1.20	3.00	15	400	1.47	6.5	151	235	304	244	197	7.1	164	292		239	161	
105	AZ-102	**AP-PIT**					400	0	2,403	6	1.20	3.00	10	400	1.38	6.3	144	99	131	364	303	6.8	157	122	172	373	302	1.20	3.00	15	400	1.47	6.5	151	119	157	357	296	7.1	164	150	211	365	292	
106	**AP-PIT**	**BNFL**		6	7/07	3/08	400	0	4,402	38	1.20	3.00	10	400	1.38	6.3	144	198	255	253	209	6.8	157	240	330	254	195	1.20	3.00	15	400	1.47	6.5	151	234	304	244	197	7.1	164	292		239	161	
107	BNFL internal equivalent pipe length and elevation								884	46	included in BNFL routes						Exceeds 275 lbf/in²						Exceeds 400 lbf/in²									Supernate liquid only transfer							Less than 140 gpm						

APPENDIX E

SENSITIVITY ANALYSIS OF THE TRANSFER ROUTE FROM TANK 241-AN-107 TO BNFL INC.

Calculations contained herein were produced in Mathcad 2000 Professional (Mathcad is a registered trademark of MathSoft, Inc. of Cambridge, Massachusetts).

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CONVERSIONS

ft	feet = 0.3048 meter (m)
in.	inch = 2.54 centimeters (cm)
lbf/in^2	pounds per square inch = 0.06895 megapascals (MPa)
mils	0.001 in. = 0.0254 millimeter (mm)
gpm	0.0631 liter/second (L/s)
cP	centipose = 0.001 kilogram/meter-second (kg/m-s)

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		Checked: 03/10/2000	By: T. C. Oten
Location:	200 Area - Hanford Site, Richland, Washington	Revised:	By:

SENSITIVITY ANALYSIS - AN-107-to-BNFL Transfer Route

The AN-107-to-BNFL transfer route was identified as one of the longest transfer routes in the Case 3S6 Transfer List. Hence, this transfer route was chosen for a sensitivity analysis on the pipeline pressure drop for the range of waste properties being considered for waste feed delivery to BNFL. The assumed particle size distribution by volume is based on a Rosin-Rammler cumulative and probability density function (Shook and Roco 1991) curve fit to the particle size distribution measurements obtain from Tank 241-SY-101 waste samples (O'Rourke 1999). The Tank 241-SY-101 particle size distribution had a median particle size (d_{50}) of 184 µm (see Appendix F). The resulting curve-fit Rosin-Rammler cumulative and probability density function was then shifted to target median particle sizes for the sensitivity analysis.

The following waste and pipe parameter were considered in the sensitivity analysis:

Internal pipe diameter (nominal)

$D_{pipe} = 3.068\,in$

Pipe roughness estimates (Anantatmula and Divine 1999, new and end-of-life (EOL) pipe conditions indicated by dashed and solid lines, respectively in following plots)

$\varepsilon_{new} = 2\,mil$	new commercial pipe
$\varepsilon_{EOL\_SS} = 10\,mil$	for stainless steel pipe at end of 40-year service life
$\varepsilon_{EOL\_CS} = 150\,mil$	for carbon steel pipe at end of 50-year service life

Waste parameters (Estey 2000)

ρ_L = 1.2 and 1.46 kg/L	liquid "carrier" density
ρ_s = 2.5 and 3 kg/L	solids particle density
T = 10 and 60 °C	temperature of waste feed
d_p = 400, 200, 100, 40, and 5 µm	median particle size (d_{50}) of shifted particle size distribution
C_s = 5, 10, and 15%	volume percent concentration of solids.

A pipeline design pressure of 400 lbf/in^2 is assumed for reference (horizontal dashed line). Critical velocity and pressure drop estimates are based on Oroskar and Turian (1980) and Wasp et al. (1977) empirical correlations, respectively (see Appendix F). Results are given in Figures E-1 through E-5 for d_p = 400, 200, 100, 40, and 5 µm, respectively for the above waste and pipe parameters. In Figure E-6 the Oroskar and Turian (1980) critical velocity correlation is compared to a critical velocity prediction based on the Wasp "vehicle" concept (see Appendix F). Figures E-7 through 10 shows the pressure drop at the critical velocity versus the median particle size for selected waste transfer parameters and pipe roughness values.

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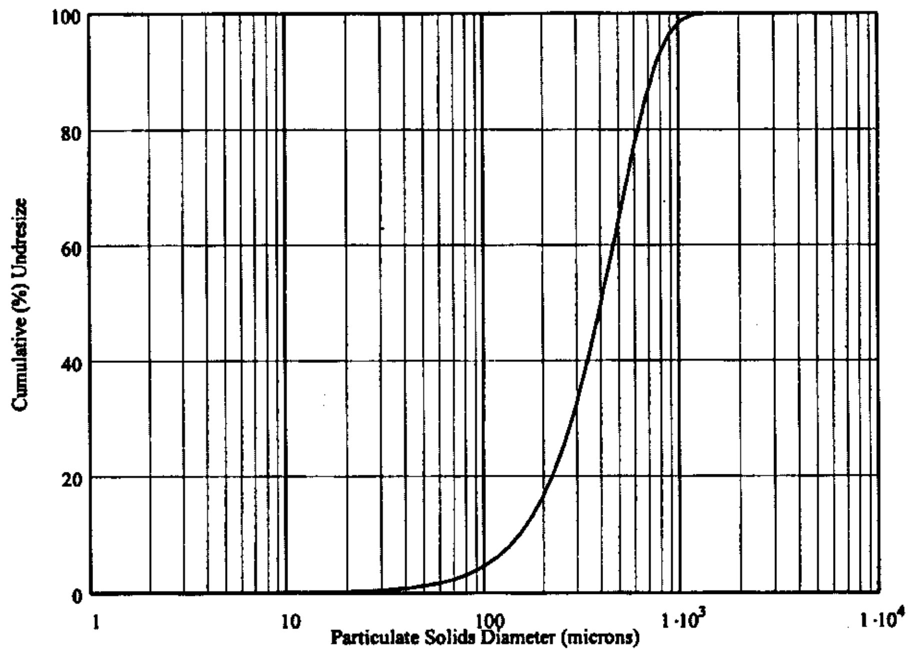
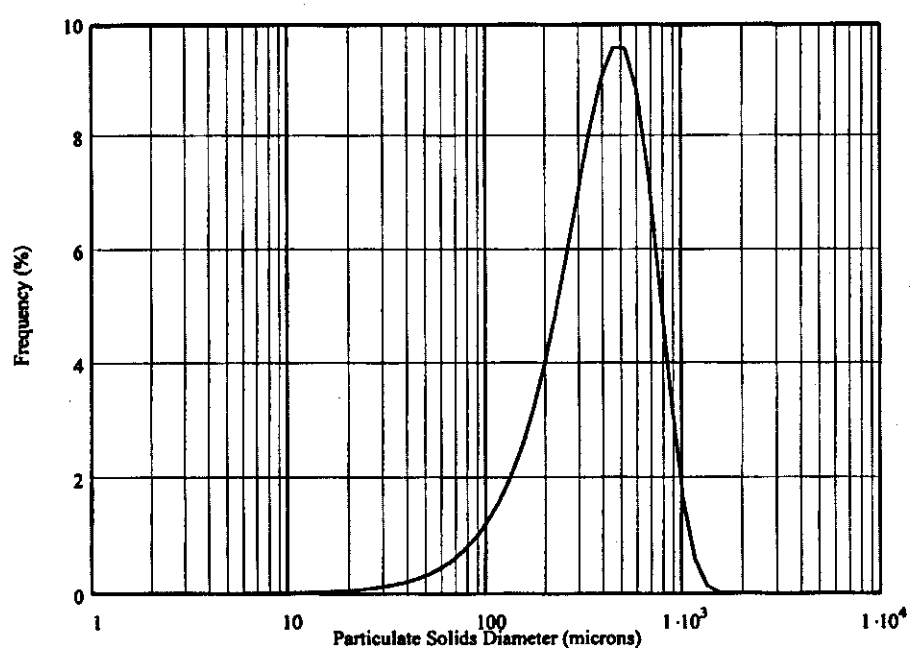
Figure E-1a. d_p=400 μm Case - Cumulative and Probability Density Particle Size Distribution by Volume.

$d_{50} := 400 \cdot \mu m$ $\quad (d_{pRR}\ \ \phi_{RR}) := dist_{RR}(d_{pR}, d_{50})$ $\quad d_{pRR} := d_{pRR} \cdot \mu m$ reset units $\quad \phi_{RRcum} := cum(\phi_{RR})$

$D_{pRR} := D_{\beta}(d_{pRR}, \phi_{RRcum}, 50\%)$ $\quad D_{pRR} = 373\ \mu m$





$TOL = 1 \times 10^{-5}$

Figure E-1b. Pressure Drop for AN-107 to BNFL - d_p=400 μm, ρ_L=1.2 kg/L, ρ_s=3 kg/L Case, T = 10 and 60 °C.

$\beta_{cv} := 1.2$ $\quad L_{CS} := 557 \cdot ft \quad L_{SS} := 7028 \cdot ft \quad H := 40 \cdot ft \quad d_{50} = 400\,\mu m$ $\quad \varepsilon_{new} = 2\,mil$

$\kappa_{cv} := 1.30$ $\quad \rho_L := 1.2 \cdot \frac{kg}{liter} \quad \rho_s := 3 \cdot \frac{kg}{liter}$ $\quad \varepsilon_{EOL\_SS} = 10\,mil$

$\kappa_f := 1$ $\quad \varepsilon_{EOL\_CS} = 150\,mil$

$T := 10\ ^\circ C \quad \mu_{cL}(\rho_L, 10) = 2\,cP$ $\qquad T := 60\ ^\circ C \quad \mu_{cL}(\rho_L, 60) = 0.8\,cP$

C_s	T = 10 °C	T = 60 °C
5%	$v_{cr}(D_{pipe}, d_{50}, \rho_s, 5\cdot\%, \rho_L, \mu_{cL}(\rho_L,10), \kappa_{cv}, \beta_{cv}) = 5.7\,\frac{ft}{sec}$	$v_{cr}(D_{pipe}, d_{50}, \rho_s, 5\cdot\%, \rho_L, \mu_{cL}(\rho_L,60), \kappa_{cv}, \beta_{cv}) = 6.3\,\frac{ft}{sec}$
10%	$v_{cr}(D_{pipe}, d_{50}, \rho_s, 10\cdot\%, \rho_L, \mu_{cL}(\rho_L,10), \kappa_{cv}, \beta_{cv}) = 6.3\,\frac{ft}{sec}$	$v_{cr}(D_{pipe}, d_{50}, \rho_s, 10\cdot\%, \rho_L, \mu_{cL}(\rho_L,60), \kappa_{cv}, \beta_{cv}) = 6.8\,\frac{ft}{sec}$
15%	$v_{cr}(D_{pipe}, d_{50}, \rho_s, 15\cdot\%, \rho_L, \mu_{cL}(\rho_L,10), \kappa_{cv}, \beta_{cv}) = 6.5\,\frac{ft}{sec}$	$v_{cr}(D_{pipe}, d_{50}, \rho_s, 15\cdot\%, \rho_L, \mu_{cL}(\rho_L,60), \kappa_{cv}, \beta_{cv}) = 7.1\,\frac{ft}{sec}$

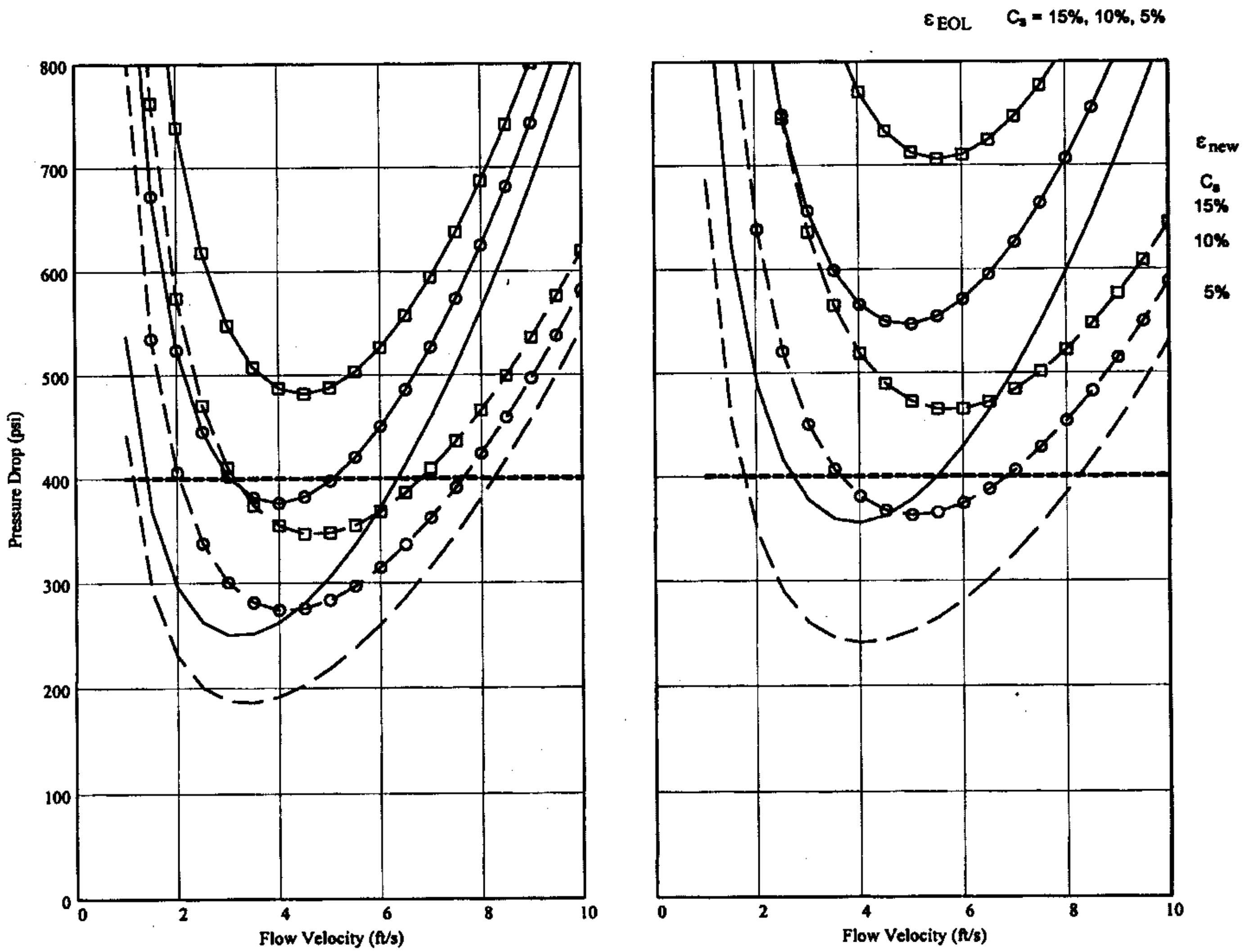


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Figure E-1c. Pressure Drop for AN-107 to BNFL - d_p=400 μm, ρ_L=1.46 kg/L, ρ_s=3 kg/L Case, T = 10 and 60 °C.

$\beta_{cv} = 1.2$ $L_{CS} = 557\,ft$ $L_{SS} = 7028\,ft$ $H = 40\,ft$ $d_{50} = 400\,\mu m$ $\varepsilon_{new} = 2\,mil$

$\kappa_{cv} = 1.3$ $\rho_L := 1.46 \cdot \frac{kg}{liter}$ $\rho_s := 3 \cdot \frac{kg}{liter}$ $\varepsilon_{EOL\_SS} = 10\,mil$

$\kappa_f = 1$ $\varepsilon_{EOL\_CS} = 150\,mil$

$T := 10\ ^oC$ $\mu_{cL}(\rho_L, 10) = 8.4\,cP$ $T := 60\ ^oC$ $\mu_{cL}(\rho_L, 60) = 3.7\,cP$

C_s	T = 10 °C	T = 60 °C
5%	$v_{cr}(D_{pipe}, d_{50}, \rho_s, 5 \cdot \%, \rho_L, \mu_{cL}(\rho_L, 10), \kappa_{cv}, \beta_{cv}) = 4.2\,\frac{ft}{sec}$	$v_{cr}(D_{pipe}, d_{50}, \rho_s, 5 \cdot \%, \rho_L, \mu_{cL}(\rho_L, 60), \kappa_{cv}, \beta_{cv}) = 4.6\,\frac{ft}{sec}$
10%	$v_{cr}(D_{pipe}, d_{50}, \rho_s, 10 \cdot \%, \rho_L, \mu_{cL}(\rho_L, 10), \kappa_{cv}, \beta_{cv}) = 4.6\,\frac{ft}{sec}$	$v_{cr}(D_{pipe}, d_{50}, \rho_s, 10 \cdot \%, \rho_L, \mu_{cL}(\rho_L, 60), \kappa_{cv}, \beta_{cv}) = 5\,\frac{ft}{sec}$
15%	$v_{cr}(D_{pipe}, d_{50}, \rho_s, 15 \cdot \%, \rho_L, \mu_{cL}(\rho_L, 10), \kappa_{cv}, \beta_{cv}) = 4.8\,\frac{ft}{sec}$	$v_{cr}(D_{pipe}, d_{50}, \rho_s, 15 \cdot \%, \rho_L, \mu_{cL}(\rho_L, 60), \kappa_{cv}, \beta_{cv}) = 5.2\,\frac{ft}{sec}$

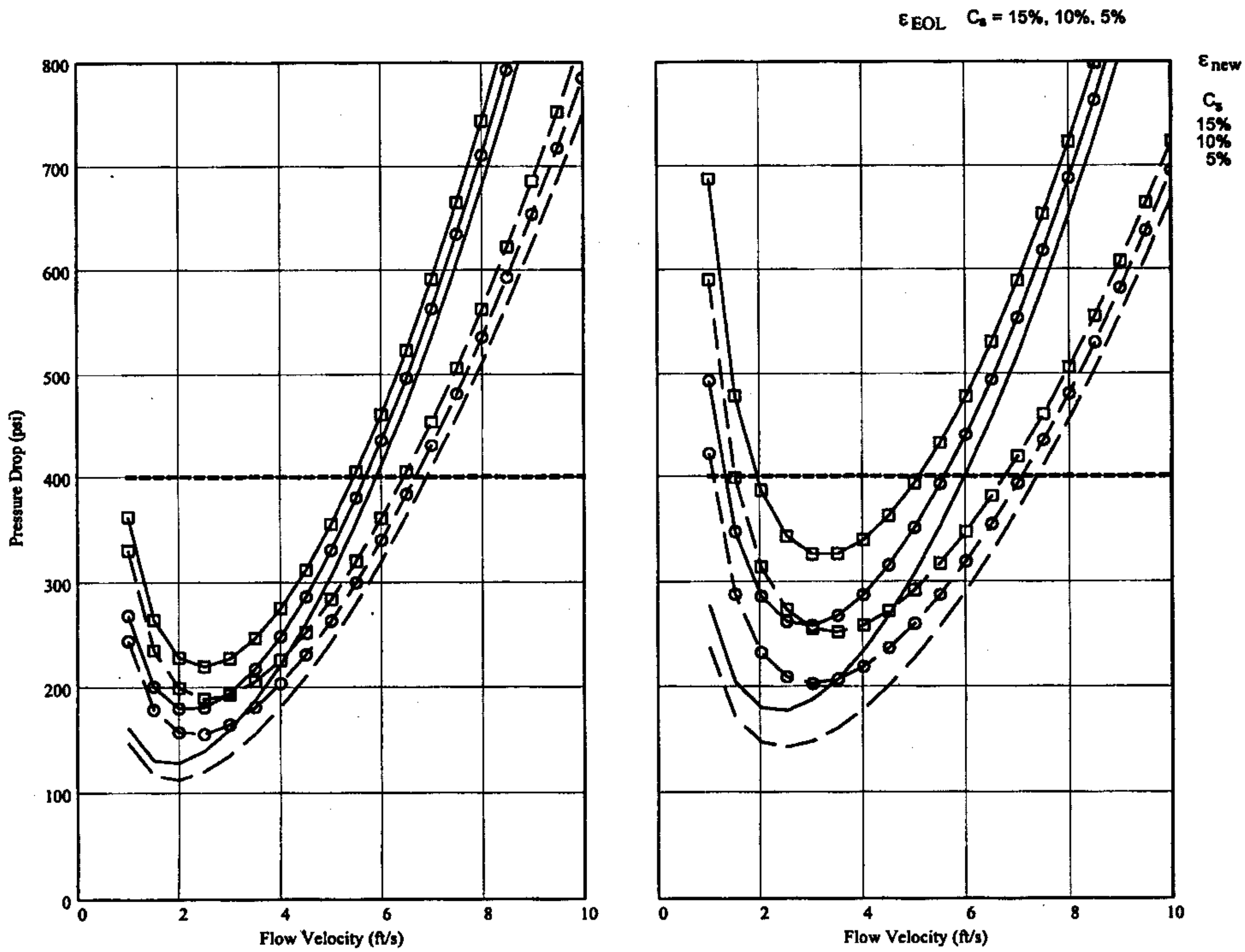

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Figure E-1d. Pressure Drop for AN-107 to BNFL - d_p=400 μm, ρ_L=1.2 kg/L, ρ_s=2.5 kg/L Case, T = 10 and 60 °C.

$\beta_{cv} = 1.2$ $L_{CS} = 557\,ft$ $L_{SS} = 7028\,ft$ $H = 40\,ft$ $d_{50} = 400\,\mu m$ $\varepsilon_{new} = 2\,mil$

$\kappa_{cv} = 1.3$ $\rho_L := 1.2\cdot\frac{kg}{liter}$ $\rho_s := 2.5\cdot\frac{kg}{liter}$ $\varepsilon_{EOL\_SS} = 10\,mil$

$\kappa_f = 1$ $\varepsilon_{EOL\_CS} = 150\,mil$

$T := 10\ °C$ $\mu_{cL}(\rho_L, 10) = 2\,cP$ $T := 60\ °C$ $\mu_{cL}(\rho_L, 60) = 0.8\,cP$

C_s

$v_{cr}(D_{pipe}, d_{50}, \rho_s, 5\cdot\%, \rho_L, \mu_{cL}(\rho_L, 10), \kappa_{cv}, \beta_{cv}) = 4.8\frac{ft}{sec}$ $v_{cr}(D_{pipe}, d_{50}, \rho_s, 5\cdot\%, \rho_L, \mu_{cL}(\rho_L, 60), \kappa_{cv}, \beta_{cv}) = 5.2\frac{ft}{sec}$ 5%

$v_{cr}(D_{pipe}, d_{50}, \rho_s, 10\cdot\%, \rho_L, \mu_{cL}(\rho_L, 10), \kappa_{cv}, \beta_{cv}) = 5.2\frac{ft}{sec}$ $v_{cr}(D_{pipe}, d_{50}, \rho_s, 10\cdot\%, \rho_L, \mu_{cL}(\rho_L, 60), \kappa_{cv}, \beta_{cv}) = 5.7\frac{ft}{sec}$ 10%

$v_{cr}(D_{pipe}, d_{50}, \rho_s, 15\cdot\%, \rho_L, \mu_{cL}(\rho_L, 10), \kappa_{cv}, \beta_{cv}) = 5.5\frac{ft}{sec}$ $v_{cr}(D_{pipe}, d_{50}, \rho_s, 15\cdot\%, \rho_L, \mu_{cL}(\rho_L, 60), \kappa_{cv}, \beta_{cv}) = 6\frac{ft}{sec}$ 15%

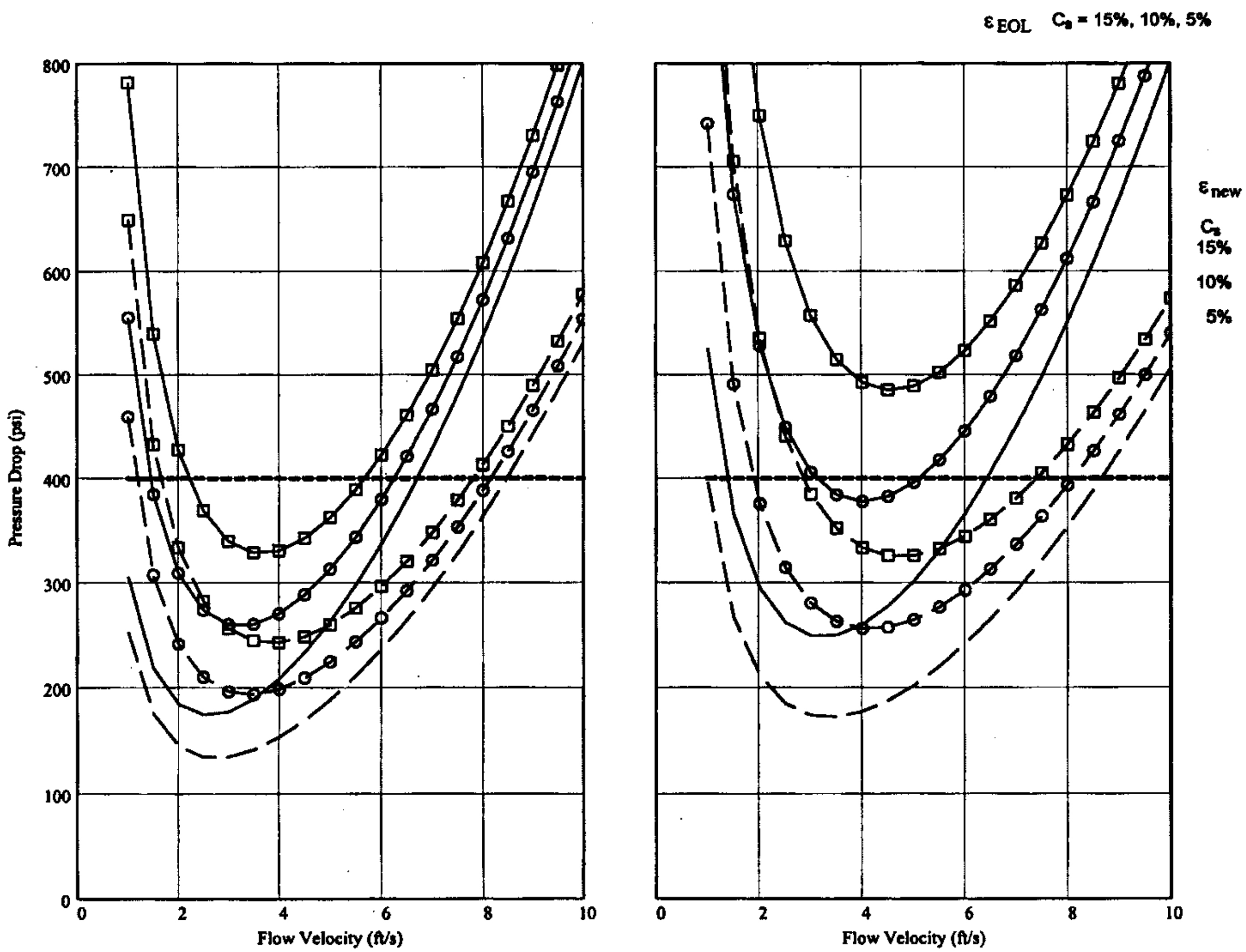


Figure E-1e. Pressure Drop for AN-107 to BNFL - d_p=400 μm, ρ_L=1.46 kg/L, ρ_s=2.5 kg/L Case, T = 10 and 60 °C.

$\beta_{cv} = 1.2$ $L_{CS} = 557\,ft$ $L_{SS} = 7028\,ft$ $H = 40\,ft$ $d_{50} = 400\,\mu m$ $\varepsilon_{new} = 2\,mil$

$\kappa_{cv} = 1.3$ $\rho_L := 1.46 \cdot \frac{kg}{liter}$ $\rho_s := 2.5 \cdot \frac{kg}{liter}$ $\varepsilon_{EOL\_SS} = 10\,mil$

$\kappa_f = 1$ $\varepsilon_{EOL\_CS} = 150\,mil$

$T := 10\ ^oC$ $\mu_{cL}(\rho_L, 10) = 8.4\,cP$ $T := 60\ ^oC$ $\mu_{cL}(\rho_L, 60) = 3.7\,cP$

		C_s
$v_{cr}(D_{pipe}, d_{50}, \rho_s, 5\cdot\%, \rho_L, \mu_{cL}(\rho_L,10), \kappa_{cv}, \beta_{cv}) = 3.4\frac{ft}{sec}$	$v_{cr}(D_{pipe}, d_{50}, \rho_s, 5\cdot\%, \rho_L, \mu_{cL}(\rho_L,60), \kappa_{cv}, \beta_{cv}) = 3.7\frac{ft}{sec}$	5%
$v_{cr}(D_{pipe}, d_{50}, \rho_s, 10\cdot\%, \rho_L, \mu_{cL}(\rho_L,10), \kappa_{cv}, \beta_{cv}) = 3.7\frac{ft}{sec}$	$v_{cr}(D_{pipe}, d_{50}, \rho_s, 10\cdot\%, \rho_L, \mu_{cL}(\rho_L,60), \kappa_{cv}, \beta_{cv}) = 4\frac{ft}{sec}$	10%
$v_{cr}(D_{pipe}, d_{50}, \rho_s, 15\cdot\%, \rho_L, \mu_{cL}(\rho_L,10), \kappa_{cv}, \beta_{cv}) = 3.9\frac{ft}{sec}$	$v_{cr}(D_{pipe}, d_{50}, \rho_s, 15\cdot\%, \rho_L, \mu_{cL}(\rho_L,60), \kappa_{cv}, \beta_{cv}) = 4.2\frac{ft}{sec}$	15%

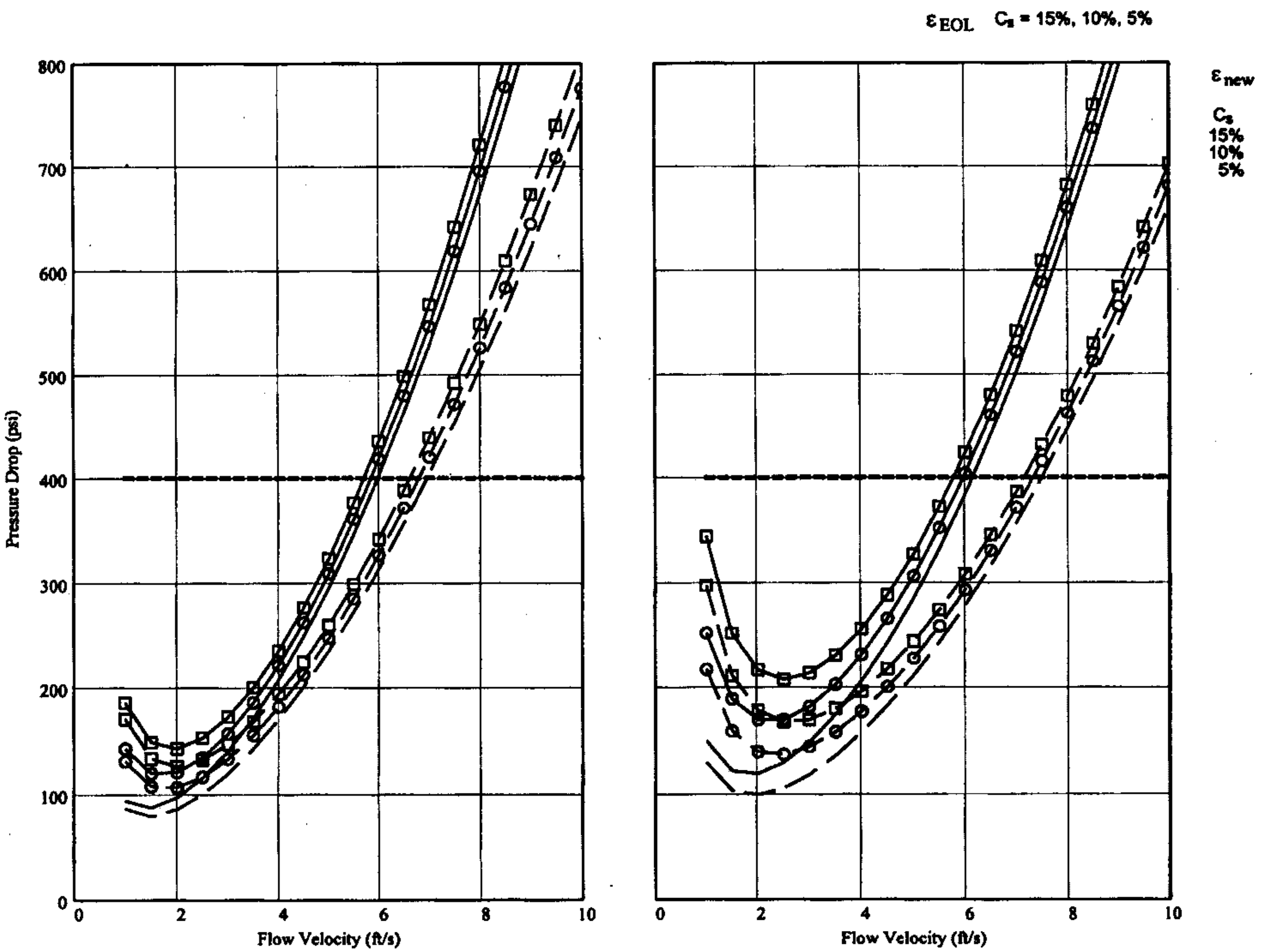
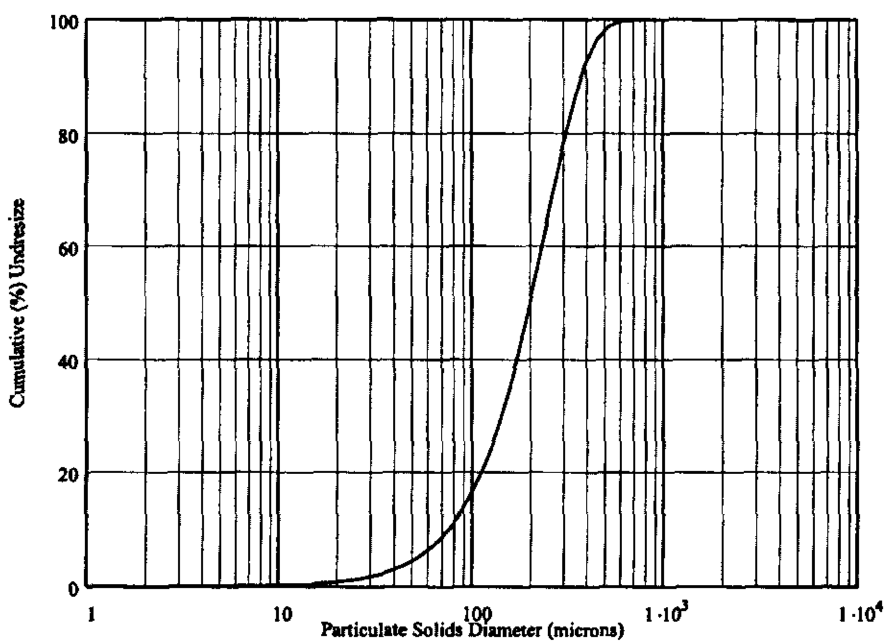


Figure E-2a. d_p=200 μm Case - Cumulative and Probability Density Particle Size Distribution by Volume.

$d_{50} := 200 \cdot \mu m$ $\quad (d_{pRR} \;\; \phi_{RR}) := dist_{RR}(d_{pR}, d_{50})$ $\quad d_{pRR} := d_{pRR} \cdot \mu m$ reset units $\quad \phi_{RRcum} := cum(\phi_{RR})$

$D_{pRR} := D_{\beta}(d_{pRR}, \phi_{RRcum}, 50\%)$ $\quad D_{pRR} = 187\ \mu m$



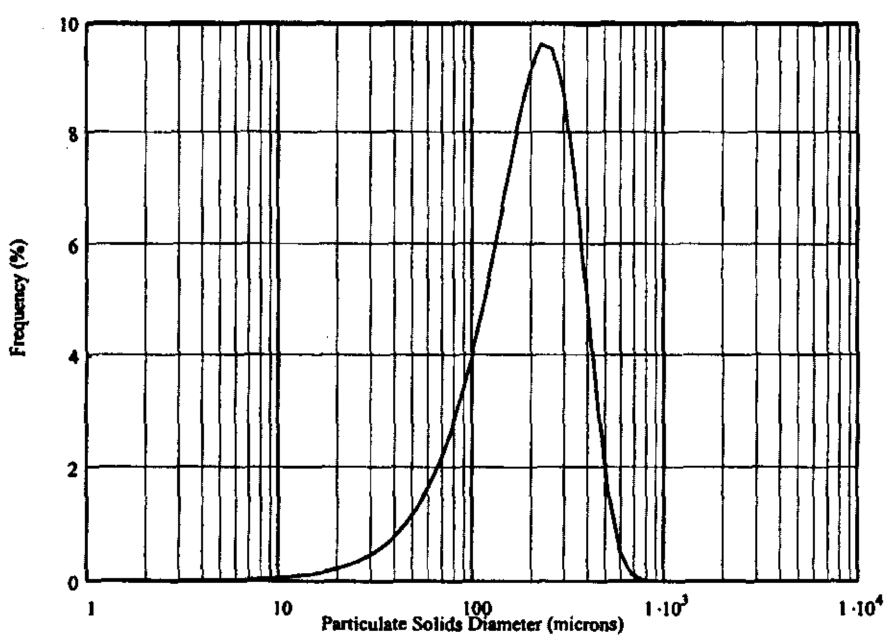


Figure E-2b. Pressure Drop for AN-107 to BNFL - d_p=200 µm, ρ_L=1.2 kg/L, ρ_s=3 kg/L Case, T = 10 and 60 °C.

$\beta_{cv} = 1.2$ $L_{CS} = 557\,ft$ $L_{SS} = 7028\,ft$ $H = 40\,ft$ $d_{50} = 200\,\mu m$ $\varepsilon_{new} = 2\,mil$

$\kappa_{cv} = 1.3$ $\rho_L := 1.2 \cdot \frac{kg}{liter}$ $\rho_s := 3 \cdot \frac{kg}{liter}$ $\varepsilon_{EOL\_SS} = 10\,mil$

$\kappa_f = 1$ $\varepsilon_{EOL\_CS} = 150\,mil$

$T := 10\ °C$ $\mu_{cL}(\rho_L, 10) = 2\,cP$ $T := 60\ °C$ $\mu_{cL}(\rho_L, 60) = 0.8\,cP$

C_s	T = 10 °C	T = 60 °C
5%	$v_{cr}(D_{pipe}, d_{50}, \rho_s, 5\cdot\%, \rho_L, \mu_{cL}(\rho_L,10), \kappa_{cv}, \beta_{cv}) = 5.1\frac{ft}{sec}$	$v_{cr}(D_{pipe}, d_{50}, \rho_s, 5\cdot\%, \rho_L, \mu_{cL}(\rho_L,60), \kappa_{cv}, \beta_{cv}) = 5.6\frac{ft}{sec}$
10%	$v_{cr}(D_{pipe}, d_{50}, \rho_s, 10\cdot\%, \rho_L, \mu_{cL}(\rho_L,10), \kappa_{cv}, \beta_{cv}) = 5.6\frac{ft}{sec}$	$v_{cr}(D_{pipe}, d_{50}, \rho_s, 10\cdot\%, \rho_L, \mu_{cL}(\rho_L,60), \kappa_{cv}, \beta_{cv}) = 6.1\frac{ft}{sec}$
15%	$v_{cr}(D_{pipe}, d_{50}, \rho_s, 15\cdot\%, \rho_L, \mu_{cL}(\rho_L,10), \kappa_{cv}, \beta_{cv}) = 5.8\frac{ft}{sec}$	$v_{cr}(D_{pipe}, d_{50}, \rho_s, 15\cdot\%, \rho_L, \mu_{cL}(\rho_L,60), \kappa_{cv}, \beta_{cv}) = 6.3\frac{ft}{sec}$

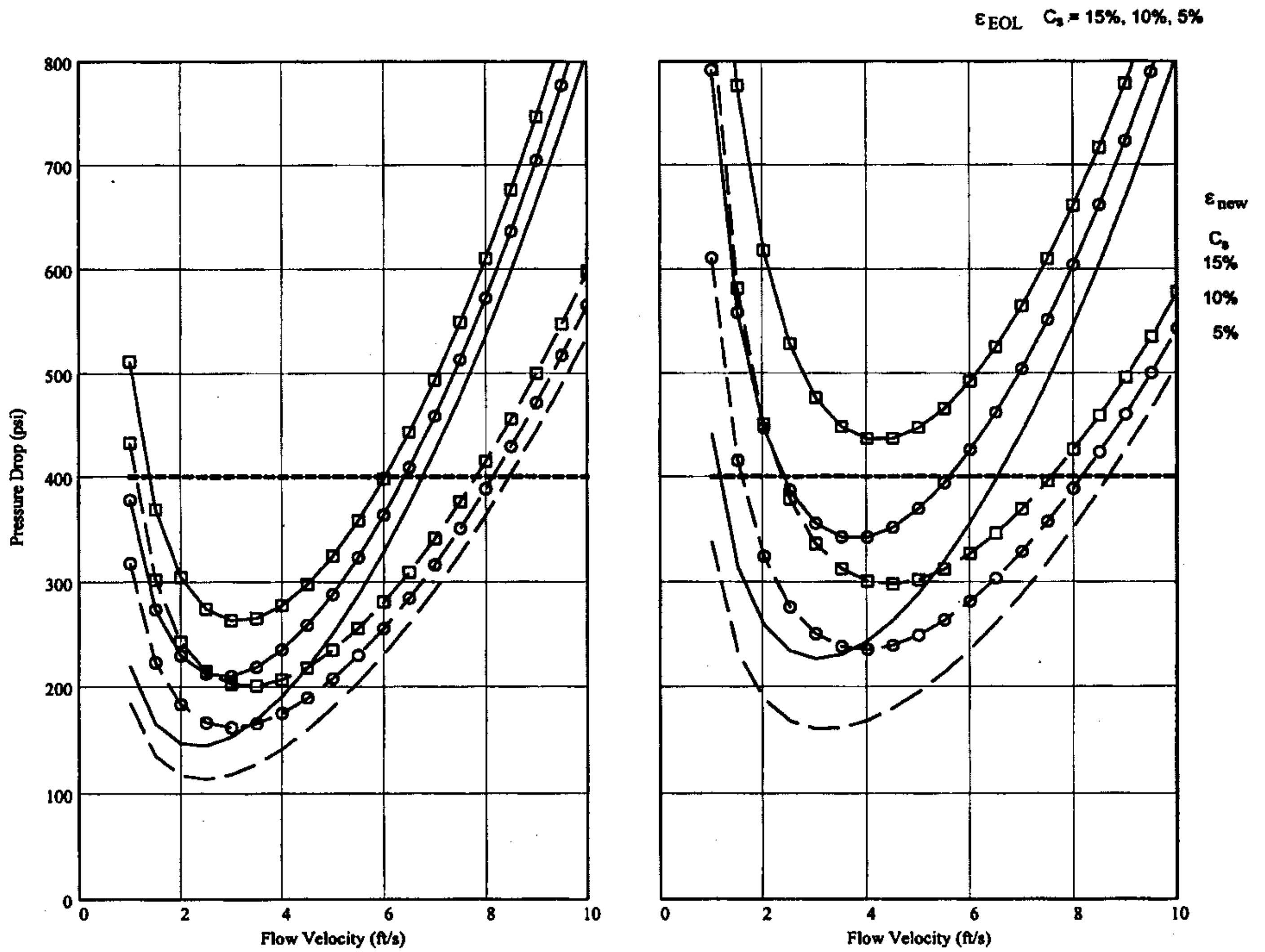


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Figure E-2c. Pressure Drop for AN-107 to BNFL - d_p=200 μm, ρ_L=1.46 kg/L, ρ_s=3 kg/L Case, T = 10 and 60 °C.

$\beta_{cv} = 1.2$ $L_{CS} = 557\,ft$ $L_{SS} = 7028\,ft$ $H = 40\,ft$ $d_{50} = 200\,\mu m$ $\varepsilon_{new} = 2\,mil$

$\kappa_{cv} = 1.3$ $\rho_L := 1.46 \cdot \frac{kg}{liter}$ $\rho_s := 3 \cdot \frac{kg}{liter}$ $\varepsilon_{EOL\_SS} = 10\,mil$

$\kappa_f = 1$ $\varepsilon_{EOL\_CS} = 150\,mil$

$T := 10\ ^{o}C$ $\mu_{cL}(\rho_L, 10) = 8.4\,cP$ $T := 60\ ^{o}C$ $\mu_{cL}(\rho_L, 60) = 3.7\,cP$

C_s	T = 10 °C	T = 60 °C
5%	$v_{cr}(D_{pipe}, d_{50}, \rho_s, 5\cdot\%, \rho_L, \mu_{cL}(\rho_L, 10), \kappa_{cv}, \beta_{cv}) = 3.8\,\frac{ft}{sec}$	$v_{cr}(D_{pipe}, d_{50}, \rho_s, 5\cdot\%, \rho_L, \mu_{cL}(\rho_L, 60), \kappa_{cv}, \beta_{cv}) = 4.1\,\frac{ft}{sec}$
10%	$v_{cr}(D_{pipe}, d_{50}, \rho_s, 10\cdot\%, \rho_L, \mu_{cL}(\rho_L, 10), \kappa_{cv}, \beta_{cv}) = 4.1\,\frac{ft}{sec}$	$v_{cr}(D_{pipe}, d_{50}, \rho_s, 10\cdot\%, \rho_L, \mu_{cL}(\rho_L, 60), \kappa_{cv}, \beta_{cv}) = 4.4\,\frac{ft}{sec}$
15%	$v_{cr}(D_{pipe}, d_{50}, \rho_s, 15\cdot\%, \rho_L, \mu_{cL}(\rho_L, 10), \kappa_{cv}, \beta_{cv}) = 4.3\,\frac{ft}{sec}$	$v_{cr}(D_{pipe}, d_{50}, \rho_s, 15\cdot\%, \rho_L, \mu_{cL}(\rho_L, 60), \kappa_{cv}, \beta_{cv}) = 4.6\,\frac{ft}{sec}$

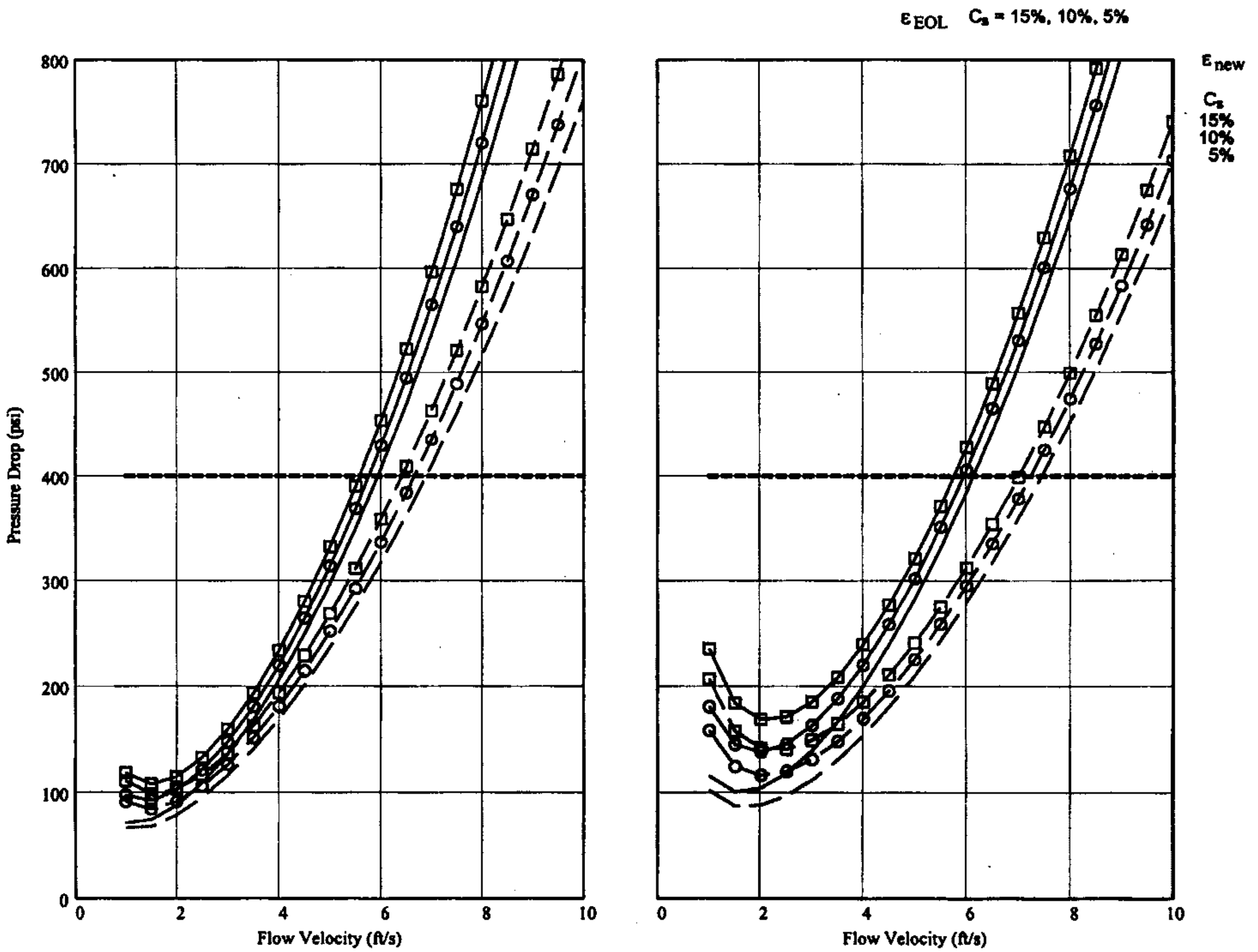

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Figure E-2d. Pressure Drop for AN-107 to BNFL - d_p=200 µm, ρ_L=1.2 kg/L, ρ_s=2.5 kg/L Case, T = 10 and 60 °C.

$\beta_{cv} = 1.2$ $L_{CS} = 557\,ft$ $L_{SS} = 7028\,ft$ $H = 40\,ft$ $d_{50} = 200\,\mu m$ $\varepsilon_{new} = 2\,mil$

$\kappa_{cv} = 1.3$ $\rho_L := 1.2 \cdot \frac{kg}{liter}$ $\rho_s := 2.5 \cdot \frac{kg}{liter}$ $\varepsilon_{EOL\_SS} = 10\,mil$

$\kappa_f = 1$ $\varepsilon_{EOL\_CS} = 150\,mil$

$T := 10\ °C$ $\mu_{cL}(\rho_L, 10) = 2\,cP$ $T := 60\ °C$ $\mu_{cL}(\rho_L, 60) = 0.8\,cP$

$T = 10\ °C$	$T = 60\ °C$	C_s
$v_{cr}(D_{pipe}, d_{50}, \rho_s, 5\cdot\%, \rho_L, \mu_{cL}(\rho_L, 10), \kappa_{cv}, \beta_{cv}) = 4.3\frac{ft}{sec}$	$v_{cr}(D_{pipe}, d_{50}, \rho_s, 5\cdot\%, \rho_L, \mu_{cL}(\rho_L, 60), \kappa_{cv}, \beta_{cv}) = 4.7\frac{ft}{sec}$	5%
$v_{cr}(D_{pipe}, d_{50}, \rho_s, 10\cdot\%, \rho_L, \mu_{cL}(\rho_L, 10), \kappa_{cv}, \beta_{cv}) = 4.7\frac{ft}{sec}$	$v_{cr}(D_{pipe}, d_{50}, \rho_s, 10\cdot\%, \rho_L, \mu_{cL}(\rho_L, 60), \kappa_{cv}, \beta_{cv}) = 5.1\frac{ft}{sec}$	10%
$v_{cr}(D_{pipe}, d_{50}, \rho_s, 15\cdot\%, \rho_L, \mu_{cL}(\rho_L, 10), \kappa_{cv}, \beta_{cv}) = 4.9\frac{ft}{sec}$	$v_{cr}(D_{pipe}, d_{50}, \rho_s, 15\cdot\%, \rho_L, \mu_{cL}(\rho_L, 60), \kappa_{cv}, \beta_{cv}) = 5.3\frac{ft}{sec}$	15%

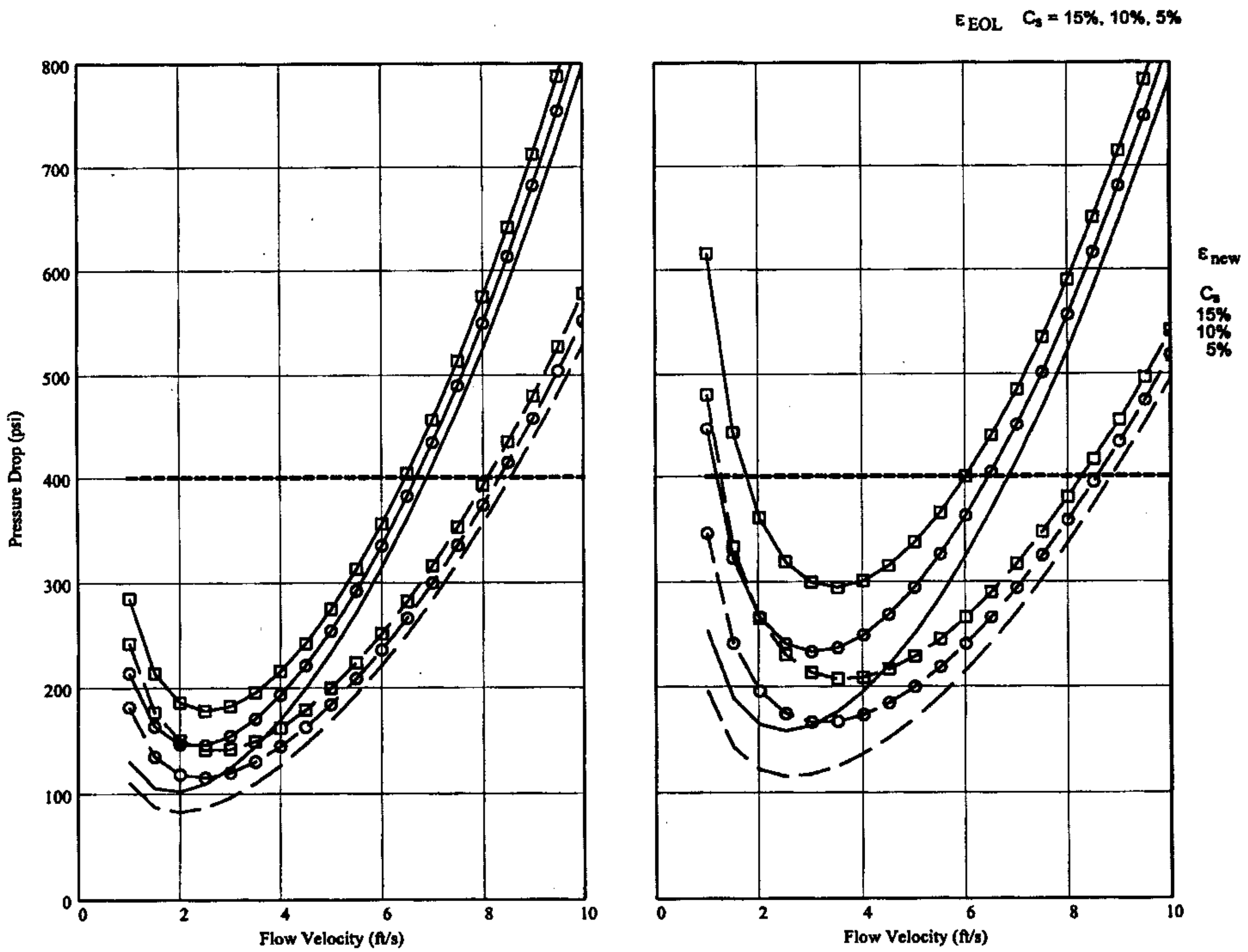

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Figure E-2e. Pressure Drop for AN-107 to BNFL - d_p=200 μm, ρ_L=1.46 kg/L, ρ_s=2.5 kg/L Case, T = 10 and 60 °C.

$\beta_{cv} = 1.2$ $\quad L_{CS} = 557\,ft \quad L_{SS} = 7028\,ft \quad H = 40\,ft \quad d_{50} = 200\,\mu m$ $\quad \varepsilon_{new} = 2\,mil$

$\kappa_{cv} = 1.3$ $\quad \rho_L := 1.46 \cdot \frac{kg}{liter} \quad \rho_s := 2.5 \cdot \frac{kg}{liter}$ $\quad \varepsilon_{EOL\_SS} = 10\,mil$

$\kappa_f = 1$ $\quad \varepsilon_{EOL\_CS} = 150\,mil$

$T := 10\ °C \quad \mu_{cL}(\rho_L, 10) = 8.4\,cP$ $\qquad T := 60\ °C \quad \mu_{cL}(\rho_L, 60) = 3.7\,cP$

C_s	T = 10 °C	T = 60 °C
5%	$v_{cr}(D_{pipe}, d_{50}, \rho_s, 5\cdot\%, \rho_L, \mu_{cL}(\rho_L, 10), \kappa_{cv}, \beta_{cv}) = 3.1\,\frac{ft}{sec}$	$v_{cr}(D_{pipe}, d_{50}, \rho_s, 5\cdot\%, \rho_L, \mu_{cL}(\rho_L, 60), \kappa_{cv}, \beta_{cv}) = 3.3\,\frac{ft}{sec}$
10%	$v_{cr}(D_{pipe}, d_{50}, \rho_s, 10\cdot\%, \rho_L, \mu_{cL}(\rho_L, 10), \kappa_{cv}, \beta_{cv}) = 3.3\,\frac{ft}{sec}$	$v_{cr}(D_{pipe}, d_{50}, \rho_s, 10\cdot\%, \rho_L, \mu_{cL}(\rho_L, 60), \kappa_{cv}, \beta_{cv}) = 3.6\,\frac{ft}{sec}$
15%	$v_{cr}(D_{pipe}, d_{50}, \rho_s, 15\cdot\%, \rho_L, \mu_{cL}(\rho_L, 10), \kappa_{cv}, \beta_{cv}) = 3.5\,\frac{ft}{sec}$	$v_{cr}(D_{pipe}, d_{50}, \rho_s, 15\cdot\%, \rho_L, \mu_{cL}(\rho_L, 60), \kappa_{cv}, \beta_{cv}) = 3.7\,\frac{ft}{sec}$

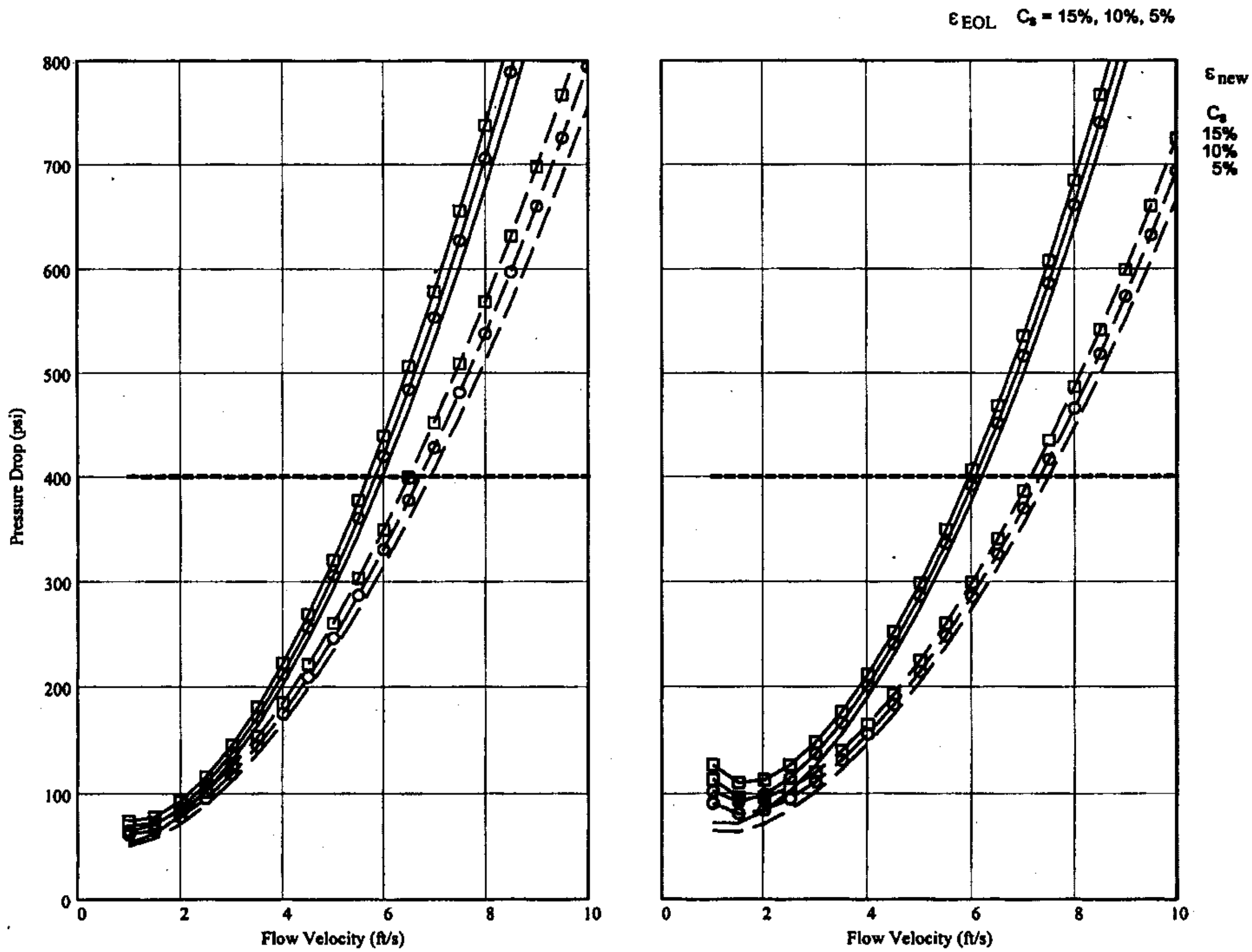
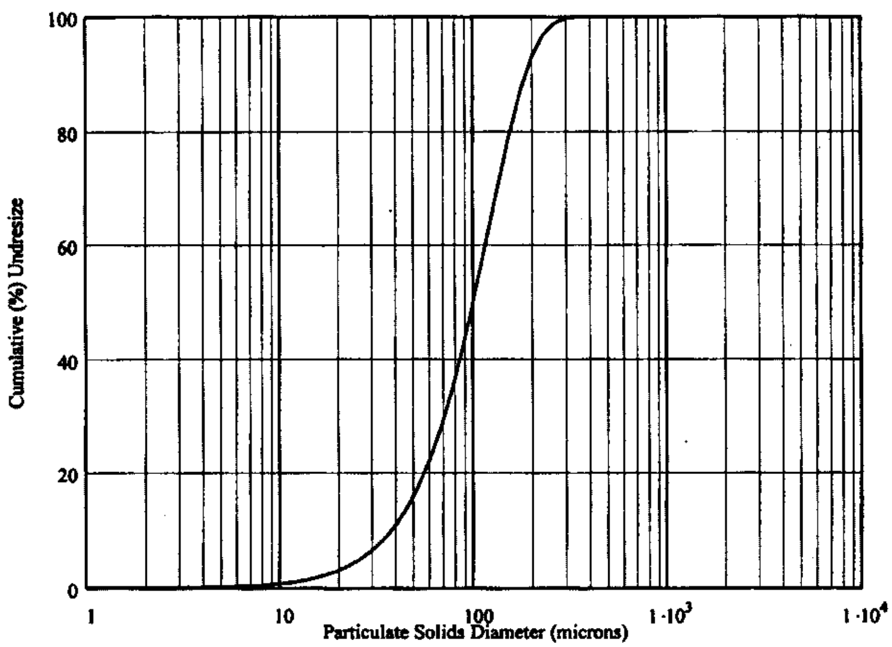


Figure E-3a. d_p=100 μm Case - Cumulative and Probability Density Particle Size Distribution by Volume.

$d_{50} := 100 \cdot \mu m$ $\quad (d_{pRR} \;\; \phi_{RR}) := dist_{RR}(d_{pR}, d_{50})$ $\quad d_{pRR} := d_{pRR} \cdot \mu m$ reset units $\quad \phi_{RRcum} := cum(\phi_{RR})$

$D_{pRR} := D_\beta(d_{pRR}, \phi_{RRcum}, 50\%)$ $\quad D_{pRR} = 93\,\mu m$



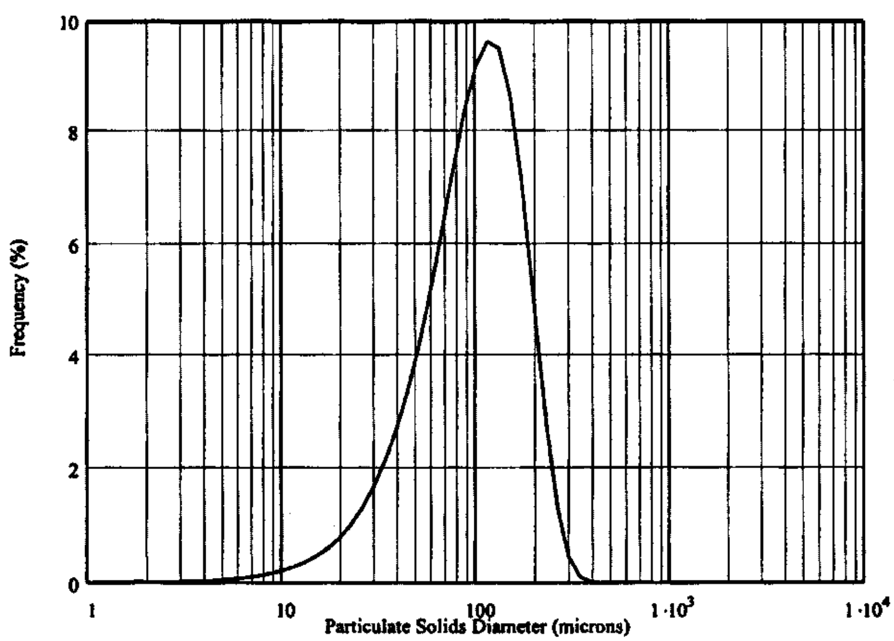


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Figure E-3b. Pressure Drop for AN-107 to BNFL - d_p=100 µm, ρ_L=1.2 kg/L, ρ_s=3 kg/L Case, T = 10 and 60 °C.

$\beta_{cv} = 1.2$ $L_{CS} = 557\,ft$ $L_{SS} = 7028\,ft$ $H = 40\,ft$ $d_{50} = 100\,\mu m$ $\varepsilon_{new} = 2\,mil$

$\kappa_{cv} = 1.3$ $\rho_L := 1.2 \cdot \frac{kg}{liter}$ $\rho_s := 3 \cdot \frac{kg}{liter}$ $\varepsilon_{EOL\_SS} = 10\,mil$

$\kappa_f = 1$ $\varepsilon_{EOL\_CS} = 150\,mil$

$T := 10\ °C$ $\mu_{cL}(\rho_L, 10) = 2\,cP$ $T := 60\ °C$ $\mu_{cL}(\rho_L, 60) = 0.8\,cP$

C_s	T = 10 °C	T = 60 °C
5%	$v_{cr}(D_{pipe}, d_{50}, \rho_s, 5\cdot\%, \rho_L, \mu_{cL}(\rho_L, 10), \kappa_{cv}, \beta_{cv}) = 4.6\frac{ft}{sec}$	$v_{cr}(D_{pipe}, d_{50}, \rho_s, 5\cdot\%, \rho_L, \mu_{cL}(\rho_L, 60), \kappa_{cv}, \beta_{cv}) = 5\frac{ft}{sec}$
10%	$v_{cr}(D_{pipe}, d_{50}, \rho_s, 10\cdot\%, \rho_L, \mu_{cL}(\rho_L, 10), \kappa_{cv}, \beta_{cv}) = 5\frac{ft}{sec}$	$v_{cr}(D_{pipe}, d_{50}, \rho_s, 10\cdot\%, \rho_L, \mu_{cL}(\rho_L, 60), \kappa_{cv}, \beta_{cv}) = 5.4\frac{ft}{sec}$
15%	$v_{cr}(D_{pipe}, d_{50}, \rho_s, 15\cdot\%, \rho_L, \mu_{cL}(\rho_L, 10), \kappa_{cv}, \beta_{cv}) = 5.2\frac{ft}{sec}$	$v_{cr}(D_{pipe}, d_{50}, \rho_s, 15\cdot\%, \rho_L, \mu_{cL}(\rho_L, 60), \kappa_{cv}, \beta_{cv}) = 5.7\frac{ft}{sec}$

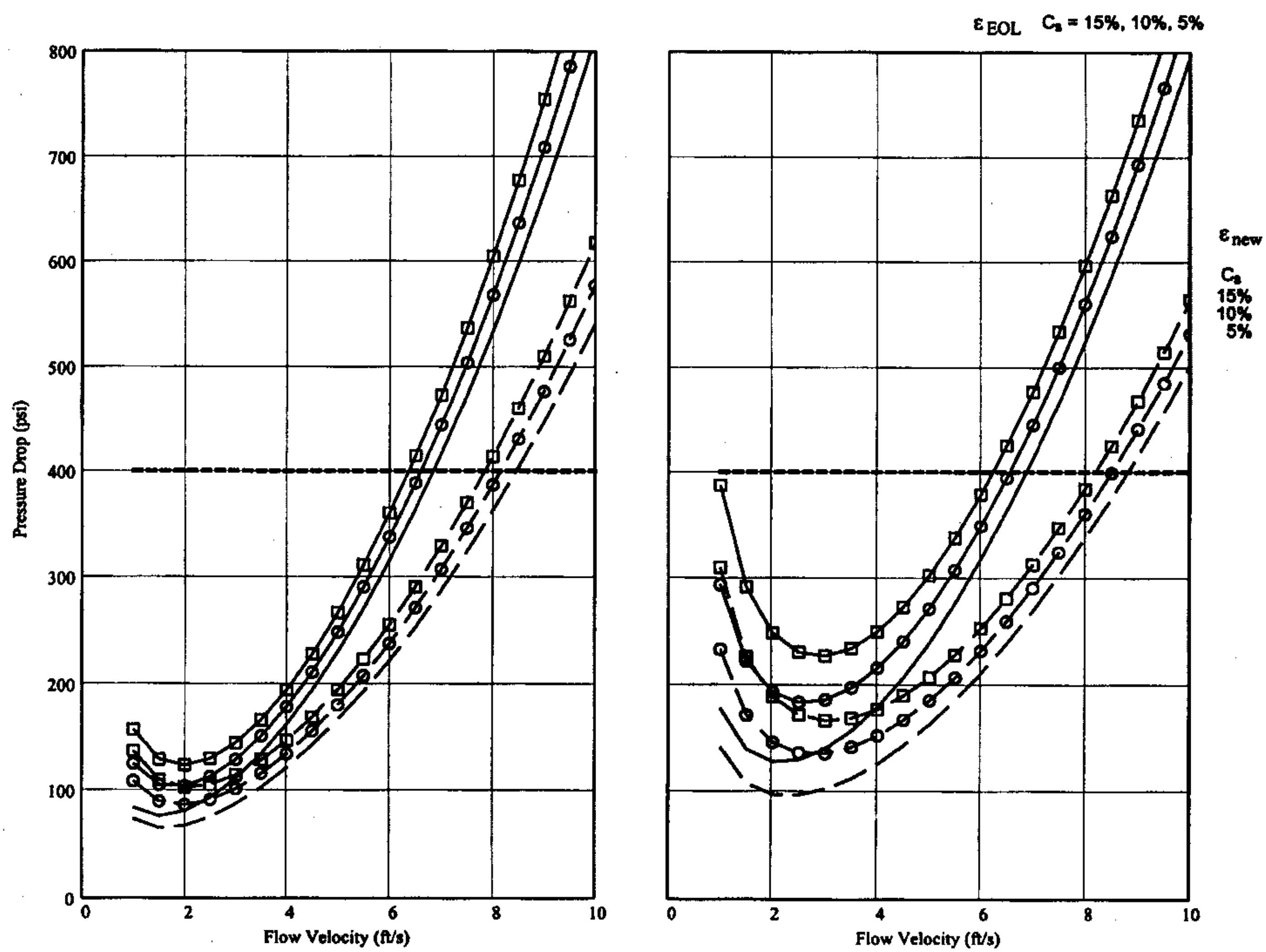


Figure E-3c. Pressure Drop for AN-107 to BNFL - d_p=100 μm, ρ_L=1.46 kg/L, ρ_s=3 kg/L Case, T = 10 and 60 °C.

$\beta_{cv} = 1.2$ $L_{CS} = 557\,ft$ $L_{SS} = 7028\,ft$ $H = 40\,ft$ $d_{50} = 100\,\mu m$ $\varepsilon_{new} = 2\,mil$

$\kappa_{cv} = 1.3$ $\rho_L := 1.46 \cdot \frac{kg}{liter}$ $\rho_s := 3 \cdot \frac{kg}{liter}$ $\varepsilon_{EOL\_SS} = 10\,mil$

$\kappa_f = 1$ $\varepsilon_{EOL\_CS} = 150\,mil$

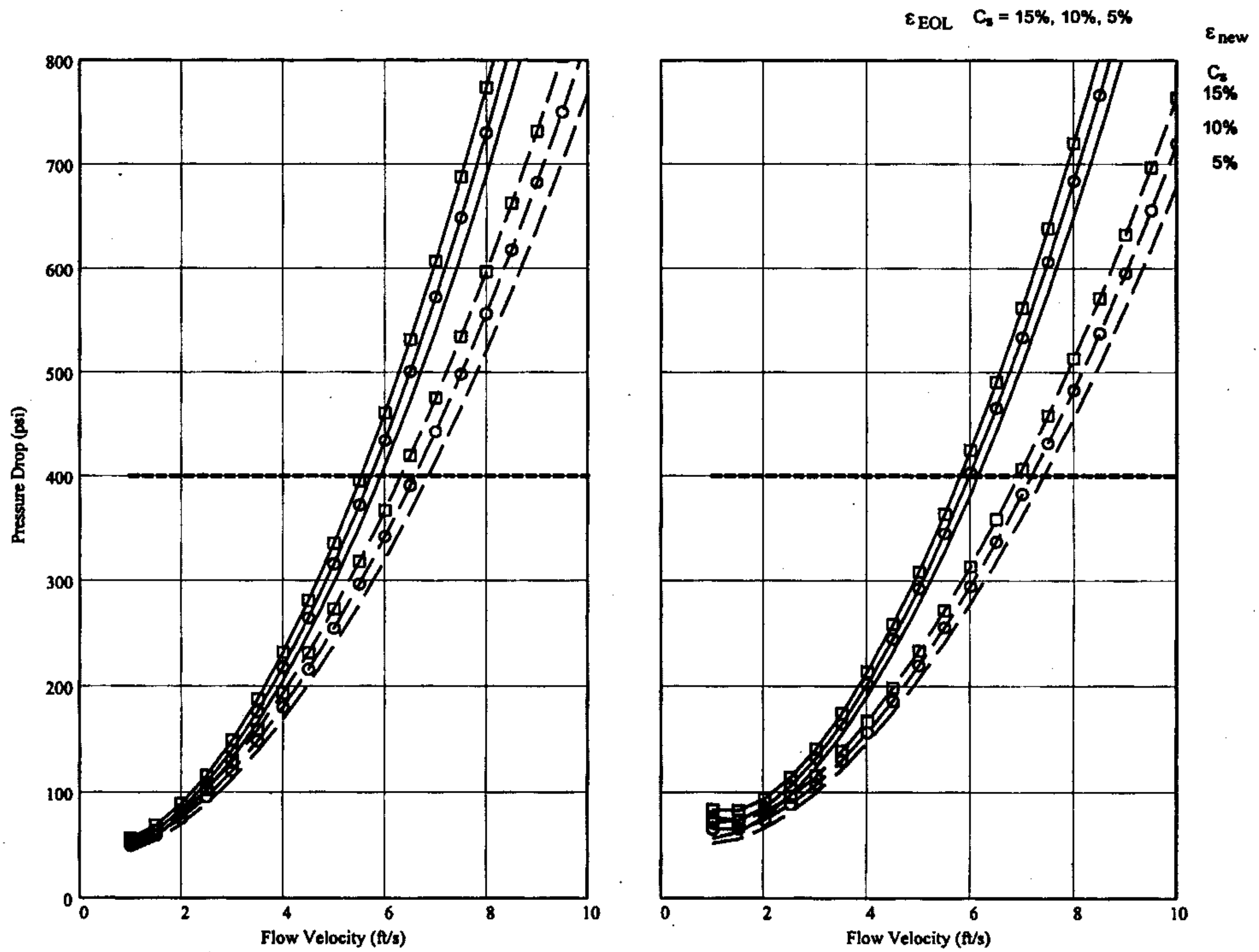
$T := 10\ ^oC$ $\mu_{cL}(\rho_L, 10) = 8.4\,cP$ $T := 60\ ^oC$ $\mu_{cL}(\rho_L, 60) = 3.7\,cP$

C_s

5%: $v_{cr}(D_{pipe}, d_{50}, \rho_s, 5\cdot\%, \rho_L, \mu_{cL}(\rho_L, 10), \kappa_{cv}, \beta_{cv}) = 3.4\,\frac{ft}{sec}$ $v_{cr}(D_{pipe}, d_{50}, \rho_s, 5\cdot\%, \rho_L, \mu_{cL}(\rho_L, 60), \kappa_{cv}, \beta_{cv}) = 3.6\,\frac{ft}{sec}$

10%: $v_{cr}(D_{pipe}, d_{50}, \rho_s, 10\cdot\%, \rho_L, \mu_{cL}(\rho_L, 10), \kappa_{cv}, \beta_{cv}) = 3.7\,\frac{ft}{sec}$ $v_{cr}(D_{pipe}, d_{50}, \rho_s, 10\cdot\%, \rho_L, \mu_{cL}(\rho_L, 60), \kappa_{cv}, \beta_{cv}) = 4\,\frac{ft}{sec}$

15%: $v_{cr}(D_{pipe}, d_{50}, \rho_s, 15\cdot\%, \rho_L, \mu_{cL}(\rho_L, 10), \kappa_{cv}, \beta_{cv}) = 3.8\,\frac{ft}{sec}$ $v_{cr}(D_{pipe}, d_{50}, \rho_s, 15\cdot\%, \rho_L, \mu_{cL}(\rho_L, 60), \kappa_{cv}, \beta_{cv}) = 4.1\,\frac{ft}{sec}$



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		Checked: 03/10/2000	By: T. C. Oten
Location:	200 Area - Hanford Site, Richland, Washington	Revised:	By:

Figure E-3d. Pressure Drop for AN-107 to BNFL - d_p=100 μm, ρ_L=1.2 kg/L, ρ_s=2.5 kg/L Case, T = 10 and 60 °C.

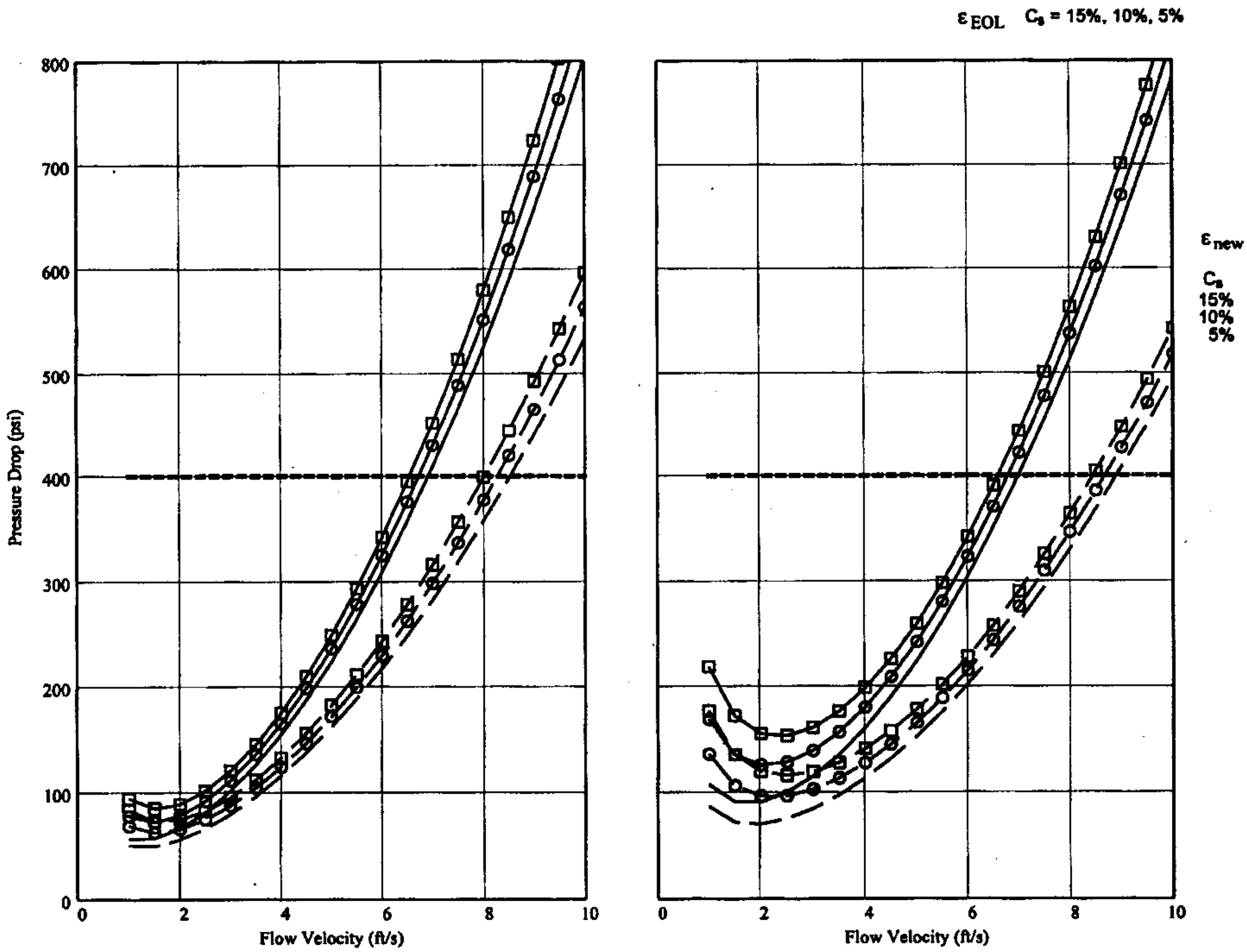
$\beta_{cv} = 1.2$ $\quad L_{CS} = 557\,ft \quad L_{SS} = 7028\,ft \quad H = 40\,ft \quad d_{50} = 100\,\mu m \quad \varepsilon_{new} = 2\,mil$

$\kappa_{cv} = 1.3 \quad \rho_L := 1.2\cdot\frac{kg}{liter} \quad \rho_s := 2.5\cdot\frac{kg}{liter} \quad \varepsilon_{EOL\_SS} = 10\,mil$

$\kappa_f = 1 \quad \varepsilon_{EOL\_CS} = 150\,mil$

$T := 10\ {}^oC \quad \mu_{cL}(\rho_L, 10) = 2\,cP \qquad T := 60\ {}^oC \quad \mu_{cL}(\rho_L, 60) = 0.8\,cP$

		C_s
$v_{cr}(D_{pipe}, d_{50}, \rho_s, 5\cdot\%, \rho_L, \mu_{cL}(\rho_L,10), \kappa_{cv}, \beta_{cv}) = 3.8\frac{ft}{sec}$	$v_{cr}(D_{pipe}, d_{50}, \rho_s, 5\cdot\%, \rho_L, \mu_{cL}(\rho_L,60), \kappa_{cv}, \beta_{cv}) = 4.2\frac{ft}{sec}$	5%
$v_{cr}(D_{pipe}, d_{50}, \rho_s, 10\cdot\%, \rho_L, \mu_{cL}(\rho_L,10), \kappa_{cv}, \beta_{cv}) = 4.2\frac{ft}{sec}$	$v_{cr}(D_{pipe}, d_{50}, \rho_s, 10\cdot\%, \rho_L, \mu_{cL}(\rho_L,60), \kappa_{cv}, \beta_{cv}) = 4.5\frac{ft}{sec}$	10%
$v_{cr}(D_{pipe}, d_{50}, \rho_s, 15\cdot\%, \rho_L, \mu_{cL}(\rho_L,10), \kappa_{cv}, \beta_{cv}) = 4.3\frac{ft}{sec}$	$v_{cr}(D_{pipe}, d_{50}, \rho_s, 15\cdot\%, \rho_L, \mu_{cL}(\rho_L,60), \kappa_{cv}, \beta_{cv}) = 4.7\frac{ft}{sec}$	15%



Wasp-sen AN-107pt1.mcd

Figure E-3e. Pressure Drop for AN-107 to BNFL - d_p=100 μm, ρ_L=1.46 kg/L, ρ_s=2.5 kg/L Case, T = 10 and 60 °C.

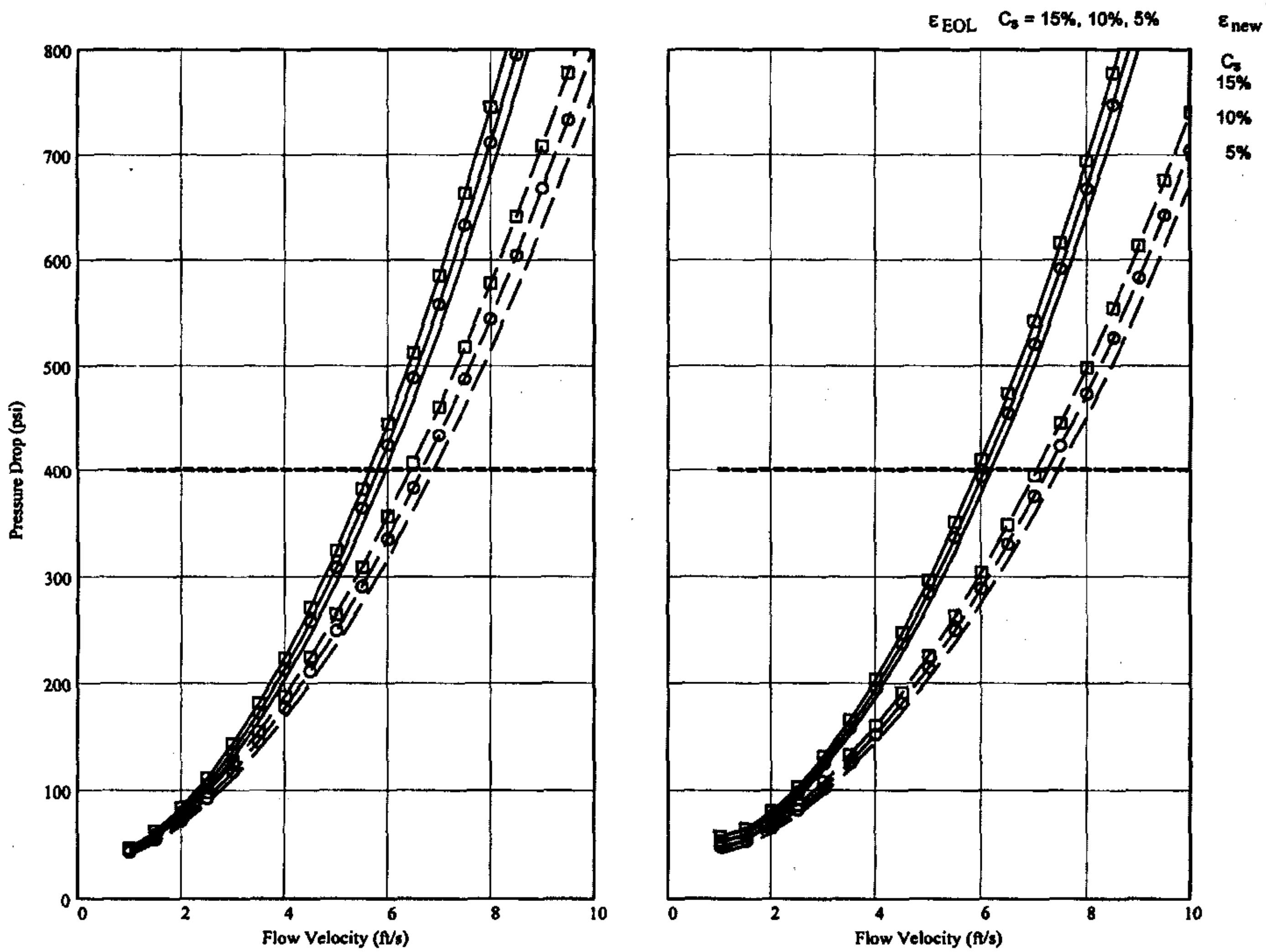
$\beta_{cv} = 1.2$ $\quad L_{CS} = 557\,ft \quad L_{SS} = 7028\,ft \quad H = 40\,ft \quad d_{50} = 100\,\mu m \quad \varepsilon_{new} = 2\,mil$

$\kappa_{cv} = 1.3 \quad \rho_L := 1.46\cdot\frac{kg}{liter} \quad \rho_s := 2.5\cdot\frac{kg}{liter} \quad \varepsilon_{EOL\_SS} = 10\,mil$

$\kappa_f = 1 \quad \varepsilon_{EOL\_CS} = 150\,mil$

$T := 10\ ^oC \quad \mu_{cL}(\rho_L,10) = 8.4\,cP \qquad T := 60\ ^oC \quad \mu_{cL}(\rho_L,60) = 3.7\,cP$

C_s	T = 10 °C	T = 60 °C
5%	$v_{cr}(D_{pipe},d_{50},\rho_s,5\cdot\%,\rho_L,\mu_{cL}(\rho_L,10),\kappa_{cv},\beta_{cv}) = 2.7\frac{ft}{sec}$	$v_{cr}(D_{pipe},d_{50},\rho_s,5\cdot\%,\rho_L,\mu_{cL}(\rho_L,60),\kappa_{cv},\beta_{cv}) = 2.9\frac{ft}{sec}$
10%	$v_{cr}(D_{pipe},d_{50},\rho_s,10\cdot\%,\rho_L,\mu_{cL}(\rho_L,10),\kappa_{cv},\beta_{cv}) = 3\frac{ft}{sec}$	$v_{cr}(D_{pipe},d_{50},\rho_s,10\cdot\%,\rho_L,\mu_{cL}(\rho_L,60),\kappa_{cv},\beta_{cv}) = 3.2\frac{ft}{sec}$
15%	$v_{cr}(D_{pipe},d_{50},\rho_s,15\cdot\%,\rho_L,\mu_{cL}(\rho_L,10),\kappa_{cv},\beta_{cv}) = 3.1\frac{ft}{sec}$	$v_{cr}(D_{pipe},d_{50},\rho_s,15\cdot\%,\rho_L,\mu_{cL}(\rho_L,60),\kappa_{cv},\beta_{cv}) = 3.3\frac{ft}{sec}$



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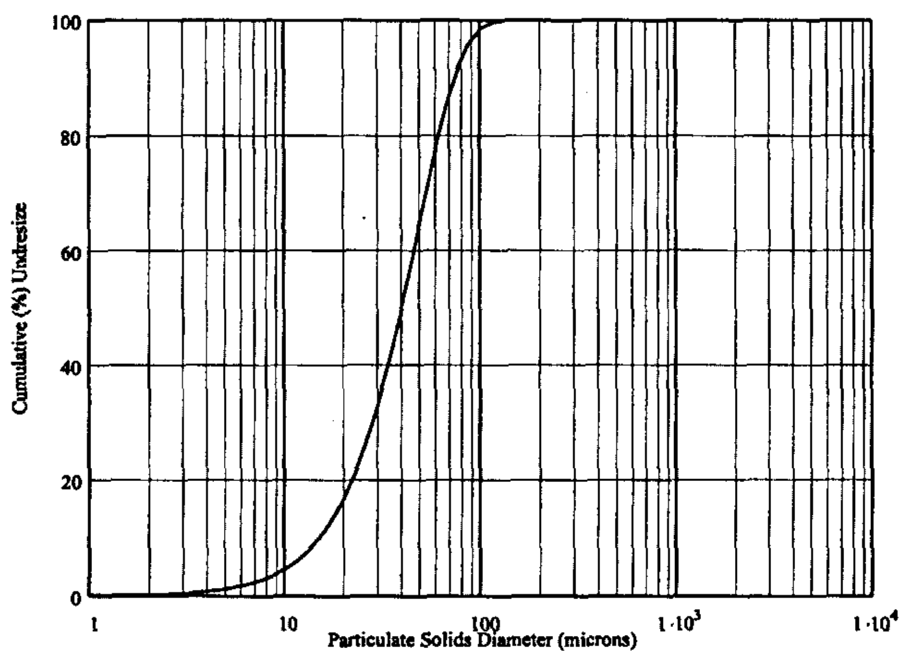
		Checked: 03/10/2000	By: T. C. Oten
Location:	200 Area - Hanford Site, Richland, Washington	Revised:	By:

Figure E-4a. d_p=40 μm Case - Cumulative and Probability Density Particle Size Distribution by Volume.

$d_{50} := 40 \cdot \mu m$ $\quad (d_{pRR} \;\; \phi_{RR}) := dist_{RR}(d_{pR}, d_{50})$ $\quad d_{pRR} := d_{pRR} \cdot \mu m$ reset units $\quad \phi_{RRcum} := cum(\phi_{RR})$

$D_{pRR} := D_\beta(d_{pRR}, \phi_{RRcum}, 50\%)$ $\quad D_{pRR} = 37\,\mu m$



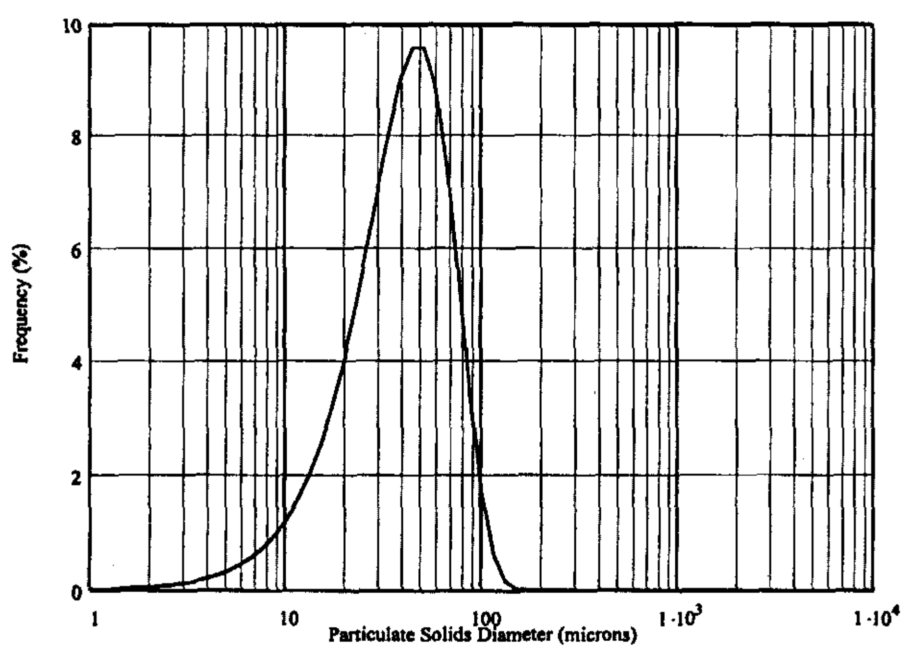


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Figure E-4b. Pressure Drop for AN-107 to BNFL - d_p=40 μm, ρ_L=1.2 kg/L, ρ_s=3 kg/L Case, T = 10 and 60 °C.

$L_{CS} = 557\,ft \quad L_{SS} = 7028\,ft \quad H = 40\,ft \quad d_{50} = 40\,\mu m$

$\varepsilon_{new} = 2\,mil$

$\beta_{cv} = 1.2$

$\kappa_{cv} = 1.3$

$\kappa_f = 1$

$\rho_L := 1.2\cdot\frac{kg}{liter} \quad \rho_s := 3\cdot\frac{kg}{liter}$

$\varepsilon_{EOL\_SS} = 10\,mil$

$\varepsilon_{EOL\_CS} = 150\,mil$

$T := 10\ ^oC \quad \mu_{cL}(\rho_L, 10) = 2\,cP$

$T := 60\ ^oC \quad \mu_{cL}(\rho_L, 60) = 0.8\,cP$

		C_s
$v_{cr}(D_{pipe}, d_{50}, \rho_s, 5\cdot\%, \rho_L, \mu_{cL}(\rho_L,10), \kappa_{cv}, \beta_{cv}) = 3.9\frac{ft}{sec}$	$v_{cr}(D_{pipe}, d_{50}, \rho_s, 5\cdot\%, \rho_L, \mu_{cL}(\rho_L,60), \kappa_{cv}, \beta_{cv}) = 4.3\frac{ft}{sec}$	5%
$v_{cr}(D_{pipe}, d_{50}, \rho_s, 10\cdot\%, \rho_L, \mu_{cL}(\rho_L,10), \kappa_{cv}, \beta_{cv}) = 4.3\frac{ft}{sec}$	$v_{cr}(D_{pipe}, d_{50}, \rho_s, 10\cdot\%, \rho_L, \mu_{cL}(\rho_L,60), \kappa_{cv}, \beta_{cv}) = 4.7\frac{ft}{sec}$	10%
$v_{cr}(D_{pipe}, d_{50}, \rho_s, 15\cdot\%, \rho_L, \mu_{cL}(\rho_L,10), \kappa_{cv}, \beta_{cv}) = 4.4\frac{ft}{sec}$	$v_{cr}(D_{pipe}, d_{50}, \rho_s, 15\cdot\%, \rho_L, \mu_{cL}(\rho_L,60), \kappa_{cv}, \beta_{cv}) = 4.9\frac{ft}{sec}$	15%

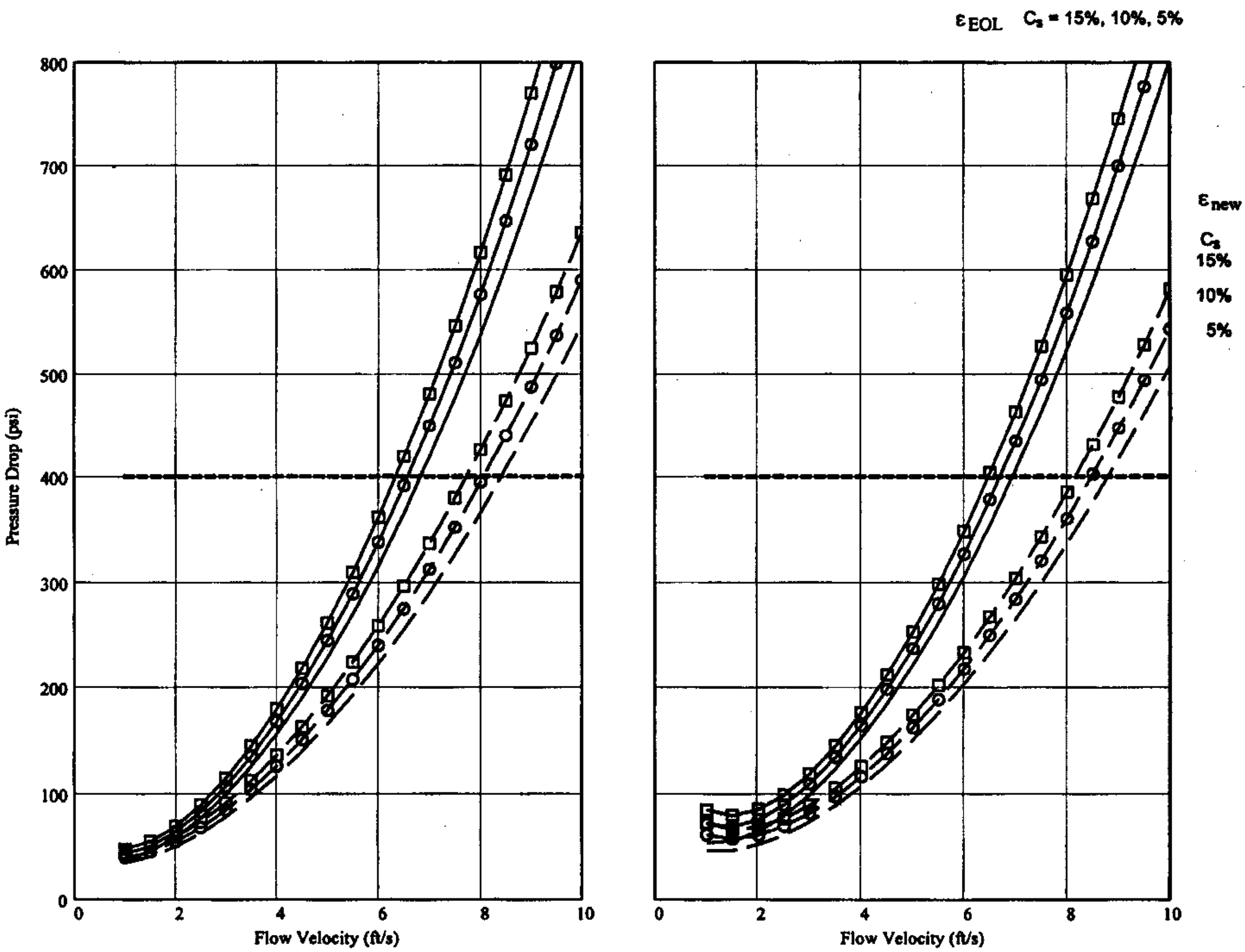

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Figure E-4c. Pressure Drop for AN-107 to BNFL - d_p=40 μm, ρ_L=1.46 kg/L, ρ_s=3 kg/L Case, T = 10 and 60 °C.

$\beta_{cv} = 1.2$ $L_{CS} = 557\,ft$ $L_{SS} = 7028\,ft$ $H = 40\,ft$ $d_{50} = 40\,\mu m$ $\varepsilon_{new} = 2\,mil$

$\kappa_{cv} = 1.3$ $\rho_L := 1.46\cdot\frac{kg}{liter}$ $\rho_s := 3\cdot\frac{kg}{liter}$ $\varepsilon_{EOL\_SS} = 10\,mil$

$\kappa_f = 1$ $\varepsilon_{EOL\_CS} = 150\,mil$

$T := 10\ ^oC$ $\mu_{cL}(\rho_L, 10) = 8.4\,cP$ $T := 60\ ^oC$ $\mu_{cL}(\rho_L, 60) = 3.7\,cP$

C_s	T = 10 °C	T = 60 °C
5%	$v_{cr}(D_{pipe}, d_{50}, \rho_s, 5\cdot\%, \rho_L, \mu_{cL}(\rho_L, 10), \kappa_{cv}, \beta_{cv}) = 2.9\,\frac{ft}{sec}$	$v_{cr}(D_{pipe}, d_{50}, \rho_s, 5\cdot\%, \rho_L, \mu_{cL}(\rho_L, 60), \kappa_{cv}, \beta_{cv}) = 3.1\,\frac{ft}{sec}$
10%	$v_{cr}(D_{pipe}, d_{50}, \rho_s, 10\cdot\%, \rho_L, \mu_{cL}(\rho_L, 10), \kappa_{cv}, \beta_{cv}) = 3.2\,\frac{ft}{sec}$	$v_{cr}(D_{pipe}, d_{50}, \rho_s, 10\cdot\%, \rho_L, \mu_{cL}(\rho_L, 60), \kappa_{cv}, \beta_{cv}) = 3.4\,\frac{ft}{sec}$
15%	$v_{cr}(D_{pipe}, d_{50}, \rho_s, 15\cdot\%, \rho_L, \mu_{cL}(\rho_L, 10), \kappa_{cv}, \beta_{cv}) = 3.3\,\frac{ft}{sec}$	$v_{cr}(D_{pipe}, d_{50}, \rho_s, 15\cdot\%, \rho_L, \mu_{cL}(\rho_L, 60), \kappa_{cv}, \beta_{cv}) = 3.5\,\frac{ft}{sec}$

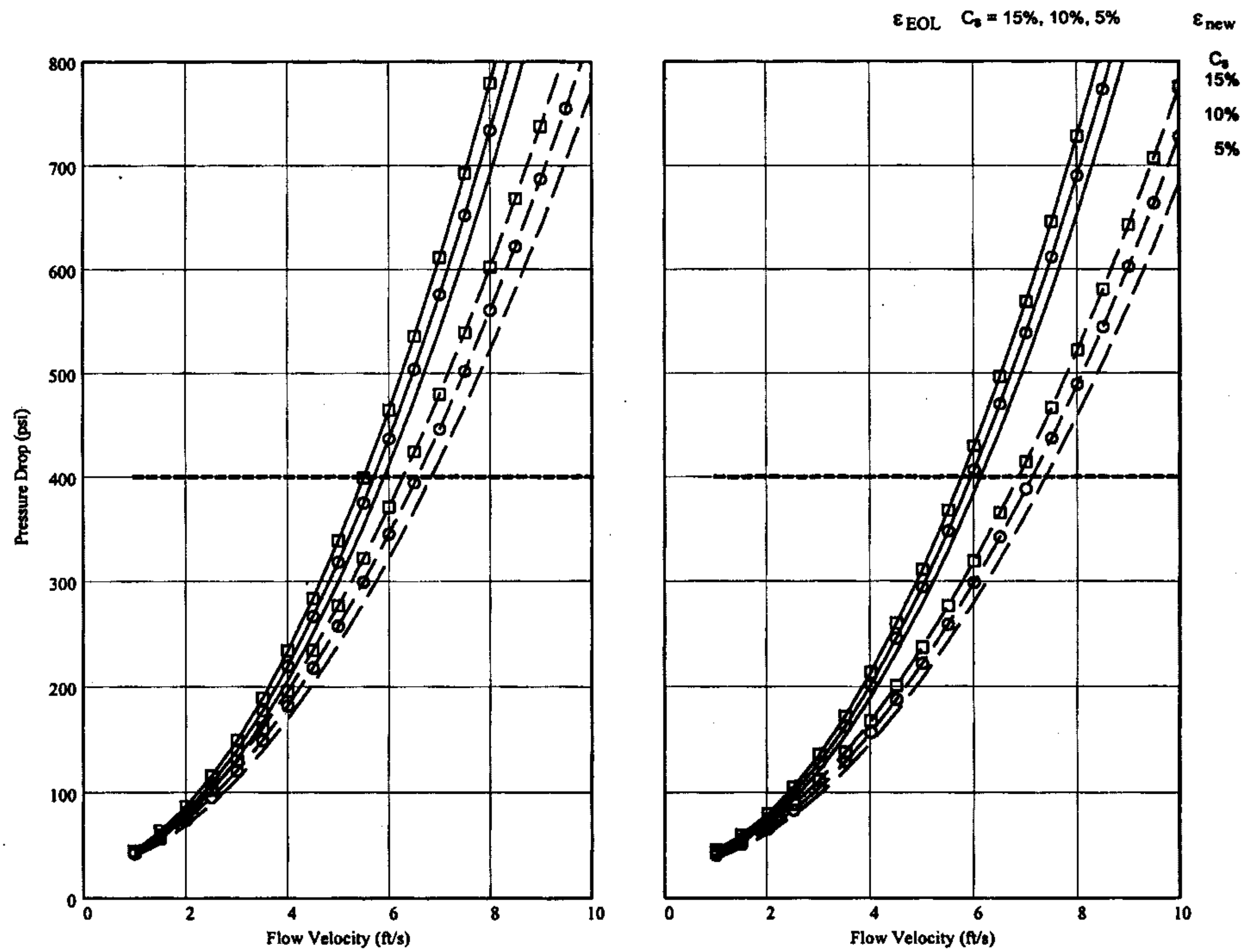

Figure E-4d. Pressure Drop for AN-107 to BNFL - d_p=40 μm, ρ_L=1.2 kg/L, ρ_s=2.5 kg/L Case, T = 10 and 60 °C.

$\beta_{cv} = 1.2$ $L_{CS} = 557\,ft$ $L_{SS} = 7028\,ft$ $H = 40\,ft$ $d_{50} = 40\,\mu m$ $\varepsilon_{new} = 2\,mil$

$\kappa_{cv} = 1.3$ $\rho_L := 1.2\cdot\frac{kg}{liter}$ $\rho_s := 2.5\cdot\frac{kg}{liter}$ $\varepsilon_{EOL\_SS} = 10\,mil$

$\kappa_f = 1$ $\varepsilon_{EOL\_CS} = 150\,mil$

$T := 10\ °C$ $\mu_{cL}(\rho_L, 10) = 2\,cP$ $T := 60\ °C$ $\mu_{cL}(\rho_L, 60) = 0.8\,cP$

C_s	T = 10 °C	T = 60 °C
5%	$v_{cr}(D_{pipe}, d_{50}, \rho_s, 5\cdot\%, \rho_L, \mu_{cL}(\rho_L, 10), \kappa_{cv}, \beta_{cv}) = 3.3\,\frac{ft}{sec}$	$v_{cr}(D_{pipe}, d_{50}, \rho_s, 5\cdot\%, \rho_L, \mu_{cL}(\rho_L, 60), \kappa_{cv}, \beta_{cv}) = 3.6\,\frac{ft}{sec}$
10%	$v_{cr}(D_{pipe}, d_{50}, \rho_s, 10\cdot\%, \rho_L, \mu_{cL}(\rho_L, 10), \kappa_{cv}, \beta_{cv}) = 3.6\,\frac{ft}{sec}$	$v_{cr}(D_{pipe}, d_{50}, \rho_s, 10\cdot\%, \rho_L, \mu_{cL}(\rho_L, 60), \kappa_{cv}, \beta_{cv}) = 3.9\,\frac{ft}{sec}$
15%	$v_{cr}(D_{pipe}, d_{50}, \rho_s, 15\cdot\%, \rho_L, \mu_{cL}(\rho_L, 10), \kappa_{cv}, \beta_{cv}) = 3.7\,\frac{ft}{sec}$	$v_{cr}(D_{pipe}, d_{50}, \rho_s, 15\cdot\%, \rho_L, \mu_{cL}(\rho_L, 60), \kappa_{cv}, \beta_{cv}) = 4.1\,\frac{ft}{sec}$

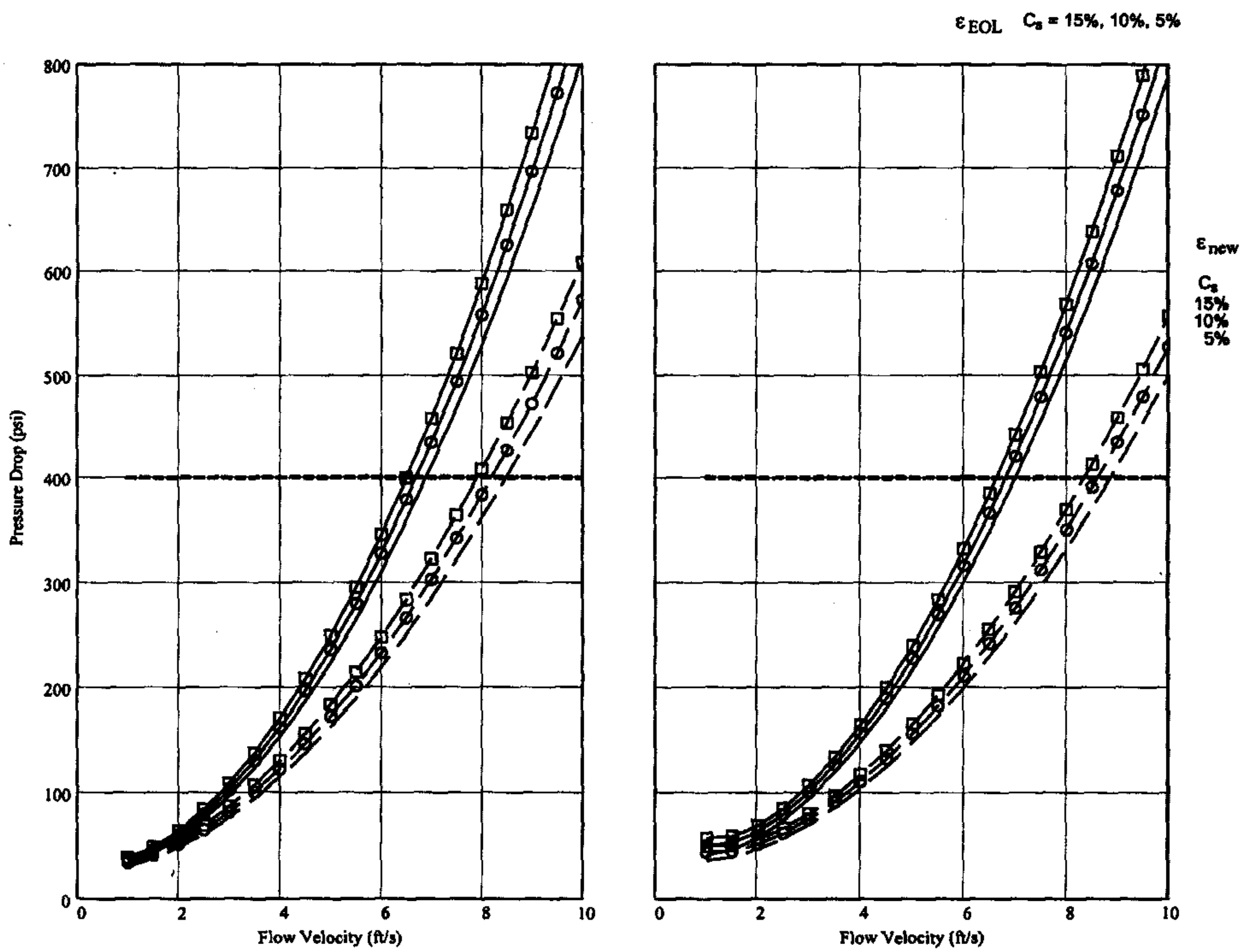

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Figure E-4e. Pressure Drop for AN-107 to BNFL - d_p=40 μm, ρ_L=1.46 kg/L, ρ_s=2.5 kg/L Case, T = 10 and 60 °C.

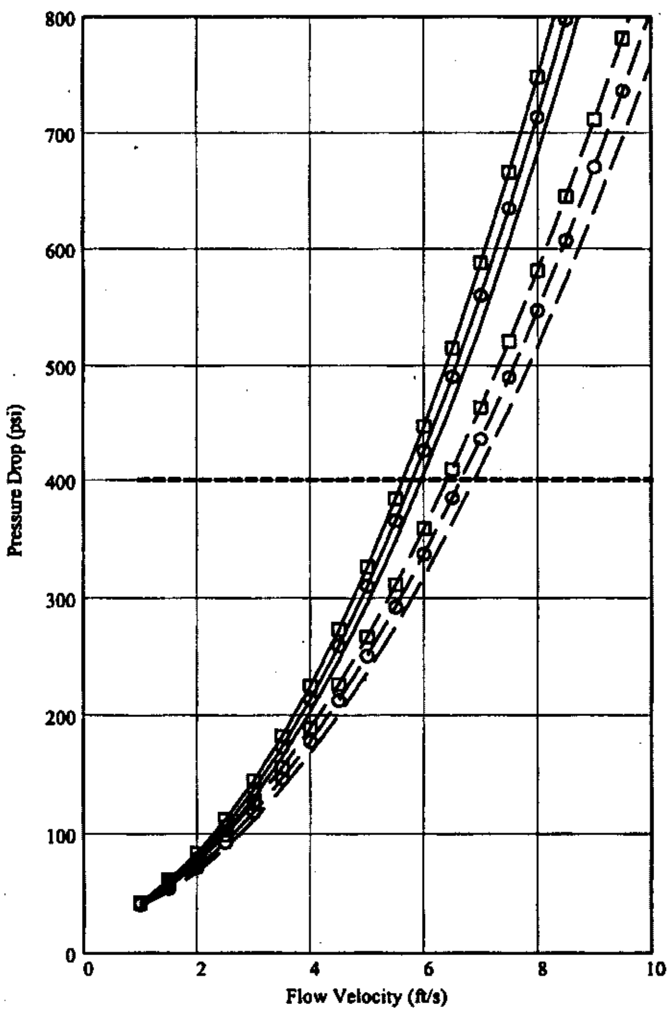
$\beta_{cv} = 1.2$ $L_{CS} = 557\,ft$ $L_{SS} = 7028\,ft$ $H = 40\,ft$ $d_{50} = 40\,\mu m$ $\varepsilon_{new} = 2\,mil$

$\kappa_{cv} = 1.3$ $\rho_L := 1.46\cdot\frac{kg}{liter}$ $\rho_s := 2.5\cdot\frac{kg}{liter}$ $\varepsilon_{EOL\_SS} = 10\,mil$

$\kappa_f = 1$ $\varepsilon_{EOL\_CS} = 150\,mil$

$T := 10\ ^{o}C$ $\mu_{cL}(\rho_L, 10) = 8.4\,cP$ $T := 60\ ^{o}C$ $\mu_{cL}(\rho_L, 60) = 3.7\,cP$

		C_s
$v_{cr}(D_{pipe}, d_{50}, \rho_s, 5\cdot\%, \rho_L, \mu_{cL}(\rho_L, 10), \kappa_{cv}, \beta_{cv}) = 2.3\frac{ft}{sec}$	$v_{cr}(D_{pipe}, d_{50}, \rho_s, 5\cdot\%, \rho_L, \mu_{cL}(\rho_L, 60), \kappa_{cv}, \beta_{cv}) = 2.5\frac{ft}{sec}$	5%
$v_{cr}(D_{pipe}, d_{50}, \rho_s, 10\cdot\%, \rho_L, \mu_{cL}(\rho_L, 10), \kappa_{cv}, \beta_{cv}) = 2.5\frac{ft}{sec}$	$v_{cr}(D_{pipe}, d_{50}, \rho_s, 10\cdot\%, \rho_L, \mu_{cL}(\rho_L, 60), \kappa_{cv}, \beta_{cv}) = 2.7\frac{ft}{sec}$	10%
$v_{cr}(D_{pipe}, d_{50}, \rho_s, 15\cdot\%, \rho_L, \mu_{cL}(\rho_L, 10), \kappa_{cv}, \beta_{cv}) = 2.7\frac{ft}{sec}$	$v_{cr}(D_{pipe}, d_{50}, \rho_s, 15\cdot\%, \rho_L, \mu_{cL}(\rho_L, 60), \kappa_{cv}, \beta_{cv}) = 2.9\frac{ft}{sec}$	15%



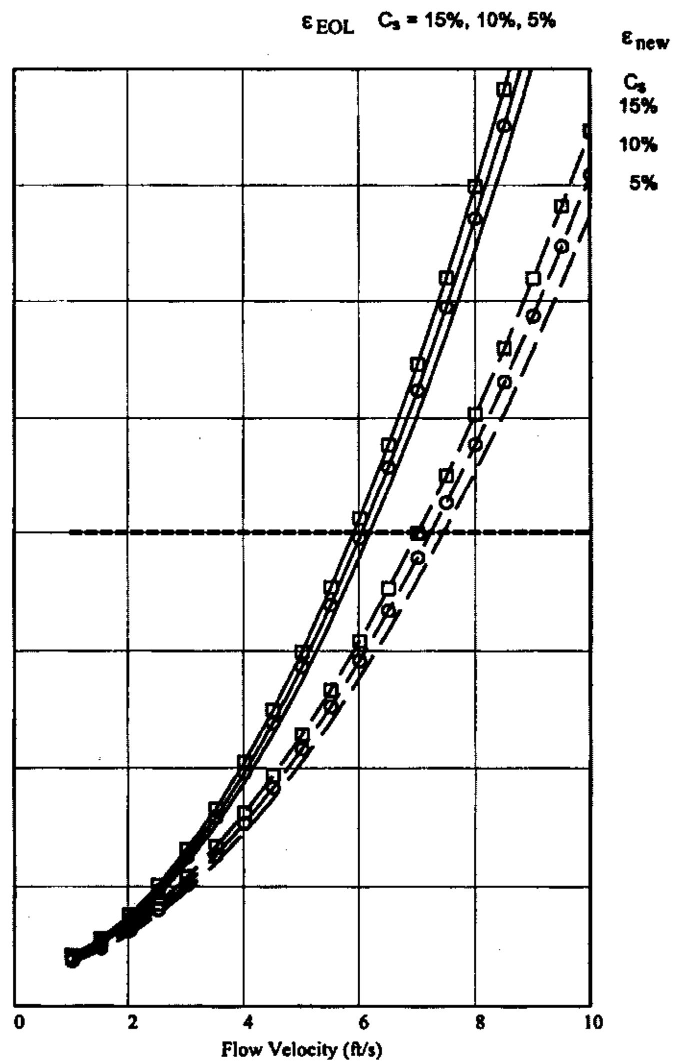
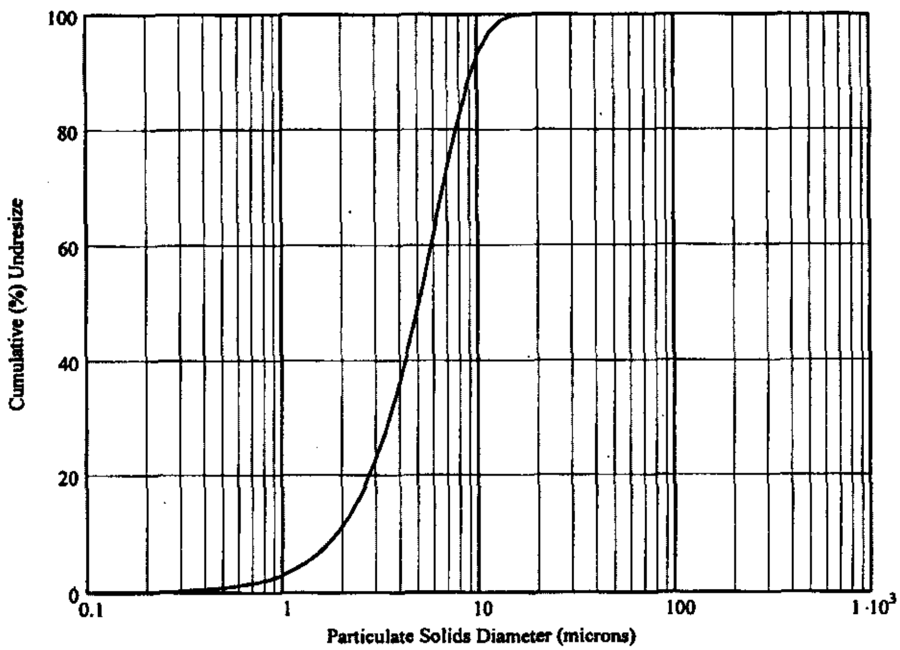


Figure E-5a. d_p=5 μm Case - Cumulative and Probability Density Particle Size Distribution by Volume.

$d_{50} := 5 \cdot \mu m$ $\quad (d_{pRR} \;\; \phi_{RR}) := dist_{RR}(d_{pR}, d_{50})$ $\quad d_{pRR} := d_{pRR} \cdot \mu m$ reset units $\quad \phi_{RRcum} := cum(\phi_{RR})$

$D_{pRR} := D_\beta(d_{pRR}, \phi_{RRcum}, 50\%)$ $\quad D_{pRR} = 5\ \mu m$



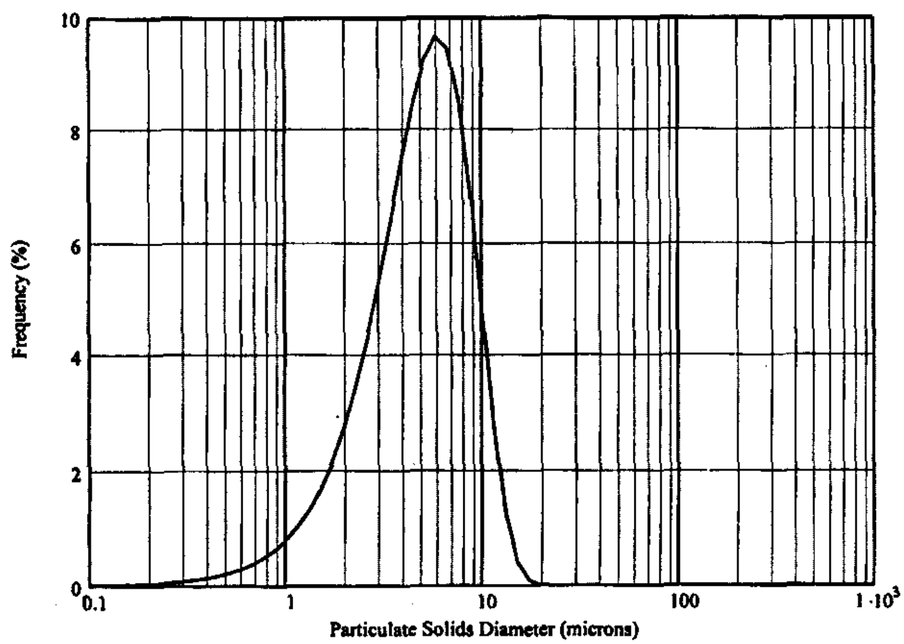


Figure E-5b. Pressure Drop for AN-107 to BNFL - d_p=5 μm, ρ_L=1.2 kg/L, ρ_s=3 kg/L Case, T = 10 and 60 °C.

$\beta_{cv} = 1.2$ $L_{CS} = 557\,ft$ $L_{SS} = 7028\,ft$ $H = 40\,ft$ $d_{50} = 5\,\mu m$ $\varepsilon_{new} = 2\,mil$

$\kappa_{cv} = 1.3$ $\rho_L := 1.2 \cdot \frac{kg}{liter}$ $\rho_s := 3 \cdot \frac{kg}{liter}$ $\varepsilon_{EOL\_SS} = 10\,mil$

$\kappa_f = 1$ $\varepsilon_{EOL\_CS} = 150\,mil$

$T := 10\ °C$ $\mu_{cL}(\rho_L, 10) = 2\,cP$ $T := 60\ °C$ $\mu_{cL}(\rho_L, 60) = 0.8\,cP$

C_s

5%: $v_{cr}(D_{pipe}, d_{50}, \rho_s, 5\cdot\%, \rho_L, \mu_{cL}(\rho_L, 10), \kappa_{cv}, \beta_{cv}) = 2.8\,\frac{ft}{sec}$ $v_{cr}(D_{pipe}, d_{50}, \rho_s, 5\cdot\%, \rho_L, \mu_{cL}(\rho_L, 60), \kappa_{cv}, \beta_{cv}) = 3\,\frac{ft}{sec}$

10%: $v_{cr}(D_{pipe}, d_{50}, \rho_s, 10\cdot\%, \rho_L, \mu_{cL}(\rho_L, 10), \kappa_{cv}, \beta_{cv}) = 3\,\frac{ft}{sec}$ $v_{cr}(D_{pipe}, d_{50}, \rho_s, 10\cdot\%, \rho_L, \mu_{cL}(\rho_L, 60), \kappa_{cv}, \beta_{cv}) = 3.3\,\frac{ft}{sec}$

15%: $v_{cr}(D_{pipe}, d_{50}, \rho_s, 15\cdot\%, \rho_L, \mu_{cL}(\rho_L, 10), \kappa_{cv}, \beta_{cv}) = 3.1\,\frac{ft}{sec}$ $v_{cr}(D_{pipe}, d_{50}, \rho_s, 15\cdot\%, \rho_L, \mu_{cL}(\rho_L, 60), \kappa_{cv}, \beta_{cv}) = 3.4\,\frac{ft}{sec}$

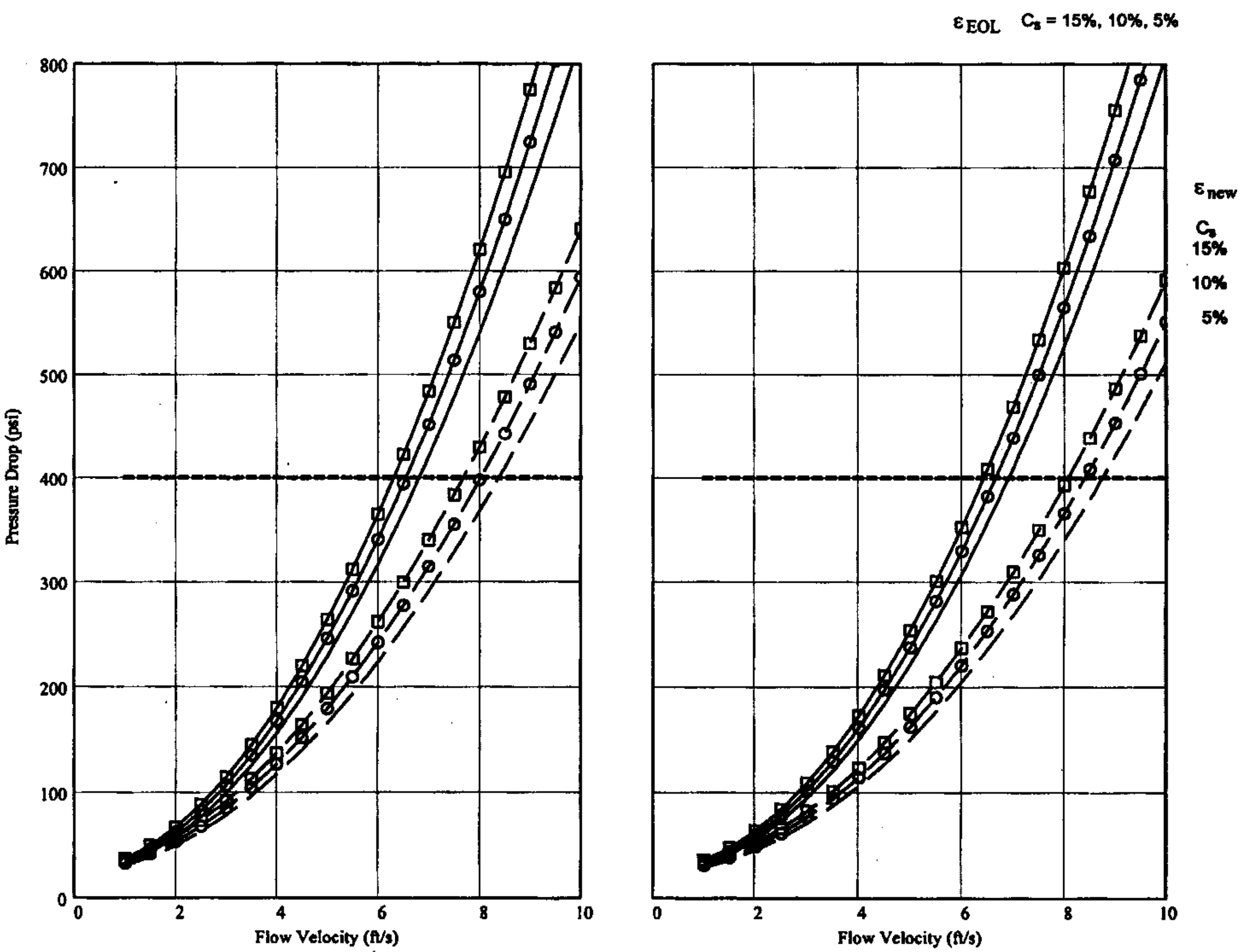


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Figure E-5c. Pressure Drop for AN-107 to BNFL - d_p=5 μm, ρ_L=1.46 kg/L, ρ_s=3 kg/L Case, T = 10 and 60 °C.

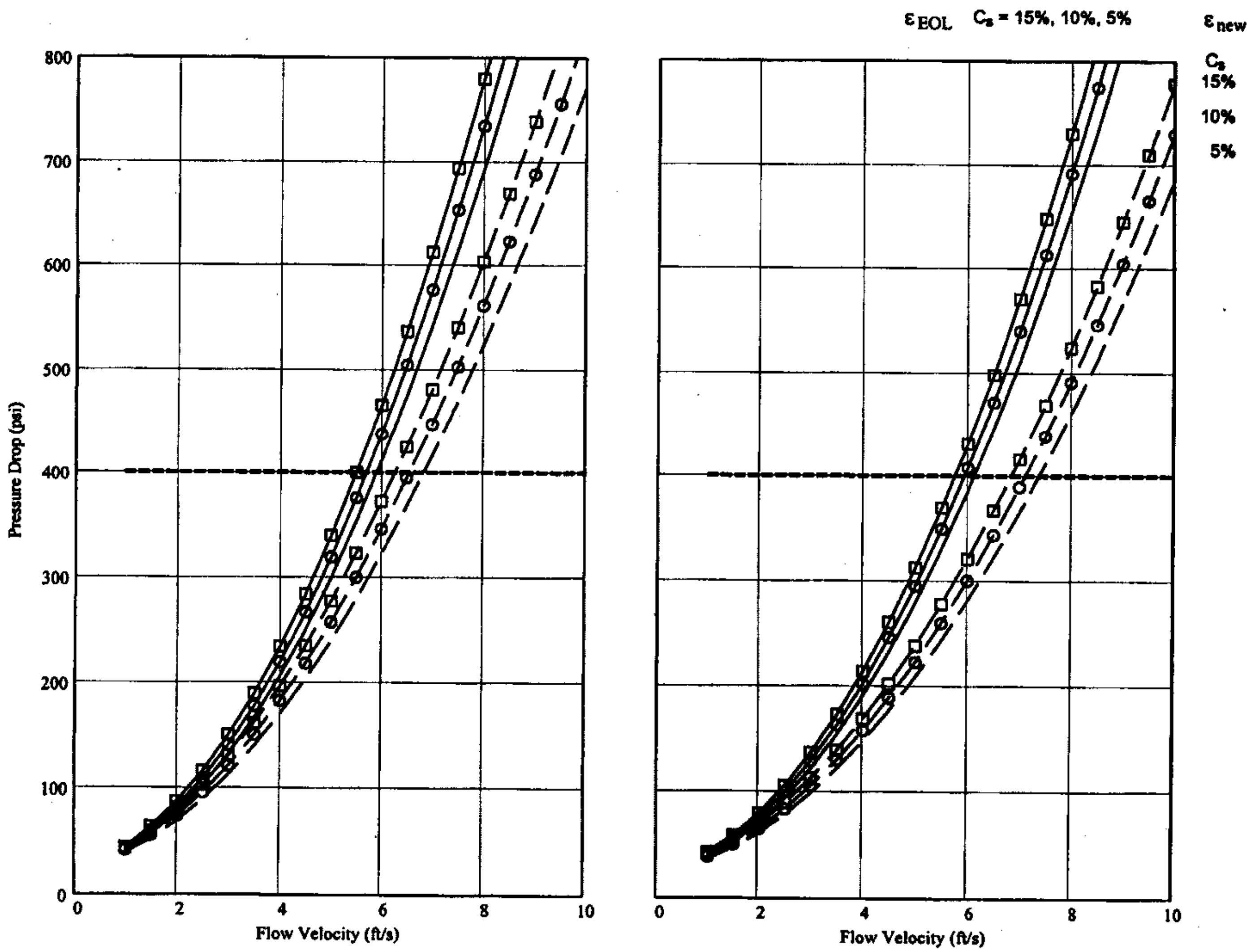
$\beta_{cv} = 1.2$ $L_{CS} = 557\,ft$ $L_{SS} = 7028\,ft$ $H = 40\,ft$ $d_{50} = 5\,\mu m$ $\varepsilon_{new} = 2\,mil$

$\kappa_{cv} = 1.3$ $\rho_L := 1.46 \cdot \frac{kg}{liter}$ $\rho_s := 3 \cdot \frac{kg}{liter}$ $\varepsilon_{EOL\_SS} = 10\,mil$

$\kappa_f = 1$ $\varepsilon_{EOL\_CS} = 150\,mil$

$T := 10\ ^{o}C$ $\mu_{cL}(\rho_L, 10) = 8.4\,cP$ $T := 60\ ^{o}C$ $\mu_{cL}(\rho_L, 60) = 3.7\,cP$

		C_s
$v_{cr}(D_{pipe}, d_{50}, \rho_s, 5\cdot\%, \rho_L, \mu_{cL}(\rho_L, 10), \kappa_{cv}, \beta_{cv}) = 2\,\frac{ft}{sec}$	$v_{cr}(D_{pipe}, d_{50}, \rho_s, 5\cdot\%, \rho_L, \mu_{cL}(\rho_L, 60), \kappa_{cv}, \beta_{cv}) = 2.2\,\frac{ft}{sec}$	5%
$v_{cr}(D_{pipe}, d_{50}, \rho_s, 10\cdot\%, \rho_L, \mu_{cL}(\rho_L, 10), \kappa_{cv}, \beta_{cv}) = 2.2\,\frac{ft}{sec}$	$v_{cr}(D_{pipe}, d_{50}, \rho_s, 10\cdot\%, \rho_L, \mu_{cL}(\rho_L, 60), \kappa_{cv}, \beta_{cv}) = 2.4\,\frac{ft}{sec}$	10%
$v_{cr}(D_{pipe}, d_{50}, \rho_s, 15\cdot\%, \rho_L, \mu_{cL}(\rho_L, 10), \kappa_{cv}, \beta_{cv}) = 2.3\,\frac{ft}{sec}$	$v_{cr}(D_{pipe}, d_{50}, \rho_s, 15\cdot\%, \rho_L, \mu_{cL}(\rho_L, 60), \kappa_{cv}, \beta_{cv}) = 2.5\,\frac{ft}{sec}$	15%



Wasp-sen AN-107pt1.mcd

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Figure E-5d. Pressure Drop for AN-107 to BNFL - d_p=5 μm, ρ_L=1.2 kg/L, ρ_s=2.5 kg/L Case, T = 10 and 60 °C.

$\beta_{cv} = 1.2$ $L_{CS} = 557\,ft$ $L_{SS} = 7028\,ft$ $H = 40\,ft$ $d_{50} = 5\,\mu m$ $\varepsilon_{new} = 2\,mil$

$\kappa_{cv} = 1.3$ $\rho_L := 1.2\cdot\frac{kg}{liter}$ $\rho_s := 2.5\cdot\frac{kg}{liter}$ $\varepsilon_{EOL\_SS} = 10\,mil$

$\kappa_f = 1$ $\varepsilon_{EOL\_CS} = 150\,mil$

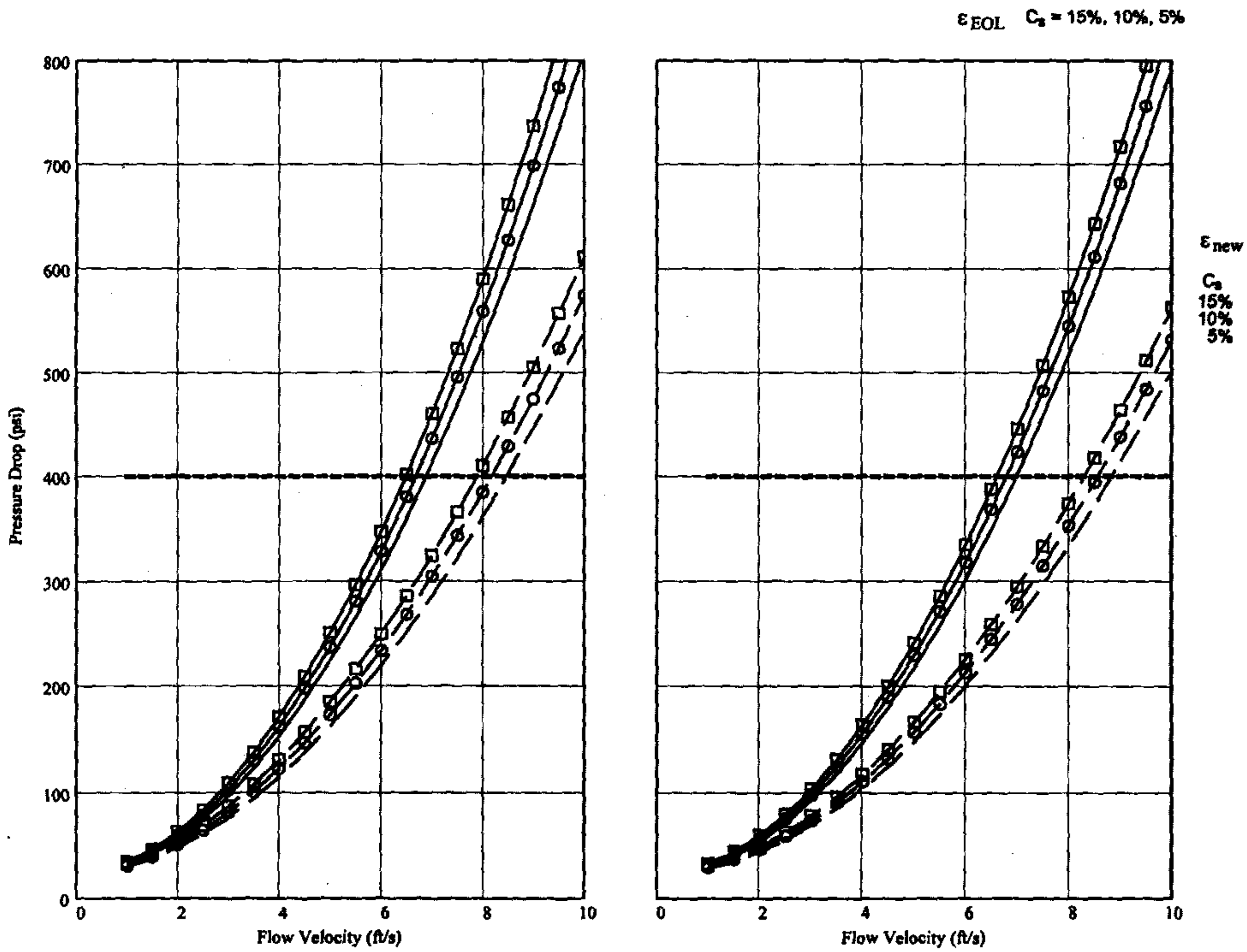
$T := 10\ {}^{o}C$ $\mu_{cL}(\rho_L, 10) = 2\,cP$ $T := 60\ {}^{o}C$ $\mu_{cL}(\rho_L, 60) = 0.8\,cP$

C_s

$v_{cr}(D_{pipe}, d_{50}, \rho_s, 5\cdot\%, \rho_L, \mu_{cL}(\rho_L,10), \kappa_{cv}, \beta_{cv}) = 2.3\,\frac{ft}{sec}$ $v_{cr}(D_{pipe}, d_{50}, \rho_s, 5\cdot\%, \rho_L, \mu_{cL}(\rho_L,60), \kappa_{cv}, \beta_{cv}) = 2.5\,\frac{ft}{sec}$ 5%

$v_{cr}(D_{pipe}, d_{50}, \rho_s, 10\cdot\%, \rho_L, \mu_{cL}(\rho_L,10), \kappa_{cv}, \beta_{cv}) = 2.5\,\frac{ft}{sec}$ $v_{cr}(D_{pipe}, d_{50}, \rho_s, 10\cdot\%, \rho_L, \mu_{cL}(\rho_L,60), \kappa_{cv}, \beta_{cv}) = 2.8\,\frac{ft}{sec}$ 10%

$v_{cr}(D_{pipe}, d_{50}, \rho_s, 15\cdot\%, \rho_L, \mu_{cL}(\rho_L,10), \kappa_{cv}, \beta_{cv}) = 2.6\,\frac{ft}{sec}$ $v_{cr}(D_{pipe}, d_{50}, \rho_s, 15\cdot\%, \rho_L, \mu_{cL}(\rho_L,60), \kappa_{cv}, \beta_{cv}) = 2.9\,\frac{ft}{sec}$ 15%



Wasp-sen AN-107pt1.mcd

Figure E-5e. Pressure Drop for AN-107 to BNFL - d_p=5 μm, ρ_L=1.46 kg/L, ρ_s=2.5 kg/L Case, T = 10 and 60 °C.

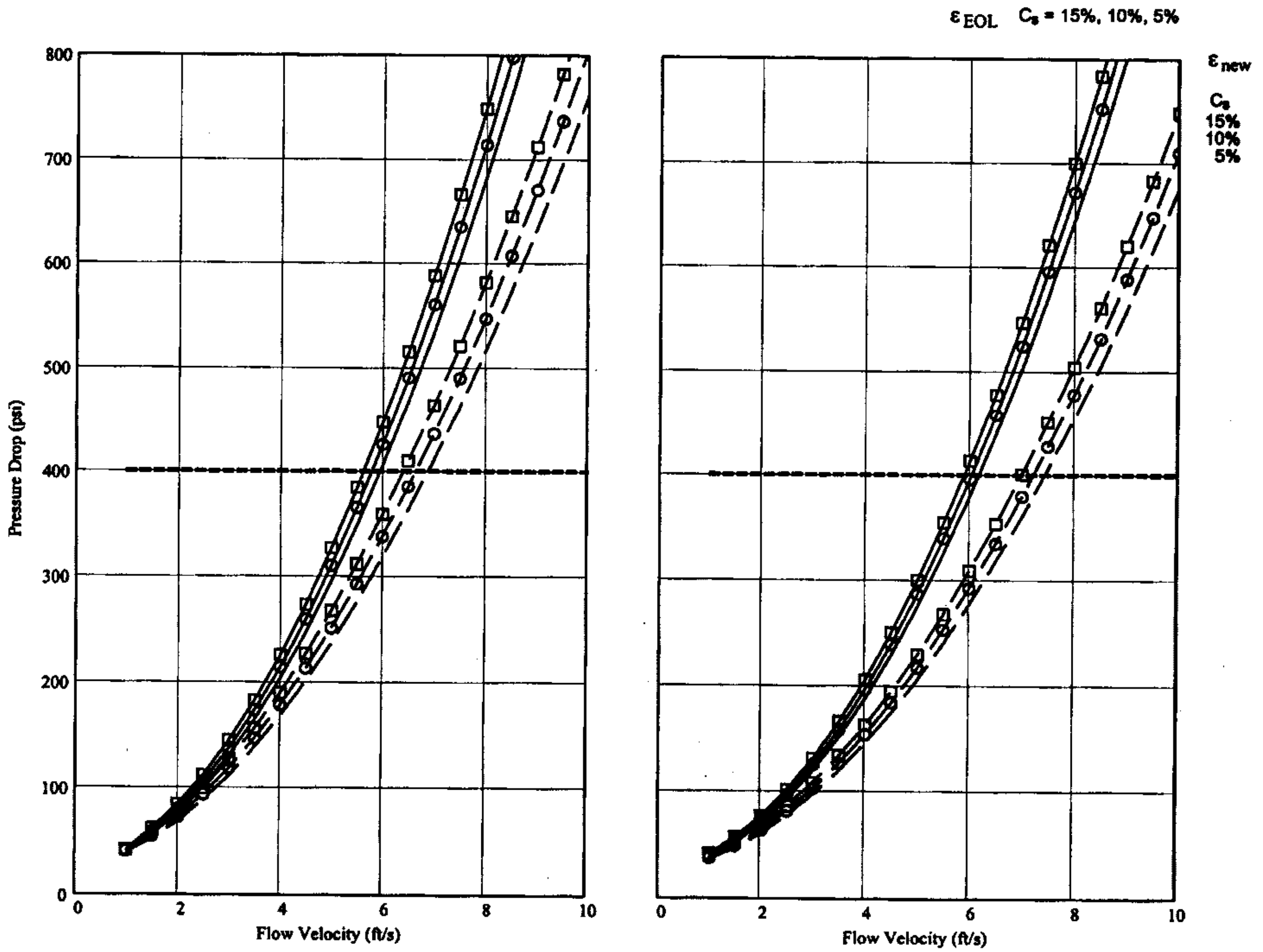
$\beta_{cv} = 1.2$ $\quad L_{CS} = 557\,ft \quad L_{SS} = 7028\,ft \quad H = 40\,ft \quad d_{50} = 5\,\mu m \quad \varepsilon_{new} = 2\,mil$

$\kappa_{cv} = 1.3 \quad \rho_L := 1.46 \cdot \frac{kg}{liter} \quad \rho_s := 2.5 \cdot \frac{kg}{liter} \quad \varepsilon_{EOL\_SS} = 10\,mil$

$\kappa_f = 1 \quad \varepsilon_{EOL\_CS} = 150\,mil$

$T := 10\ °C \quad \mu_{cL}(\rho_L, 10) = 8.4\,cP$ $\qquad T := 60\ °C \quad \mu_{cL}(\rho_L, 60) = 3.7\,cP$

		C_s
$v_{cr}(D_{pipe}, d_{50}, \rho_s, 5\cdot\%, \rho_L, \mu_{cL}(\rho_L, 10), \kappa_{cv}, \beta_{cv}) = 1.6\,\frac{ft}{sec}$	$v_{cr}(D_{pipe}, d_{50}, \rho_s, 5\cdot\%, \rho_L, \mu_{cL}(\rho_L, 60), \kappa_{cv}, \beta_{cv}) = 1.8\,\frac{ft}{sec}$	5%
$v_{cr}(D_{pipe}, d_{50}, \rho_s, 10\cdot\%, \rho_L, \mu_{cL}(\rho_L, 10), \kappa_{cv}, \beta_{cv}) = 1.8\,\frac{ft}{sec}$	$v_{cr}(D_{pipe}, d_{50}, \rho_s, 10\cdot\%, \rho_L, \mu_{cL}(\rho_L, 60), \kappa_{cv}, \beta_{cv}) = 1.9\,\frac{ft}{sec}$	10%
$v_{cr}(D_{pipe}, d_{50}, \rho_s, 15\cdot\%, \rho_L, \mu_{cL}(\rho_L, 10), \kappa_{cv}, \beta_{cv}) = 1.9\,\frac{ft}{sec}$	$v_{cr}(D_{pipe}, d_{50}, \rho_s, 15\cdot\%, \rho_L, \mu_{cL}(\rho_L, 60), \kappa_{cv}, \beta_{cv}) = 2\,\frac{ft}{sec}$	15%



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Client:	Numatec Hanford Corporation	WO/Job No.	110299 & 110300/BA10
Subject:	Critical Velocity and Pressure Drop Study in Support of Waste Tank Feed Transfer System	Date: 03/08/2000	By: L. J. Julyk
		Checked: 03/10/2000	By: T. C. Oten
Location:	200 Area - Hanford Site, Richland, Washington	Revised:	By:

Figure E-6a. Critical Velocity Comparison - New Pipe.

$D_{pipe} := 3.068 \cdot in$ $\rho_L := 1.2 \cdot \frac{kg}{liter}$ $T := 60$ °C $\mu_L := \mu_{cL}(\rho_L, T)$ $\mu_L = 0.77\,cP$ $\rho_s := 3 \cdot \frac{kg}{liter}$ $\varepsilon := \varepsilon_{new}$

$\kappa_f = 1$ $\kappa_{cv} := 1$ best-estimate $d_{50} := 400 \cdot \mu m$ $C_s := 15 \cdot \%$ $TOL = 1 \times 10^{-5}$ $\varepsilon = 2\,mil$

$(d_{pRR}\ \ \phi_{RR}) := dist_{RR}(d_{pR}, d_{50})$ $d_{pRR} := d_{pRR} \cdot \mu m$ reset units

$\phi_{RRcum} := cum(\phi_{RR})$ $length(\phi_{RR}) - 1 = 57$

Settling velocity

$v_\infty(d_{50}, \rho_s, \rho_L, \mu_L) = 0.22 \frac{ft}{sec}$

$v_\infty(d_{50}, \rho_s, \rho_c(\rho_s, \rho_L, C_s), \mu_c(\mu_L, C_s)) = 0.15 \frac{ft}{sec}$

$\beta_{cv} = 2$

1 Oroskar and Turian (1980) maximum of semi-theoretical and empirical equation
1.1 Oroskar and Turian (1980) semi-theoretical equation
1.2 Oroskar and Turian (1980) empirical equation
2 Wasp et al. (1977)
3 Zandi and Govatos (1967)
4 Shook (1969)
5 Gogus and Kokpinar (1999)
6 Robinson and Graf (1972)

Critical velocity using β_{cv} selected correlations

$v_{cr}(D_{pipe}, d_{50}, \rho_s, C_s, \rho_L, \mu_L, \kappa_{cv}, 1.2) = 5.48 \frac{ft}{sec}$

$v_{cr}(D_{pipe}, d_{50}, \rho_s, C_s, \rho_L, \mu_L, \kappa_{cv}, 2) = 4.52 \frac{ft}{sec}$

$v_{cr}(D_{pipe}, d_{50}, \rho_s, C_s, \rho_L, \mu_L, \kappa_{cv}, 3) = 7.48 \frac{ft}{sec}$

$v_{cr}(D_{pipe}, d_{50}, \rho_s, C_s, \rho_L, \mu_L, \kappa_{cv}, 4) = 5.58 \frac{ft}{sec}$

$v_{cr}(D_{pipe}, d_{50}, \rho_s, C_s, \rho_L, \mu_L, \kappa_{cv}, 5) = 6.23 \frac{ft}{sec}$

$v_{cr}(D_{pipe}, d_{50}, \rho_s, C_s, \rho_L, \mu_L, \kappa_{cv}, 6) = 3.66 \frac{ft}{sec}$

Critical velocity using β_{cv} selected correlations with Wasp vehicle concept

$v_{crD\_Wasp}(D_{pipe}, d_{pRR}, \rho_s, C_s \cdot \phi_{RR}, \rho_L, \mu_L, \varepsilon, \kappa_{cv}, 1.2) = 5.333 \frac{ft}{sec}$

$v_{crD\_Wasp}(D_{pipe}, d_{pRR}, \rho_s, C_s \cdot \phi_{RR}, \rho_L, \mu_L, \varepsilon, \kappa_{cv}, 2) = 4.37 \frac{ft}{sec}$

$v_{crD\_Wasp}(D_{pipe}, d_{pRR}, \rho_s, C_s \cdot \phi_{RR}, \rho_L, \mu_L, \varepsilon, \kappa_{cv}, 3) = 6.99 \frac{ft}{sec}$

$v_{crD\_Wasp}(D_{pipe}, d_{pRR}, \rho_s, C_s \cdot \phi_{RR}, \rho_L, \mu_L, \varepsilon, \kappa_{cv}, 4) = 5.29 \frac{ft}{sec}$

$v_{crD\_Wasp}(D_{pipe}, d_{pRR}, \rho_s, C_s \cdot \phi_{RR}, \rho_L, \mu_L, \varepsilon, \kappa_{cv}, 5) = 6.05 \frac{ft}{sec}$

$v_{crD\_Wasp}(D_{pipe}, d_{pRR}, \rho_s, C_s \cdot \phi_{RR}, \rho_L, \mu_L, \varepsilon, \kappa_{cv}, 6) = 3.56 \frac{ft}{sec}$

$v := 3 \cdot \frac{ft}{sec}$ $f_W := f_{Wasp}(D_{pipe}, v, \rho_L, \mu_L, \varepsilon, d_{pRR}, \rho_s, C_s \cdot \phi_{RR}, \kappa_f, \theta)$ $f_W = 0.28277$ $\beta_{cv} := 1.2$

$\Phi_v := \Phi_c(v, \rho_L, \mu_L, d_{pRR}, \rho_s, C_s \cdot \phi_{RR}, f_W)$

$\Phi_v = 1.539\%$

$\rho_c(\rho_s, \rho_L, \Phi_v) = 1.228 \frac{kg}{liter}$

$\mu_c(\mu_L, \Phi_v) = 0.805\,cP$

$v_{cr\_Wasp}(D_{pipe}, d_{pRR}, \rho_s, C_s \cdot \phi_{RR}, \rho_L, \mu_L, \varepsilon, \kappa_{cv}, \beta_{cv}) = 5.333 \frac{ft}{sec}$

$v_{crT\_Wasp}(D_{pipe}, d_{pRR}, \rho_s, C_s \cdot \phi_{RR}, \rho_L, \mu_L, \varepsilon, \kappa_{cv}) = 0.123 \frac{ft}{sec}$

Figure E-6b. Pressure Drop at Critical Velocity Comparison for New Pipe at Selected Median Particle Sizes - AN-107-to-BNFL Transfer Route.

$\varepsilon_{CS} := \varepsilon_{new}$ $\quad \varepsilon_{SS} := \varepsilon_{new}$

$D_{pipe} = 3.068\,in$ $\quad L_{CS} := 557\cdot ft$ $\quad L_{SS} := 7028\cdot ft$ $\quad H := 40\cdot ft$ $\quad \theta := atan\left(\frac{H}{L_{CS}+L_{SS}}\right)$

$C_s = 15\%$ $\quad \rho_s = 3\,\frac{kg}{liter}$ $\quad T = 60\ {}^oC$ $\quad \rho_L = 1.2\,\frac{kg}{liter}$ $\quad \mu_L = 0.771\,cP$

$i := 0..12$

$\kappa_f = 1$

$\kappa_{cv} = 1$ Best-estimate

$\beta_{cv} = 1.2$ Critical velocity - Oroskar and Turian (1980) empirical equation

$d_{50_i} :=$

5
10
40
60
100
150
200
250
300
350
400
450
500

$d_{50} := d_{50}\cdot \mu m$

$d_{pRR} := 0$ $\quad \phi_{RR} := 0$

$\left(d_{pRR}^{\langle i\rangle}\ \ \phi_{RR}^{\langle i\rangle}\right) := dist_{RR}\left(d_{pR}, d_{50_i}\right)$ $\quad d_{pRR} := d_{pRR}\cdot \mu m$ reset units

$v_{cm_i} := v_{cr}\left(D_{pipe}, d_{50_i}, \rho_s, C_s, \rho_L, \mu_L, \kappa_{cv}, \beta_{cv}\right)$ Critical velocity -Oroskar and Turian (1980) empirical equation

$\Delta p_{cm_i} := \Delta p_{T\_Wasp}\ D_{pipe}, v_{cm_i}, \rho_L, \mu_L, \varepsilon_{CS}, \varepsilon_{SS}, d_{pRR}^{\langle i\rangle}, \rho_s, C_s\cdot\phi_{RR}^{\langle i\rangle}, L_{CS}, L_{SS}, \kappa_f, \theta)$

$v_{cm\_Wasp_i} := v_{cr\_Wasp}\left(D_{pipe}, d_{pRR}^{\langle i\rangle}, \rho_s, C_s\cdot\phi_{RR}^{\langle i\rangle}, \rho_L, \mu_L, \varepsilon, \kappa_{cv}, \beta_{cv}\right)$ Critical velocity using Wasp vehicle concept

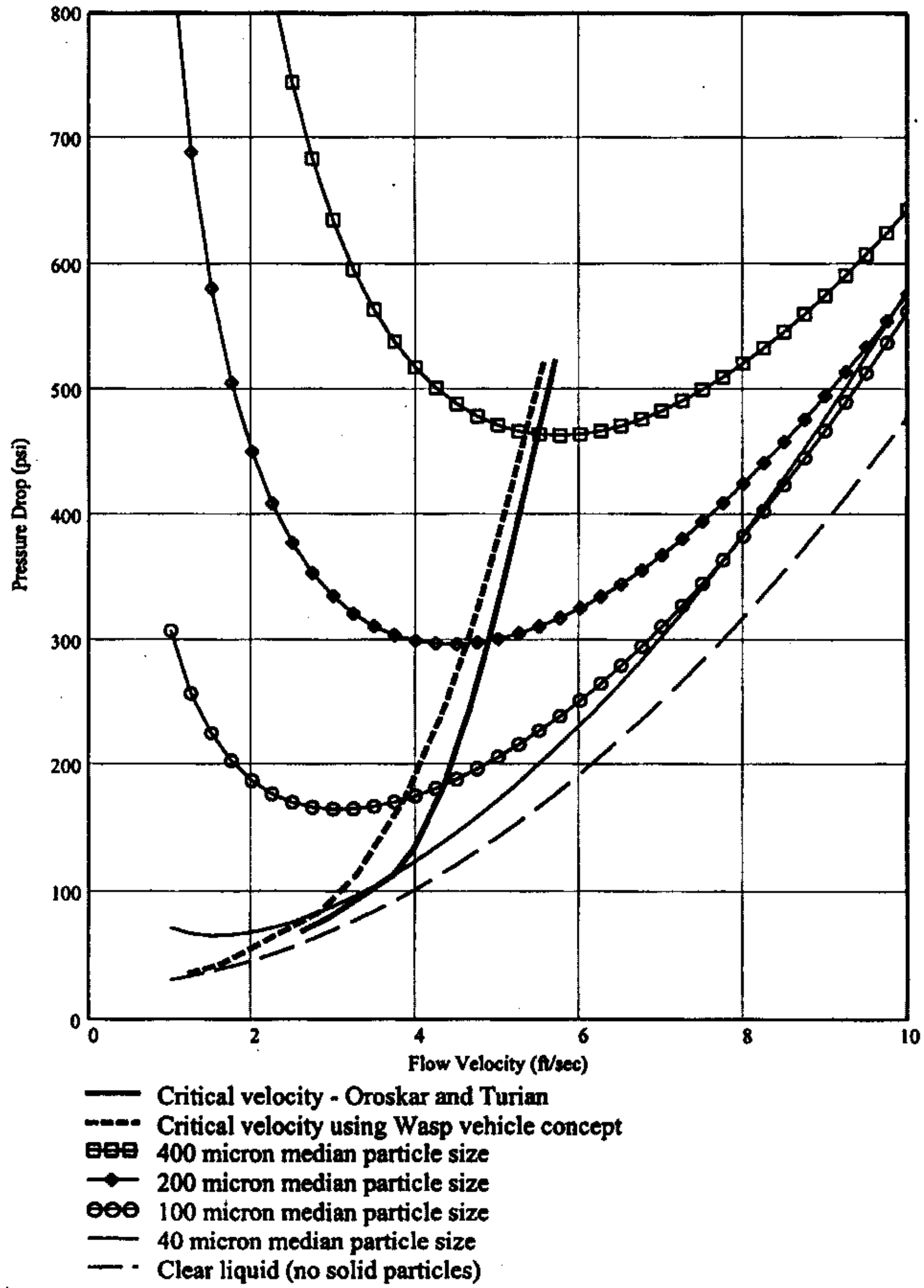
$\Delta p_{cm\_Wasp_i} := \Delta p_{T\_Wasp}\ D_{pipe}, v_{cm\_Wasp_i}, \rho_L, \mu_L, \varepsilon_{CS}, \varepsilon_{SS}, d_{pRR}^{\langle i\rangle}, \rho_s, C_s\cdot\phi_{RR}^{\langle i\rangle}, L_{CS}, L_{SS}, \kappa_f, \theta)$

$\frac{d_{50}}{\mu m}$	$\frac{v_{cm}}{ft/sec}$ (Critical velocity -Oroskar and Turian (1980) empirical equation)	$\frac{\Delta p_{cm}}{lbf/in^2}$	$\frac{v_{cm\_Wasp}}{ft/sec}$ (Critical velocity using Wasp vehicle concept)	$\frac{\Delta p_{cm\_Wasp}}{lbf/in^2}$
5	2.64	70	1.24	37
10	2.96	81	1.63	44
40	3.73	114	2.84	85
60	3.99	136	3.29	115
100	4.35	185	3.87	174
150	4.65	246	4.31	241
200	4.88	301	4.62	299
250	5.07	349	4.85	349
300	5.23	392	5.04	393
350	5.36	431	5.2	432
400	5.48	465	5.33	467
450	5.59	496	5.45	498
500	5.69	524	5.56	525

Figure E-6c. Pressure Drop and Critical Velocity Comparison for New Pipe at Selected Median Particle Sizes - AN-107-to-BNFL Transfer Route.

$D_{pipe} = 3.068$ in $L_{CS} = 557$ ft $L_{SS} = 7028$ ft $H = 40$ ft $\varepsilon_{CS} = 2$ mil $\varepsilon_{SS} = 2$ mil

$C_s = 15\%$ $\rho_s = 3\,\frac{kg}{liter}$ $T = 60\ ^0C$ $\rho_L = 1.2\,\frac{kg}{liter}$ $\mu_L = 0.771$ cP $\kappa_f = 1$ $\kappa_{cv} = 1$ $\beta_{cv} = 1.2$



$\kappa_f := 1 \quad \beta_f := 1$

$\kappa_{cv} := 1.3 \quad \beta_{cv} := 1.2$

Pressure Drop (Wasp et al. 1977) at Critical Velocity (Oroskar and Turian 1980)

$TOL = 1 \times 10^{-5}$

$$\Delta p_{cr}(D_{pipe}, \rho_L, T, \varepsilon_{CS}, \varepsilon_{SS}, d_{50}, \rho_s, C_s, L_{CS}, L_{SS}, H) := \begin{array}{|l} \theta \leftarrow \text{atan}\left(\dfrac{H}{L_{CS} + L_{SS}}\right) \\ \mu \leftarrow \mu_{cL}(\rho_L, T) \\ v_{crm} \leftarrow v_{cr}(D_{pipe}, d_{50}, \rho_s, C_s, \rho_L, \mu, \kappa_{cv}, \beta_{cv}) \\ J \leftarrow \text{length}(d_{pR}) - 1 \\ \Delta d \leftarrow \Delta(d_{pR}) \\ \text{for } j \in 0..J \\ \quad \phi_j \leftarrow PDF_{RR}(d_{pR_j}, d_{50}, p_{RR}) \cdot \Delta d_j \\ d_{pRR} \leftarrow \text{pack}(d_{pR}, \phi) \\ \phi_{RR} \leftarrow \text{pack}(\phi, \phi) \\ \Delta p_{T\_Wasp}(D_{pipe}, v_{crm}, \rho_L, \mu, \varepsilon_{CS}, \varepsilon_{SS}, d_{pRR}, \rho_s, C_s \cdot \phi_{RR}, L_{CS}, L_{SS}, \kappa_f, \theta) \end{array}$$

$d_{50_i} :=$

5
10
20
40
80
100
150
200
250
300
350
400

Shifted Tank 241-SY-101 particle size distribution by volume (O'Rourke 1999) for specified median particle size (d_{50})

$d_{50} := d_{50} \cdot \mu m$

AN-107-to-BNFL transfer route pipe parameters

$D_{pipe} := 3.068 \cdot in \quad L_{CS} := 557 \cdot ft \quad L_{SS} := 7028 \cdot ft \quad H := 40 \cdot ft$

Temperature of slurry at transfer

$T_1 := 10 \quad °C \qquad T_2 := 60 \quad °C$

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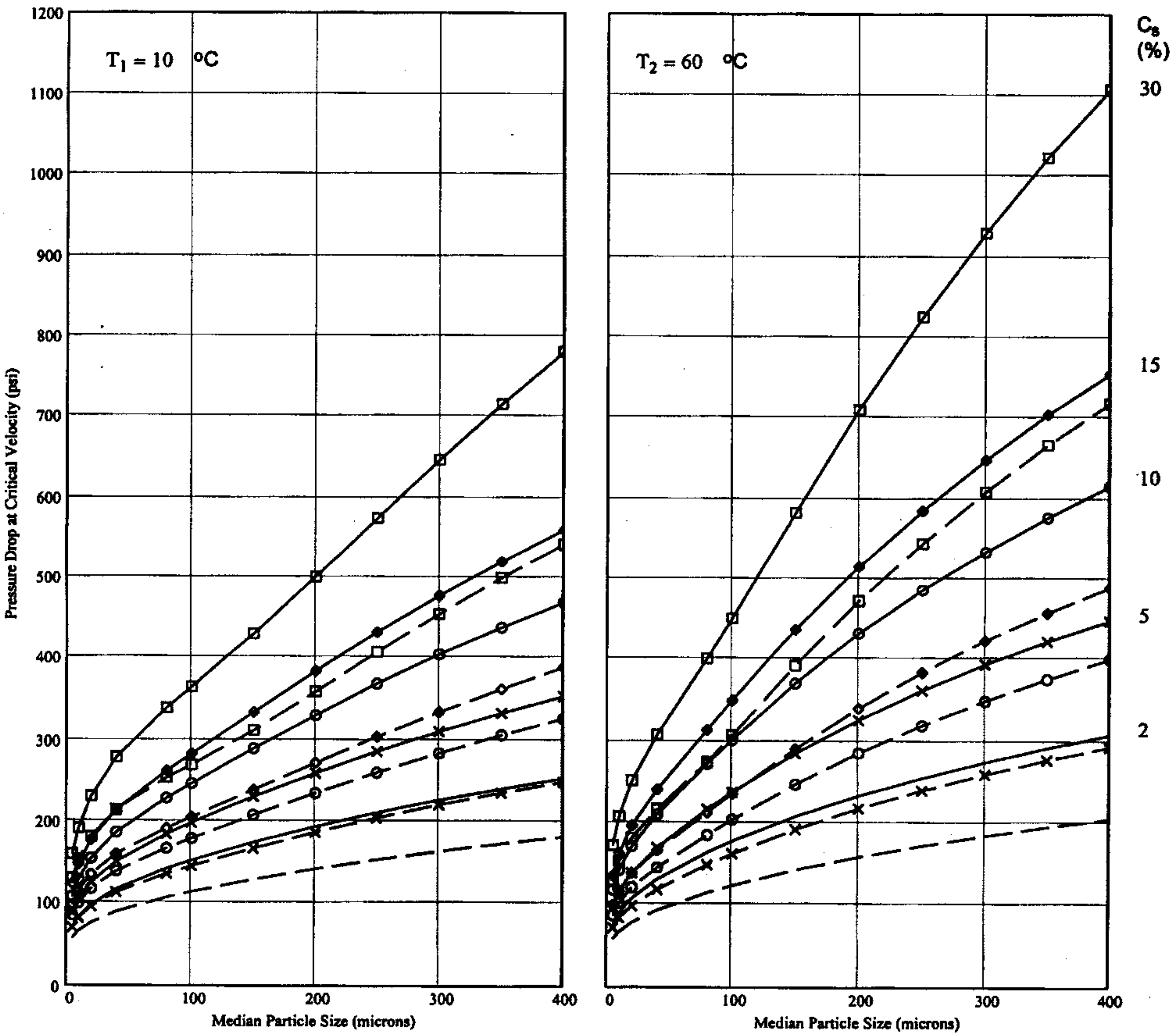
Date: 03/08/2000 By: L. J. Julyk
Checked: 03/10/2000 By: T. C. Oten
Revised: By:

$\kappa_f = 1$ $\beta_f = 1$ $D_{pipe} = 3.068\,in$ $L_{CS} = 557\,ft$ $L_{SS} = 7028\,ft$ $H = 40\,ft$ $\varepsilon_{new} = 2\,mil$ $\varepsilon_{EOL\_CS} = 150\,mil$

$\kappa_{cv} = 1.3$ $\beta_{cv} = 1.2$ $\rho_L := 1.2 \cdot \frac{kg}{liter}$ $\rho_s := 3 \cdot \frac{kg}{liter}$ $\mu_{cL}(\rho_L, T_1) = 2.021\,cP$ $\mu_{cL}(\rho_L, T_2) = 0.771\,cP$ $\varepsilon_{EOL\_SS} = 10\,mil$

Figure E-7a. Pressure Drop at Critical Velocity for AN-107-to-BNFL Transfer Route vs. Median Particle Size and Selected Solid Volume Concentrations - ρ_L=1.2 kg/L, ρ_s=3 kg/L, T = 10 and 60°C, for New (dashed lines) and EOL (solid lines) Pipe Roughness Estimates.



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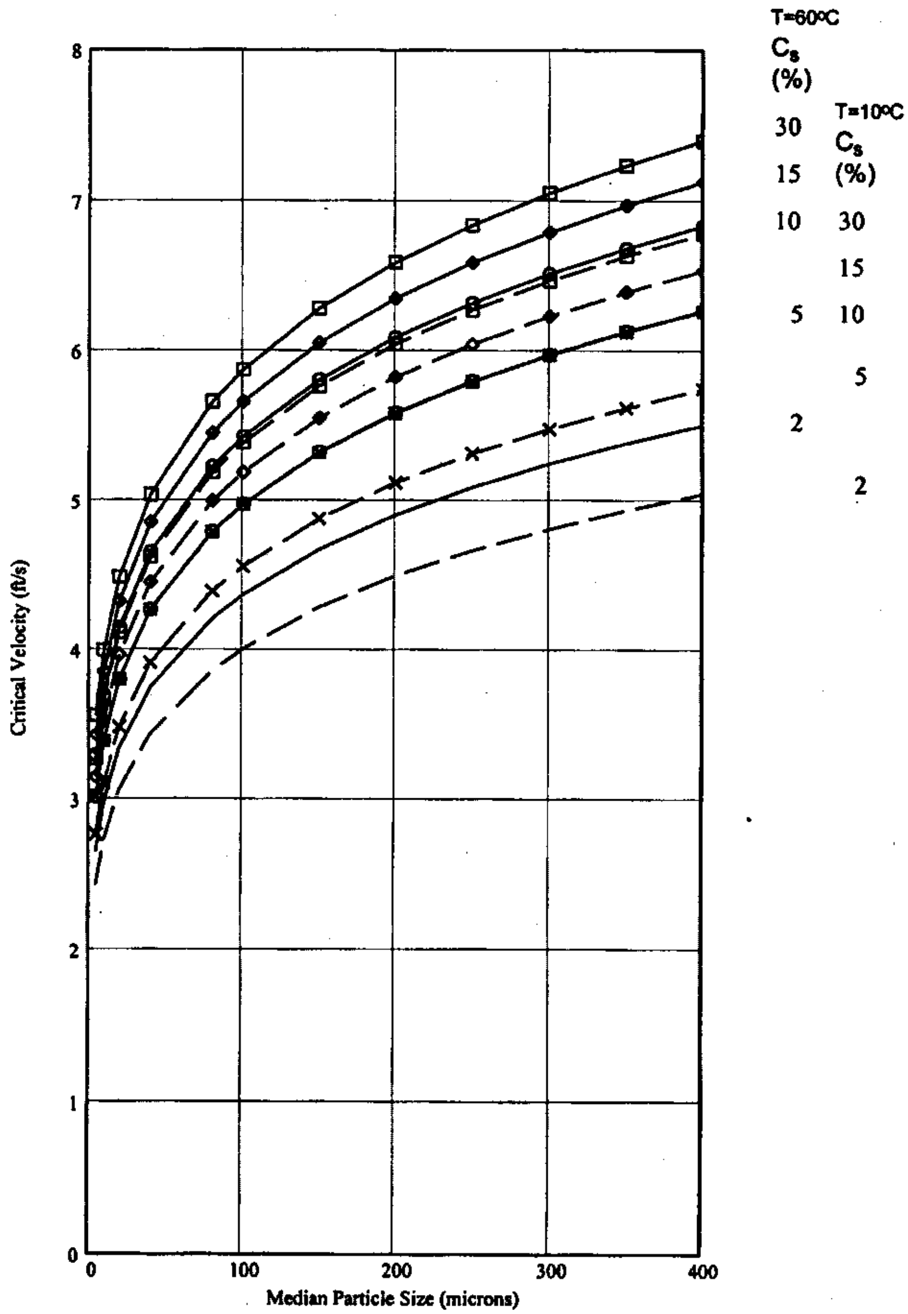
$\kappa_{cv} = 1.3$ $\beta_{cv} = 1.2$ $\rho_L = 1.2\frac{kg}{liter}$ $\rho_s = 3\frac{kg}{liter}$ $\mu_{cL}(\rho_L, T_1) = 2.021\,cP$ $\mu_{cL}(\rho_L, T_2) = 0.771\,cP$ $\varepsilon_{EOL\_SS} = 10\,mil$

Figure E-7b. Critical Velocity for AN-107-to-BNFL Transfer Route vs. Median Particle Size and Selected Solid Volume Concentrations - ρ_L=1.2 kg/L, ρ_s=3 kg/L, T = 10 (dashed lines) and 60°C (solid lines).



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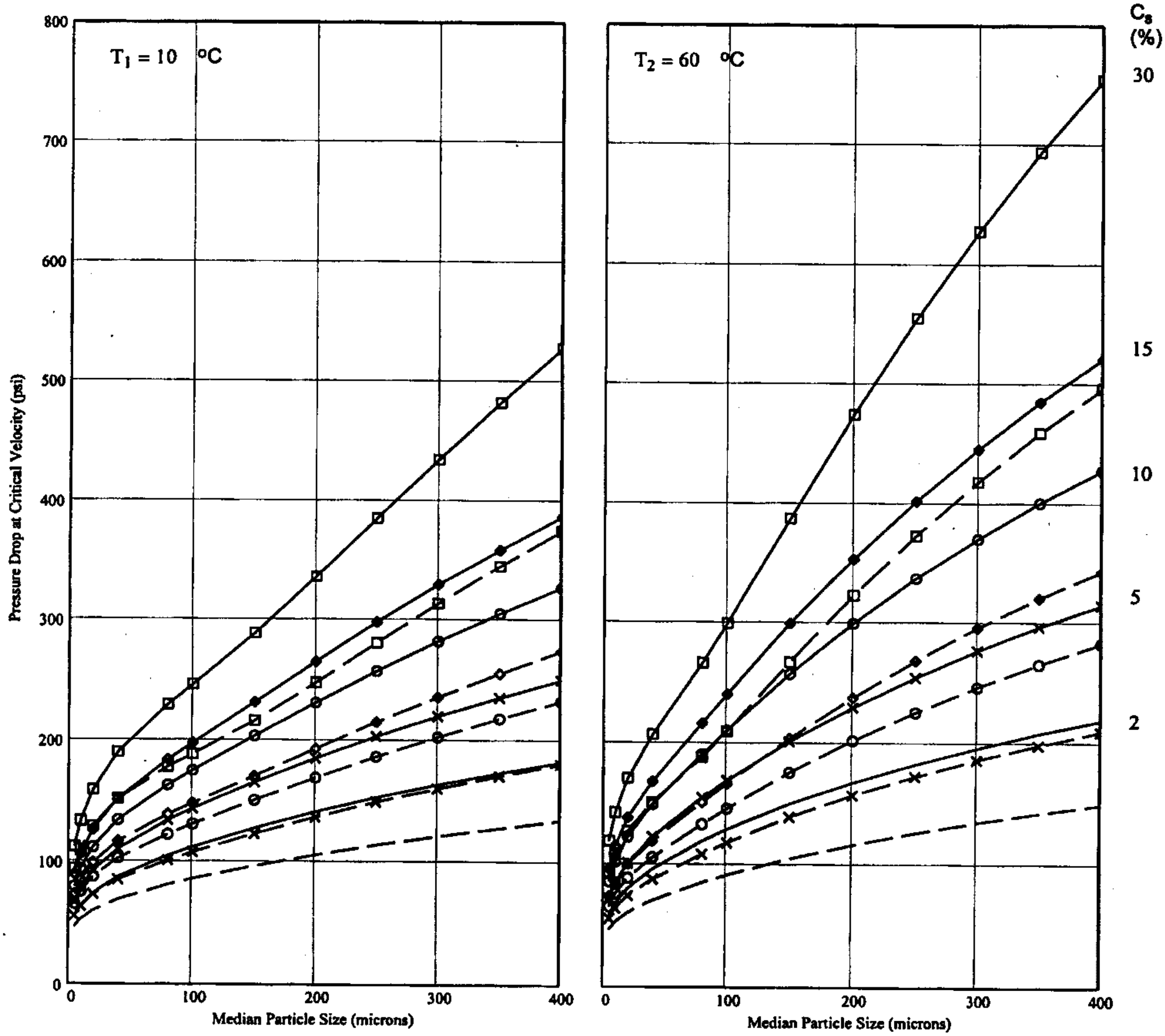
$\kappa_{cv} = 1.3$ $\beta_{cv} = 1.2$ $\rho_L := 1.2 \cdot \frac{kg}{liter}$ $\rho_s := 2.5 \cdot \frac{kg}{liter}$ $\mu_{cL}(\rho_L, T_1) = 2.021\,cP$ $\mu_{cL}(\rho_L, T_2) = 0.771\,cP$ $\varepsilon_{EOL\_SS} = 10\,mil$

Figure E-8a. Pressure Drop at Critical Velocity for AN-107-to-BNFL Transfer Route vs. Median Particle Size and Selected Solid Volume Concentrations - ρ_L=1.2 kg/L, ρ_s=2.5 kg/L, T = 10 and 60°C, for New (dashed lines) and EOL (solid lines) Pipe Roughness Estimates.



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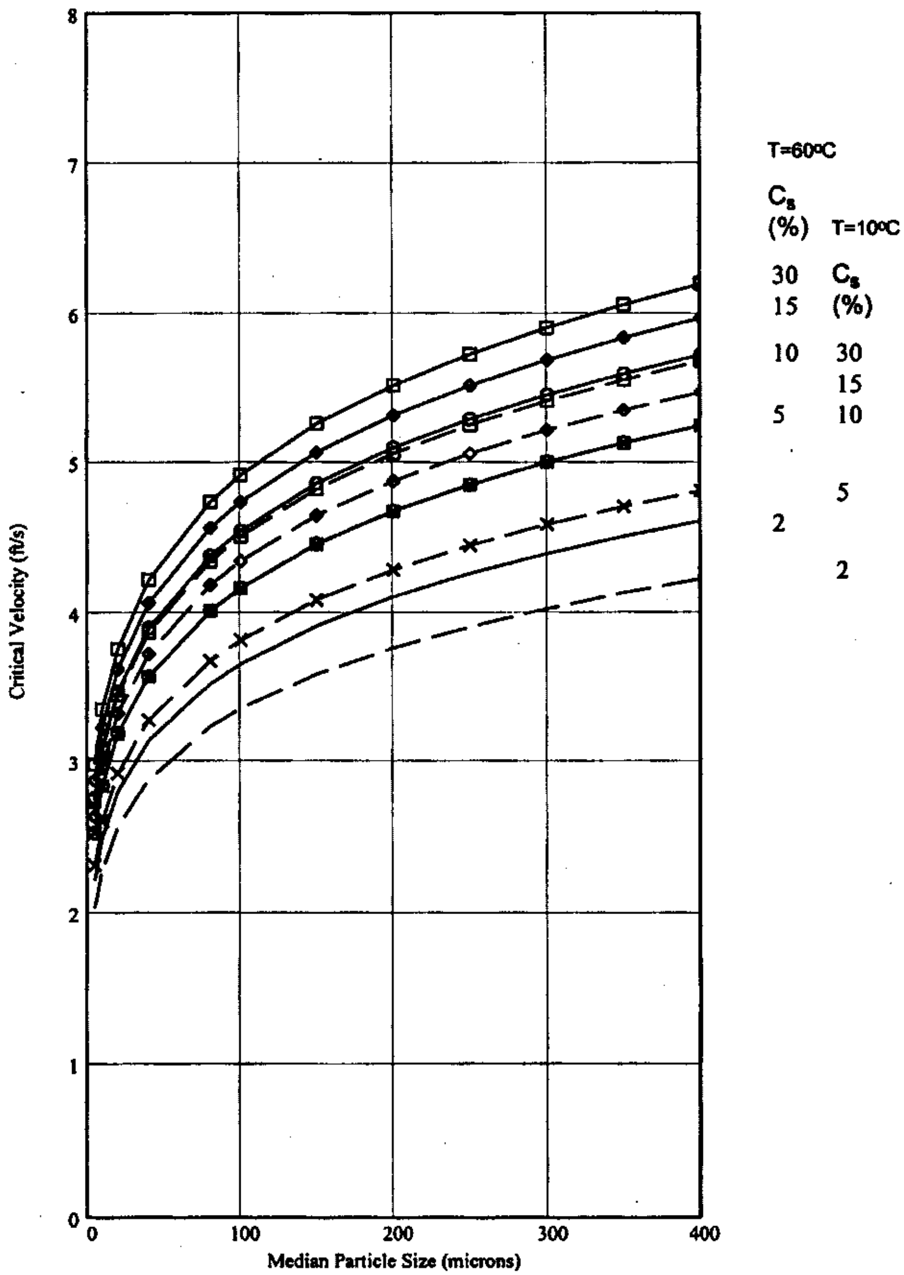
$\kappa_{cv} = 1.3$ $\beta_{cv} = 1.2$ $\rho_L = 1.2\frac{kg}{liter}$ $\rho_s = 2.5\frac{kg}{liter}$ $\mu_{cL}(\rho_L, T_1) = 2.021\,cP$ $\mu_{cL}(\rho_L, T_2) = 0.771\,cP$ $\varepsilon_{EOL\_SS} = 10\,mil$

Figure E-8b. Critical Velocity for AN-107-to-BNFL Transfer Route vs. Median Particle Size and Selected Solid Volume Concentrations - ρ_L=1.2 kg/L, ρ_s=2.5 kg/L, T= 10 (dashed lines) and 60°C (solid lines).



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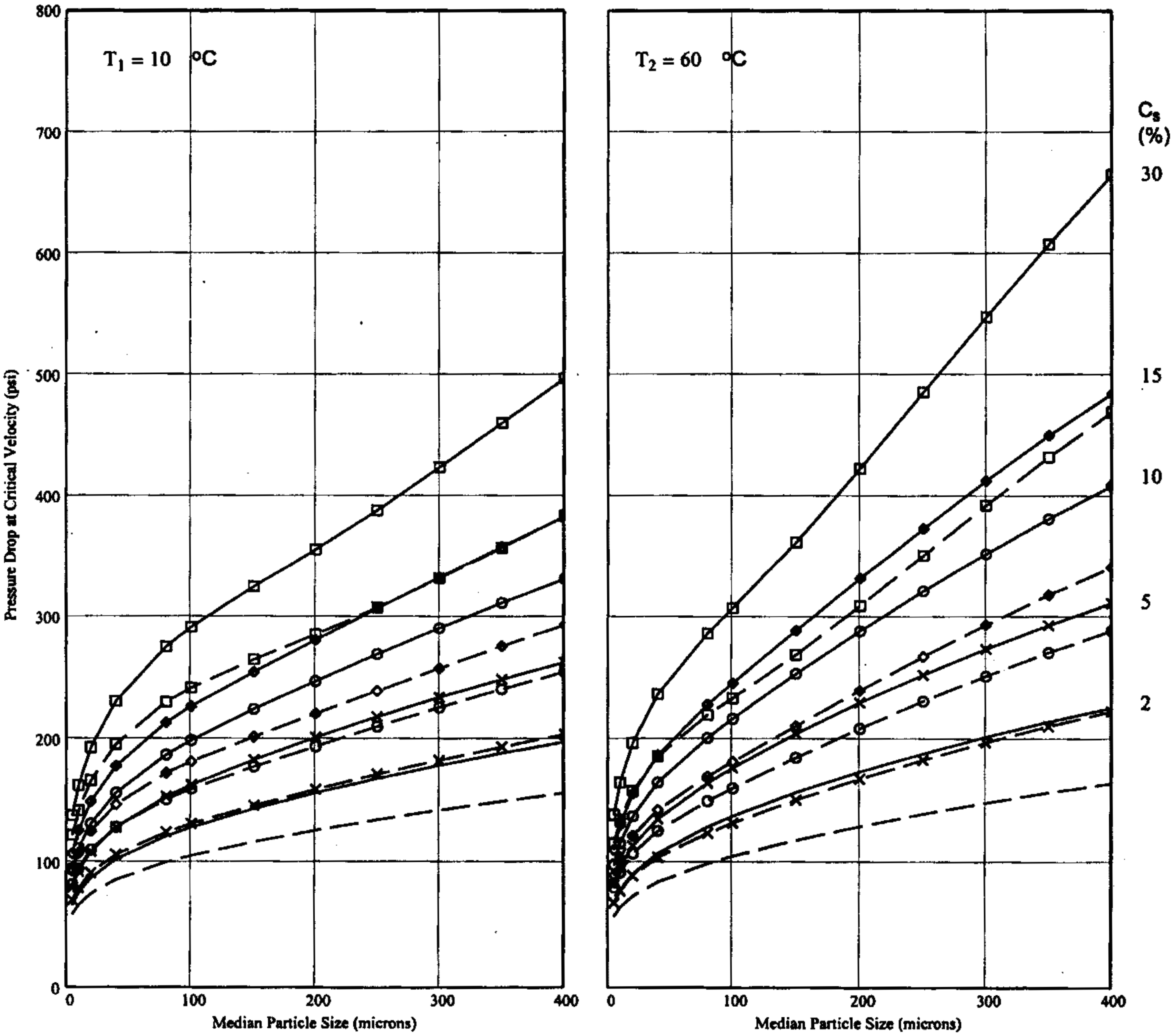
$\kappa_{cv} = 1.3$ $\beta_{cv} = 1.2$ $\rho_L := 1.4 \cdot \frac{kg}{liter}$ $\rho_s := 3 \cdot \frac{kg}{liter}$ $\mu_{cL}(\rho_L, T_1) = 5.401\,cP$ $\mu_{cL}(\rho_L, T_2) = 2.274\,cP$ $\varepsilon_{EOL\_SS} = 10\,mil$

Figure E-9a. Pressure Drop at Critical Velocity for AN-107-to-BNFL Transfer Route vs. Median Particle Size and Selected Solid Volume Concentrations - ρ_L=1.4 kg/L, ρ_s=3 kg/L, T = 10 and 60°C, for New (dashed lines) and EOL (solid lines) Pipe Roughness Estimates.



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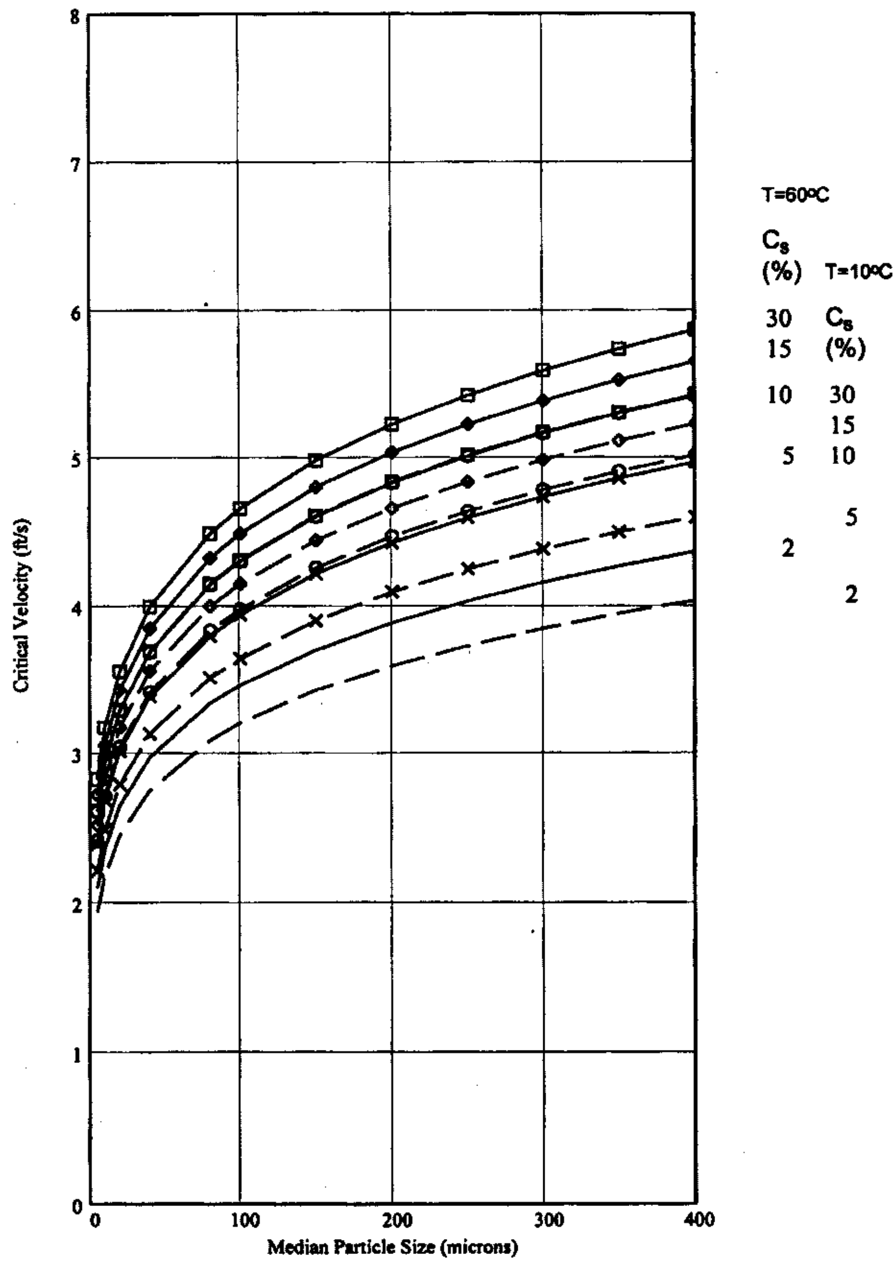
$\kappa_f = 1$ $\beta_f = 1$ $D_{pipe} = 3.068\,in$ $L_{CS} = 557\,ft$ $L_{SS} = 7028\,ft$ $H = 40\,ft$ $\varepsilon_{new} = 2\,mil$ $\varepsilon_{EOL\_CS} = 150\,mil$

$\kappa_{cv} = 1.3$ $\beta_{cv} = 1.2$ $\rho_L = 1.4\frac{kg}{liter}$ $\rho_s = 3\frac{kg}{liter}$ $\mu_{cL}(\rho_L, T_1) = 5.401\,cP$ $\mu_{cL}(\rho_L, T_2) = 2.274\,cP$ $\varepsilon_{EOL\_SS} = 10\,mil$

Figure E-9b. Critical Velocity for AN-107-to-BNFL Transfer Route vs. Median Particle Size and Selected Solid Volume Concentrations - ρ_L=1.4 kg/L, ρ_s=3 kg/L, T = 10 (dashed lines) and 60°C (solid lines).



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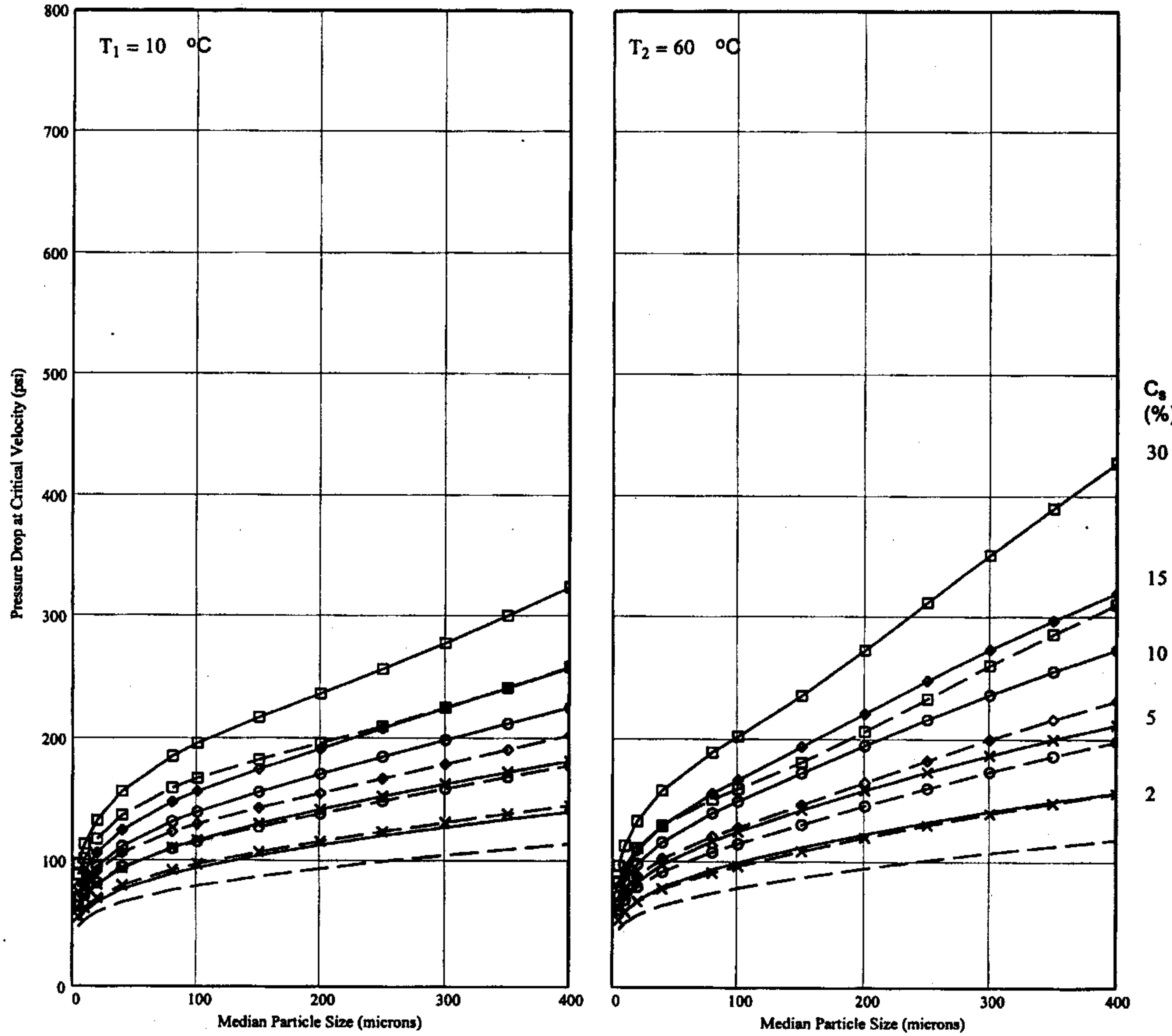
$\kappa_{cv} = 1.3$ $\beta_{cv} = 1.2$ $\rho_L := 1.4\cdot\frac{kg}{liter}$ $\rho_s := 2.5\cdot\frac{kg}{liter}$ $\mu_{cL}(\rho_L, T_1) = 5.401\,cP$ $\mu_{cL}(\rho_L, T_2) = 2.274\,cP$ $\varepsilon_{EOL\_SS} = 10\,mil$

Figure E-10a. Pressure Drop at Critical Velocity for AN-107-to-BNFL Transfer Route vs. Median Particle Size and Selected Solid Volume Concentrations - ρ_L=1.4 kg/L, ρ_s=2.5 kg/L, T = 10 and 60°C, for New (dashed lines) and EOL (solid lines) Pipe Roughness Estimates.



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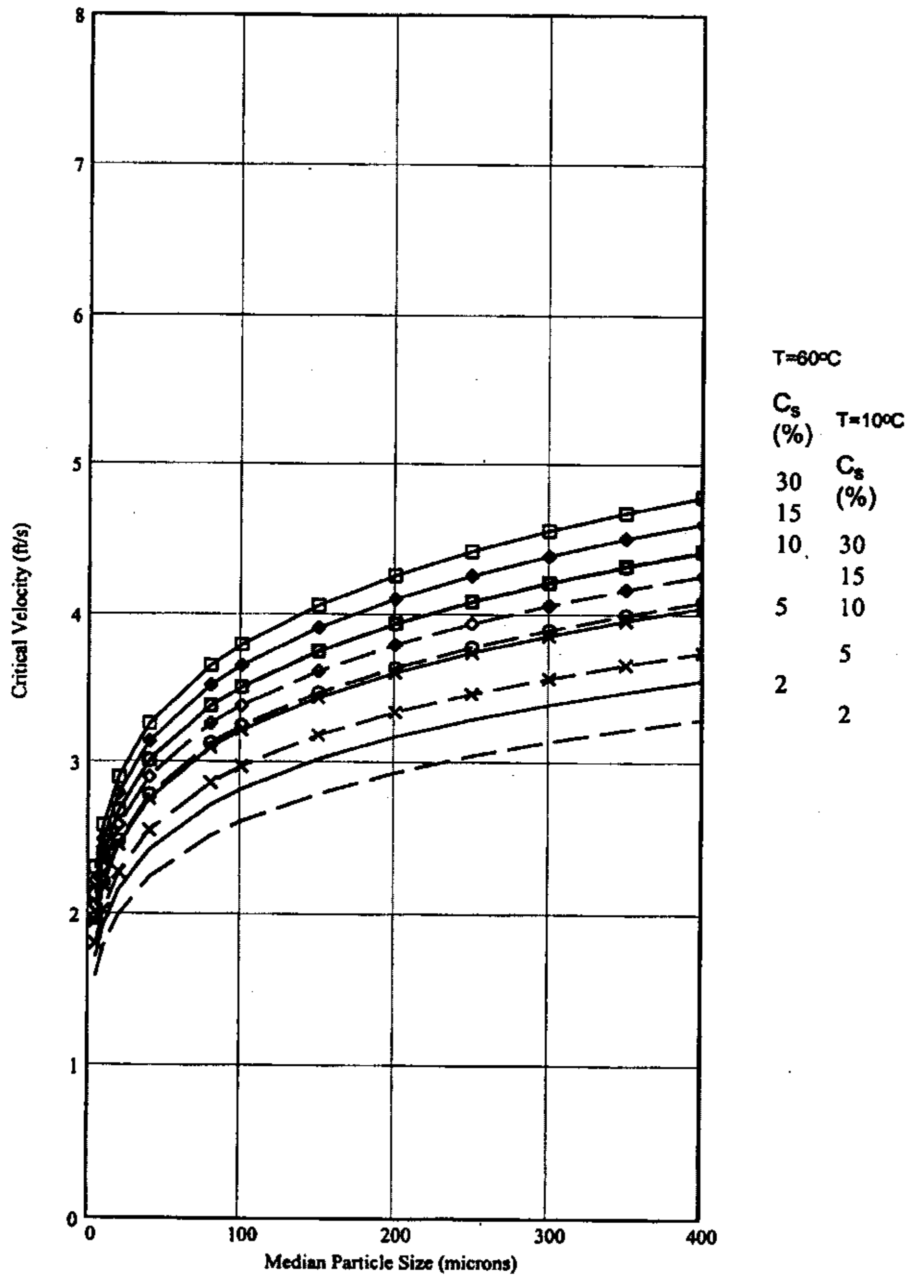
$\kappa_{cv} = 1.3$ $\beta_{cv} = 1.2$ $\rho_L = 1.4\frac{kg}{liter}$ $\rho_s = 2.5\frac{kg}{liter}$ $\mu_{cL}(\rho_L, T_1) = 5.401\,cP$ $\mu_{cL}(\rho_L, T_2) = 2.274\,cP$ $\varepsilon_{EOL\_SS} = 10\,mil$

Figure E-10b. Critical Velocity for AN-107-to-BNFL Transfer Route vs. Median Particle Size and Selected Solid Volume Concentrations - ρ_L=1.4 kg/L, ρ_s=2.5 kg/L, T = 10 (dashed lines) and 60°C (solid lines).



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APPENDIX F

CRITICAL VELOCITY AND PRESSURE DROP CORRELATION EQUATIONS

Calculations contained herein were produced in Mathcad 2000 Professional (Mathcad is a registered trademark of MathSoft, Inc. of Cambridge, Massachusetts).

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CONVERSIONS

ft	feet = 0.3048 meter (m)
in.	inch = 2.54 centimeters (cm)
lbf/in^2	pounds per square inch = 0.06895 megapascals (MPa)
mils	0.001 in. = 0.0254 millimeter (mm)
gpm	0.0631 liter/second (L/s)
cP	centipose = 0.001 kilogram/meter-second (kg/m-s)

CH2MHILL Hanford Group, Inc.
EVALUATION ANALYSIS

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Page No. 1 of 60

Client: Numatec Hanford Corporation
Subject: Critical Velocity and Pressure Drop Study in Support of Waste Tank Feed Transfer System
Location: 200 Area - Hanford Site, Richland, Washington

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1.0 INTRODUCTION

Current pressure ratings of existing and proposed additions to the tank-to-tank, 3-inch diameter, Schedule-40, transfer pipelines for the double-shell tanks (DSTs) in the 200 East Area are 275 and 400 lbf/in^2. The 275 lbf/in^2 lines are carbon steel pipelines that were installed approximately 20 years ago. All new lines are expected to be stainless steel.

Corrosion of in-place Hanford waste tank transfer pipelines could restrict proposed waste feed activities. Corrosion of the inner pipe surface reduces the effective wall thickness necessary to maintain pipe structural integrity and increases the effective roughness of the pipe causing increased frictional resistance or pressure loss. The increased pressure loss requires greater pump capacity to achieve required flow. The flow rate must be maintained above a minimum flow rate to assure that solid particles in the waste stream do not settle in the pipeline, leading to line plugging. The maximum flow rate is restricted by the design pressure rating of the pipeline system.

Hence, increased corrosion leads to a reduction in the effective operating flow range of the pump and pipe system. An investigation of the proposed transfer conditions, pipeline configurations, and potential corrosion is necessary to evaluate pump requirements and adequacy of existing pipeline pressure ratings, as well as, requirements for any pipe additions.

2.0 APPROACH

Minimum flow rates (critical velocity) to maintain particle suspension and flow rate at the design pipeline pressure rating is estimated based on critical velocity and pipeline pressure drop correlations for slurry flow. Estey and Hu (1998) compared various critical velocity correlations and recommended the correlation developed by Oroskar and Turian (1980).

The pipeline pressure drop correlation for slurry flow developed by Wasp et al. (1977) is applied to obtain pressure drop estimates for each of the proposed transfer routes and waste conditions. New pipe and end-of-life (EOL) pipe roughness values for carbon and stainless steel pipe were applied from estimates given by Anantatmula and Divine (1999) to envelop the pressure drop estimates.

3.0 SUMMARY RESULTS

Although alternate critical velocity and pressure drop correlations were investigated, the Oroskar and Turian (1980) critical velocity and Wasp et al. (1977) pressure drop correlations were selected as being the most appropriate based on current limited knowledge of the waste physical properties during proposed transfers. Hanford waste feed delivery physical property data was estimated from the data summary provided in Estey 2000 for the in situ waste physical properties, as well as, from various waste characterization reports and flowsheets for Cases 3S4 and 3S6 from the Hanford Tank Waste Operation Simulator (HTWOS) model (Kirkbride et al. 1999). The range of waste and transfer pipe physical properties of interest are identified in Section 5.0 of this appendix. The assumed particle size distribution for the solid particles is based on the measured particle size distribution by volume for Tank 241-SY-101 (O'Rourke 1999). The measured distribution was curve fit to a Rosin-Rammler distribution function (Shook and Roco 1991) and then shifted to obtain a distribution with the target median particle size of interest. Appendix D provides a tabular listing of the critical velocity, pressure drop at critical velocity, and flow rate at a reference pipeline design pressure of 400 lbf/in^2 for each of the 200-East Area transfer routes identified in Cases 3S4 and 3S6 from the HTWOS model for a range of waste transfer properties. An alternate solutions to reduce the predicted pressure drops for wost-case conditions was also considered. This alternate solution assumed a pump lift station in AP Farms located at the AP "new" valve pit. Selected long intermediate tank-to-tank transfers and all transfers to BNFL (Case 4-st) would go through the pump lift station. Appendix E provides the results of a "sensitivity" analysis on the longest transfer route (AN-107 to BNFL) for the range of waste transfer properties considered appropriate. See main body of this report for a discussion of the detail results. Appendix G provides results of Wasp model verification.

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5.0 HANFORD WASTE AND TRANSFER PIPE PHYSICAL PROPERTIES

$TOL = 1 \times 10^{-5}$

Development of the expressions for the critical velocity and pressure drop correlations require knowledge of the following transfer pipe and waste physical property parameters.

Transfer pipeline parameters

D_{pipe} inside diameter of transfer pipeline $D_{pipe} := 3.068 \cdot in$

p_{pipe_design} pipe design pressure $p_{pipe\_design} := 400 \cdot \frac{lbf}{in^2}$ or $275 \cdot \frac{lbf}{in^2}$

The following roughness values are assumed for the 3-in. transfer pipe lines (Anantatmula and Divine 1999)

new pipe upper bound roughness | assumed corroded upper bound roughness | $mil := 10^{-3} \cdot in$

$\varepsilon_{new} := 2 \cdot mil$ $\varepsilon_{EOL\_CS} := 150 \cdot mil$ for carbon steel pipe at end of 50-year service life

$\varepsilon_{new} = 2\ mil$ $\varepsilon_{EOL\_SS} := 10 \cdot mil$ for stainless steel pipe at end of 40-year service life

$\frac{\varepsilon_{new}}{D_{pipe}} = 0.00065$ $\frac{\varepsilon_{EOL\_CS}}{D_{pipe}} = 0.049$ $\frac{\varepsilon_{EOL\_SS}}{D_{pipe}} = 0.00326$ corresponding relative roughness values for D_{pipe}

Waste transfer parameters

α_d or C_s particulate solids volume fraction $0 < \alpha_d \le 0.30$ $\alpha_d < 0.10$ (typical)

$\alpha_c(\alpha_d) := (1 - \alpha_d)$ carrier liquid volume fraction

D_d or d_p particulate solid phase effective median diameter (μm) $1 \le D_d \le 400$ $\mu m \equiv 10^{-6} \cdot m$

ρ_d or ρ_s particulate solid phase density (kg/L) $1.4 \le \rho_d \le 4$

ρ_c or ρ_L carrier liquid phase density (kg/L) $\rho_{water} \le \rho_c \le 1.5$

μ_c or μ_L carrier liquid phase viscosity (cP) $\mu_{water}(t_C) \le \mu_c \le 10$ $cP \equiv 10^{-2} \cdot poise$

The density and viscosity of water as a function of temperature (°C) were obtained from Shook and Roco (1991) and Estey and Hu (1998) as

$$\rho_{water}(t_C) := \left[999.7 - 0.10512 \cdot (t_C - 10) - 0.005121 \cdot (t_C - 10)^2 + 0.00001329 \cdot (t_C - 10)^3\right] \cdot \frac{kg}{m^3} \quad \text{(F-1)}$$

mass density of water (5 °C < t_C <100 °C)

viscosity of water as a function of temperature (°C)

$$\mu_{water}(t_C) := \begin{cases} 100 \cdot \exp\left[\ln(10) \cdot \left[\frac{1301}{998.333 + 8.1855 \cdot (t_C - 20) + 0.00585 \cdot (t_C - 20)^2} - 3.30233\right]\right] \cdot cP & \text{if } t_C \le 20 \\ (1.002) \cdot \exp\left[\ln(10) \cdot \left[\frac{\left[1.3272 \cdot (20 - t_C) - 0.001053 \cdot (t_C - 20)^2\right]}{t_C + 105}\right]\right] \cdot cP & \text{otherwise} \end{cases} \quad \text{(F-2)}$$

The above properties of water can be assumed for the pipeline flush condition as a function of the temperature of the flush water. These properties can vary if the flush water is treated.

The viscosity of water based on the above correlation is plotted in Figure F-1a as a function of temperature.

The viscosity of the carrier liquid is given in Estey 2000 by the following relation:

ρ_L density of carrier liquid with dissolved solids

$x_{salt} := 0.9$ fraction of dissolved solids composed of sodium and other salts

$x_{caustic} := 0.1$ fraction of dissolved solids composed of sodium hydroxide

$$\mu_{cL}(\rho_L, t_C) := \mu_{water}(t_C)\cdot\left[x_{salt}\cdot\left[1 + 1.071\cdot\left(\frac{\rho_L}{\rho_{water}(t_C)} - 1\right)\right] + x_{caustic}\cdot \exp\left[\left[7.143\cdot\left(\frac{\rho_L}{\rho_{water}(t_C)} - 1\right)\right]^{1.15}\right]\right] \quad \text{(F-3)}$$

This relation is shown in Figure F-1b vs. the density of the carrier liquid at selected temperatures.

The following temperature conversion functions are defined to convert between Fahrenheit and Celsius temperature scales.

$$T_F(t_C) := \frac{9}{5}\cdot t_C + 32$$

$$T_C(t_F) := \frac{5}{9}\cdot(t_F - 32) \quad \text{(F-4)}$$

6.0 CRITICAL VELOCITY AND PRESSURE DROP CORRELATIONS

Empirical correlations for critical velocity (minimum slurry transport flow velocity to maintain suspension of solid particles) and pipeline friction pressure drop loss are available in the literature for various slurry types (homogeneous, heterogeneous, or compound homogeneous-heterogeneous) based on solid particle size and density, concentration of solids by weight or volume relative to total mass or volume of material being transported, carrier fluid density and viscosity, and pipe diameter and roughness. The slurry may exhibit Newtonian or non-Newtonian behavior. Non-Newtonian behavior is more likely at high concentrations (approaching 30% by volume) of fine particle solids (particle diameter less than approximately 100 microns). The slurry may be considered homogenous if the solid particles do not settle out independent of the flow velocity. In the following only heterogeneous and compound homogeneous-heterogeneous Newtonian flow conditions are addressed. This restriction appears to be appropriate for the Hanford waste feed transfers being considered based on the limited sample data available at this time.

6.1 HETEROGENEOUS FLOW

6.1.1 Critical Velocity

Estey and Hu (1998) recommended that the **Oroskar and Turian (1980)** critical velocity empirical correlation be used for Hanford waste transfer conditions. The flow should be maintained above the critical velocity to prevent particles from settling in the pipe which could lead to pipe plugging. This correlation as well as alternate correlation's from the open literature are provided below for comparison. These alternate correlation's expand on the comparison given in Estey and Hu (1998). However, the Oroskar and Turian (1980) correlation is still selected for application to the Hanford waste transfer conditions as it is generally more conservative when compared to the alternate correlation's without direct experimental data for the Hanford waste.

The Oroskar and Turian (1980) critical velocity and alternate correlation's are given below.

The Reynolds Number for Newtonian flow is defined as

$$Re(D,v,\rho,\mu) := D\cdot v\cdot\frac{\rho}{\mu} \qquad \textbf{(F-5)}$$

where D is a characteristic length, v is the flow velocity, ρ is the fluid density, and μ is the fluid viscosity.

The terminal settling velocity (v_∞) of spherical particle settling in a stagnant unbound liquid is given by the following:

For Stokes flow ($Re < 0.1$) the drag coefficient of a spherical particle is given by

$$C_D(D_d,v,\rho_c,\mu_c) := \frac{24}{Re(D_d,v,\rho_c,\mu_c)} \qquad \textbf{(F-6)}$$

which leads the following explicit relation for v_∞

$$v_\infty(D_d,\rho_d,\rho_c,\mu_c) := g\cdot(\rho_d-\rho_c)\cdot(D_d)^2\cdot(18\cdot\mu_c)^{-1} \qquad \textbf{(F-7)}$$

For Stokes and non-Stokes flow Turian (1971) gives the following correlation for C_D valid for $Re < 1.5\cdot10^5$

$$C_D(D_d,v,\rho_c,\mu_c) := \left[\left(\frac{24}{Re(D_d,v,\rho_c,\mu_c)}\right)^{\frac{1}{2}} + 0.34035\cdot\left(Re(D_d,v,\rho_c,\mu_c)^{0.06071} \ldots + \frac{1}{1.72013+0.018\cdot Re(D_d,v,\rho_c,\mu_c)}\right)\right]^2 \qquad \textbf{(F-8)}$$

and v_∞ is then given by

$$v_{\infty v}(D_d,\rho_d,\rho_c,\mu_c,v) := \sqrt{\frac{\frac{4}{3}\cdot D_d\cdot\left(\frac{\rho_d}{\rho_c}-1\right)\cdot g}{C_D(D_d,v,\rho_c,\mu_c)}} \qquad \textbf{(F-9)}$$

which is implicit in v_∞ but can be iteratively solved as follows $\quad v' := 0.1\cdot\frac{ft}{sec}$ initial guess

$$v_\infty(D_d,\rho_d,\rho_c,\mu_c) := root(v' - v_{\infty v}(D_d,\rho_d,\rho_c,\mu_c,v'),v') \qquad \textbf{(F-10)}$$

To preclude an iterative solution Turian (1971) developed the following approximate correlation for v_∞ with the introduction of the following non dimensional parameter

$$\Lambda(D_d,\rho_d,\rho_c,\mu_c) := \sqrt{\frac{4}{3}\cdot\frac{g\cdot D_d^{\,3}\cdot\rho_c\cdot(\rho_d-\rho_c)}{\mu_c^{\,2}}} \quad \text{with} \qquad \textbf{(F-11)}$$

$$\lambda(\Lambda) := -1.38 + 1.94\cdot\log(\Lambda) - 8.6\cdot10^{-2}\cdot\log(\Lambda)^2 - 2.52\cdot10^{-2}\cdot\log(\Lambda)^3 + 9.19\cdot10^{-4}\cdot\log(\Lambda)^4 + 5.35\cdot10^{-4}\cdot\log(\Lambda)^5 \qquad \textbf{(F-12)}$$

to give the terminal settling velocity as

$$v_{\infty\_a}(D_d,\rho_d,\rho_c,\mu_c) := \frac{\mu_c}{D_d\cdot\rho_c}\cdot 10^{\lambda(\Lambda(D_d,\rho_d,\rho_c,\mu_c))} \qquad \text{(F-13)}$$

Reynolds Number for a settling spherical particle at terminal velocity is given by

$$Re_{\infty}(D_d,\rho_d,\rho_c,\mu_c) := Re(D_d, v_{\infty}(D_d,\rho_d,\rho_c,\mu_c),\rho_c,\mu_c) \qquad \text{(F-14)}$$

The above drag coefficients correlations, as well as a third correlation referenced in Estey and Hu (1998), are compared in Figure F-2. Equations F-8 through F-10 are used herein for greater accuracy over a full range of particle sizes.

In accordance with Oroskar and Turian (1980), the hindered settling velocity of a spherical particle is given by the following relations:

$$n = 4.65 - 2.32\cdot\frac{1}{\sqrt{0.5\cdot\pi}}\cdot\int_{-\infty}^{\infty}\exp\left(\frac{-\log(Re_{\infty})^2}{0.5}\right)d\log(Re_{\infty}) \qquad \text{(F-15)}$$

$$n(D_d,\rho_d,\rho_c,\mu_c) := (4.65 - 2.32\cdot\text{pnorm}(\log(Re_{\infty}(D_d,\rho_d,\rho_c,\mu_c)),0,0.5)) \qquad \text{(F-16)}$$

$$v_{hindered}(D_d,\rho_d,\alpha_d,\rho_c,\mu_c) := (\alpha_c(\alpha_d))^{n(D_d,\rho_d,\rho_c,\mu_c)}\cdot v_{\infty}(D_d,\rho_d,\rho_c,\mu_c) \qquad \text{hindered settling velocity} \qquad \text{(F-17)}$$

A plot of the hindered settling velocity exponent versus Reynolds Number is shown in Figure F-3 for comparison with Figure 5 given in Oroskar and Turian (1980). Equations F-15 and F-16 were derived by Estey and Hu (1998) as an analytical approximation to the graphical relation given in Figure 5 of Oroskar and Turian (1980).

The ratio of particle hindered settling velocity to critical velocity

$$\gamma = \frac{v_{hindered}}{v_{critical}} \quad \text{or} \quad \gamma(D_d,\rho_d,\alpha_d,\rho_c,\mu_c,v) := \frac{v_{hindered}(D_d,\rho_d,\alpha_d,\rho_c,\mu_c)}{v} \qquad \text{(F-18)}$$

The fraction of the turbulent fluid eddies possessing a velocity larger than the particulate settling velocity is given (in corrected form derived from Equation 42 of Oroskar and Turian 1980) as

$$\chi(\gamma) := \frac{2}{\sqrt{\pi}}\cdot\left[\frac{2}{\sqrt{\pi}}\cdot\gamma\cdot\exp\left(\frac{-4}{\pi}\cdot\gamma^2\right) + \frac{\sqrt{\pi}}{2}\cdot\left(1 - \text{erf}\left(\frac{2}{\sqrt{\pi}}\cdot\gamma\right)\right)\right] \qquad \text{(F-19)}$$

χ versus γ is plotted in Figure F-4 for comparison with Figure 6 in Oroskar and Turian (1980).

The Oroskar and Turian (1980) semi-theoretical correlation for the critical velocity (v_t) is given by:

$$v_d(D_d,\rho_d,\rho_c) := \sqrt{g \cdot D_d \cdot \left(\frac{\rho_d}{\rho_c} - 1\right)}$$ characteristic velocity of a settling particle **(F-20)**

$$F_1(D_{pipe},D_d,\rho_d,\alpha_d,\rho_c,\mu_c,v) := \left[\frac{5\cdot(\alpha_d)\cdot(\alpha_c(\alpha_d))^{(2\cdot n(D_d,\rho_d,\rho_c,\mu_c)-1)}\cdot\left(\frac{D_{pipe}}{D_d}\right)\cdot\left(\frac{D_{pipe}\cdot\rho_c}{\mu_c}\cdot v_d(D_d,\rho_d,\rho_c)\right)^{\frac{1}{8}}}{\chi(\gamma(D_d,\rho_d,\alpha_d,\rho_c,\mu_c,v))}\right]^{\frac{8}{15}}$$ **(F-21)**

$$v_{tv}(D_{pipe},D_d,\rho_d,\alpha_d,\rho_c,\mu_c,v) := v_d(D_d,\rho_d,\rho_c)\cdot F_1(D_{pipe},D_d,\rho_d,\alpha_d,\rho_c,\mu_c,v)$$ **(F-22)**

$$v_{crOTt}(D_{pipe},D_d,\rho_d,\alpha_d,\rho_c,\mu_c,\kappa_{cv}) := \kappa_{cv}\cdot \mathrm{root}(v - v_{tv}(D_{pipe},D_d,\rho_d,\alpha_d,\rho_c,\mu_c,v),v)$$ semi-theoretical critical velocity correlation **(F-23)**

where D_{pipe} is the inside diameter of pipe and the other parameters are as defined above.

The Oroskar and Turian (1980) empirical correlation for the critical velocity (v_e) is given by:

$$F_2(D_{pipe},D_d,\rho_d,\alpha_d,\rho_c,\mu_c) := 1.85\cdot(\alpha_d)^{0.1536}\cdot(\alpha_c(\alpha_d))^{0.3564}\cdot\left(\frac{D_{pipe}}{D_d}\right)^{0.378}\cdot\left(D_{pipe}\cdot\frac{\rho_c}{\mu_c}\cdot v_d(D_d,\rho_d,\rho_c)\right)^{0.09}$$ **(F-24)**

$$v_{ev}(D_{pipe},D_d,\rho_d,\alpha_d,\rho_c,\mu_c,v) := v_d(D_d,\rho_d,\rho_c)\cdot F_2(D_{pipe},D_d,\rho_d,\alpha_d,\rho_c,\mu_c)\cdot\chi(\gamma(D_d,\rho_d,\alpha_d,\rho_c,\mu_c,v))^{0.30}$$ **(F-25)**

$$v_{crOTe}(D_{pipe},D_d,\rho_d,\alpha_d,\rho_c,\mu_c,\kappa_{cv}) := \kappa_{cv}\cdot \mathrm{root}(v - v_{ev}(D_{pipe},D_d,\rho_d,\alpha_d,\rho_c,\mu_c,v),v)$$ empirical critical velocity correlation **(F-26)**

The Oroskar and Turian (1980) semi-theoretical and empirical equations given above were considered to do the best overall job of predicting the critical velocity. The overall percent rms deviation was 25.94 and 21.82, respectively compared to at least twice this for the other seven correlations considered.

Estey and Hsu (1998) recommended that the slurry flow critical velocity be taken as the maximum value of the Oroskar and Turian (1980) semi-theoretical and empirical equations, i.e.,

$$v_{crOT}(D_{pipe},D_d,\rho_d,\alpha_d,\rho_c,\mu_c,\kappa_{cv}) := \frac{m}{sec}\cdot \left| \begin{array}{l} u_t \leftarrow v_{crOTt}(D_{pipe},D_d,\rho_d,\alpha_d,\rho_c,\mu_c,\kappa_{cv})\cdot\left(\frac{m}{sec}\right)^{-1} \\ u_e \leftarrow v_{crOTe}(D_{pipe},D_d,\rho_d,\alpha_d,\rho_c,\mu_c,\kappa_{cv})\cdot\left(\frac{m}{sec}\right)^{-1} \\ u_t \ \text{if}\ u_t > u_e \\ u_e \ \text{otherwise} \end{array}\right.$$ **(F-27)**

κ_{cv} is the uncertainty factor on the predicted critical velocity, set to 1 to obtain "best-estimate" value.

Turian, Hsu, and Ma (1987) compared 36 critical velocity correlations. Correlations proposed by Robinson and Graf (1972), Oroskar and Turian (1980), and by Wasp et al. (1977) were determined to do a better job of predicting the critical velocity than the other correlations considered. The relations by **Robinson and Graf (1972)** and **Wasp et al. (1977)** are given, respectively as

$$v_{crRG}(D_{pipe}, D_d, \rho_d, \alpha_d, \rho_c, \mu_c, \kappa_{cv}) := \kappa_{cv} \cdot 0.901 \cdot \alpha_d^{0.106} \cdot \sqrt{2 \cdot g \cdot D_{pipe} \cdot \left(\frac{\rho_d}{\rho_c} - 1\right)} \quad \textbf{(F-28)}$$

$$v_{crWasp}(D_{pipe}, D_d, \rho_d, \alpha_d, \rho_c, \mu_c, \kappa_{cv}) := \kappa_{cv} \cdot 3.116 \cdot \alpha_d^{0.186} \cdot \left(\frac{D_d}{D_{pipe}}\right)^{\frac{1}{6}} \cdot \sqrt{2 \cdot g \cdot D_{pipe} \cdot \left(\frac{\rho_d}{\rho_c} - 1\right)} \quad \textbf{(F-29)}$$

Also of interest are the following correlations.

Zandi and Govatos (1967) proposed a critical velocity relation developed from more than 1000 data points collected from 11 references. The critical velocity at transition from saltation to heterogeneous flow was given as

$$v_{crZG}(D_{pipe}, D_d, \rho_d, \alpha_d, \rho_c, \mu_c, \kappa_{cv}) := \kappa_{cv} \cdot \sqrt{\frac{40 \cdot \alpha_d \cdot g \cdot D_{pipe} \cdot \left(\frac{\rho_d}{\rho_c} - 1\right)}{\sqrt{C_D(D_d, v_\infty(D_d, \rho_d, \rho_c, \mu_c), \rho_c, \mu_c)}}} \quad \textbf{(F-30)}$$

Shook (1969) used the Durand's pressure loss correlation and determined the velocity corresponding to minimum pressure loss and proposed the following relation which is similar to the Zandi and Govatos (1967) relation.

$$v_{crShook}(D_{pipe}, D_d, \rho_d, \alpha_d, \rho_c, \mu_c, \kappa_{cv}) := \kappa_{cv} \cdot 2.43 \cdot \alpha_d^{\frac{1}{3}} \cdot \sqrt{\frac{2 \cdot g \cdot D_{pipe} \cdot \left(\frac{\rho_d}{\rho_c} - 1\right)}{\sqrt{C_D(D_d, v_\infty(D_d, \rho_d, \rho_c, \mu_c), \rho_c, \mu_c)}}} \quad \textbf{(F-31)}$$

Gogus and Kokpinar (1999) developed the following empirical correlation based on experimental data for the ranges 230 μm < D_d < 5430 μm, 1.04 kg/liter < ρ_d < 2.68 kg/liter, 0.0254 m < D_{pipe} < 0.1524 m, and 0.0075 < α_d < 0.30.

$$\mu_c(\mu_L, \alpha_d) := \mu_L \cdot \left(1 + 2.5 \cdot \alpha_d + 10.05 \cdot \alpha_d^2 + 0.00273 \cdot \exp(16.6 \cdot \alpha_d)\right)$$ Thomas correlation (Wasp et al. 1977)

$$\rho_c(\rho_s, \rho_L, \alpha_d) := \rho_s \cdot \alpha_d + \rho_L \cdot (1 - \alpha_d) \quad \textbf{(F-32)}$$

$$v_{\infty m}(D_d, \rho_s, \rho_L, \mu_L, \alpha_d) := v_\infty(D_d, \rho_s, \rho_c(\rho_s, \rho_L, \alpha_d), \mu_c(\mu_L, \alpha_d))$$ particle settling velocity in slurry mixture

$$v_{crGK}(D_{pipe}, D_d, \rho_s, \alpha_d, \rho_L, \mu_L, \kappa_{cv}) := \kappa_{cv} \cdot 0.0548 \cdot \left(\frac{D_d}{D_{pipe}}\right)^{-0.60} \cdot \alpha_d^{0.27} \cdot \left(\frac{\rho_s}{\rho_L} - 1\right)^{0.07} \cdot \left(\frac{\rho_L \cdot v_{\infty m}(D_d, \rho_s, \rho_L, \mu_L, \alpha_d) \cdot D_d}{\mu_L}\right)^{0.30} \cdot \sqrt{g \cdot D_{pipe}} \quad \textbf{(F-33)}$$

The authors claim only 15% average error in this prediction equation.

Figure F-5 indicates that the Oroskar and Turian (1980) empirical equation generally predicts a higher critical velocity than the Oroskar and Turian (1980) semi-theoretical equation. The sensitivity of the Oroskar and Turian (1980) empirical equation to the liquid density, liquid viscosity, particle solids density, particle solids diameter, and solids volume fraction are shown in Figures F-6 through F-10 for solid-liquid flow in a 3-inch diameter pipe.

The following relation provides easy access to each of the above correlations and assures that the critical velocity returned is greater than the transition to turbulence velocity

$$v_{cr}(D_{pipe}, D_d, \rho_d, \alpha_d, \rho_c, \mu_c, \kappa_{cv}, \beta_{cv}) := \frac{m}{sec} \cdot \left| \begin{array}{l} v_T \leftarrow \dfrac{4000 \cdot \mu_c}{D_{pipe} \cdot \rho_c} \quad \text{transition to turbulence velocity} \\ v_{crit} \leftarrow v_T \ \text{ if } \alpha_d < 0.0001 \\ \text{otherwise} \\ \quad \left| \begin{array}{l} v_{crit} \leftarrow v_{crOT}(D_{pipe}, D_d, \rho_d, \alpha_d, \rho_c, \mu_c, \kappa_{cv}) \ \text{ if } \beta_{cv} = 1 \\ v_{crit} \leftarrow v_{crOTt}(D_{pipe}, D_d, \rho_d, \alpha_d, \rho_c, \mu_c, \kappa_{cv}) \ \text{ if } \beta_{cv} = 1.1 \\ v_{crit} \leftarrow v_{crOTe}(D_{pipe}, D_d, \rho_d, \alpha_d, \rho_c, \mu_c, \kappa_{cv}) \ \text{ if } \beta_{cv} = 1.2 \\ v_{crit} \leftarrow v_{crWasp}(D_{pipe}, D_d, \rho_d, \alpha_d, \rho_c, \mu_c, \kappa_{cv}) \ \text{ if } \beta_{cv} = 2 \\ v_{crit} \leftarrow v_{crZG}(D_{pipe}, D_d, \rho_d, \alpha_d, \rho_c, \mu_c, \kappa_{cv}) \ \text{ if } \beta_{cv} = 3 \\ v_{crit} \leftarrow v_{crShook}(D_{pipe}, D_d, \rho_d, \alpha_d, \rho_c, \mu_c, \kappa_{cv}) \ \text{ if } \beta_{cv} = 4 \\ v_{crit} \leftarrow v_{crGK}(D_{pipe}, D_d, \rho_d, \alpha_d, \rho_c, \mu_c, \kappa_{cv}) \ \text{ if } \beta_{cv} = 5 \\ v_{crit} \leftarrow v_{crRG}(D_{pipe}, D_d, \rho_d, \alpha_d, \rho_c, \mu_c, \kappa_{cv}) \ \text{ if } \beta_{cv} = 6 \end{array} \right. \\ v_T \ \text{ if } v_T > v_{crit} \\ v_{crit} \ \text{ otherwise} \end{array} \right. \quad \textbf{(F-34)}$$

The critical velocity correlation selection key for equation F-34 is given as follows:

$\beta_{cv} =$
- 1 Oroskar and Turian (1980) maximum of semi-theoretical and empirical equation
- 1.1 Oroskar and Turian (1980) semi-theoretical equation
- 1.2 Oroskar and Turian (1980) empirical equation
- 2 Wasp et al. (1977)
- 3 Zandi and Govatos (1967)
- 4 Shook (1969)
- 5 Gogus and Kokpinar (1999)
- 6 Robinson and Graf (1972)

κ_{cv} is the uncertainty factor on the critical, set to 1 to obtain the "best-estimate" prediction. Recommend at least 1.3 for upper bound estimate to account for uncertainties in the empirical correlation and to include sufficient margin above the critical velocity for minimum operating flow rate.

Figures F-6 through F-10 show the sensitivity of the slurry parameters on the Oroskar and Turian (1980) empirical equation for the critical velocity best-estimate predication. The other correlations are compared to the Oroskar and Turian (1980) semi-theoretical and empirical equations in Figure F-16 along with the Turian, Hsu, and Ma (1987) regime transition correlation discussed in Section 6.1.2.2 below.

6.1.2 Friction Factors

In addition to pipe roughness, the friction factor for pipe flow is affected by the physical properties of the carrier liquid and the particles in suspension.

6.1.2.1 Friction Factor for Pipe Flow Due to Carrier Liquid

Slurry volume entirely liquid, $\alpha_d = 0$.

Colebrook-White correlation for the Darcy or Moody friction factor (f) in the turbulent regime is given by

$$\frac{1}{\sqrt{f}} = -2\cdot\log\left(\frac{\eta}{3.7} + \frac{2.51}{Re\cdot\sqrt{f}}\right)$$ strictly valid for $4\cdot 10^3 \le Re \le 10^8$ where $f = \frac{h_L}{\frac{L}{D}\cdot\frac{v^2}{2\cdot g}} = \frac{\Delta p}{\left(\frac{L}{D}\cdot\frac{\rho\cdot v^2}{2}\right)}$ $\eta = \frac{\varepsilon}{D_{pipe}}$ ε roughness of pipe

This relation is implicit in the friction factor but Olujic (1981) obtained the following explicit approximation

$$f_t(Re,\eta) := \left[-2\cdot\log\left[\frac{\eta}{3.7} - \frac{5.02}{Re}\cdot\log\left[\frac{\eta}{3.7} + \left(\frac{14.5}{Re}\right)\right]\right]\right]^{-2}$$ turbulent regime, Re >4000 **(F-35)**

For the laminar regime, Re < 2100

$$f_l(Re) := \frac{64}{Re}$$ (independent of roughness) **(F-36)**

Olujic (1981) also reports the following approximation developed by Churchill in 1977 that includes the laminar and turbulent regimes as well as the transition regime between laminar and turbulent flow

$$f_c(Re,\eta) := \begin{array}{|l} A \leftarrow \left[2.457\cdot\ln\left[\frac{1}{\left(\frac{7}{Re}\right)^{0.9} + (0.27\cdot\eta)}\right]\right]^{16} \\ B \leftarrow \left(\frac{37530}{Re}\right)^{16} \\ 8\cdot\left[\left(\frac{8}{Re}\right)^{12} + \left(\frac{1}{A+B}\right)^{\frac{3}{2}}\right]^{\frac{1}{12}} \end{array}$$ **(F-37)**

(Note that the transition regime is not well defined in practice but is approximated with a "smooth" transition curve for numerical convenience only. This approximation slightly over shoots the Colebrook-White friction factor correlation at the start of the turbulent regime.)

or $f_c(D_{pipe}, v_c, \rho_c, \mu_c, \varepsilon) := f_c\left(Re(D_{pipe}, v_c, \rho_c, \mu_c), \frac{\varepsilon}{D_{pipe}}\right)$

where v_c flow velocity of carrier liquid

Figure 11 shows the resulting Darcy friction factor for pipe flow of Newtonian carrier fluid as a function of Reynolds Number and relative roughness ($\eta = \varepsilon / D_{pipe}$).

6.1.2.2 Friction Factor for Pipe Flow Due to Particles

A refined correlation of the particle contribution to the friction factor was given by Turian and Yuan (1977) and Turian, Hsu, and Ma (1987) as a function of flow regime based on the Fanning friction factor definition. The Darcy friction factor is equal to 4 times the Fanning friction factor. The corresponding results in terms of the Darcy friction factor definition become

Turian, Hsu, and Ma (1987) / Turian and Yuan (1977)

$s =$	$K_s :=$	$\alpha_s :=$	$\beta_s :=$	$\gamma_s :=$	$\delta_s :=$		$K'_s :=$
0	12.127	0.7389	0.7717	-0.4054	-1.096	flow regime 0 (stationary bed)	0.4036
1	107.09	1.018	1.046	-0.4213	-1.354	flow regime 1 (saltation)	0.9857
2	30.115	0.8687	1.2	-0.1677	-0.6938	flow regime 2 (heterogeneous)	0.5513
3	8.538	0.5024	1.428	0.1516	-0.3531	flow regime 3 (homogeneous)	0.8444

$$f_{dm}(D_{pipe}, v, \rho_c, \mu_c, \varepsilon, D_d, \rho_d, \alpha_d, m, \beta_f) := 4 \cdot \frac{\text{if}(\beta_f = 1, K_m, K'_m) \cdot \alpha_d^{\alpha_m} \cdot \left(\frac{f_c(D_{pipe}, v, \rho_c, \mu_c, \varepsilon)}{4} \right)^{\beta_m}}{C_D(D_d, v_\infty(D_d, \rho_d, \rho_c, \mu_c), \rho_c, \mu_c)^{-\gamma_m}} \cdot \left[\frac{v^2}{g \cdot D_{pipe} \cdot \left(\frac{\rho_d}{\rho_c} - 1 \right)} \right]^{\delta_m} \quad \text{(F-38)}$$

$$K_t(a,b) := \left(\frac{K_b}{K_a} \right)^{\frac{1}{\delta_a - \delta_b}} \qquad \alpha_t(a,b) := \frac{\alpha_b - \alpha_a}{\delta_a - \delta_b} \qquad \beta_t(a,b) := \frac{\beta_b - \beta_a}{\delta_a - \delta_b} \qquad \gamma_t(a,b) := \frac{\gamma_b - \gamma_a}{\delta_a - \delta_b} \qquad K'_t(a,b) := \left(\frac{K'_b}{K'_a} \right)^{\frac{1}{\delta_a - \delta_b}}$$

$K_t(0,1) = 4641.4$	$\alpha_t(0,1) = 1.0818$	$\beta_t(0,1) = 1.0632$	$\gamma_t(0,1) = -0.0616$	$K'_t(0,1) = 31.8$
$K_t(1,2) = 6.8319$	$\alpha_t(1,2) = 0.2261$	$\beta_t(1,2) = -0.2333$	$\gamma_t(1,2) = -0.3841$	$K'_t(1,2) = 2.4113$
$K_t(2,3) = 40.4362$	$\alpha_t(2,3) = 1.0751$	$\beta_t(2,3) = -0.6692$	$\gamma_t(2,3) = -0.9372$	$K'_t(2,3) = 0.2861$
$K_t(1,3) = 12.5143$	$\alpha_t(1,3) = 0.5151$	$\beta_t(1,3) = -0.3817$	$\gamma_t(1,3) = -0.5724$	$K'_t(1,3) = 1.1672$
$K_t(0,2) = 0.1042$	$\alpha_t(0,2) = -0.3227$	$\beta_t(0,2) = -1.0649$	$\gamma_t(0,2) = -0.591$	$K'_t(0,2) = 0.4605$
$K_t(0,3) = 1.6038$	$\alpha_t(0,3) = 0.3183$	$\beta_t(0,3) = -0.8834$	$\gamma_t(0,3) = -0.7498$	$K'_t(0,3) = 0.3702$

Flow regime numbers for selecting appropriate flow regime is given by

$$R_{ab}(D_{pipe}, v, \rho_c, \mu_c, \varepsilon, D_d, \rho_d, \alpha_d, a, b, \beta_f) := \frac{C_D(D_d, v_\infty(D_d, \rho_d, \rho_c, \mu_c), \rho_c, \mu_c)^{-\gamma_t(a,b)}}{\text{if}(\beta_f = 1, K_t(a,b), K'_t(a,b)) \cdot \alpha_d^{\alpha_t(a,b)} \cdot \left(\frac{f_c(D_{pipe}, v, \rho_c, \mu_c, \varepsilon)}{4} \right)^{\beta_t(a,b)}} \cdot \frac{v^2}{g \cdot D_{pipe} \cdot \left(\frac{\rho_d}{\rho_c} - 1 \right)} \quad \text{(F-39)}$$

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Location: 200 Area - Hanford Site, Richland, Washington

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The flow regime number retrieval function is given by

$$R_d(D_{pipe},v,\rho_c,\mu_c,\varepsilon,D_d,\rho_d,\alpha_d,\beta_f) := \left| \begin{array}{l} r_{01} \leftarrow R_{ab}(D_{pipe},v,\rho_c,\mu_c,\varepsilon,D_d,\rho_d,\alpha_d,0,1,\beta_f) - 1 \\ r_{12} \leftarrow R_{ab}(D_{pipe},v,\rho_c,\mu_c,\varepsilon,D_d,\rho_d,\alpha_d,1,2,\beta_f) - 1 \\ r_{23} \leftarrow R_{ab}(D_{pipe},v,\rho_c,\mu_c,\varepsilon,D_d,\rho_d,\alpha_d,2,3,\beta_f) - 1 \\ r_{02} \leftarrow R_{ab}(D_{pipe},v,\rho_c,\mu_c,\varepsilon,D_d,\rho_d,\alpha_d,0,2,\beta_f) - 1 \\ r_{03} \leftarrow R_{ab}(D_{pipe},v,\rho_c,\mu_c,\varepsilon,D_d,\rho_d,\alpha_d,0,3,\beta_f) - 1 \\ r_{13} \leftarrow R_{ab}(D_{pipe},v,\rho_c,\mu_c,\varepsilon,D_d,\rho_d,\alpha_d,1,3,\beta_f) - 1 \\ 0 \text{ if } (r_{01} < 0)\cdot(r_{12} < 0)\cdot(r_{23} < 0) \\ 1 \text{ if } (r_{01} > 0)\cdot(r_{12} < 0)\cdot(r_{23} < 0) \\ 2 \text{ if } (r_{01} > 0)\cdot(r_{12} > 0)\cdot(r_{23} < 0) \\ 3 \text{ if } (r_{01} > 0)\cdot(r_{12} > 0)\cdot(r_{23} > 0) \\ \text{if } (r_{01} < 0)\cdot(r_{12} < 0)\cdot(r_{23} > 0) \\ \quad \left| \begin{array}{l} 0 \text{ if } r_{03} < 0 \\ 3 \text{ otherwise} \end{array} \right. \\ \text{if } (r_{01} < 0)\cdot(r_{12} > 0)\cdot(r_{23} > 0) \\ \quad \left| \begin{array}{l} 0 \text{ if } r_{03} < 0 \\ 3 \text{ otherwise} \end{array} \right. \\ \text{if } (r_{01} < 0)\cdot(r_{12} > 0)\cdot(r_{23} < 0) \\ \quad \left| \begin{array}{l} 0 \text{ if } r_{02} < 0 \\ 2 \text{ otherwise} \end{array} \right. \\ \text{if } (r_{01} > 0)\cdot(r_{12} < 0)\cdot(r_{23} > 0) \\ \quad \left| \begin{array}{l} 1 \text{ if } r_{13} < 0 \\ 3 \text{ otherwise} \end{array} \right. \\ -1 \text{ otherwise} \end{array} \right. \qquad \text{(F-40)}$$

The added particle contribution to the friction factor based on flow regime is then given by

$$f_{dTurian}(D_{pipe},v,\rho_c,\mu_c,\varepsilon,D_d,\rho_d,\alpha_d,\kappa_f,\beta_f) := \kappa_f \cdot f_{dm}(D_{pipe},v,\rho_c,\mu_c,\varepsilon,D_d,\rho_d,\alpha_d,R_d(D_{pipe},v,\rho_c,\mu_c,\varepsilon,D_d,\rho_d,\alpha_d,\beta_f),\beta_f) \qquad \text{(F-41)}$$

Critical velocity based on flow regime transition identification is given by

$$v_{cRabv}(D_{pipe}, D_d, \rho_d, \alpha_d, \rho_c, \mu_c, \varepsilon, a, b, v, \beta_f) := \left[\frac{\text{if}(\beta_f = 1, K_t(a,b), K'_t(a,b)) \cdot \alpha_d^{\alpha_t(a,b)} \cdot \left(\frac{f_c(D_{pipe}, v, \rho_c, \mu_c, \varepsilon)}{4}\right)^{\beta_t(a,b)} \cdot g \cdot D_{pipe} \cdot \left(\frac{\rho_d}{\rho_c} - 1\right)}{C_D(D_d, v_\infty(D_d, \rho_d, \rho_c, \mu_c), \rho_c, \mu_c)^{-\gamma_t(a,b)}}\right]^{\frac{1}{2}}$$

$$v_{cRab}(D_{pipe}, D_d, \rho_d, \alpha_d, \rho_c, \mu_c, \varepsilon, a, b, \beta_f) := \text{root}(v' - v_{cRabv}(D_{pipe}, D_d, \rho_d, \alpha_d, \rho_c, \mu_c, \varepsilon, a, b, v', \beta_f), v') \quad \textbf{(F-42)}$$

$$v_{crR}(D_{pipe}, D_d, \rho_d, \alpha_d, \rho_c, \mu_c, \varepsilon, \kappa_{cv}, \beta_f) := \kappa_{cv} \cdot \frac{m}{sec} \cdot \left| \begin{array}{l} v_{01} \leftarrow v_{cRab}(D_{pipe}, D_d, \rho_d, \alpha_d, \rho_c, \mu_c, \varepsilon, 0, 1, \beta_f) \\ v_{02} \leftarrow v_{cRab}(D_{pipe}, D_d, \rho_d, \alpha_d, \rho_c, \mu_c, \varepsilon, 0, 2, \beta_f) \\ v_{03} \leftarrow v_{cRab}(D_{pipe}, D_d, \rho_d, \alpha_d, \rho_c, \mu_c, \varepsilon, 0, 3, \beta_f) \\ R_{02\_01} \leftarrow R_{ab}(D_{pipe}, v_{01}, \rho_c, \mu_c, \varepsilon, D_d, \rho_d, \alpha_d, 0, 2, \beta_f) \\ R_{03\_01} \leftarrow R_{ab}(D_{pipe}, v_{01}, \rho_c, \mu_c, \varepsilon, D_d, \rho_d, \alpha_d, 0, 3, \beta_f) \\ R_{01\_02} \leftarrow R_{ab}(D_{pipe}, v_{02}, \rho_c, \mu_c, \varepsilon, D_d, \rho_d, \alpha_d, 0, 1, \beta_f) \\ R_{03\_02} \leftarrow R_{ab}(D_{pipe}, v_{02}, \rho_c, \mu_c, \varepsilon, D_d, \rho_d, \alpha_d, 0, 3, \beta_f) \\ R_{01\_03} \leftarrow R_{ab}(D_{pipe}, v_{03}, \rho_c, \mu_c, \varepsilon, D_d, \rho_d, \alpha_d, 0, 1, \beta_f) \\ R_{02\_03} \leftarrow R_{ab}(D_{pipe}, v_{03}, \rho_c, \mu_c, \varepsilon, D_d, \rho_d, \alpha_d, 0, 2, \beta_f) \\ v_{01} \text{ if } (R_{02\_01} \le 1) \cdot (R_{03\_01} \le 1) \\ v_{02} \text{ if } (R_{01\_02} \le 1) \cdot (R_{03\_02} \le 1) \\ v_{03} \text{ if } (R_{01\_03} \le 1) \cdot (R_{02\_03} \le 1) \\ -1 \text{ otherwise} \end{array} \right. \quad \textbf{(F-43)}$$

The following relation is used to plot flow regime (v-D_d) diagrams as shown in Figures 12 through 14.

$$D_{dab}(D_{pipe}, v, \rho_c, \mu_c, \varepsilon, \rho_d, \alpha_d, a, b, \beta_f) := -1 \cdot \mu m \text{ on error root}(R_{ab}(D_{pipe}, v, \rho_c, \mu_c, \varepsilon, D'_d, \rho_d, \alpha_d, a, b, \beta_f) - 1, D'_d) \quad \textbf{(F-44)}$$

Turian and Oroskar's (1978) Figure 1 flow regime diagrams for pipe inside diameters 1.58 and 5.25 cm (1/2 and 2 in.) based on Turian, Hsu, and Ma 1987 corrected equations are given in Figures 12 and 13 as a check and also demonstrate the effect of pipe size on the flow regime locations. A smooth pipe with water at 22.5 °C for the carrier liquid is assumed with a 5% solids concentration by volume with a 2.977 gm/cm³ particle solids density. The flow regime diagrams for the 1.58 and 5.25 cm inside pipe diameters are shown in Figures 12 and 13, respectively. Flow regime diagrams for the 3-inch diameter pipeline of interest are shown in Figure 14 for the conditions indicated.

Figure 15 compares the best-estimate critical velocity predictions from Robinson and Graf (1972), Wasp et al. (1977), Oroskar and Turian (1980) semi-theoretical and empirical equations, and the critical velocity derived from the regime transition boundaries defined in Turian and Yuan (1977) for a smooth pipe with corrected relations given in Turian, Hsu, and Ma (1987).

Note that the critical velocity correlations compared in Figure 15 were obtained for narrow band distributions of median diameter solid particles greater than 100 μm. Hence, the results shown in Figure 15 for solid particles less than 100 μm requires extrapolation and should be used with caution. In addition, it must be recognized that the critical velocity data is based on subjective observations and hence introduce uncertainty in the data upon which the correlations were developed. These correlations were developed for solid particles with a narrow distributions. The effect of solid particles with a wide distribution needs to be addressed.

For fine particles (diameter mush less than 100 μm) the two-phase approach to determining pressure loss and minimum settling (critical) velocity begins to break down. In this case the liquid-solid flow approaches a homogeneous type behavior in which the fine particle remain suspended but the mixture may exhibit non-Newtonian shear characteristics.

The following additional friction factor correlations ($f - f_c = f_d$) based on large particles are provided for comparison:

Durand (1953) friction factor correlation per equation 11.84a as reported in Grovier and Aziz 1972

$$f_{dDurand}(D_{pipe}, v, \rho_c, \mu_c, \varepsilon, D_d, \rho_d, \alpha_d, \kappa_f, K_D) := \kappa_f \cdot K_D \cdot \alpha_d \cdot f_c(D_{pipe}, v, \rho_c, \mu_c, \varepsilon) \cdot \left[\frac{v^2 \cdot \sqrt{C_D(D_d, v_\infty(D_d, \rho_d, \rho_c, \mu_c), \rho_c, \mu_c)}}{g \cdot D_{pipe} \cdot \left(\frac{\rho_d}{\rho_c} - 1 \right)} \right]^{\frac{-3}{2}} \quad \textbf{(F-45)}$$

Note that Grovier and Aziz (1972) indicate that the abscissa of Figure 10 in the paper by Durand (1953) appears to be mislabeled, and others appear to have erroneously determined from it the value of the constant (K_D) as either 81, 82, or 84.9 rather than 150.

Zandi and Govatos (1967) friction factor correlation per equation 11.85 of Grovier and Aziz 1972

(valid for $N_I = \psi / \alpha_d > 40$)

$$f_{dZandi}(D_{pipe}, v, \rho_c, \mu_c, \varepsilon, D_d, \rho_d, \alpha_d, \kappa_f) := \kappa_f \cdot \alpha_d \cdot f_c(D_{pipe}, v, \rho_c, \mu_c, \varepsilon) \cdot \left| \begin{array}{l} \psi \leftarrow \dfrac{v^2 \cdot \sqrt{C_D(D_d, v_\infty(D_d, \rho_d, \rho_c, \mu_c), \rho_c, \mu_c)}}{g \cdot D_{pipe} \cdot \left(\dfrac{\rho_d}{\rho_c} - 1 \right)} \\ 280 \cdot \psi^{-1.93} \text{ if } \psi < 10 \\ 6.30 \cdot \psi^{-0.354} \text{ otherwise} \end{array} \right. \quad \textbf{(F-46)}$$

Heywood (1999) refers to a "recent" reassessment of all available data covering both heterogeneous and moving-bed flow patterns which suggested the following correlation:

$$f_{dHeywood}(D_{pipe}, v, \rho_c, \mu_c, \varepsilon, D_d, \rho_d, \alpha_d, \kappa_f) := \kappa_f \cdot 55.6 \cdot f_c(D_{pipe}, v, \rho_c, \mu_c, \varepsilon) \cdot \left[\frac{v^2 \cdot \sqrt{C_D(D_d, v_\infty(D_d, \rho_d, \rho_c, \mu_c), \rho_c, \mu_c)}}{\alpha_d \cdot g \cdot D_{pipe} \cdot \left(\frac{\rho_d}{\rho_c} - 1 \right)} \right]^{-1.08} \quad \textbf{(F-47)}$$

The above Durand (1953) and Zandi and Govatos (1967) Darcy friction factor correlations for two-phase liquid-solid particle type pipe flow are compared in Figure 16 to the Turian and Yuan (1977) correlation with the Turian, Hsu, and Ma (1987) correction. The correlations give similar results but the Turian correlation was selected for application because of its purported overall better performance over the full range of flow velocities over each flow regime. However, it is clear that there is a large uncertainty band for any of these correlations.

The combined friction factor for pipe with positive incline to horizontal of θ (deg) per Blevins (1984) is given by

$$f_d(D_{pipe},v,\rho_c,\mu_c,\varepsilon,D_d,\rho_d,\alpha_d,\beta_f,\kappa_f,\theta) := \begin{cases} f_{dTurian}(D_{pipe},v,\rho_c,\mu_c,\varepsilon,D_d,\rho_d,\alpha_d,\kappa_f,\beta_f)\cdot\cos(\theta) & \text{if } (\beta_f = 1) + (\beta_f = 2) \\ f_{dZandi}(D_{pipe},v,\rho_c,\mu_c,\varepsilon,D_d,\rho_d,\alpha_d,\kappa_f)\cdot\cos(\theta) & \text{if } \beta_f = 3 \\ f_{dHeywood}(D_{pipe},v,\rho_c,\mu_c,\varepsilon,D_d,\rho_d,\alpha_d,\kappa_f)\cdot\cos(\theta) & \text{if } \beta_f = 4 \\ f_{dDurand}(D_{pipe},v,\rho_c,\mu_c,\varepsilon,D_d,\rho_d,\alpha_d,\kappa_f,\beta_f)\cdot\cos(\theta) & \text{otherwise} \end{cases} \qquad \textbf{(F-48a)}$$

$$f(D_{pipe},v,\rho_c,\mu_c,\varepsilon,D_d,\rho_d,\alpha_d,\beta_f,\kappa_f,\theta) := \begin{array}{|l} f \leftarrow f_c(D_{pipe},v,\rho_c,\mu_c,\varepsilon) \\ f \ \text{ if } (\beta_f = 0) + (\alpha_d = 0) \\ f + f_d(D_{pipe},v,\rho_c,\mu_c,\varepsilon,D_d,\rho_d,\alpha_d,\beta_f,\kappa_f,\theta) \ \text{ otherwise} \end{array} \qquad \textbf{(F-48b)}$$

The friction factor correlation selection key is given by

β_f =
- 0 liquid only, no solid particles, $\alpha_d = 0$
- 1 Turian, Hsu, and Ma (1987)
- 2 Turian and Yuan (1977)
- 3 Zandi and Govatos (1967)
- 4 Heywood (1999)
- 82
- 150 = K_D Durand (1953)

κ_f is the uncertainty factor on the friction factor due to solid particles, set to 1 to obtain the "best-estimate" prediction. Recommend at least 1.25 for upper bound estimate to account for uncertainties in the correlations.

Figure 17 compares the best-estimate predications of the total friction factor for pipe slurry flow based on Turian, Hsu, and Ma (1987), Durand (1953), Zandi and Govatos (1967), and Heywood (1999) as a function of the flow velocity and pipe roughness estimates of interest. The friction factor (f_c) for the liquid only is also shown for comparison. At velocities below the critical velocity, the friction factor of Turian, Hsu, and Ma (1987) or Heywood (1999) are expected to be more reliable because the data was more systematically evaluated in this regime.

Note that application of the above predicted friction factors for slurry flows with median solid particle diameters less than 100 μm requires extrapolation beyond the database used in the development of the correlations and hence should be used with caution.

6.1.3 Pressure Drop

Head loss for pipe with positive incline to horizontal of θ (deg) per Blevins (1984) is given by

$$\Delta h_L(D_{pipe}, v, \rho_c, \mu_c, \varepsilon, D_d, \rho_d, \alpha_d, L, \beta_f, \kappa_f, \theta) := \frac{L}{D_{pipe}} \cdot \frac{v^2}{2 \cdot g} \cdot f(D_{pipe}, v, \rho_c, \mu_c, \varepsilon, D_d, \rho_d, \alpha_d, \beta_f, \kappa_f, \theta) \ldots + \left[\left(\frac{\rho_d}{\rho_c} - 1\right) \cdot \alpha_d + 1\right] \cdot L \cdot \sin(\theta) \qquad \text{(F-49)}$$

The corresponding pressure loss is given by

$$\Delta p(D_{pipe}, v, \rho_c, \mu_c, \varepsilon, D_d, \rho_d, \alpha_d, L, \beta_f, \kappa_f, \theta) := \Delta h_L(D_{pipe}, v, \rho_c, \mu_c, \varepsilon, D_d, \rho_d, \alpha_d, L, \beta_f, \kappa_f, \theta) \cdot \rho_c \cdot g \qquad \text{(F-50)}$$

Hence, the total pressure loss for a combined carbon (CS) and stainless steel (SS) pipeline is given by

$$\Delta p_T(D_{pipe}, v, \rho_c, \mu_c, \varepsilon_{CS}, \varepsilon_{SS}, D_d, \rho_d, \alpha_d, L_{CS}, L_{SS}, \beta_f, \kappa_f, \theta) := \Delta p(D_{pipe}, v, \rho_c, \mu_c, \varepsilon_{CS}, D_d, \rho_d, \alpha_d, L_{CS}, \beta_f, \kappa_f, \theta) \ldots + \Delta p(D_{pipe}, v, \rho_c, \mu_c, \varepsilon_{SS}, D_d, \rho_d, \alpha_d, L_{SS}, \beta_f, \kappa_f, \theta) \qquad \text{(F-51)}$$

where

L Length of pipe

The flow area and flow rate are given by

$D_{pipe} := 3.068 \cdot in$

$A(D_{pipe}) := \pi \cdot \frac{D_{pipe}^2}{4}$ flow area of pipe $A(D_{pipe}) = 7.393\,in^2$ **(F-52)**

$Q(v_c, D_{pipe}) := v_c \cdot A(D_{pipe})$ pipe flow rate

The following sample pressure drop calculation is provided for comparison of the results from the various pressure drop correlations:

Sample Pressure Drop Calculation - AN-107-to-BNFL Transfer Route

$D_{pipe} := 3.068 \cdot in$ $\quad v := 6 \cdot \dfrac{ft}{sec}$ $\quad \rho_c := 1.2 \cdot \dfrac{kg}{liter}$ $\quad \kappa_f := 1$ $\quad \varepsilon_{CS} := \varepsilon_{new}$ $\quad \varepsilon_{SS} := \varepsilon_{new}$ $\quad D_d := 400 \cdot \mu m$

$\beta_{cv} := 1.2$ $\quad \kappa_{cv} := 1$ $\quad \rho_d := 3 \cdot \dfrac{kg}{liter}$ $\quad \alpha_d := 15\%$ $\quad L_{CS} := 557 \cdot ft$ $\quad L_{SS} := 7028 \cdot ft$ $\quad H := 40 \cdot ft$

$T := 60 \quad {}^{o}C$ $\quad \mu_c := \mu_{cL}(\rho_c, T)$ $\quad \mu_c = 0.771\, cP$ $\quad \theta := \mathrm{atan}\left(\dfrac{H}{L_{CS} + L_{SS}}\right)$

$v_{cr}(D_{pipe}, D_d, \rho_d, \alpha_d, \rho_c, \mu_c, \kappa_{cv}, \beta_{cv}) = 5.482 \dfrac{ft}{sec}$ critical velocity

Total pressure drop

$\Delta p_T(D_{pipe}, v, \rho_c, \mu_c, \varepsilon_{CS}, \varepsilon_{SS}, D_d, \rho_d, \alpha_d, L_{CS}, L_{SS}, 0, \kappa_f, \theta) = 194 \dfrac{lbf}{in^2}$ liquid only, no solid particles

$\Delta p_T(D_{pipe}, v, \rho_c, \mu_c, \varepsilon_{CS}, \varepsilon_{SS}, D_d, \rho_d, \alpha_d, L_{CS}, L_{SS}, 1, \kappa_f, \theta) = 574 \dfrac{lbf}{in^2}$ Turian, Hsu, and Ma (1987)

$\Delta p_T(D_{pipe}, v, \rho_c, \mu_c, \varepsilon_{CS}, \varepsilon_{SS}, D_d, \rho_d, \alpha_d, L_{CS}, L_{SS}, 2, \kappa_f, \theta) = 198 \dfrac{lbf}{in^2}$ Turian and Yuan (1977)

$\Delta p_T(D_{pipe}, v, \rho_c, \mu_c, \varepsilon_{CS}, \varepsilon_{SS}, D_d, \rho_d, \alpha_d, L_{CS}, L_{SS}, 3, \kappa_f, \theta) = 717 \dfrac{lbf}{in^2}$ Zandi and Govatos (1967)

$\Delta p_T(D_{pipe}, v, \rho_c, \mu_c, \varepsilon_{CS}, \varepsilon_{SS}, D_d, \rho_d, \alpha_d, L_{CS}, L_{SS}, 4, \kappa_f, \theta) = 475 \dfrac{lbf}{in^2}$ Heywood (1999)

$\Delta p_T(D_{pipe}, v, \rho_c, \mu_c, \varepsilon_{CS}, \varepsilon_{SS}, D_d, \rho_d, \alpha_d, L_{CS}, L_{SS}, 82, \kappa_f, \theta) = 468 \dfrac{lbf}{in^2}$ $K_D = 82$, Durand (1953)

$\Delta p_T(D_{pipe}, v, \rho_c, \mu_c, \varepsilon_{CS}, \varepsilon_{SS}, D_d, \rho_d, \alpha_d, L_{CS}, L_{SS}, 150, \kappa_f, \theta) = 694 \dfrac{lbf}{in^2}$ $K_D = 150$, Durand (1953)

Note that there is a wide variation in results between the various correlations.

For slurry flow in a 3-inch pipe, Figures 18 through 20 show best-estimate pressure drop contour plots per 1,000 ft of pipe, corresponding flow regime contour plots, and critical velocity contour plots for the range of carrier liquid density and particle density of interest for the Hanford waste. The pressure drop results are based on the Turian, Hsu, and Ma (1987) friction factor correlation and the critical velocity results are based on the Oroskar and Turian (1980) empirical correlation. The pressure drop results are shown at a flow velocity of 5 ft/s for end-of-life (EOF) pipe roughness estimates for carbon and stainless steel as given above. The solid particle size, solid fraction by volume, and temperature of the flow are indicated in the figures. These figures provide an upper bound estimate to the friction pressure loss, particularly for solid particle diameters less than 100 μm. For slurry flows with broad solid particle distributions the method of Wasp et al. (1977) which accounts for the effect of the "fine" and large particles is expected to provide more realistic predictions.

6.2 COMBINED HOMOGENEOUS-HETEROGENEOUS SLURRY FLOW - WASP METHOD

Wasp (1977) developed a method to estimate the pipe pressure loss for a combined homogeneous-heterogeneous flow with multiple particle sizes based on the concept of a "two-phase vehicle." Fine particles join with the carrier liquid to form a homogeneous "vehicle" while the course particles are suspended as a heterogeneous "bed" within this homogeneous vehicle. The fine particles in the vehicle modify the effective liquid density and rheology of the liquid. High concentrations (approaching 30% by volume) of "fine" particles (particle size diameters less than 100 µm) can result in non-Newtonian viscosity characteristics. In the application herein the viscosity of the vehicle is assumed to remain Newtonian and increase with increasing fine particle concentration in accordance with the Thomas correlation

$$\mu_c(\mu_L, \Phi_v) := \mu_L \cdot \left(1 + 2.5 \cdot \Phi_v + 10.05 \cdot \Phi_v^{\ 2} + 0.00273 \cdot \exp(16.6 \cdot \Phi_v)\right)$$

Thomas correlation (Wasp et al. 1977) **(F-53)**

and the effective density of the vehicle is given by

$$\rho_c(\rho_s, \rho_L, \Phi_v) := \rho_s \cdot \Phi_v + \rho_L \cdot (1 - \Phi_v) \qquad \textbf{(F-54)}$$

where Φ_v is the concentration of fine particles joining with the carrier fluid.

Although other viscosity correlations are available, they require additional empirical parameters. Hence, the Thomas correlation was selected as a first approximation due to the lack of data applicable to the Hanford waste. The above relations are shown in Figure F-21 for the selected conditions indicated.

The Wasp method requires a particle size distribution. The assumed particle size distribution for the solid particles is based on the measured particle size distribution by volume for Tank 241-SY-101 (O'Rourke 1999). The measured distribution was curve fit to a Rosin-Rammler distribution function (Shook and Roco 1991) and then shifted to obtain a distribution with the target median particle size of interest.

6.2.1 Preliminaries

$TOL = 1 \times 10^{-5}$

$\Delta\varepsilon := TOL \cdot 10^{-1} \quad \Delta\varepsilon = 1 \times 10^{-6}$

Return cumulative vector ϕ_{cum} for frequency distribution vector ϕ

```
cum(φ) := | for j ∈ 0..length(φ) − 1
          |     φcum_j ← Σ_{i=0}^{j} φ_i
          | φcum
```
(F-55)

Return values of vector ϕ_p in accordance with nonzero values in vector $\phi_z > \Delta\varepsilon$

```
pack(φp, φz) := | J ← length(φz) − 1
                | k ← 0
                | for j ∈ 0..J
                |   if φz_j > Δε
                |     | φ_k ← φp_j
                |     | k ← k + 1
                | if k = 0
                |   | φ_0 ← Δε
                |   | φ_1 ← Δε
                | φ
```
(F-56)

Return class size intervals of density distribution data

$$\Delta(d_p) := \begin{array}{|l} J \leftarrow \text{length}(d_p) - 1 \\ \Delta d_0 \leftarrow \dfrac{d_{p_1} - d_{p_0}}{2} \\ \text{for } j \in 1..J-1 \\ \quad \Delta d_j \leftarrow \dfrac{d_{p_{j+1}} - d_{p_{j-1}}}{2} \\ \Delta d_J \leftarrow \dfrac{d_{p_J} - d_{p_{J-1}}}{2} \\ \Delta d \end{array} \qquad \textbf{(F-57)}$$

Return d_β particle diameter that is βth percentile value by volumes

$$D_\beta(d_p, \phi_{cum}, \beta) := \begin{array}{|l} J \leftarrow \text{length}(\phi_{cum}) - 1 \\ \text{for } k \in 0..J \\ \quad \text{break if } \phi_{cum_k} > \beta \\ \dfrac{d_{p_k} - d_{p_{k-1}}}{\phi_{cum_k} - \phi_{cum_{k-1}}} \cdot (\beta - \phi_{cum_{k-1}}) + d_{p_{k-1}} \end{array} \qquad \textbf{(F-58)}$$

The following cumulative and probability density function from Table 1-1 Shook and Roco (1991) were considered for curve fits of the SY-101 particle size distribution.

Cumulative distribution function

Probability density function

Rosin-Rammler

$$CDF_{RR}(d, d_{50}, p) := \left[1 - \exp\left[-\ln(2) \cdot \left(\frac{d}{d_{50}}\right)^p\right]\right]$$

$$PDF_{RR}(d, d_{50}, p) := \ln(2) \cdot \left(\frac{d}{d_{50}}\right)^p \cdot \frac{p}{d} \cdot \exp\left[-\ln(2) \cdot \left(\frac{d}{d_{50}}\right)^p\right] \qquad \textbf{(F-59)}$$

Partial derivative of Rosin-Rammler CDF with respect to parameter p

$$CDF_{RR'p}(d, d_{50}, p) := \ln(2) \cdot \left(\frac{d}{d_{50}}\right)^p \cdot \ln\left(\frac{d}{d_{50}}\right) \cdot \exp\left[-\ln(2) \cdot \left(\frac{d}{d_{50}}\right)^p\right]$$

Log normal

$$CDF_{LN}(d, d_{50}, p) := \frac{1}{\sqrt{2 \cdot \pi}} \cdot \int_{-\infty}^{\frac{\ln\left(\frac{d}{d_{50}}\right)}{\ln(p)}} \exp\left(\frac{-t^2}{2}\right) dt$$

$$PDF_{LN}(d, d_{50}, p) := \frac{1}{\sqrt{2 \cdot \pi}} \cdot \exp\left[\frac{-1}{2} \cdot \frac{\left(\ln\left(\frac{d}{d_{50}}\right)\right)^2}{\ln(p)^2}\right] \cdot \frac{1}{d \cdot \ln(p)} \qquad \textbf{(F-60)}$$

Partial derivative of Log-normal CDF
with respect to parameter p

$$CDF_{LN'p}(d, d_{50}, p) := \frac{-1}{\sqrt{2\cdot\pi}}\cdot\exp\left[\frac{-1}{2}\cdot\frac{\left(\ln\left(\frac{d}{d_{50}}\right)\right)^2}{\ln(p)^2}\right]\cdot\frac{\ln\left(\frac{d}{d_{50}}\right)}{\ln(p)^2\cdot p}$$

6.2.2 Wasp's Method for Pressure Drop Estimate

In accordance with Wasp et al. 1977, assume $\beta := 1$ $\kappa := 0.4$ von Karman constant

$$\phi_v(v, \rho_L, \rho_c, \mu_c, d_p, \rho_s, \phi_s, f) := \phi_s\cdot 10^{\frac{-1.8}{\beta\cdot\kappa}\cdot\frac{v_\infty(d_p, \rho_s, \rho_c, \mu_c)}{v\cdot\sqrt{\frac{f\cdot\frac{\rho_L}{\rho_c}}{8}}}} \quad \text{(F-61)}$$

Return total concentration of solid particle attributed to "vehicle" liquid from each particle of particle size distribution using vehicle properties

$$\Phi_c(v, \rho_L, \mu_L, d_p, \rho_s, \phi_s, f) := \left| \begin{array}{l} J \leftarrow \text{length}(d_p) - 1 \\ \Phi'_v \leftarrow 0.5\cdot\sum_{j=0}^{J} \phi_{s_j} \qquad \text{initial guess} \\ \text{root}\left(\Phi'_v - \sum_{j=0}^{J} \phi_v\left(v, \rho_L, \rho_c(\rho_s, \rho_L, \Phi'_v), \mu_c(\mu_L, \Phi'_v), d_{p_j}, \rho_s, \phi_{s_j}, f\right), \Phi'_v\right) \end{array}\right. \quad \text{(F-62)}$$

Darcy friction factor and pressure loss based on Wasp method using Durand friction factor correlation (see Equation F-45) with

$K_D := 82$

$$f_{Wasp\_f}(D_{pipe}, v, \rho_L, \mu_L, \varepsilon, d_p, \rho_s, \phi_s, \theta, f) := \begin{array}{|l} J \leftarrow \text{length}(d_p) - 1 \\ \Phi_v \leftarrow \Phi_c(v, \rho_L, \mu_L, d_p, \rho_s, \phi_s, f) \\ \rho_v \leftarrow \rho_c(\rho_s, \rho_L, \Phi_v) \\ \mu_v \leftarrow \mu_c(\mu_L, \Phi_v) \\ f_W \leftarrow f_c(D_{pipe}, v, \rho_v, \mu_v, \varepsilon) \cdot \dfrac{\rho_v}{\rho_L} \\ \text{for } j \in 0..J \\ \quad \begin{array}{|l} \phi_{vj} \leftarrow \phi_v(v, \rho_L, \rho_v, \mu_v, d_{p_j}, \rho_s, \phi_{s_j}, f) \\ \phi_{aj} \leftarrow \phi_{s_j} - \phi_{vj} \\ f_W \leftarrow f_W + f_d(D_{pipe}, v, \rho_L, \mu_L, \varepsilon, d_{p_j}, \rho_s, \phi_{aj}, K_D, 1, \theta) \end{array} \\ f_W \end{array} \qquad \text{(F-63a)}$$

homogeneous vehicle friction contribution normalized to clear liquid

plus friction contribution from remaining heterogeneous particles using clear liquid properties

$\Delta\Phi := TOL \cdot 10^{-1}$ $f_f := 0.025$ initial guess

$$f_{Wasp}(D_{pipe}, v, \rho_L, \mu_L, \varepsilon, d_p, \rho_s, \phi_s, \kappa_f, \theta) := \begin{array}{|l} J \leftarrow \text{length}(d_p) - 1 \\ \Phi_s \leftarrow \displaystyle\sum_{j=0}^{J} \phi_{s_j} \\ f_c(D_{pipe}, v, \rho_L, \mu_L, \varepsilon) \text{ if } \Phi_s < \Delta\Phi \\ \kappa_f \cdot \text{root}\left(f_f - f_{Wasp\_f}(D_{pipe}, v, \rho_L, \mu_L, \varepsilon, d_p, \rho_s, \phi_s, \theta, f_f), f_f\right) \text{ otherwise} \end{array} \qquad \text{(F-63b)}$$

Pressure drop

$$\Delta p_{Wasp}(D_{pipe}, v, \rho_L, \mu_L, \varepsilon, d_p, \rho_s, \phi_s, L, \kappa_f, \theta) := \begin{array}{|l} J \leftarrow \text{length}(d_p) - 1 \\ \Phi_s \leftarrow \displaystyle\sum_{j=0}^{J} \phi_{s_j} \\ \rho_L \cdot g \cdot \left[\dfrac{L}{D_{pipe}} \cdot \dfrac{v^2}{2 \cdot g} \cdot f_{Wasp}(D_{pipe}, v, \rho_L, \mu_L, \varepsilon, d_p, \rho_s, \phi_s, \kappa_f, \theta) \ldots \atop + \left[\left(\dfrac{\rho_s}{\rho_L} - 1\right) \cdot \Phi_s + 1\right] \cdot L \cdot \sin(\theta) \right] \end{array} \qquad \text{(F-64)}$$

The total pressure drop for a combined carbon (CS) and stainless steel (SS) pipeline is given by

$$\Delta p_{T\_Wasp}(D_{pipe}, v, \rho_L, \mu_L, \varepsilon_{CS}, \varepsilon_{SS}, d_p, \rho_s, \phi_s, L_{CS}, L_{SS}, \kappa_f, \theta) := \Delta p_{Wasp}(D_{pipe}, v, \rho_L, \mu_L, \varepsilon_{CS}, d_p, \rho_s, \phi_s, L_{CS}, \kappa_f, \theta) \ldots + \Delta p_{Wasp}(D_{pipe}, v, \rho_L, \mu_L, \varepsilon_{SS}, d_p, \rho_s, \phi_s, L_{SS}, \kappa_f, \theta) \quad \textbf{(F-65)}$$

6.2.3 Critical Velocity Based on Wasp "Vehicle" Concept

This procedure predicts a lower critical velocity for a given particle size distribution as the median particle size for the distribution decreases. Although this procedure appears logical, it is provided here for comparison only because it has not been validated by experimental results.

Critical Deposition Velocity

$$v_{crDvWasp}(D_{pipe}, d_p, \rho_s, \phi_s, \rho_L, \mu_L, \varepsilon, \beta_{cv}, v) := \quad \textbf{(F-66a)}$$

$$\begin{aligned}
& J \leftarrow \text{length}(d_p) - 1 \\
& f_W \leftarrow f_{Wasp}(D_{pipe}, v, \rho_L, \mu_L, \varepsilon, d_p, \rho_s, \phi_s, 1, \theta) \\
& \Phi_v \leftarrow \Phi_c(v, \rho_L, \mu_L, d_p, \rho_s, \phi_s, f_W) \\
& \rho_v \leftarrow \rho_c(\rho_s, \rho_L, \Phi_v) \\
& \mu_v \leftarrow \mu_c(\mu_L, \Phi_v) \\
& \phi_a \leftarrow 0 \\
& \text{for } j \in 0..J \\
& \quad \phi_{vj} \leftarrow \phi_v(v, \rho_L, \rho_v, \mu_v, d_{p_j}, \rho_s, \phi_{s_j}, f_W) \\
& \quad \phi_{a_j} \leftarrow \phi_{s_j} - \phi_{vj} \\
& d_{pp} \leftarrow 0 \\
& \phi_{ap} \leftarrow 0 \\
& d_{pp} \leftarrow \text{pack}(d_p, \phi_a) \\
& \phi_{ap} \leftarrow \text{pack}(\phi_a, \phi_a) \\
& \phi_{cum} \leftarrow \text{cum}(\phi_{ap}) \\
& \Phi_a \leftarrow \sum_{j=0}^{\text{length}(\phi_{ap})-1} \phi_{ap_j} \\
& D_{p\beta} \leftarrow D_\beta\left(d_{pp}, \frac{\phi_{cum}}{\Phi_a}, 0.5\right) \\
& v_{cr}(D_{pipe}, D_{p\beta}, \rho_s, \Phi_a, \rho_v, \mu_v, 1, \beta_{cv})
\end{aligned}$$

$v' := 1 \cdot \frac{ft}{sec}$ initial guess

$$v_{crD\_Wasp}(D_{pipe}, d_p, \rho_s, \phi_s, \rho_L, \mu_L, \varepsilon, \kappa_{cv}, \beta_{cv}) := \kappa_{cv} \cdot root(v' - v_{crDvWasp}(D_{pipe}, d_p, \rho_s, \phi_s, \rho_L, \mu_L, \varepsilon, \beta_{cv}, v'), v') \quad \textbf{(F-66b)}$$

Transition to Turbulence Velocity $Re_T := 4000$

$$v_{crTvWasp}(D_{pipe}, d_p, \rho_s, \phi_s, \rho_L, \mu_L, \varepsilon, \kappa_{cv}, v) := \left| \begin{array}{l} J \leftarrow length(d_p) - 1 \\ f_W \leftarrow f_{Wasp}(D_{pipe}, v, \rho_L, \mu_L, \varepsilon, d_p, \rho_s, \phi_s, 1, \theta) \\ \Phi_v \leftarrow \Phi_c(v, \rho_L, \mu_L, d_p, \rho_s, \phi_s, f_W) \\ \rho_v \leftarrow \rho_c(\rho_s, \rho_L, \Phi_v) \\ \mu_v \leftarrow \mu_c(\mu_L, \Phi_v) \\ \dfrac{Re_T \cdot \mu_v}{D_{pipe} \cdot \rho_v} \end{array} \right. \quad \textbf{(F-67a)}$$

$$v_{crT\_Wasp}(D_{pipe}, d_p, \rho_s, \phi_s, \rho_L, \mu_L, \varepsilon, \kappa_{cv}) := root(v' - v_{crTvWasp}(D_{pipe}, d_p, \rho_s, \phi_s, \rho_L, \mu_L, \varepsilon, \kappa_{cv}, v'), v') \quad \textbf{(F-67b)}$$

Critical Velocity

$$v_{cr\_Wasp}(D_{pipe}, d_p, \rho_s, \phi_s, \rho_L, \mu_L, \varepsilon, \kappa_{cv}, \beta_{cv}) := \frac{m}{sec} \cdot \left| \begin{array}{l} J \leftarrow length(d_p) - 1 \\ \Phi_s \leftarrow \sum_{j=0}^{J} \phi_{s_j} \\ \max\left(\left(\begin{array}{c} v_{crD\_Wasp}(D_{pipe}, d_p, \rho_s, \phi_s, \rho_L, \mu_L, \varepsilon, \kappa_{cv}, \beta_{cv}) \\ v_{crT\_Wasp}(D_{pipe}, d_p, \rho_s, \phi_s, \rho_L, \mu_L, \varepsilon, \kappa_{cv}) \end{array}\right)\right) \text{ if } \Phi_s > \Delta\Phi \\ \dfrac{Re_T \cdot \mu_L}{D_{pipe} \cdot \rho_L} \text{ otherwise} \end{array} \right. \quad \textbf{(F-68)}$$

where

β_{cv} =
- 1 Oroskar and Turian (1980) maximum of semi-theoretical and empirical equation
- 1.1 semi-theoretical equation
- 1.2 empirical equation
- 2 Wasp et al. (1977)
- 3 Zandi and Govatos (1967)
- 4 Shook (1969)
- 5 Gogus and Kokpinar (1999)
- 6 Robinson and Graf (1972)

κ_{cv} is the uncertainty factor on the critical, set to 1 to obtain the "best-estimate" prediction. Recommend at least 1.3 for upper bound estimate to account for uncertainties in the empirical correlation and to include sufficient margin above the critical velocity for minimum operating flow rate.

6.2.4 Generic Particle Size Distribution for Hanford Waste Feed Delivery

Tank SY-101 particle size distribution (partial listing displayed) (O'Rourke 1999)

SY101 :=

d_p (μm)	volume frequency (%)
0.022	0.000
0.026	0.000
0.029	0.000
0.034	0.000
0.039	0.000
0.044	0.000
0.051	0.000
0.058	0.000
0.067	0.000
0.076	0.000
0.087	0.000
0.100	0.000
0.115	0.000
0.131	0.000
0.150	0.000
0.172	0.000
0.197	0.000
0.226	0.160
0.259	0.340
0.296	0.270
0.339	0.120

$d_p := SY101^{\langle 0 \rangle} \cdot \mu m$

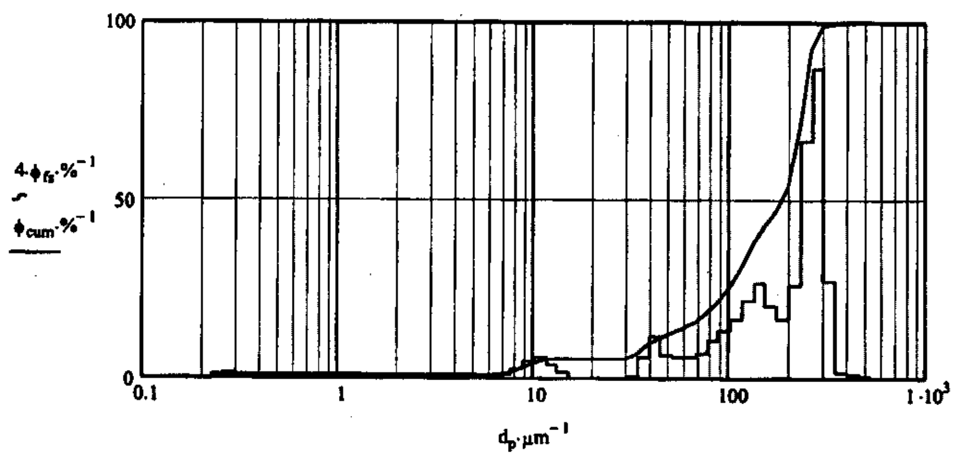
$\phi_{fs} := SY101^{\langle 1 \rangle} \cdot \%$

$\text{length}(\phi_{fs}) - 1 = 113$

$\Phi_{fs} := \sum_{j=0}^{\text{length}(\phi_{fs})-1} \phi_{fs_j} \qquad \Phi_{fs} = 1$

Cumulative undersize volume distribution

$\phi_{cum} := \text{cum}(\phi_{fs})$



$d_{50R} := D_\beta(d_p, \phi_{cum}, 50\%) \qquad d_{50R} = 184.063\ \mu m$

Curve fit to Rosin-Rammler and Log Normal distribution functions

$F_{RR}(d,p) := \begin{pmatrix} CDF_{RR}(d, d_{50R} \cdot \mu m^{-1}, p) \\ CDF_{RR'p}(d, d_{50R} \cdot \mu m^{-1}, p) \end{pmatrix} \qquad F_{LN}(d,p) := \begin{pmatrix} CDF_{LN}(d, d_{50R} \cdot \mu m^{-1}, p) \\ CDF_{LN'p}(d, d_{50R} \cdot \mu m^{-1}, p) \end{pmatrix}$ **(F-69)**

$vp_{RR} := 1.5 \qquad vp_{LN} := 1.5$

$p_{RR} := \text{genfit}(d_p \cdot \mu m^{-1}, \phi_{cum}, vp_{RR}, F_{RR})$

$p_{LN} := \text{genfit}(d_p \cdot \mu m^{-1}, \phi_{cum}, vp_{LN}, F_{LN}) \qquad \Delta d_p := \Delta(d_p)$

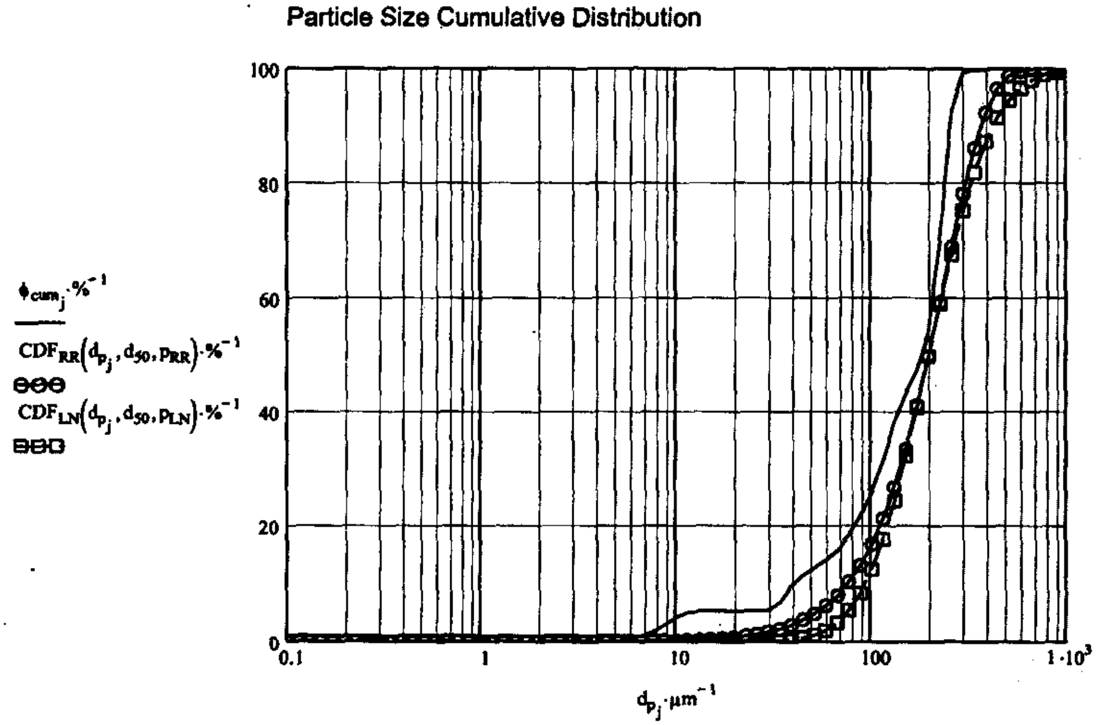
$p_{RR} = 1.933 \qquad d_{50} := d_{50R}$

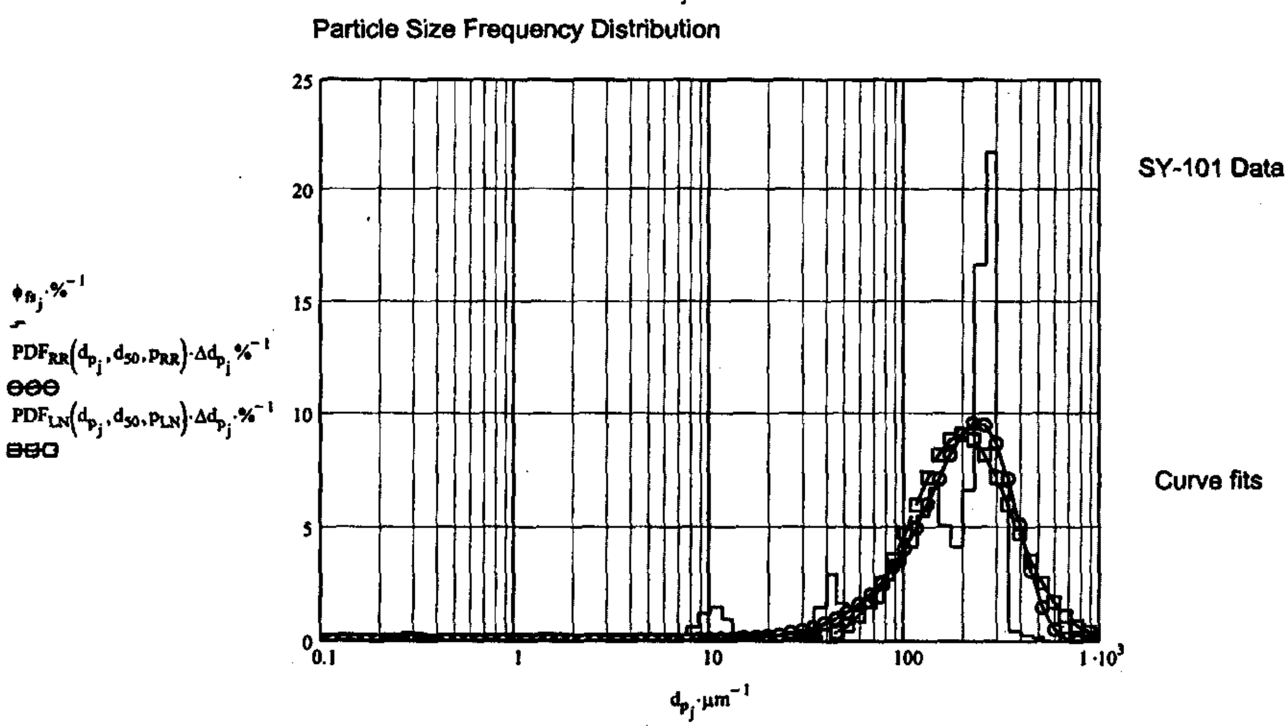
$d_{50} := 200 \cdot \mu m$

$p_{LN} = 1.811$

$J := \text{length}(\phi_{fs}) - 1 \qquad j := 0..J$

Comparison of SY-101 cumulative and frequency data to Rosin-Rammler and Log Normal distribution function curve fits.





$d_{pR} := d_p$ $\Delta d_{pR} := \Delta d_p$ $j_R := 0..\,\text{length}(d_p) - 1$ $\phi_R := \phi_{fs}$ $\phi_{cumR} := \phi_{cum}$

Pack original solid particle distribution for analysis to remove zero frequency data

$d_p := \text{pack}(d_p, \phi_{fs})$

$\phi_{fs} := \text{pack}(\phi_{fs}, \phi_{fs})$ $\phi_{cum} := \text{cum}(\phi_{fs})$ $\text{length}(\phi_{fs}) - 1 = 30$

$D_p := D_\beta(d_p, \phi_{cum}, 50\%)$ $C_s := 10\%$

$D_p = 184.063\ \mu m$ $\phi_s := \phi_{fs} \cdot C_s$ $\Phi_s := \sum_{j=0}^{\text{length}(\phi_s)-1} \phi_{s_j}$ $\Phi_s = 0.1$

Return Rosin-Rammler probability density function values (d ϕ) shifted to d_{50} from reference distribution and packed for analysis

$$\text{dist}_{RR}(d_p, d_{50}) := \begin{array}{|l} J \leftarrow \text{length}(d_p) - 1 \\ \Delta d \leftarrow \Delta(d_p) \\ \text{for } j \in 0..J \\ \quad \phi_j \leftarrow \text{PDF}_{RR}(d_{p_j}, d_{50}, p_{RR}) \cdot \Delta d_j \\ d \leftarrow \text{pack}(d_p, \phi) \cdot \mu m^{-1} \\ \phi \leftarrow \text{pack}(\phi, \phi) \\ (d \ \ \phi) \end{array}$$

Return Log-Normal probability density function values (d ϕ) shifted to d_{50} from reference distribution and packed for analysis

$$\text{dist}_{LN}(d_p, d_{50}) := \begin{array}{|l} J \leftarrow \text{length}(d_p) - 1 \\ \Delta d \leftarrow \Delta(d_p) \\ \text{for } j \in 0..J \\ \quad \phi_j \leftarrow \text{PDF}_{LN}(d_{p_j}, d_{50}, p_{LN}) \cdot \Delta d_j \\ d \leftarrow \text{pack}(d_p, \phi) \cdot \mu m^{-1} \\ \phi \leftarrow \text{pack}(\phi, \phi) \\ (d \ \ \phi) \end{array} \qquad \text{(F-70)}$$

$(d_{pRR}\ \ \phi_{RR}) := \text{dist}_{RR}(d_{pR}, d_{50})$ $d_{pRR} := d_{pRR} \cdot \mu m$ reset units

$\phi_{RRcum} := \text{cum}(\phi_{RR})$ $\text{length}(\phi_{RR}) - 1 = 57$

$D_{pRR} := D_\beta(d_{pRR}, \phi_{RRcum}, 50\%)$

$D_{pRR} = 186.7\ \mu m$

$(d_{pLN}\ \ \phi_{LN}) := \text{dist}_{LN}(d_{pR}, d_{50})$ $d_{pLN} := d_{pLN} \cdot \mu m$ reset units

$\phi_{LNcum} := \text{cum}(\phi_{LN})$ $\text{length}(\phi_{LN}) - 1 = 40$

$D_{pLN} := D_\beta(d_{pLN}, \phi_{LNcum}, 50\%)$

$D_{pLN} = 186.872\ \mu m$

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Appendix D provides a tabular listing of the critical velocity, pressure drop at critical velocity, and flow rate at a reference pipeline design pressure of 400 lbf/in^2 for each of the 200-East Area transfer routes identified in Cases 3S4 and 3S6 from the HTWOS model for a range of waste transfer properties. An alternate solutions to reduce the predicted pressure drops for wost-case conditions was also considered. This alternate solution assumed a pump lift station in AP Farms located at the AP "new" valve pit. Selected long intermediate tank-to-tank transfers and all transfers to BNFL (Case 4-st) would go through the pump lift station. Appendix E provides the results of a "sensitivity" analysis on the longest transfer route (AN-107 to BNFL) for the range of waste transfer properties considered appropriate. See main body of this report for a discussion of the detail results. Appendix G provides results of Wasp model verification.

7.0 ANALYSIS OF TRANSFER PIPELINES FOR PROPOSED TRANSFERS - Wasp Method

$\begin{pmatrix} DL \\ D0 \\ D1 \end{pmatrix} :=$ Worksheet

read transfer pipeline physical parameters and data sets for waste transfer parameters from worksheet

$TOL = 5 \times 10^{-4}$

$D_{pipe} := 3.068 \cdot in$

Pipe design pressure

$p_{pipe\_design} := 400 \cdot \frac{lbf}{in^2}$

$\beta_{cv} := 1.2$

$L_{CS} := DL^{\langle 0 \rangle} \cdot ft$ $\quad L_{SS} := DL^{\langle 1 \rangle} \cdot ft$ $\quad H := DL^{\langle 2 \rangle} \cdot ft$ $\quad N := length(L_{CS})$ $\quad N = 75$ $\quad i := 0..N-1$ $\quad j := 0..5$

$$\Theta := \overrightarrow{atan\left(\frac{H}{L_{CS} + L_{SS}}\right)}$$

The above critical velocity and pressure drop correlations are "best-estimate" correlations. In application of these correlations, the uncertainty in the predictive correlation must be considered.

approximate 2σ uncertainty factors on predictive correlations

$\kappa_{cv} := 1.30$ uncertainty factor on predicted critical velocity plus factor to assure operation above the critical velocity

$\kappa_f := 1$ uncertainty factor on predicted friction factor - for best-estimate $\kappa_f = 1$

Data Set 0 - Group 1 Properties $\quad T := 10$ °C

$\rho_{c0} := D0^{\langle 0 \rangle} \cdot \frac{kg}{liter}$ $\quad \rho_{d0} := D0^{\langle 1 \rangle} \cdot \frac{kg}{liter}$ $\quad R0_{i,j} := 0$ $\quad d_{pRR} := 0$ $\quad \phi_{RR} := 0$

$\mu_{c0_i} := \mu_{cL}\left(\rho_{c0_i}, T\right)$ $\quad \alpha_{d0} := D0^{\langle 2 \rangle} \cdot \%$ $\quad D_{d0} := D0^{\langle 3 \rangle} \cdot \mu m$

$\left(d_{pRR}^{\langle i \rangle} \;\; \phi_{RR}^{\langle i \rangle}\right) := dist_{RR}\left(d_{pR}, D_{d0_i}\right)$ $\quad d_{pRR} := d_{pRR} \cdot \mu m$ $\quad$ reset units

$v_{cm0_i} := v_{cr}\left(D_{pipe}, D_{d0_i}, \rho_{d0_i}, \alpha_{d0_i}, \rho_{c0_i}, \mu_{c0_i}, \kappa_{cv}, \beta_{cv}\right)$ $\quad Q_{cm0_i} := Q\left(v_{cm0_i}, D_{pipe}\right)$

$$\Delta p_{new0_i} := \Delta p_{T\_Wasp}\left(D_{pipe}, v_{cm0_i}, \rho_{c0_i}, \mu_{c0_i}, \varepsilon_{new}, \varepsilon_{new}, d_{pRR}^{\langle i \rangle}, \rho_{d0_i}, \alpha_{d0_i} \cdot \phi_{RR}^{\langle i \rangle}, L_{CS_i}, L_{SS_i}, \kappa_f, \Theta_i\right)$$

$$\Delta p_{EOL0_i} := \Delta p_{T\_Wasp}\left(D_{pipe}, v_{cm0_i}, \rho_{c0_i}, \mu_{c0_i}, \varepsilon_{EOL\_CS}, \varepsilon_{EOL\_SS}, d_{pRR}^{\langle i \rangle}, \rho_{d0_i}, \alpha_{d0_i} \cdot \phi_{RR}^{\langle i \rangle}, L_{CS_i}, L_{SS_i}, \kappa_f, \Theta_i\right)$$

$v0 := 10 \cdot \frac{ft}{sec}$

$$v_{max\_new0_i} := -1 \cdot \frac{ft}{sec} \text{ on error } root\left(\begin{array}{l} p_{pipe\_design} \cdots \\ + -\Delta p_{T\_Wasp}\left(D_{pipe}, v0, \rho_{c0_i}, \mu_{c0_i}, \varepsilon_{new}, \varepsilon_{new}, d_{pRR}^{\langle i \rangle}, \rho_{d0_i}, \alpha_{d0_i} \cdot \phi_{RR}^{\langle i \rangle}, L_{CS_i}, L_{SS_i}, \kappa_f, \Theta_i\right) \end{array}, v0\right)$$

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$$v_{max\_EOL0_i} := -1\cdot\frac{ft}{sec} \text{ on error root}\left(p_{pipe\_design} \cdots + -\Delta p_{T\_Wasp}\left(D_{pipe}, v0, \rho_{c0_i}, \mu_{c0_i}, \varepsilon_{EOL\_CS}, \varepsilon_{EOL\_SS}, d_{pRR}^{\langle i\rangle}, \rho_{d0_i}, \alpha_{d0_i}\cdot\phi_{RR}^{\langle i\rangle}, L_{CS_i}, L_{SS_i}, \kappa_f, \Theta_i\right., v0\right)$$

$$R0^{\langle 0\rangle} := v_{cm0}\cdot\left(\frac{ft}{sec}\right)^{-1} \quad R0^{\langle 1\rangle} := Q_{cm0}\cdot\left(\frac{gal}{min}\right)^{-1} \quad R0^{\langle 2\rangle} := \Delta p_{new0}\cdot\left(\frac{lbf}{in^2}\right)^{-1} \quad R0^{\langle 3\rangle} := \Delta p_{EOL0}\cdot\left(\frac{lbf}{in^2}\right)^{-1}$$

$$R0^{\langle 4\rangle} := Q\left(v_{max\_new0}, D_{pipe}\right)\cdot\left(\frac{gal}{min}\right)^{-1} \quad R0^{\langle 5\rangle} := Q\left(v_{max\_EOL0}, D_{pipe}\right)\cdot\left(\frac{gal}{min}\right)^{-1}$$

Data Set 0 - Group 1 Properties $T := 60\ °C$ $R1_{i,j} := 0$

$$\mu_{c0_i} := \mu_{cL}\left(\rho_{c0_i}, T\right)$$

$$v_{cm0_i} := v_{cr}\left(D_{pipe}, D_{d0_i}, \rho_{d0_i}, \alpha_{d0_i}, \rho_{c0_i}, \mu_{c0_i}, \kappa_{cv}, \beta_{cv}\right) \qquad Q_{cm0_i} := Q\left(v_{cm0_i}, D_{pipe}\right)$$

$$\Delta p_{new0_i} := \Delta p_{T\_Wasp}\left(D_{pipe}, v_{cm0_i}, \rho_{c0_i}, \mu_{c0_i}, \varepsilon_{new}, \varepsilon_{new}, d_{pRR}^{\langle i\rangle}, \rho_{d0_i}, \alpha_{d0_i}\cdot\phi_{RR}^{\langle i\rangle}, L_{CS_i}, L_{SS_i}, \kappa_f, \Theta_i\right.$$

$$\Delta p_{EOL0_i} := \Delta p_{T\_Wasp}\ D_{pipe}, v_{cm0_i}, \rho_{c0_i}, \mu_{c0_i}, \varepsilon_{EOL\_CS}, \varepsilon_{EOL\_SS}, d_{pRR}^{\langle i\rangle}, \rho_{d0_i}, \alpha_{d0_i}\cdot\phi_{RR}^{\langle i\rangle}, L_{CS_i}, L_{SS_i}, \kappa_f, \Theta_i)$$

$$v_{max\_new0_i} := -1\cdot\frac{ft}{sec} \text{ on error root}\left(p_{pipe\_design} \cdots + -\Delta p_{T\_Wasp}\left(D_{pipe}, v0, \rho_{c0_i}, \mu_{c0_i}, \varepsilon_{new}, \varepsilon_{new}, d_{pRR}^{\langle i\rangle}, \rho_{d0_i}, \alpha_{d0_i}\cdot\phi_{RR}^{\langle i\rangle}, L_{CS_i}, L_{SS_i}, \kappa_f, \Theta_i\right), v0\right)$$

$$v_{max\_EOL0_i} := -1\cdot\frac{ft}{sec} \text{ on error root}\left(p_{pipe\_design} \cdots + -\Delta p_{T\_Wasp}\left(D_{pipe}, v0, \rho_{c0_i}, \mu_{c0_i}, \varepsilon_{EOL\_CS}, \varepsilon_{EOL\_SS}, d_{pRR}^{\langle i\rangle}, \rho_{d0_i}, \alpha_{d0_i}\cdot\phi_{RR}^{\langle i\rangle}, L_{CS_i}, L_{SS_i}, \kappa_f, \Theta_i\right., v0\right)$$

$$R1^{\langle 0\rangle} := v_{cm0}\cdot\left(\frac{ft}{sec}\right)^{-1} \quad R1^{\langle 1\rangle} := Q_{cm0}\cdot\left(\frac{gal}{min}\right)^{-1} \quad R1^{\langle 2\rangle} := \Delta p_{new0}\cdot\left(\frac{lbf}{in^2}\right)^{-1} \quad R1^{\langle 3\rangle} := \Delta p_{EOL0}\cdot\left(\frac{lbf}{in^2}\right)^{-1}$$

$$R1^{\langle 4\rangle} := Q\left(v_{max\_new0}, D_{pipe}\right)\cdot\left(\frac{gal}{min}\right)^{-1} \quad R1^{\langle 5\rangle} := Q\left(v_{max\_EOL0}, D_{pipe}\right)\cdot\left(\frac{gal}{min}\right)^{-1}$$

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Checked: 03/10/2000 By: T. C. Oten
Revised: By:

Data Set 1 - Group 2 Properties $T := 10\ ^{o}C$

$\rho_{c0} := D1^{\langle 0\rangle}\cdot\frac{kg}{liter}$ $\rho_{d0} := D1^{\langle 1\rangle}\cdot\frac{kg}{liter}$ $R2_{i,j} := 0$ $d_{pRR} := 0$ $\phi_{RR} := 0$

$\mu_{c0_i} := \mu_{cL}\left(\rho_{c0_i}, T\right)$ $\alpha_{d0} := D1^{\langle 2\rangle}\cdot\%$ $D_{d0} := D1^{\langle 3\rangle}\cdot\mu m$

$\left(d_{pRR}{}^{\langle i\rangle}\ \ \phi_{RR}{}^{\langle i\rangle}\right) := dist_{RR}\left(d_{pR}, D_{d0_i}\right)$ $d_{pRR} := d_{pRR}\cdot\mu m$ reset units

$v_{cm0_i} := v_{cr}\left(D_{pipe}, D_{d0_i}, \rho_{d0_i}, \alpha_{d0_i}, \rho_{c0_i}, \mu_{c0_i}, \kappa_{cv}, \beta_{cv}\right)$ $Q_{cm0_i} := Q\left(v_{cm0_i}, D_{pipe}\right)$

$\Delta p_{new0_i} := \Delta p_{T\_Wasp}\left(D_{pipe}, v_{cm0_i}, \rho_{c0_i}, \mu_{c0_i}, \varepsilon_{new}, \varepsilon_{new}, d_{pRR}{}^{\langle i\rangle}, \rho_{d0_i}, \alpha_{d0_i}\cdot\phi_{RR}{}^{\langle i\rangle}, L_{CS_i}, L_{SS_i}, \kappa_f, \Theta_i\right.$

$\Delta p_{EOL0_i} := \Delta p_{T\_Wasp}\ D_{pipe}, v_{cm0_i}, \rho_{c0_i}, \mu_{c0_i}, \varepsilon_{EOL\_CS}, \varepsilon_{EOL\_SS}, d_{pRR}{}^{\langle i\rangle}, \rho_{d0_i}, \alpha_{d0_i}\cdot\phi_{RR}{}^{\langle i\rangle}, L_{CS_i}, L_{SS_i}, \kappa_f, \Theta_i\Big)$ $v0 := 10\cdot\frac{ft}{sec}$

$v_{max\_new0_i} := -1\cdot\frac{ft}{sec}$ on error $root\left(\begin{array}{l}p_{pipe\_design}\ \cdots\\ + -\Delta p_{T\_Wasp}\left(D_{pipe}, v0, \rho_{c0_i}, \mu_{c0_i}, \varepsilon_{new}, \varepsilon_{new}, d_{pRR}{}^{\langle i\rangle}, \rho_{d0_i}, \alpha_{d0_i}\cdot\phi_{RR}{}^{\langle i\rangle}, L_{CS_i}, L_{SS_i}, \kappa_f, \Theta_i\right)\end{array}, v0\right)$

$v_{max\_EOL0_i} := -1\cdot\frac{ft}{sec}$ on error $root\left(\begin{array}{l}p_{pipe\_design}\ \cdots\\ + -\Delta p_{T\_Wasp}\left(D_{pipe}, v0, \rho_{c0_i}, \mu_{c0_i}, \varepsilon_{EOL\_CS}, \varepsilon_{EOL\_SS}, d_{pRR}{}^{\langle i\rangle}, \rho_{d0_i}, \alpha_{d0_i}\cdot\phi_{RR}{}^{\langle i\rangle}, L_{CS_i}, L_{SS_i}, \kappa_f, \Theta_i\right.\end{array}, v0\right.$

$R2^{\langle 0\rangle} := v_{cm0}\cdot\left(\frac{ft}{sec}\right)^{-1}$ $R2^{\langle 1\rangle} := Q_{cm0}\cdot\left(\frac{gal}{min}\right)^{-1}$ $R2^{\langle 2\rangle} := \Delta p_{new0}\cdot\left(\frac{lbf}{in^2}\right)^{-1}$ $R2^{\langle 3\rangle} := \Delta p_{EOL0}\cdot\left(\frac{lbf}{in^2}\right)^{-1}$

$R2^{\langle 4\rangle} := Q\left(v_{max\_new0}, D_{pipe}\right)\cdot\left(\frac{gal}{min}\right)^{-1}$ $R2^{\langle 5\rangle} := Q\left(v_{max\_EOL0}, D_{pipe}\right)\cdot\left(\frac{gal}{min}\right)^{-1}$

Data Set 1 - Group 2 Properties $T := 60\ ^{o}C$

$$\mu_{c0_i} := \mu_{cL}\left(\rho_{c0_i}, T\right) \qquad R3_{i,j} := 0$$

$$v_{cm0_i} := v_{cr}\left(D_{pipe}, D_{d0_i}, \rho_{d0_i}, \alpha_{d0_i}, \rho_{c0_i}, \mu_{c0_i}, \kappa_{cv}, \beta_{cv}\right) \qquad Q_{cm0_i} := Q\left(v_{cm0_i}, D_{pipe}\right)$$

$$\Delta p_{new0_i} := \Delta p_{T\_Wasp}\left(D_{pipe}, v_{cm0_i}, \rho_{c0_i}, \mu_{c0_i}, \varepsilon_{new}, \varepsilon_{new}, d_{pRR}^{\langle i \rangle}, \rho_{d0_i}, \alpha_{d0_i} \cdot \phi_{RR}^{\langle i \rangle}, L_{CS_i}, L_{SS_i}, \kappa_f, \Theta_i\right)$$

$$\Delta p_{EOL0_i} := \Delta p_{T\_Wasp}\left(D_{pipe}, v_{cm0_i}, \rho_{c0_i}, \mu_{c0_i}, \varepsilon_{EOL\_CS}, \varepsilon_{EOL\_SS}, d_{pRR}^{\langle i \rangle}, \rho_{d0_i}, \alpha_{d0_i} \cdot \phi_{RR}^{\langle i \rangle}, L_{CS_i}, L_{SS_i}, \kappa_f, \Theta_i\right)$$

$$v_{max\_new0_i} := -1 \cdot \frac{ft}{sec} \text{ on error root}\left(p_{pipe\_design} \cdots + -\Delta p_{T\_Wasp}\left(D_{pipe}, v0, \rho_{c0_i}, \mu_{c0_i}, \varepsilon_{new}, \varepsilon_{new}, d_{pRR}^{\langle i \rangle}, \rho_{d0_i}, \alpha_{d0_i} \cdot \phi_{RR}^{\langle i \rangle}, L_{CS_i}, L_{SS_i}, \kappa_f, \Theta_i\right), v0\right)$$

$$v_{max\_EOL0_i} := -1 \cdot \frac{ft}{sec} \text{ on error root}\left(p_{pipe\_design} \cdots + -\Delta p_{T\_Wasp}\left(D_{pipe}, v0, \rho_{c0_i}, \mu_{c0_i}, \varepsilon_{EOL\_CS}, \varepsilon_{EOL\_SS}, d_{pRR}^{\langle i \rangle}, \rho_{d0_i}, \alpha_{d0_i} \cdot \phi_{RR}^{\langle i \rangle}, L_{CS_i}, L_{SS_i}, \kappa_f, \Theta_i\right., v0$$

$$R3^{\langle 0 \rangle} := v_{cm0} \cdot \left(\frac{ft}{sec}\right)^{-1} \quad R3^{\langle 1 \rangle} := Q_{cm0} \cdot \left(\frac{gal}{min}\right)^{-1} \quad R3^{\langle 2 \rangle} := \Delta p_{new0} \cdot \left(\frac{lbf}{in^2}\right)^{-1} \quad R3^{\langle 3 \rangle} := \Delta p_{EOL0} \cdot \left(\frac{lbf}{in^2}\right)^{-1}$$

$$R3^{\langle 4 \rangle} := Q\left(v_{max\_new0}, D_{pipe}\right) \cdot \left(\frac{gal}{min}\right)^{-1} \qquad R3^{\langle 5 \rangle} := Q\left(v_{max\_EOL0}, D_{pipe}\right) \cdot \left(\frac{gal}{min}\right)^{-1}$$

Worksheet

return summary results
of analysis to worksheet

(R0 R1 R2 R3)

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Revised: By:

$TOL = 1 \times 10^{-6}$

Figure F-1a. Viscosity of Water vs. Temperature.

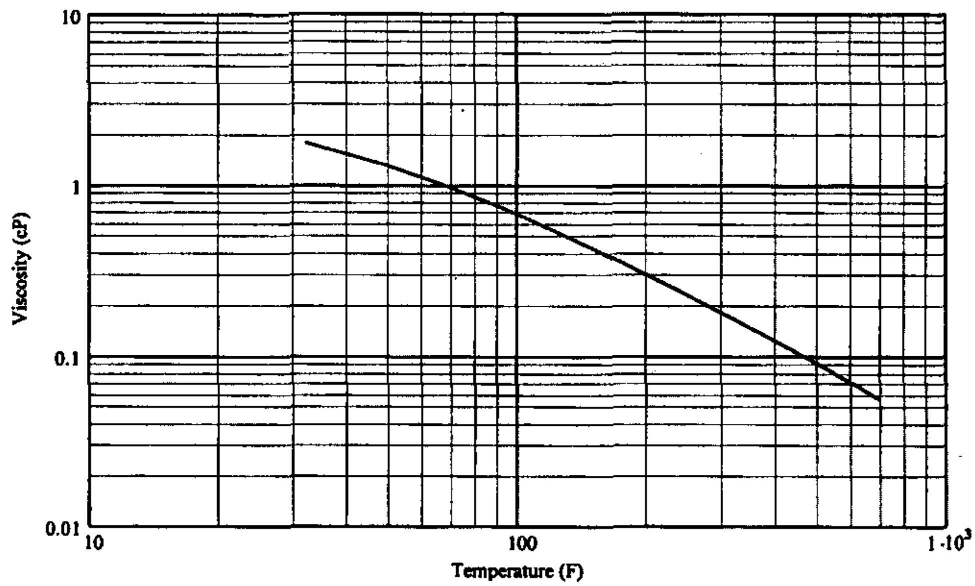


Figure F-1b. Viscosity of Hanford Waste vs. Density of Carrier Liquid at Selected Temperatures.

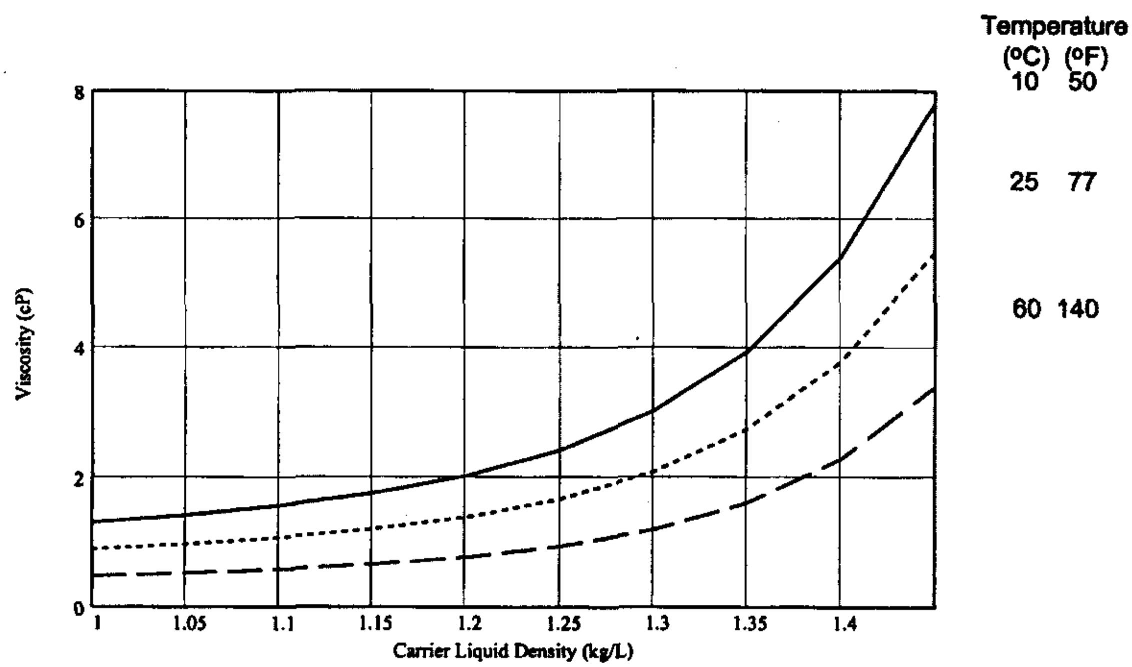


Figure F-2. Correlations for the Drag Coefficient of a Sphere in Free Fall in a Stagnant Unbound Liquid.

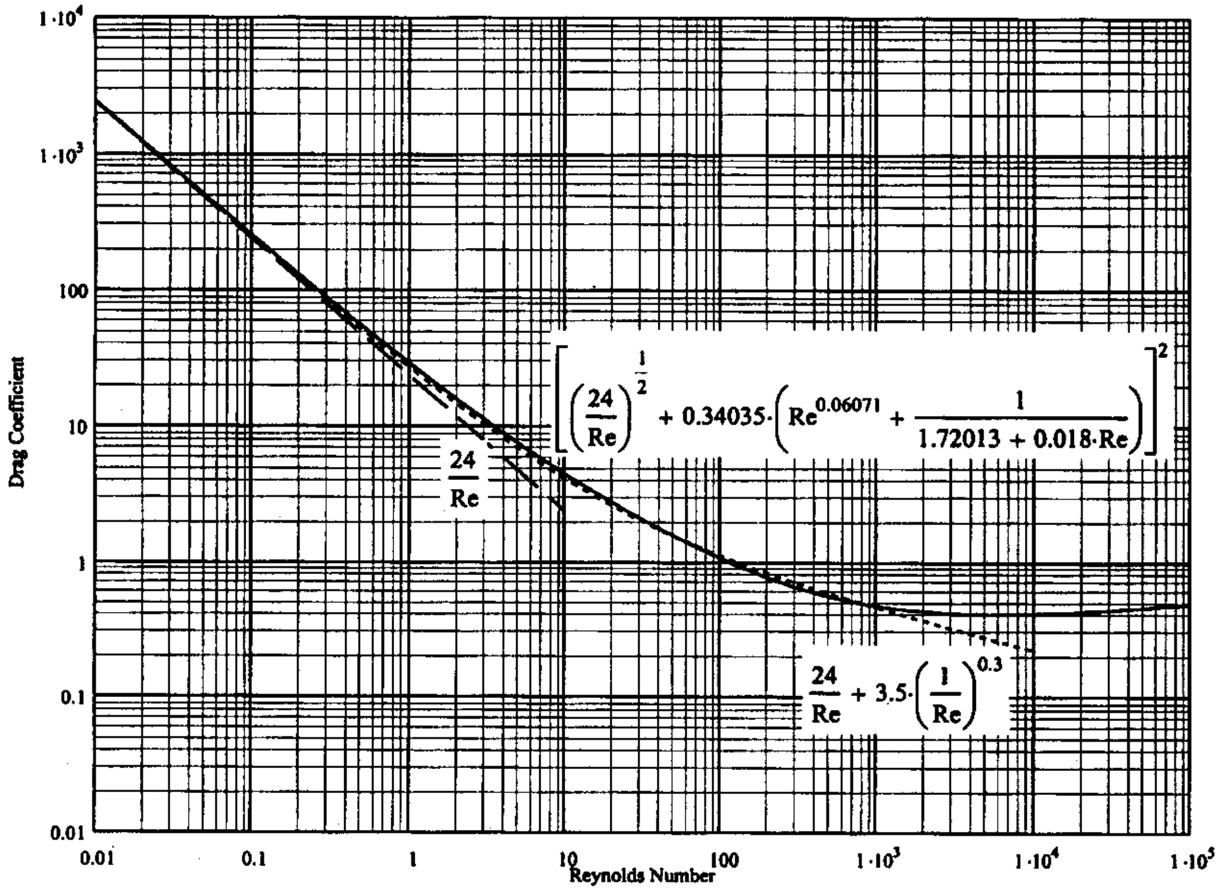


Figure F-3. Hindering Settling Velocity Exponent as a Function of Particle Reynolds Number.

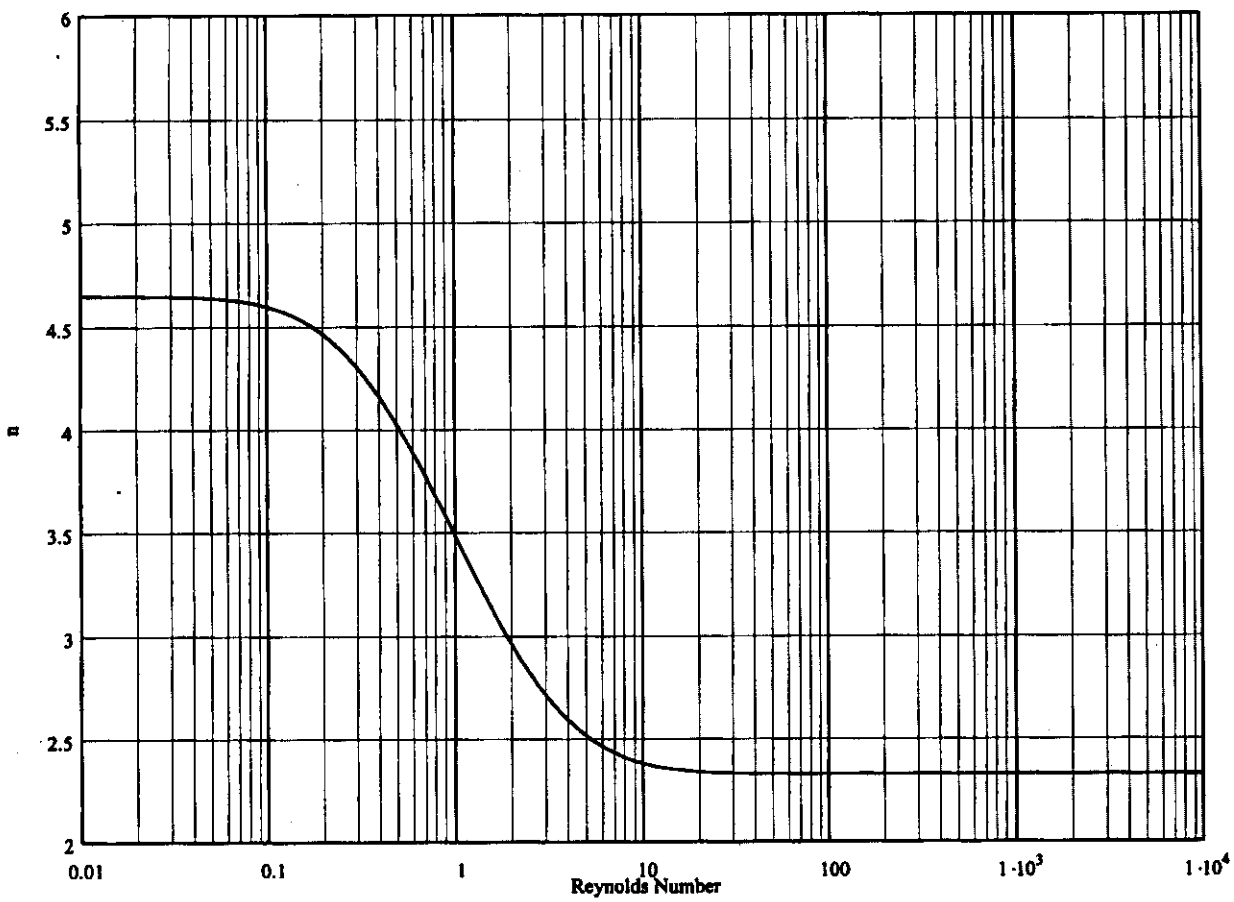
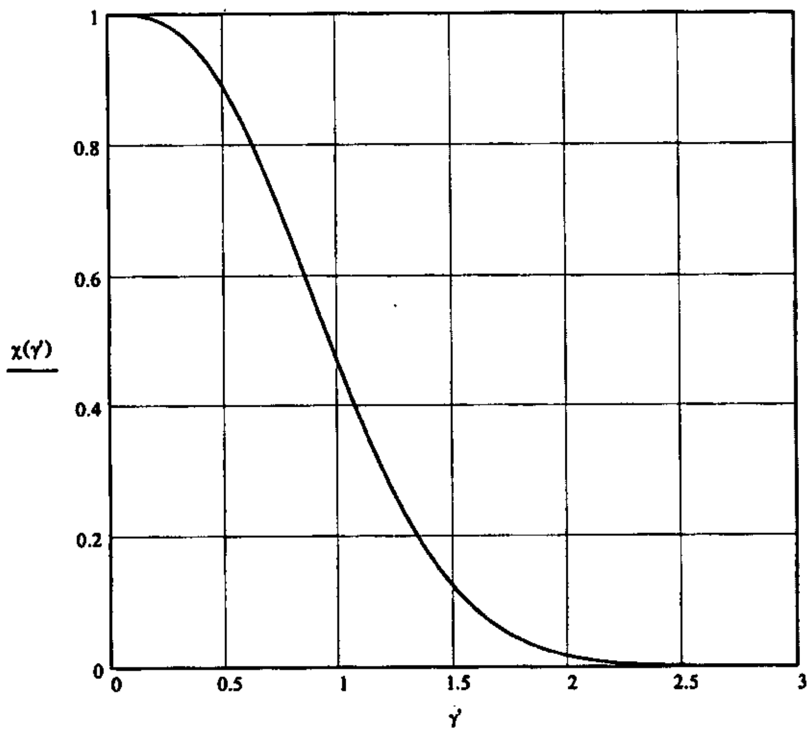


Figure F-4. Plot of $\chi(\gamma)$.



$D_d := 400 \cdot \mu m$ $\alpha_d := 10 \cdot \%$ $D_{pipe} := 3.068 \cdot in$ $\kappa_{cv} := 1$

$N := 50$ $i := 0..N$ $j := 0..N$ $\rho_{dLL} := 1.401 \cdot \frac{kg}{liter}$ $\rho_{dUL} := 4 \cdot \frac{kg}{liter}$ $\Delta\rho_d := \frac{\rho_{dUL} - \rho_{dLL}}{N}$ $\rho_{d_j} := \rho_{dLL} + \Delta\rho_d \cdot j$

$\rho_{cLL} := 1 \cdot \frac{kg}{liter}$ $\rho_{cUL} := 1.4 \cdot \frac{kg}{liter}$ $\Delta\rho_c := \frac{\rho_{cUL} - \rho_{cLL}}{N}$ $\rho_{c_i} := \rho_{cLL} + \Delta\rho_c \cdot i$

$T := 60$ $\mu_{c_i} := \mu_{cL}\left(\rho_{c_i}, T\right)$

$vt_{cr60_{i,j}} := v_{crOTt}\left(D_{pipe}, D_d, \rho_{d_j}, \alpha_d, \rho_{c_i}, \mu_{c_i}, \kappa_{cv}\right)$ $ve_{cr60_{i,j}} := v_{crOTe}\left(D_{pipe}, D_d, \rho_{d_j}, \alpha_d, \rho_{c_i}, \mu_{c_i}, \kappa_{cv}\right)$

$T := 10$ $\mu_{c_i} := \mu_{cL}\left(\rho_{c_i}, T\right)$

$vt_{cr10_{i,j}} := v_{crOTt}\left(D_{pipe}, D_d, \rho_{d_j}, \alpha_d, \rho_{c_i}, \mu_{c_i}, \kappa_{cv}\right)$ $ve_{cr10_{i,j}} := v_{crOTe}\left(D_{pipe}, D_d, \rho_{d_j}, \alpha_d, \rho_{c_i}, \mu_{c_i}, \kappa_{cv}\right)$

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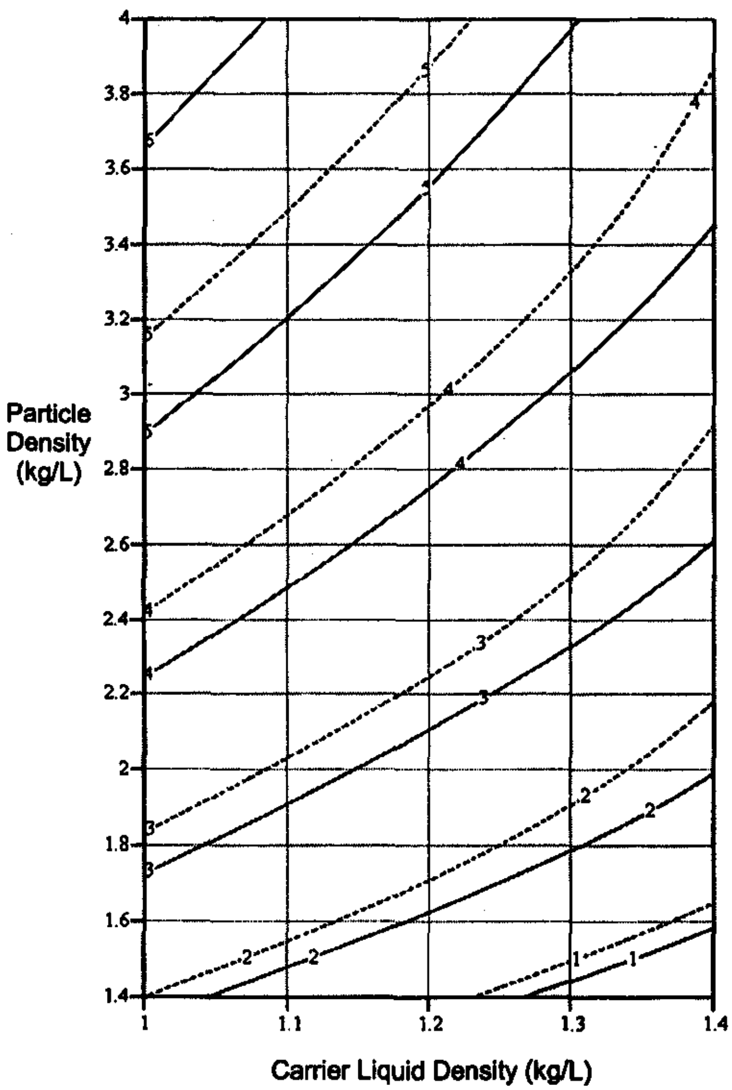
Figure F-5a. Contour Plot of Oroskar and Turian (1980) Semi-Theoretical Equation for the Critical Velocity (ft/s) vs. Particle Solids Density and Carrier Liquid Density - T=60°C (solid line), T=10°C (dash line).

Figure F-5b. Contour Plot of Oroskar and Turian (1980) Empirical Equation for the Critical Velocity (ft/s) vs. Particle Solids Density and Carrier Liquid Density - T=60°C (solid line), T=10°C (dash line).

$\kappa_{cv} = 1$ $D_{pipe} = 3.068$ in $D_d = 400\ \mu m$ $\alpha_d = 10\%$



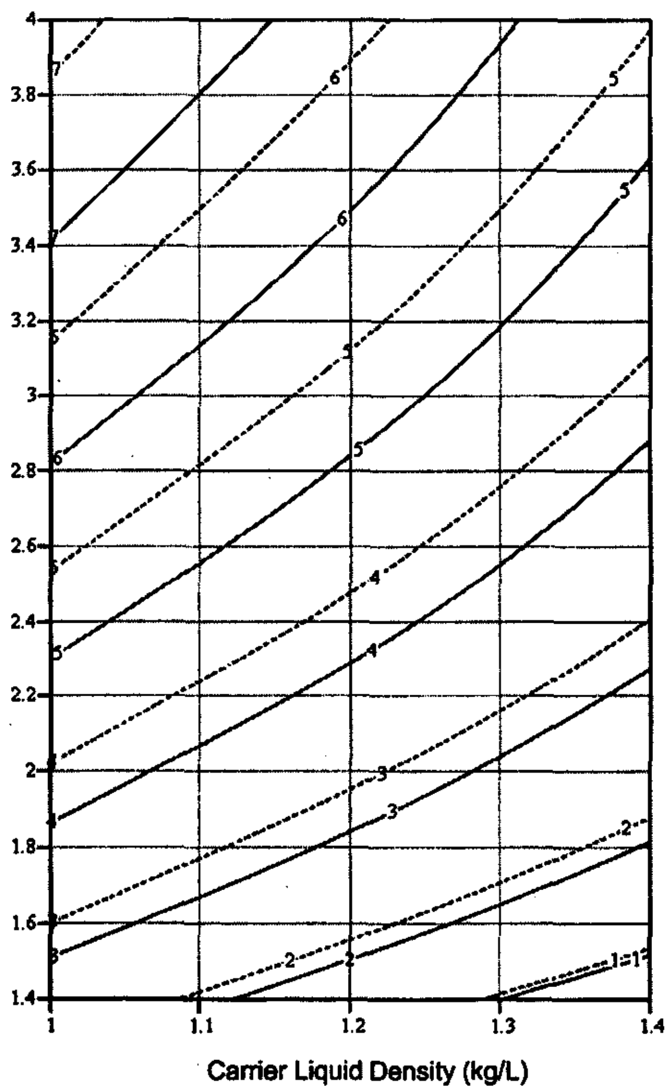


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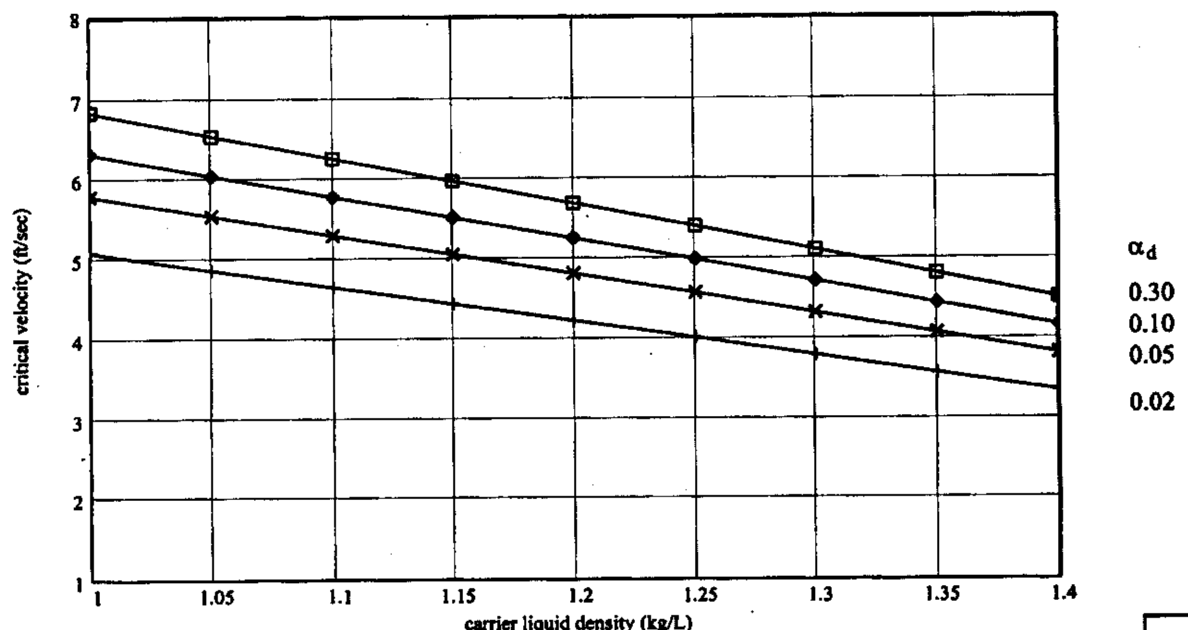
Figure F-6a. Best-Estimate Critical Velocity Prediction vs. Carrier Liquid Density at Selected Solids Volume Fractions - Oroskar and Turian (1980).

$T := 60$ °C $\beta_{cv} := 1.2$ $\kappa_{cv} := 1$ $D_{pipe} = 3.068\,in$ $D_d := 400 \cdot \mu m$ $\rho_d := 3 \cdot \frac{kg}{liter}$



$\rho_c := 1.2 \cdot \frac{kg}{liter}$

Figure F-6b. Best-Estimate Critical Velocity Prediction vs. Particle Solids Density at Selected Solids Volume Fractions - Oroskar and Turian (1980).

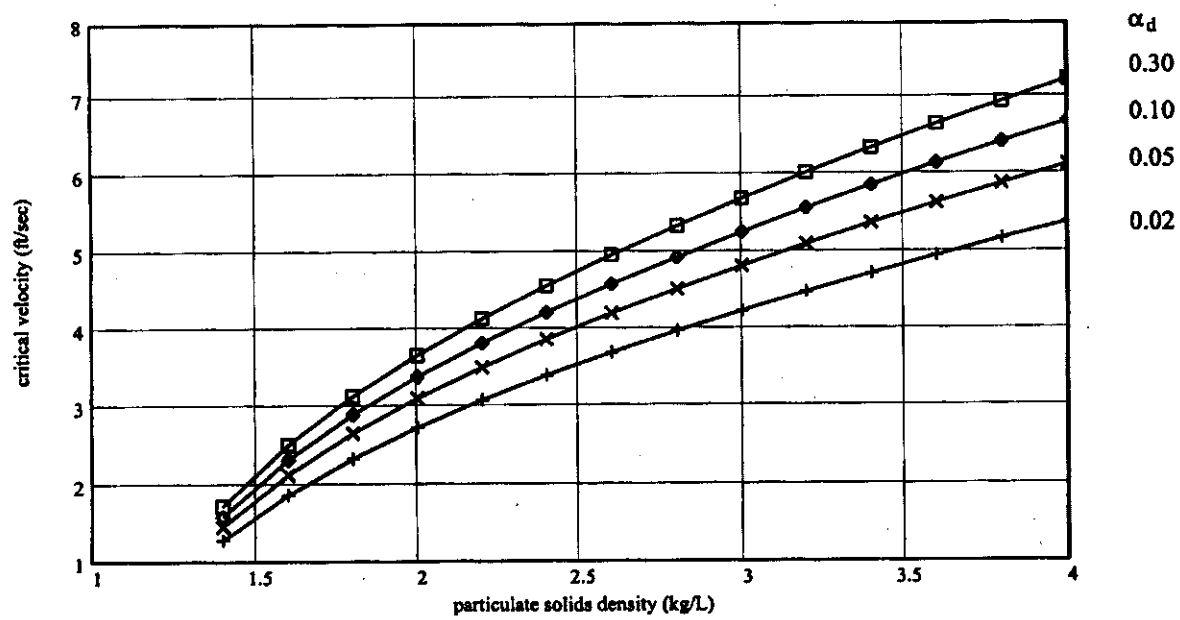
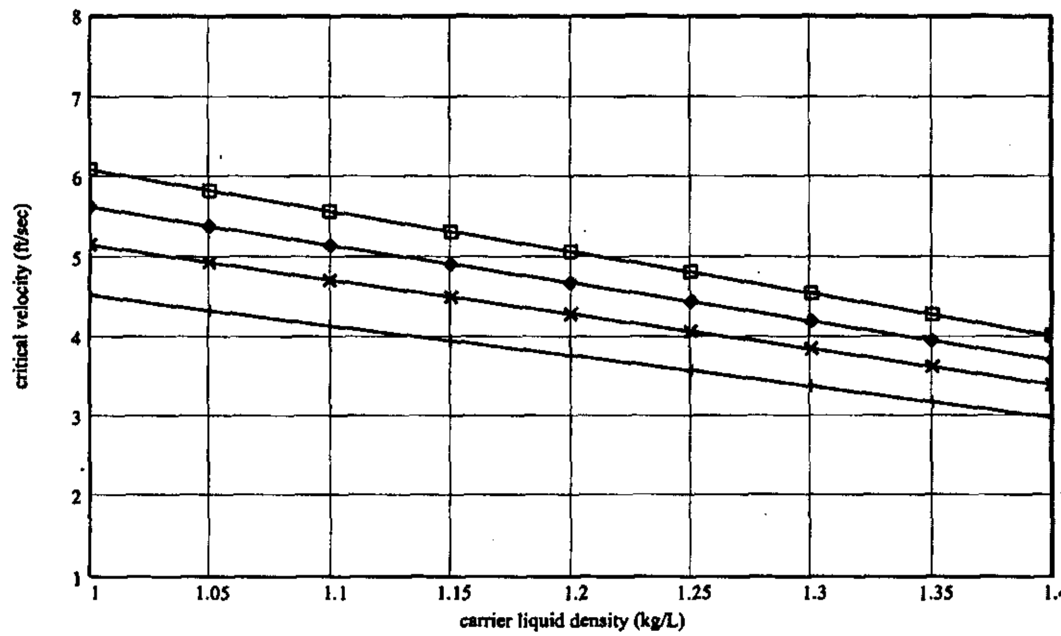


Figure F-7a. Best-Estimate Critical Velocity Prediction vs. Carrier Liquid Density at Selected Solids Volume Fractions - Oroskar and Turian (1980).

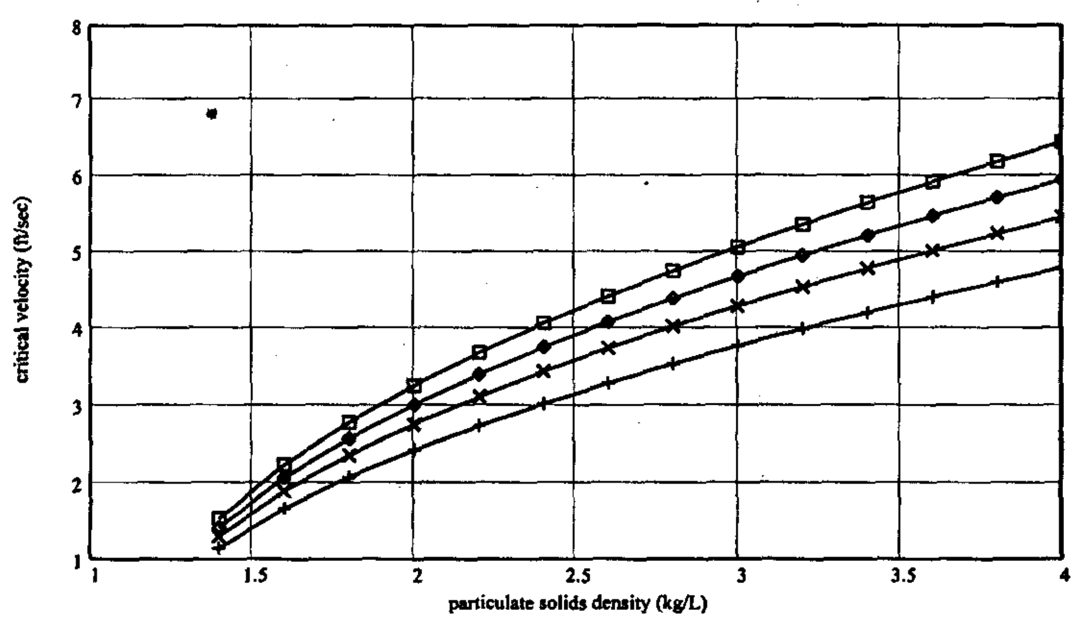
$T = 60$ °C $\beta_{cv} = 1.2$ $\kappa_{cv} = 1$ $D_{pipe} = 3.068\,in$ $D_d := 200\cdot\mu m$ $\rho_d := 3\cdot\frac{kg}{liter}$



α_d
0.30
0.10
0.05
0.02

$\rho_c := 1.2\cdot\frac{kg}{liter}$

Figure F-7b. Best-Estimate Critical Velocity Prediction vs. Particle Solids Density at Selected Solids Volume Fractions - Oroskar and Turian (1980).



α_d
0.30
0.10
0.05
0.02

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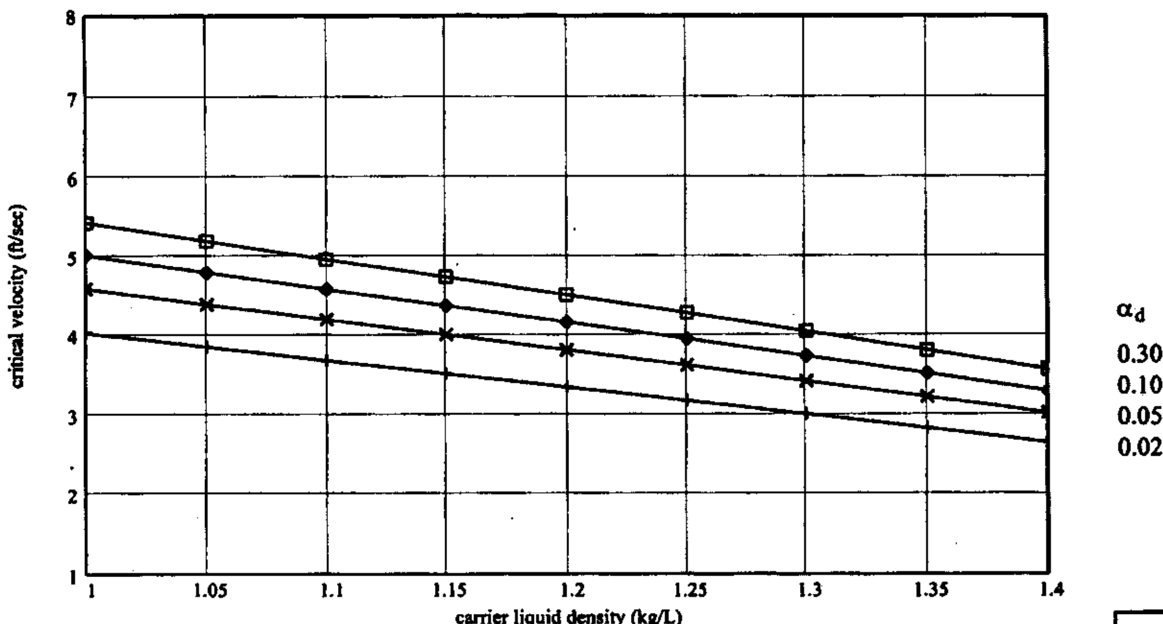
Figure F-8a. Best-Estimate Critical Velocity Prediction vs. Carrier Liquid Density at Selected Solids Volume Fractions - Oroskar and Turian (1980).

$T = 60$ °C $\beta_{cv} = 1.2$ $\kappa_{cv} = 1$ $D_{pipe} = 3.068$ in $D_d := 100\cdot\mu m$ $\rho_d := 3\cdot\frac{kg}{liter}$



$\rho_c := 1.2\cdot\frac{kg}{liter}$

Figure F-8b. Best-Estimate Critical Velocity Prediction vs. Particle Solids Density at Selected Solids Volume Fractions - Oroskar and Turian (1980).

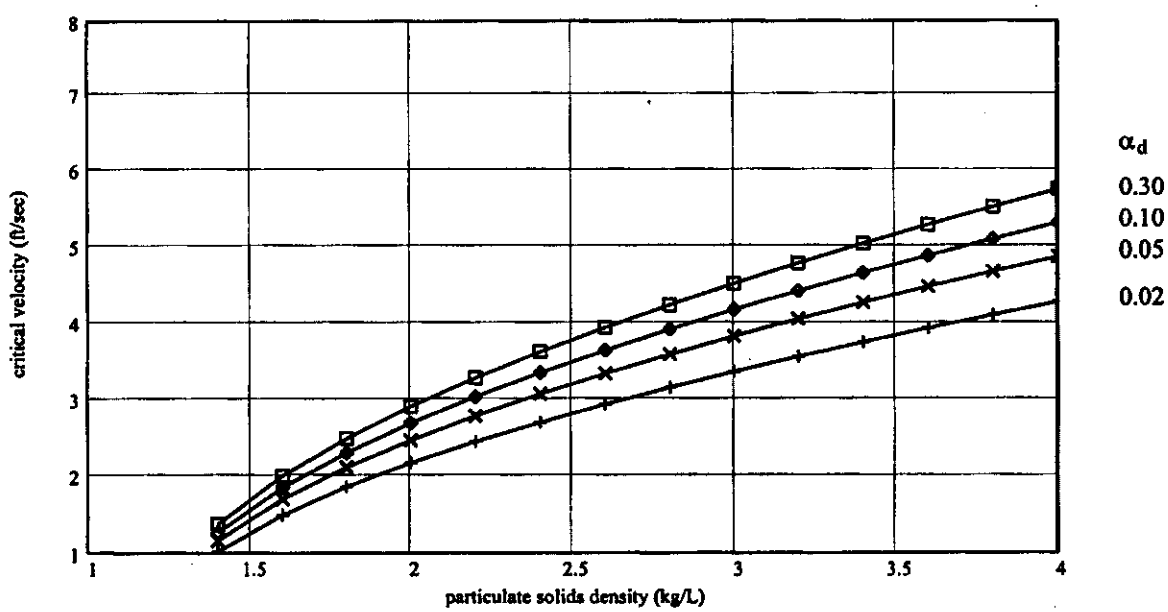


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Figure F=9a. Best-Estimate Critical Velocity Prediction vs. Particle Solids Median Diameter at Selected Solids Volume Fractions - Oroskar and Turian (1980).

$T = 60$ °C $\beta_{cv} = 1.2$ $\kappa_{cv} = 1$ $D_{pipe} = 3.068\,in$ $\rho_c := 1.2 \cdot \frac{kg}{liter}$ $\rho_d := 3 \cdot \frac{kg}{liter}$

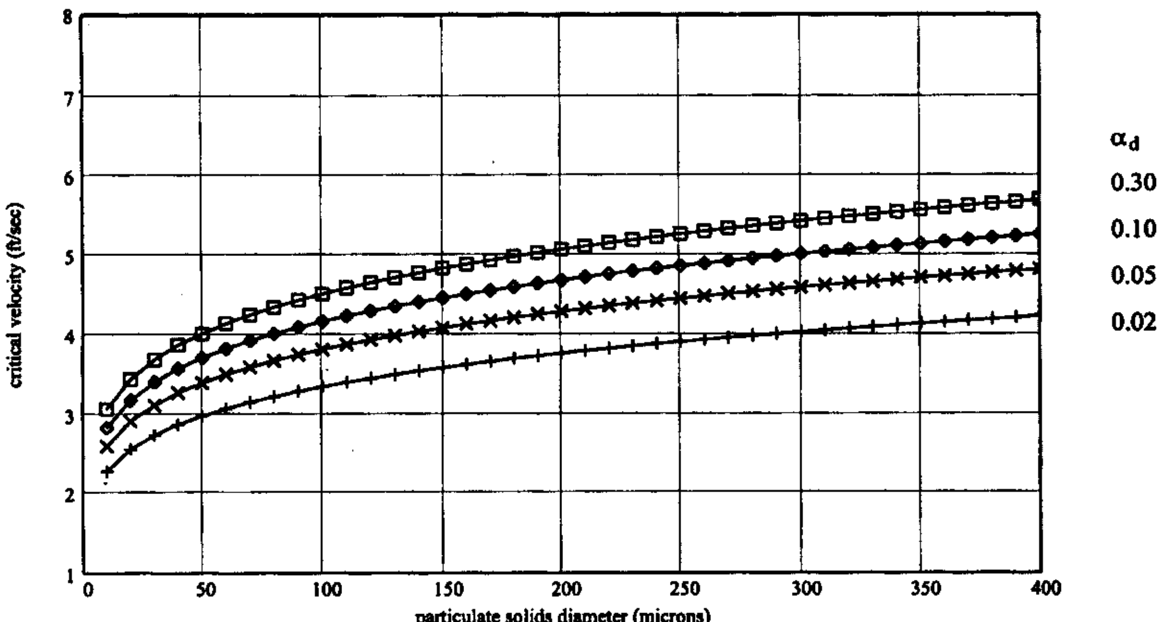

Figure F-9b. Best-Estimate Critical Velocity Prediction vs. Particle Solids Median Diameter at Selected Particle Solids Densities - Oroskar and Turian (1980).

$\alpha_d := 0.30$

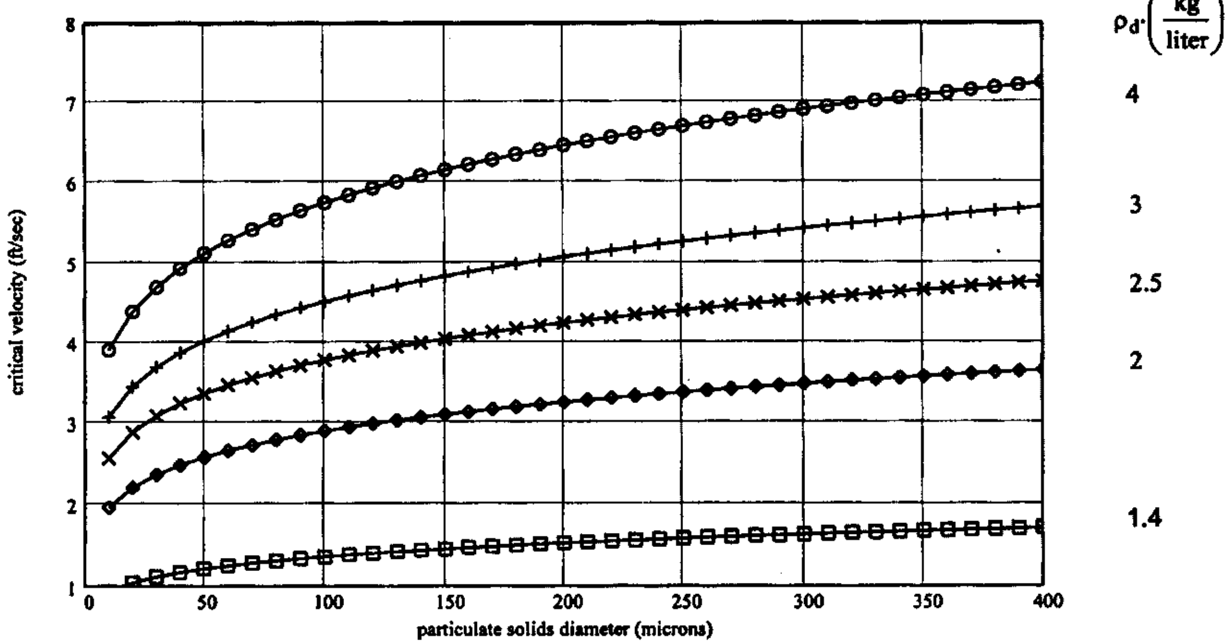

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Figure F-9c. Best-Estimate Critical Velocity Prediction vs. Particle Solids Median Diameter at Selected Particle Solids Densities - Oroskar and Turian (1980).

$T = 60$ °C $\beta_{cv} = 1.2$ $\kappa_{cv} = 1$ $D_{pipe} = 3.068$ in $\rho_c := 1.2 \cdot \frac{kg}{liter}$ $\alpha_d := 0.10$

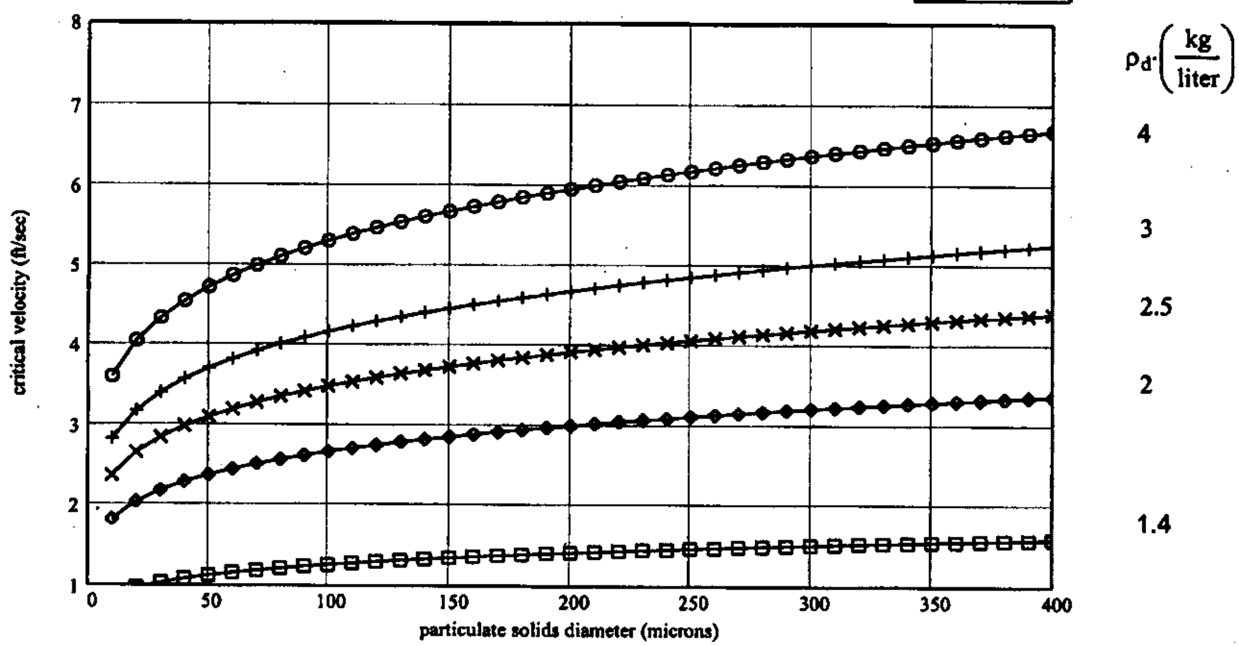

Figure F-9d. Best-Estimate Critical Velocity Prediction vs. Particle Solids Median Diameter at Selected Particle Solids Densities - Oroskar and Turian (1980).

$\alpha_d := 0.05$

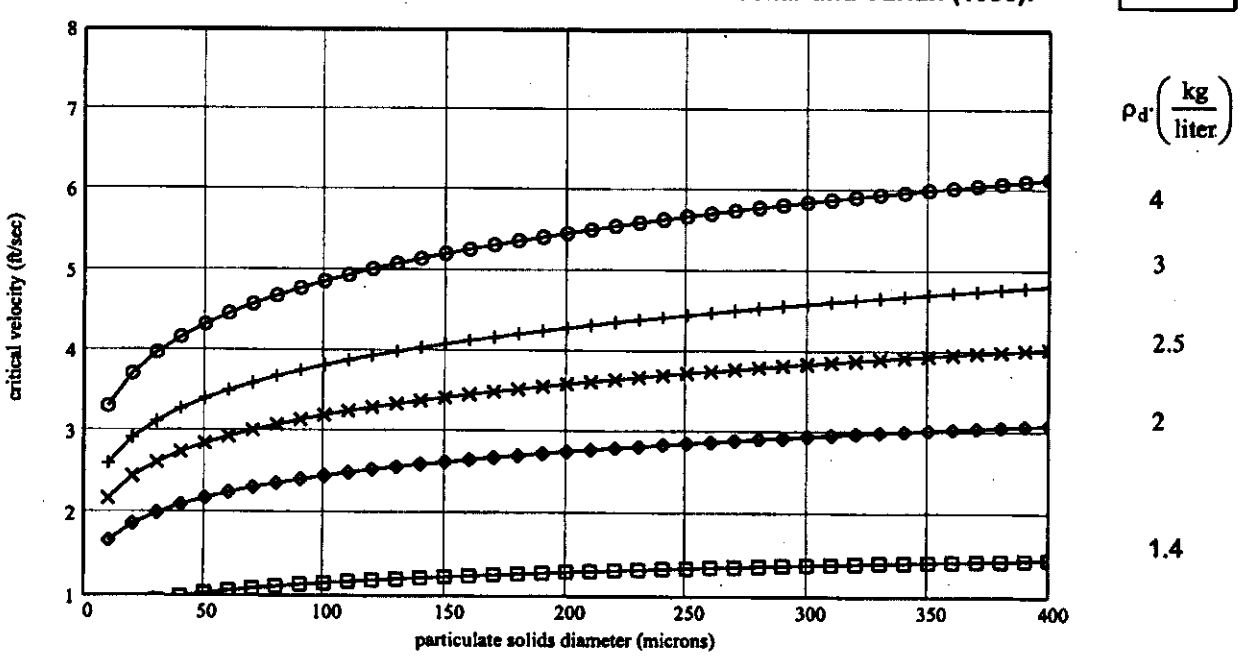

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Figure F-10a. Best-Estimate Critical Velocity Prediction vs. Carrier Liquid Density at Selected Solids Volume Fractions - Oroskar and Turian (1980).

$T := 10$ °C $\beta_{cv} = 1.2$ $\kappa_{cv} = 1$ $D_{pipe} = 3.068\,in$ $\rho_d := 3\cdot\frac{kg}{liter}$ $D_d := 400\cdot\mu m$

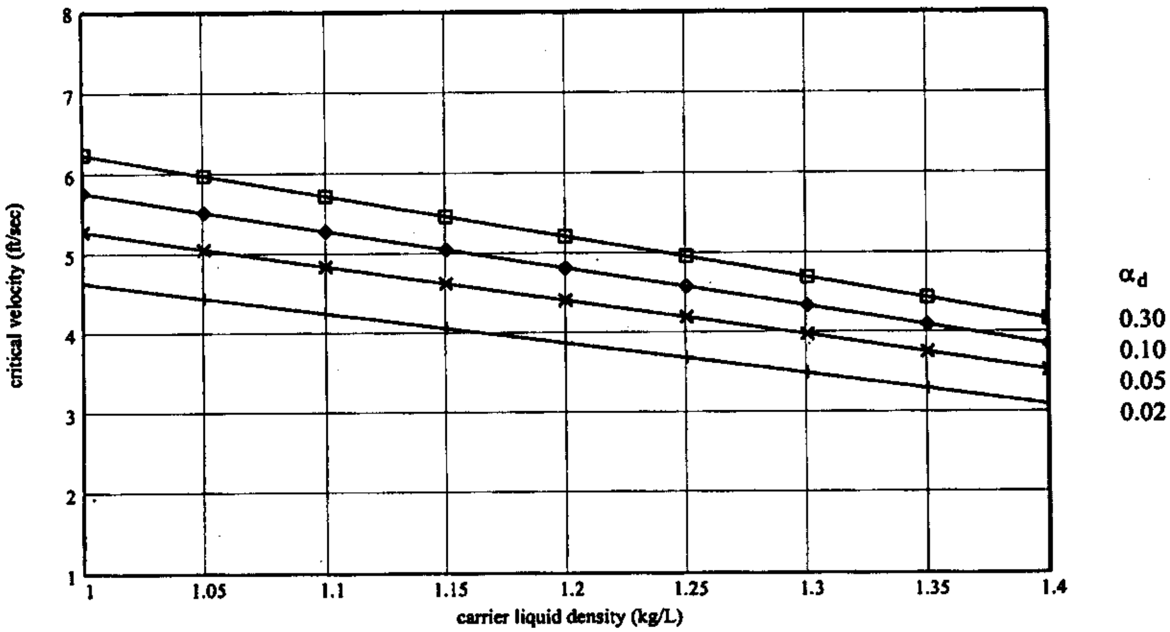

Figure 10b. Best-Estimate Critical Velocity Prediction vs. Carrier Liquid Density at Selected Solids Volume Fractions - Oroskar and Turian (1980).

$D_d := 100\cdot\mu m$

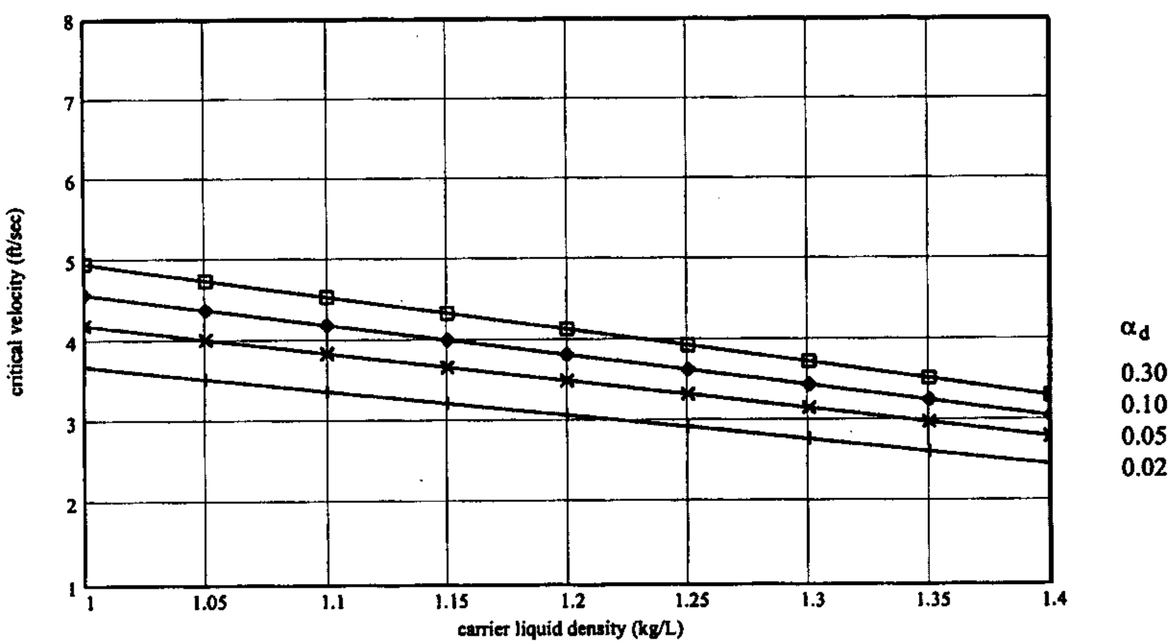

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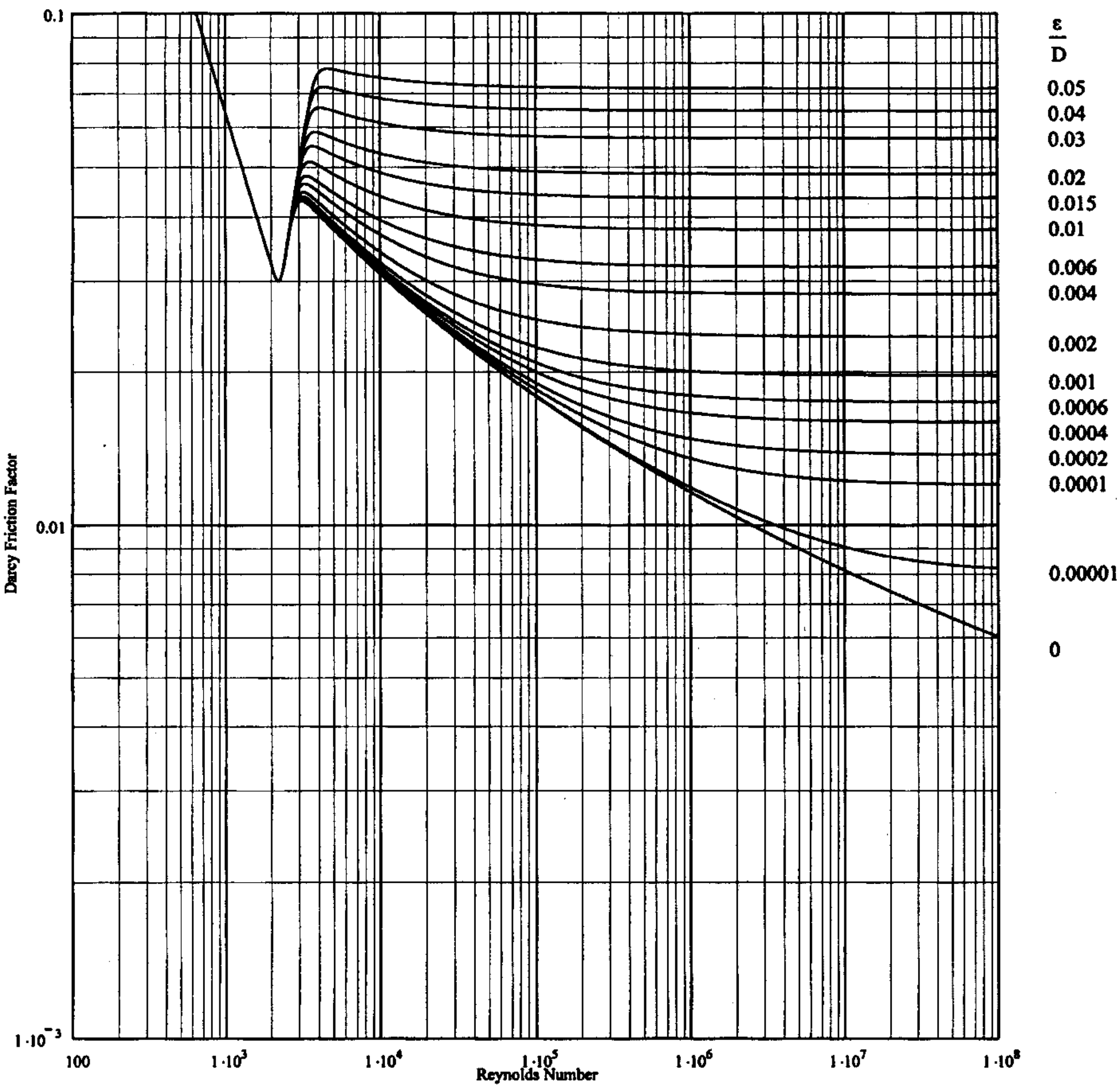
Figure F-11. Darcy Friction Factor vs. Reynolds Number and Relative Roughness.



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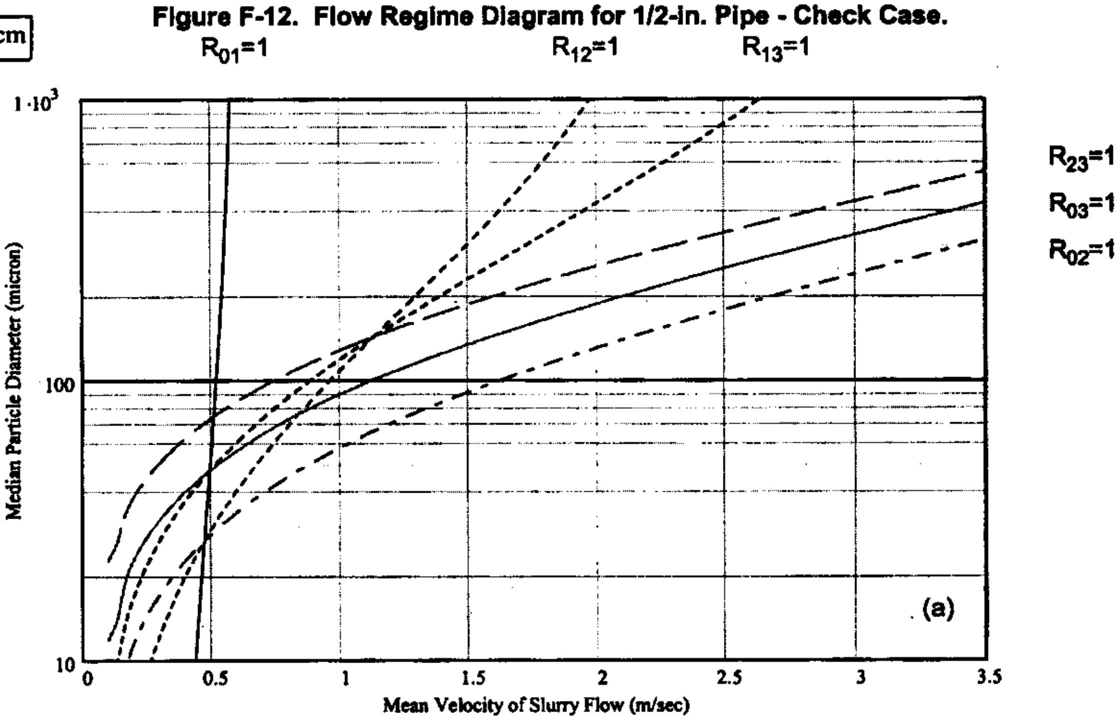
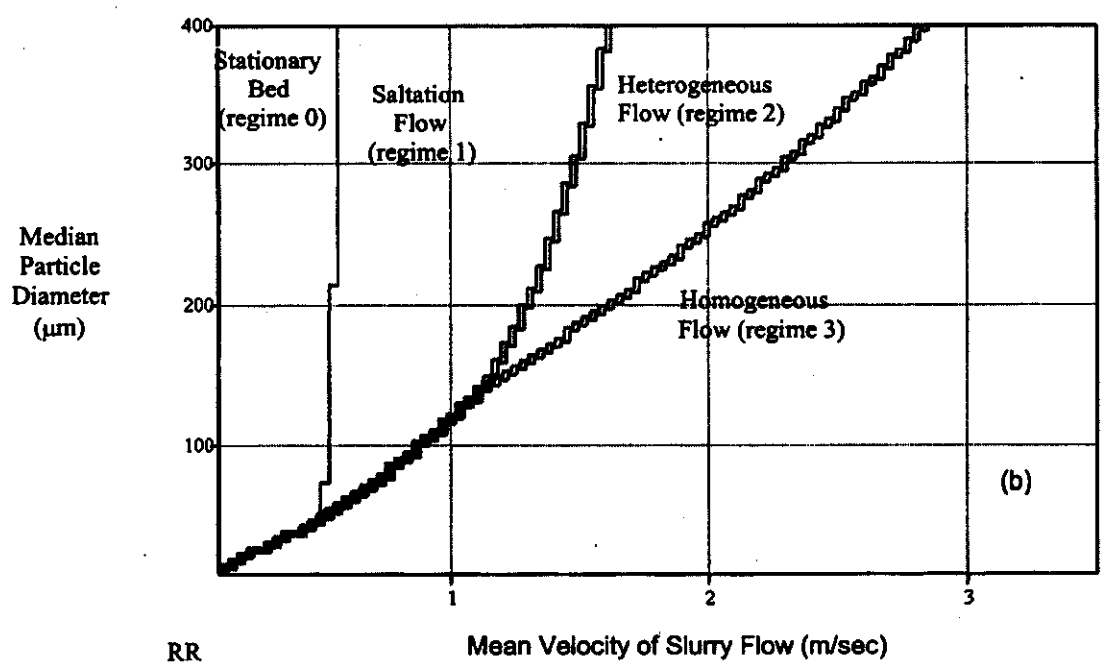
$T := 22.5\ ^{o}C$ $\rho_c := \rho_{water}(T)$ $\rho_c = 0.998\frac{kg}{liter}$ $\rho_d := 2.977\cdot\frac{gm}{cm^3}$ $\theta := 0\cdot deg$ $\beta_f := 1$

$\mu_c := \mu_{water}(T)$ $\mu_c = 0.944\,cP$ $\alpha_d := 5\cdot\%$ $\varepsilon := 0\cdot\mu m$ $\kappa_f := 1$

$D_{pipe} := 1.58\cdot cm$

Figure F-12. Flow Regime Diagram for 1/2-in. Pipe - Check Case.





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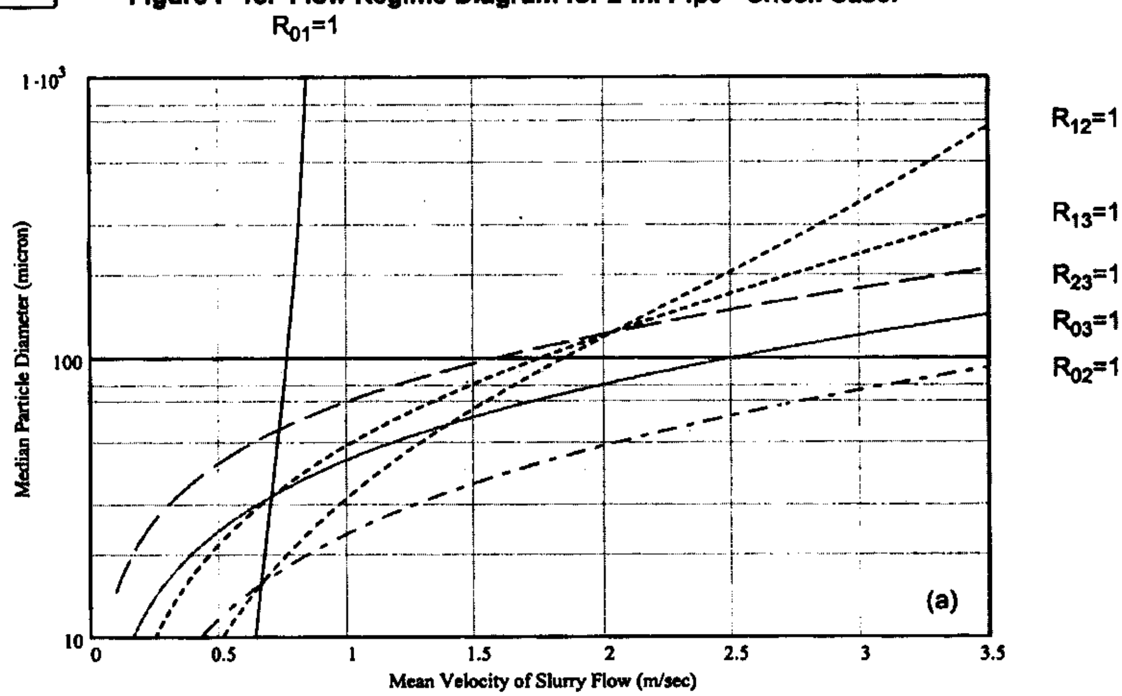
$D_{pipe} := 5.25\cdot cm$

Figure F-13. Flow Regime Diagram for 2-in. Pipe - Check Case.



$RR_{i,j} := R_d\left(D_{pipe}, v_{c_i}, \rho_c, \mu_c, \varepsilon, D_{d_j}, \rho_d, \alpha_d, 1\right)$

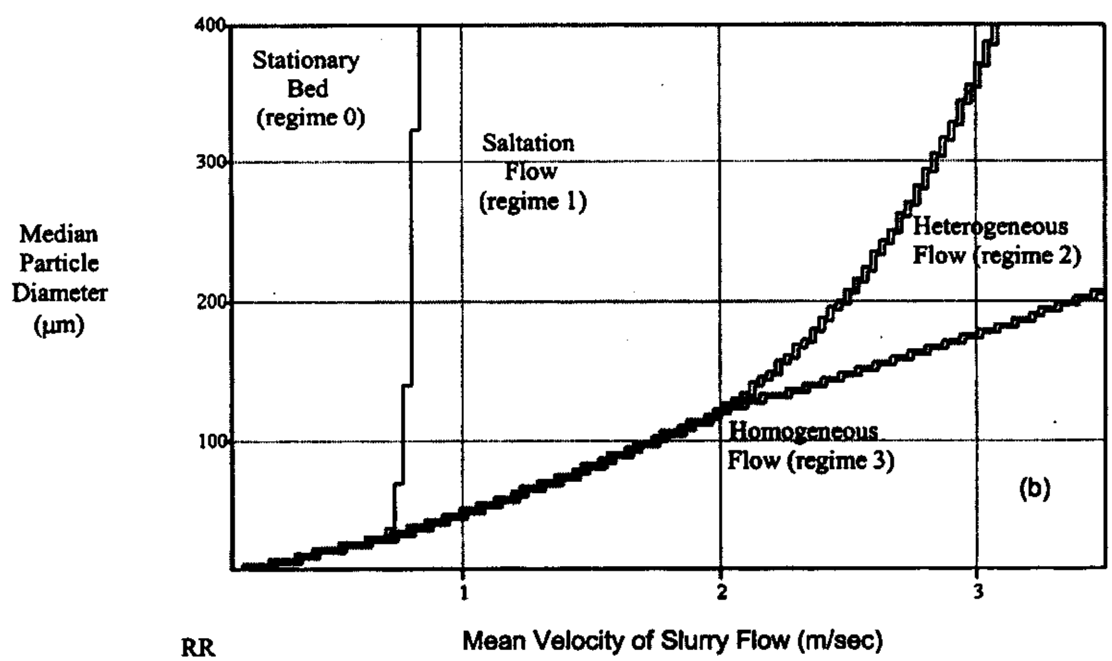


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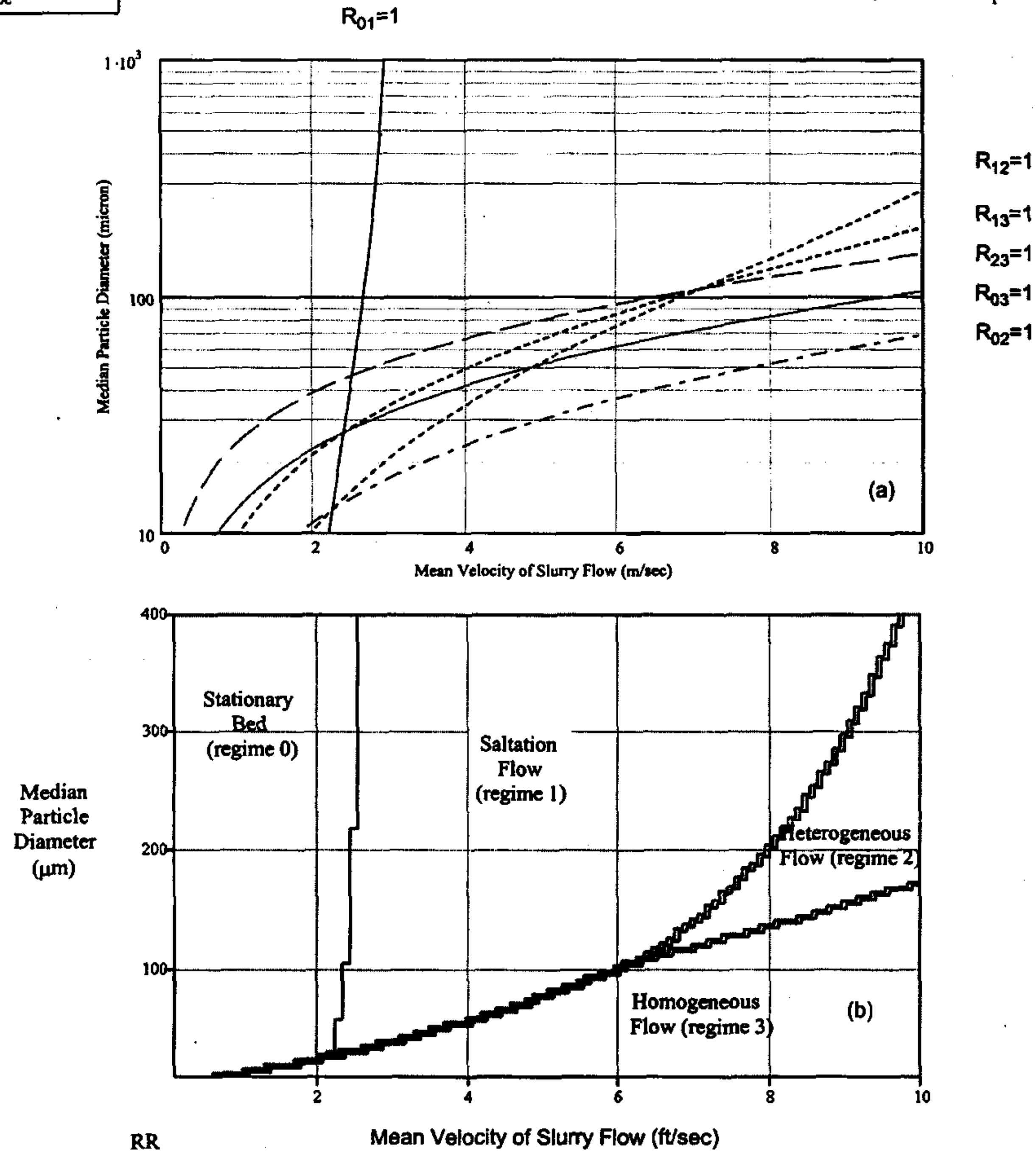
Figure F-14. Flow Regime Diagram for 3-in. Pipe.

$T := 60$ °C $\rho_c := 1.2 \cdot \frac{kg}{liter}$ $\mu_c := \mu_{cL}(\rho_c, T)$ $\mu_c = 0.771\, cP$ $\rho_d := 3 \cdot \frac{kg}{liter}$ $\alpha_d := 5 \cdot \%$ $\varepsilon := \varepsilon_{new}$ $\beta_f := 1$

$D_{pipe} := 3.068 \cdot in$ $\varepsilon = 2\, mil$ $\kappa_f := 1$



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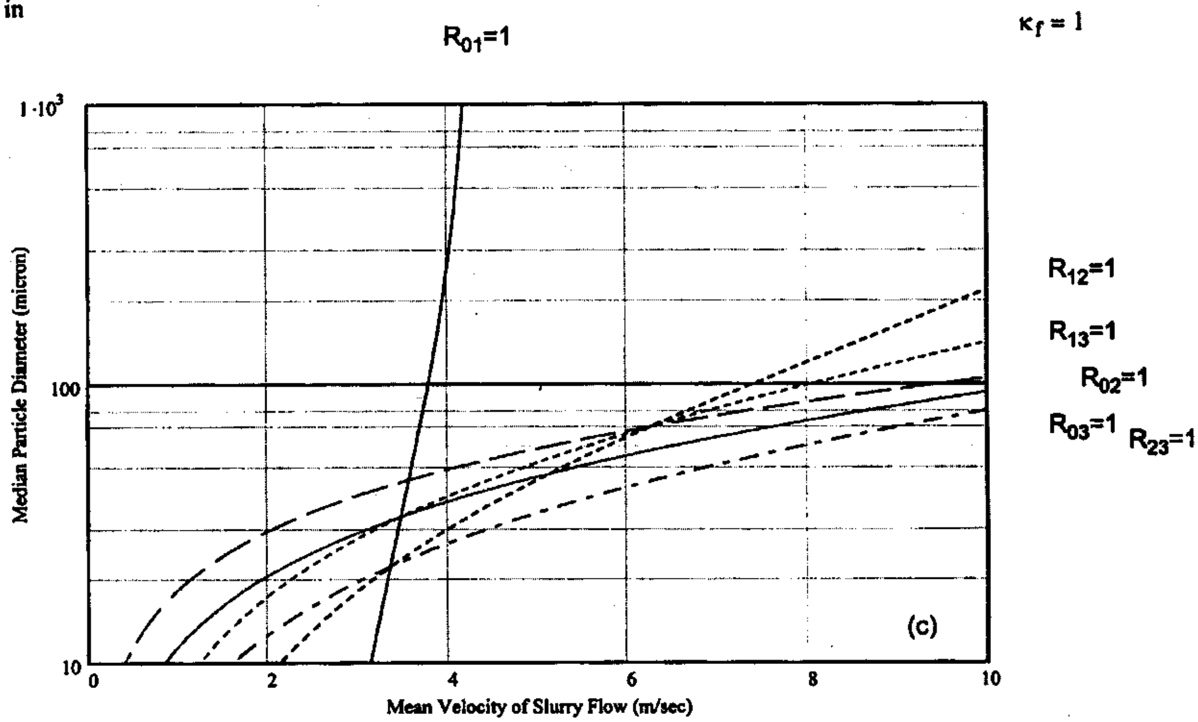
$T = 60\ ^oC$ $\rho_c = 1.2 \frac{kg}{liter}$ $\mu_c = 0.771\,cP$ $\rho_d = 3 \frac{kg}{liter}$ $\alpha_d := 10\cdot\%$ $\varepsilon = 2\,mil$ $\beta_f = 1$

$D_{pipe} = 3.068\,in$ $\kappa_f = 1$



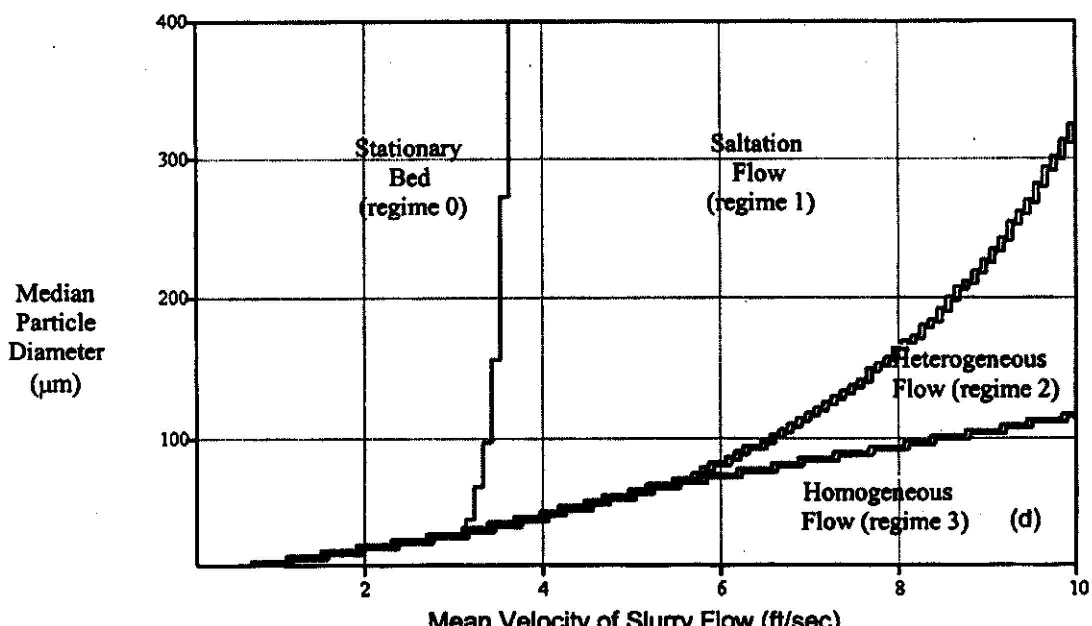


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Figure F-15a. Comparison of Best-Estimate Critical Velocity Predictions vs. Particle Solids Median Diameter.

$T := 60$ °C $\kappa_{cv} = 1$ $D_{pipe} := 3.068 \cdot in$ $\rho_c := 1.2 \cdot \frac{kg}{liter}$ $\mu_c := \mu_{cL}(\rho_c, T)$ $\mu_c = 0.771\ cP$ $\rho_d := 3 \cdot \frac{kg}{liter}$ $\alpha_d := 15\%$

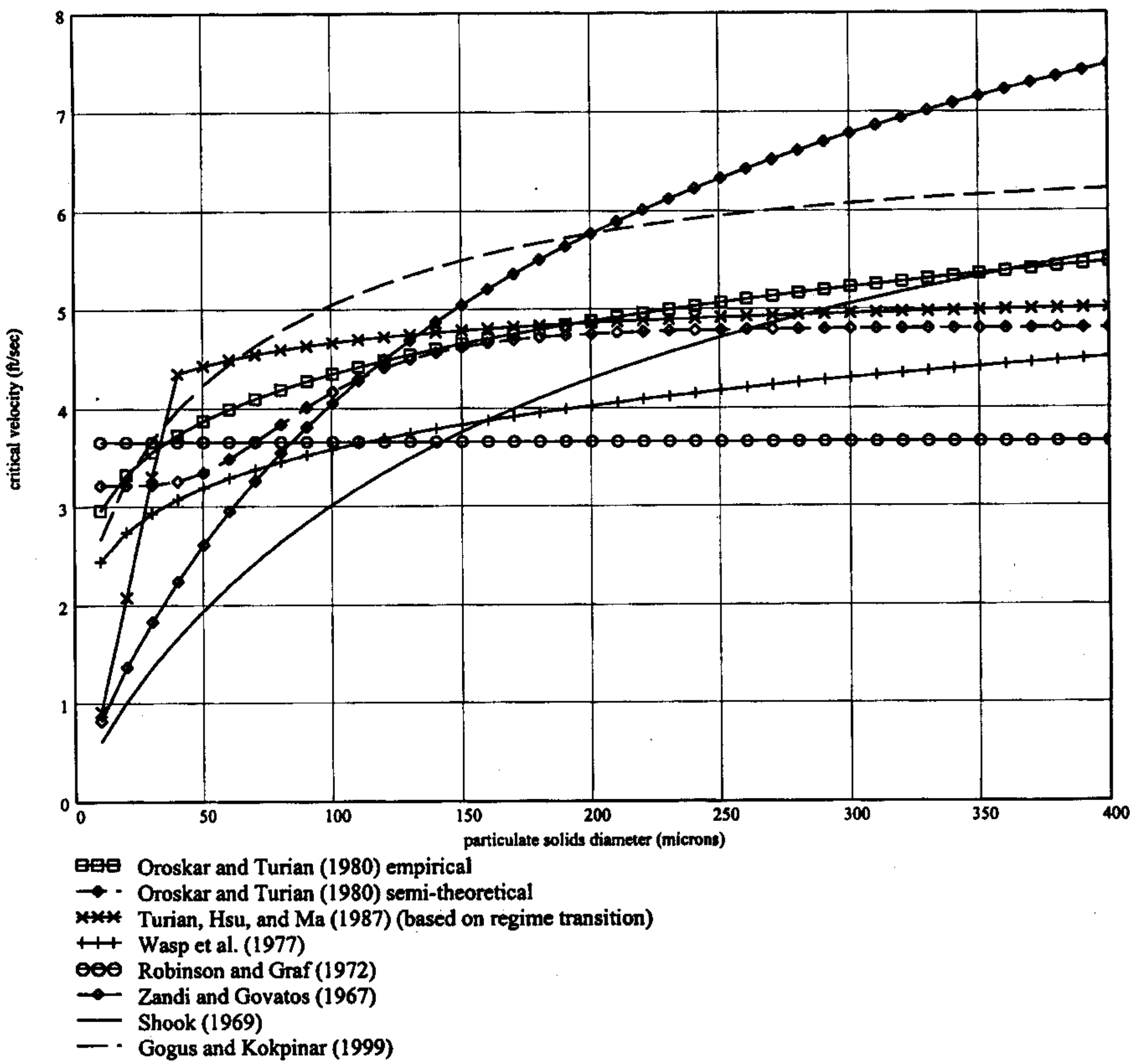

Figure F-15b. Comparison of Best-Estimate Critical Velocity Predictions vs. Particle Solids Median Diameter.

$T = 60$ °C $\kappa_{cv} = 1$ $D_{pipe} = 3.068\,in$ $\rho_c = 1.2\,\frac{kg}{liter}$ $\mu_c = 0.771\,cP$ $\rho_d = 3\,\frac{kg}{liter}$ $\alpha_d := 10\cdot\%$

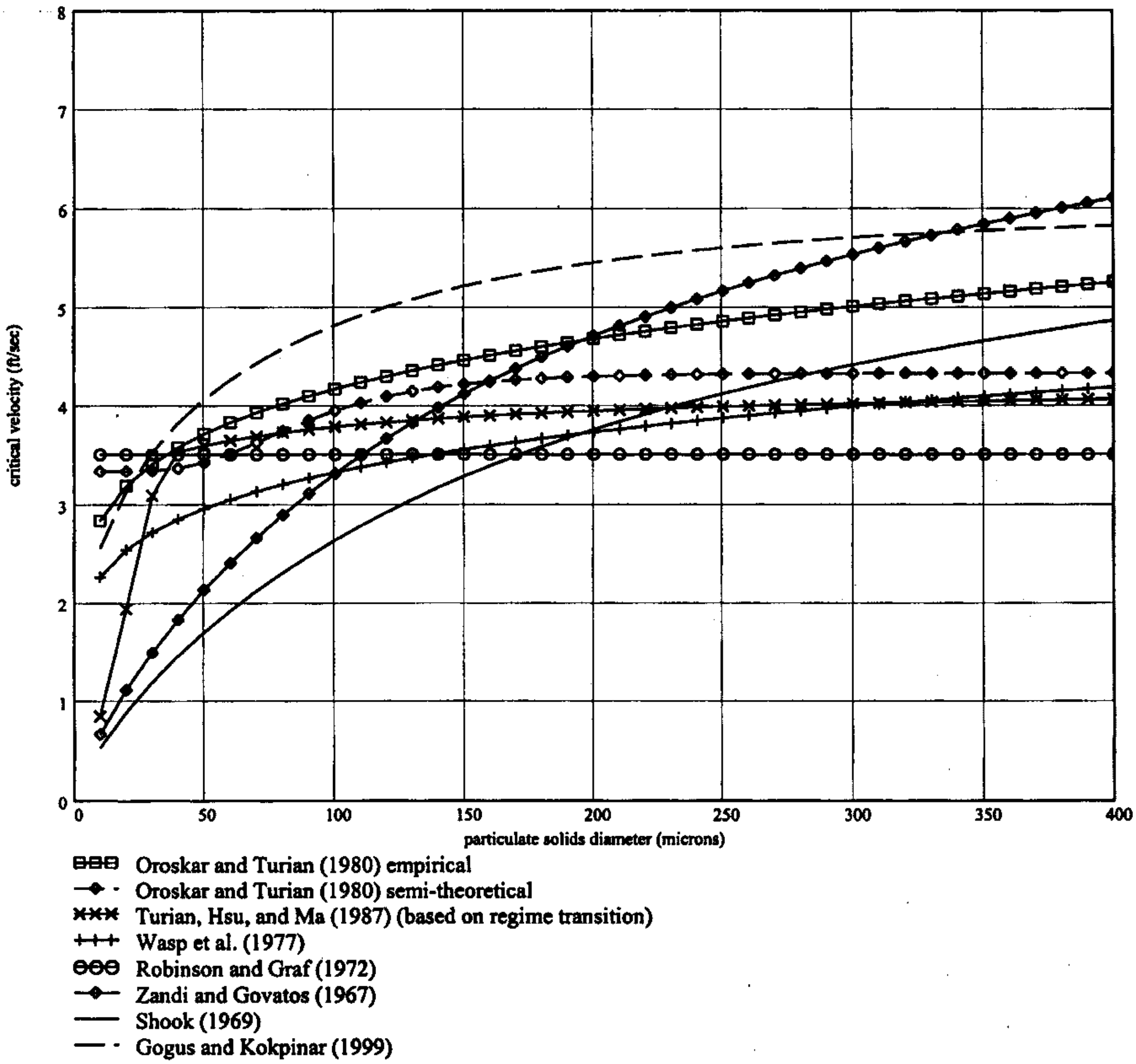

Figure F-15c. Comparison of Best-Estimate Critical Velocity Predictions vs. Solid Particle Volume Fraction.

T = 60 °C $\kappa_{cv} = 1$ $D_{pipe} = 3.068\,in$ $\rho_c = 1.2\frac{kg}{liter}$ $\mu_c = 0.771\,cP$ $\rho_d = 3\frac{kg}{liter}$ $D_d := 400\cdot\mu m$

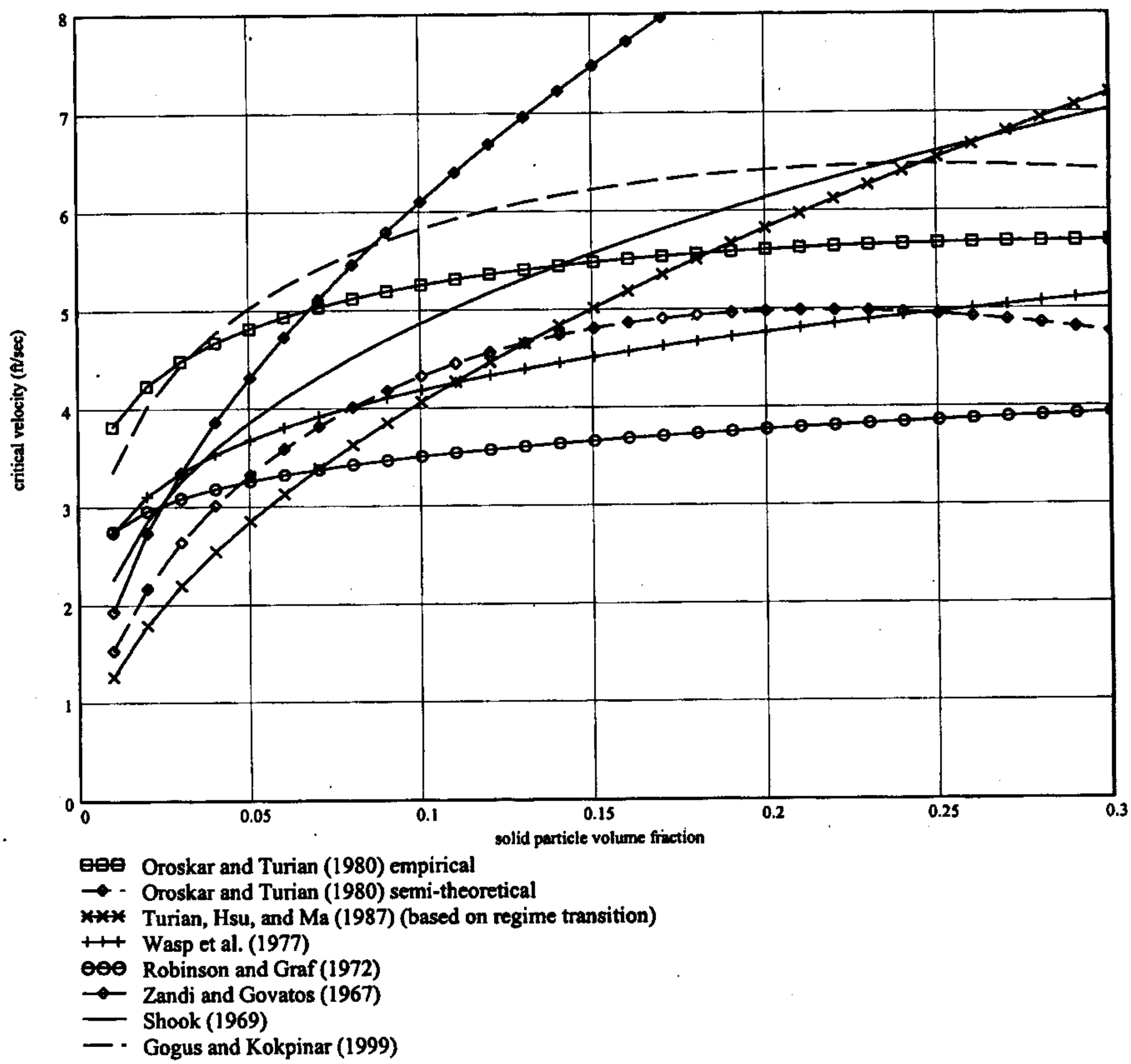

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Figure F-15d. Comparison of Best-Estimate Critical Velocity Predictions vs. Solid Particle Volume Fraction.

T = 60 °C $\kappa_{cv} = 1$ $D_{pipe} = 3.068\,in$ $\rho_c = 1.2\,\frac{kg}{liter}$ $\mu_c = 0.771\,cP$ $\rho_d = 3\,\frac{kg}{liter}$ $D_d := 40\cdot\mu m$

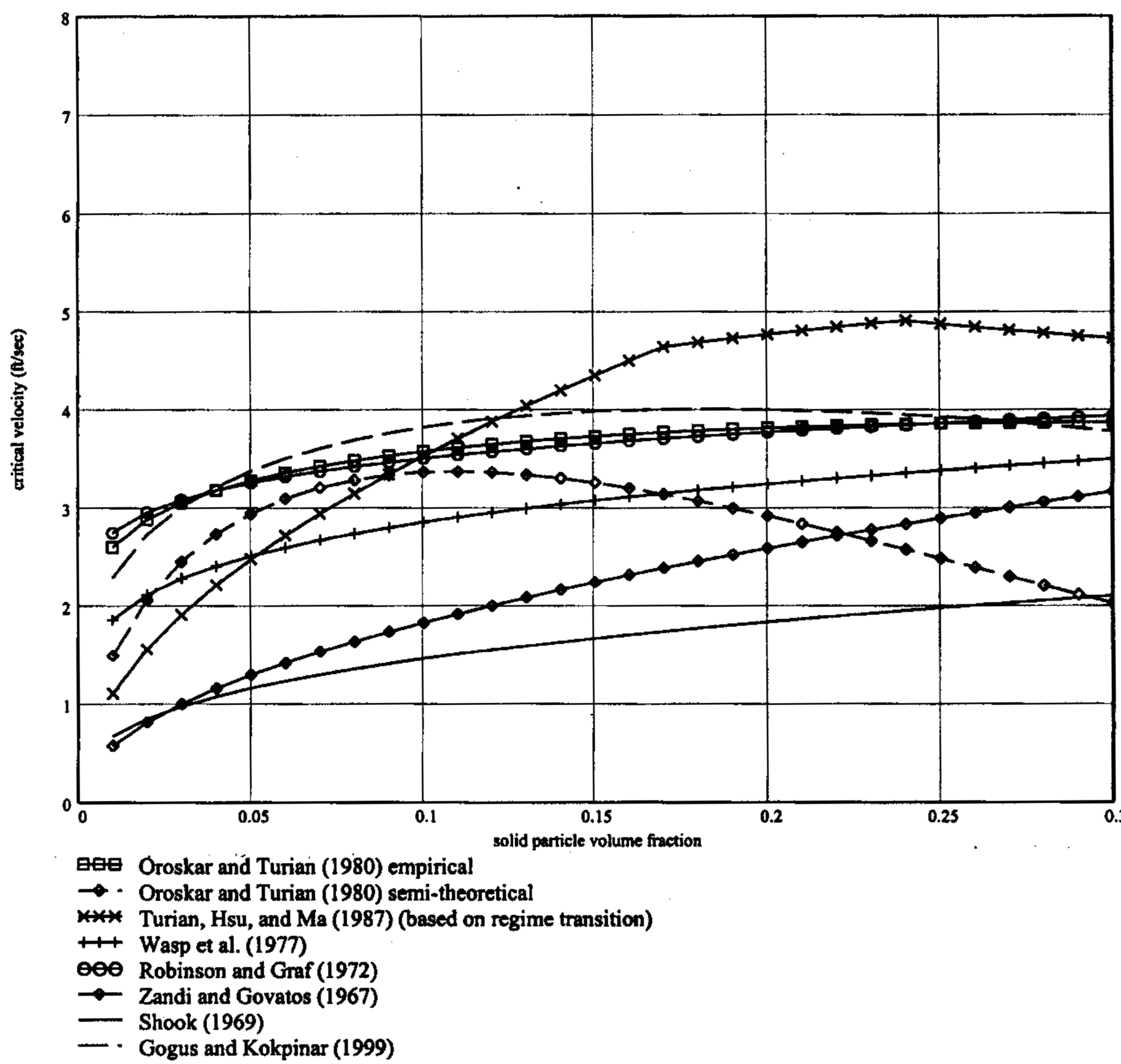

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Figure F-16. Δ Friction Factor ($f_d = f - f_c$) Comparison.

$T = 60$ °C $D_{pipe} = 3.068\,in$ $\rho_c := 1.2 \cdot \frac{kg}{liter}$ $D_d := 200 \cdot \mu m$ $\rho_d := 3 \cdot \frac{kg}{liter}$ $\theta := 0 \cdot deg$ $\kappa_f := 1$

$\mu_c := \mu_{cL}(\rho_c, T)$ $\mu_c = 0.771\,cP$ $\alpha_d := 10 \cdot \%$ $\kappa_{cv} := 1$

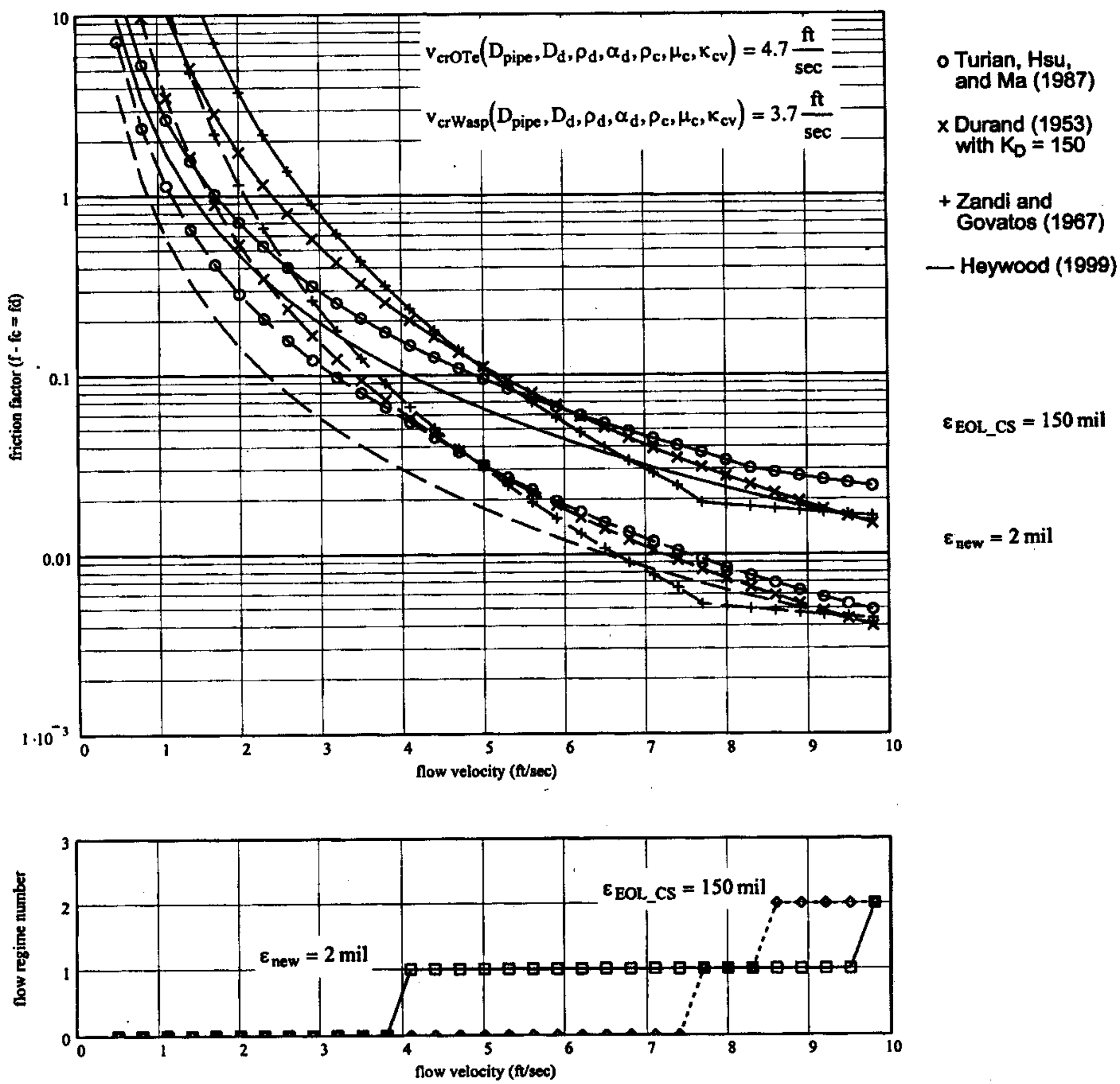

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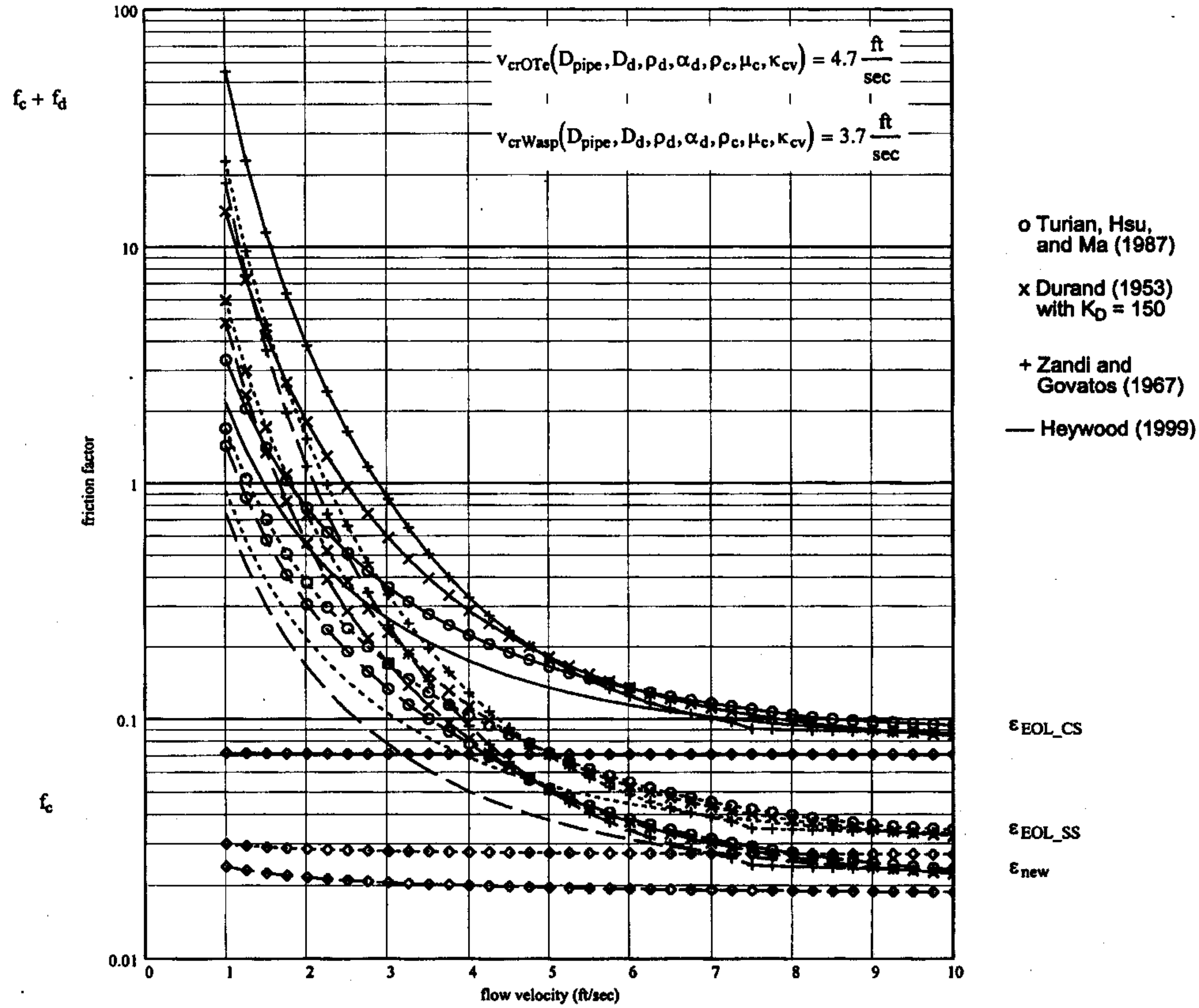
Figure 17. Friction Factor vs. Carrier Liquid Flow Velocity Comparison.

$T = 60\ °C$ $D_{pipe} = 3.068\,in$ $\rho_c = 1.2\,\frac{kg}{liter}$ $D_d := 200\cdot\mu m$ $\kappa_{cv} := 1$

$\mu_c = 0.771\,cP$ $\alpha_d = 10\%$ $\rho_d := 3\cdot\frac{kg}{liter}$ $\theta = 0\,deg$ $\kappa_f := 1$



f_c, non-slurry liquid without particles, $\alpha_d = 0$
$f_c + f_d$, slurry with particles

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$\kappa_f := 1 \quad \beta_f := 1 \quad T = 60\ ^{o}C \quad \boxed{D_d := 400 \cdot \mu m} \quad \boxed{\alpha_d := 10 \cdot \%} \quad D_{pipe} := 3.068 \cdot in \quad L := 1000 \cdot ft \quad \theta := 0 \cdot deg \quad \boxed{v_c := 5 \cdot \frac{ft}{sec}}$

$$\Delta p_{CS_{i,j}} := \Delta p\left(D_{pipe}, v_c, \rho_{c_i}, \mu_{c_i}, \varepsilon_{EOL\_CS}, D_d, \rho_{d_j}, \alpha_d, L, \beta_f, \kappa_f, \theta\right) \qquad R_{CS_{i,j}} := R_d\left(D_{pipe}, v_c, \rho_{c_i}, \mu_{c_i}, \varepsilon_{EOL\_CS}, D_d, \rho_{d_j}, \alpha_d, 1\right)$$

$$\Delta p_{SS_{i,j}} := \Delta p\left(D_{pipe}, v_c, \rho_{c_i}, \mu_{c_i}, \varepsilon_{EOL\_SS}, D_d, \rho_{d_j}, \alpha_d, L, \beta_f, \kappa_f, \theta\right) \qquad R_{SS_{i,j}} := R_d\left(D_{pipe}, v_c, \rho_{c_i}, \mu_{c_i}, \varepsilon_{EOL\_SS}, D_d, \rho_{d_j}, \alpha_d, 1\right)$$

Figure 18a. Contour Plot of Best-Estimate Pressure Drop (psi) per 1000 ft of Pipe at Specified Flow Velocity (5 ft/s) (CS solid line, SS dashed line) vs.Particle Solids Density and Carrier Liquid Density - (Turian, Hsu, and Ma 1987)

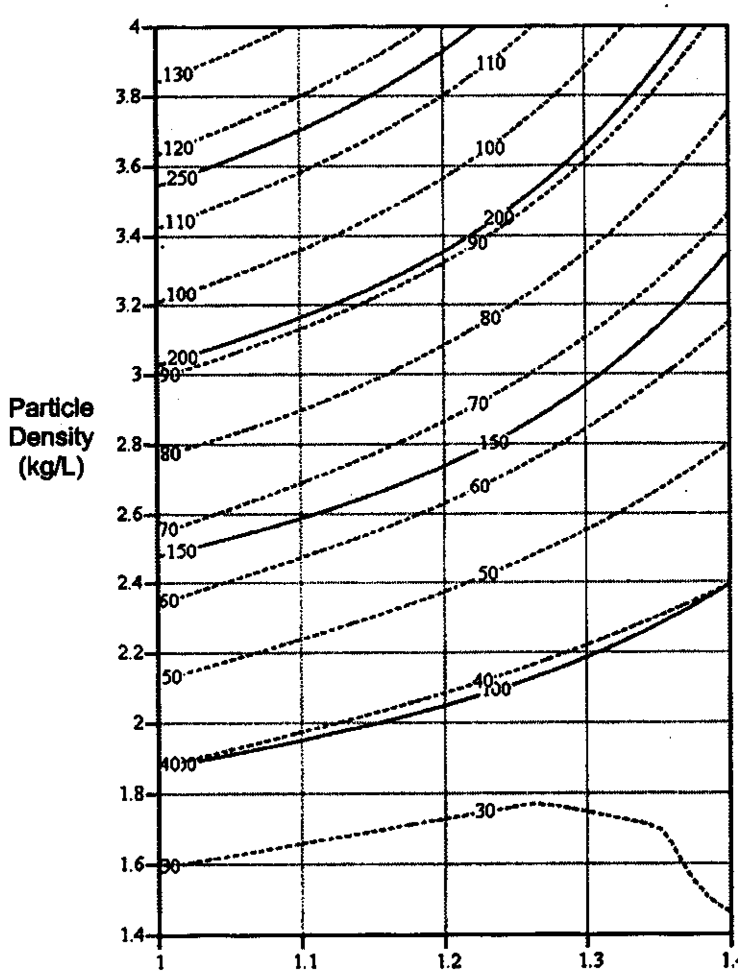
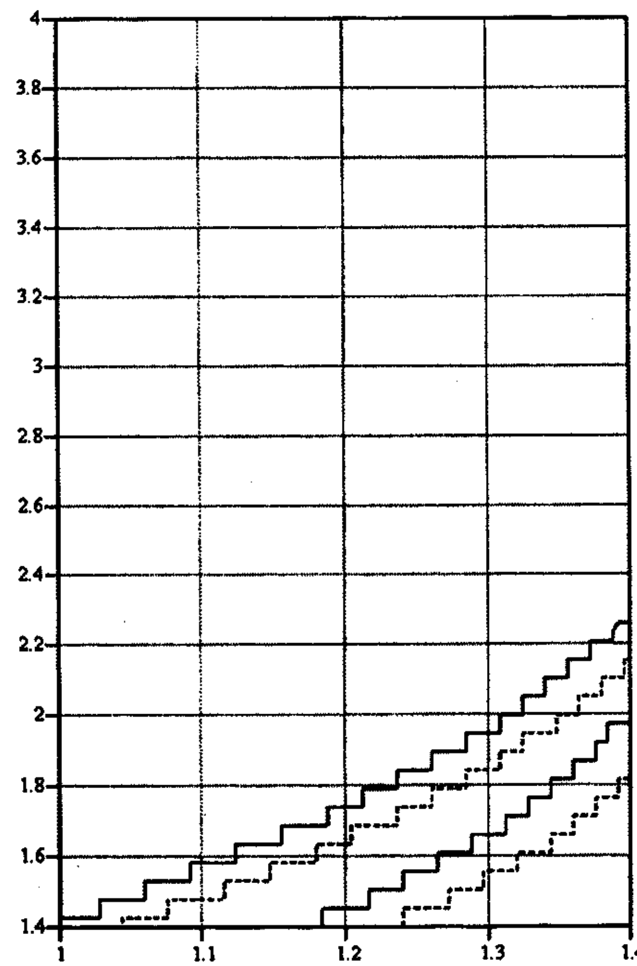


Figure 18b. Corresponding Flow Regime Contour Plot.

$R_{CS_{0,N}} = 0 \quad R_{SS_{0,N}} = 0 \quad R_{CS_{N,N}} = 0 \quad R_{SS_{N,N}} = 0$

$R_{CS_{0,0}} = 2 \quad R_{SS_{0,0}} = 1 \quad R_{CS_{N,0}} = 3 \quad R_{SS_{N,0}} = 3$



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EVALUATION ANALYSIS

Calc. No. RPP-LJJ-002
Revision: 0

Client: Numatec Hanford Corporation
Subject: Critical Velocity and Pressure Drop Study in Support of Waste Tank Feed Transfer System
Location: 200 Area - Hanford Site, Richland, Washington

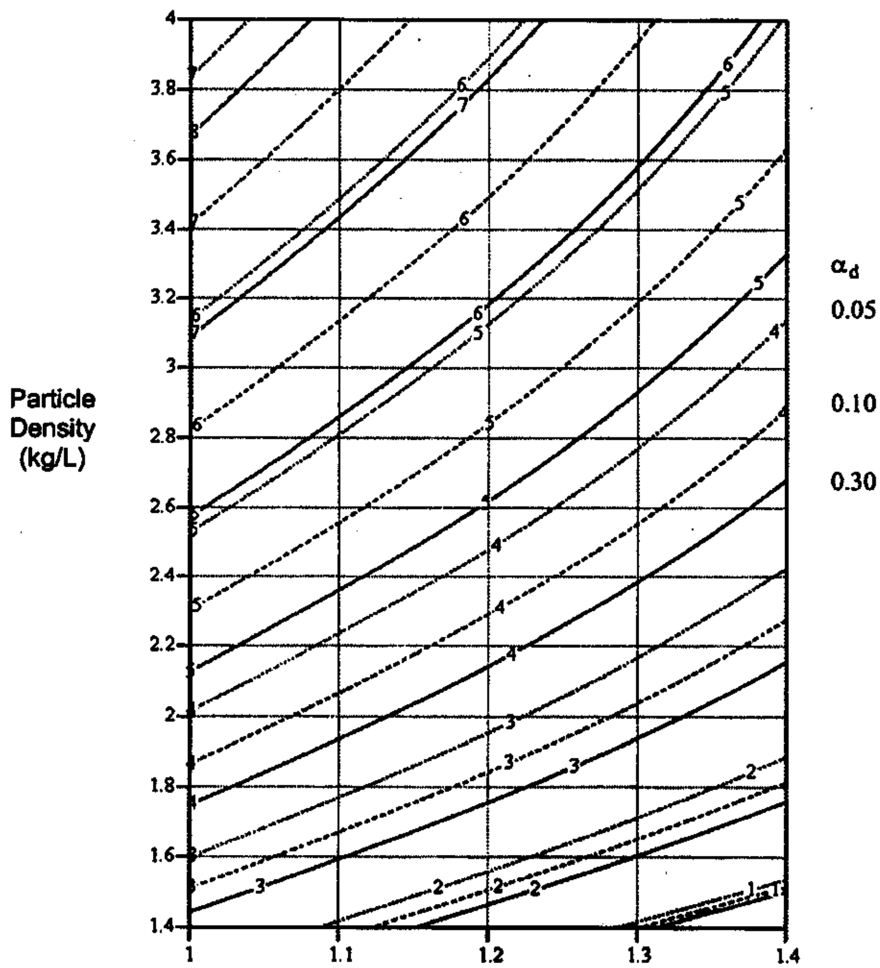
WO/Job No. 110299 & 110300/BA10
Date: 03/08/2000 By: L. J. Julyk
Checked: 03/10/2000 By: T. C. Oten
Revised: By:

$\kappa_{cv} := 1$ $\beta_{cv} := 1.2$ $T = 60$ °C $D_d = 400\,\mu m$ $D_{pipe} = 3.068\,in$

$v1_{crit_{i,j}} := v_{cr}(D_{pipe}, D_d, \rho_{d_j}, 0.30, \rho_{c_i}, \mu_{c_i}, \kappa_{cv}, \beta_{cv})$

$v2_{crit_{i,j}} := v_{cr}(D_{pipe}, D_d, \rho_{d_j}, 0.10, \rho_{c_i}, \mu_{c_i}, \kappa_{cv}, \beta_{cv})$ $v3_{crit_{i,j}} := v_{cr}(D_{pipe}, D_d, \rho_{d_j}, 0.05, \rho_{c_i}, \mu_{c_i}, \kappa_{cv}, \beta_{cv})$

Figure 18c. Contour Plot of Best-Estimate Critical Velocity (ft/s) (Oroskar and Turian 1980) vs. Carrier Liquid Density and Particle Density for Selected Particle Volume Fractions.



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Location: 200 Area - Hanford Site, Richland, Washington

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Date: 03/08/2000 By: L. J. Julyk
Checked: 03/10/2000 By: T. C. Oten
Revised: By:

$\kappa_f = 1$ $T = 60$ °C $D_d := 100 \cdot \mu m$ $\alpha_d := 10 \cdot \%$ $D_{pipe} = 3.068\,in$ $L = 1000\,ft$ $\theta = 0\,deg$ $v_c := 5 \cdot \frac{ft}{sec}$

$\Delta p_{CS_{i,j}} := \Delta p\left(D_{pipe}, v_c, \rho_{c_i}, \mu_{c_i}, \varepsilon_{EOL\_CS}, D_d, \rho_{d_j}, \alpha_d, L, \beta_f, \kappa_f, \theta\right)$

$\Delta p_{SS_{i,j}} := \Delta p\left(D_{pipe}, v_c, \rho_{c_i}, \mu_{c_i}, \varepsilon_{EOL\_SS}, D_d, \rho_{d_j}, \alpha_d, L, \beta_f, \kappa_f, \theta\right)$

$R_{CS_{i,j}} := R_d\left(D_{pipe}, v_c, \rho_{c_i}, \mu_{c_i}, \varepsilon_{EOL\_CS}, D_d, \rho_{d_j}, \alpha_d, 1\right)$

$R_{SS_{i,j}} := R_d\left(D_{pipe}, v_c, \rho_{c_i}, \mu_{c_i}, \varepsilon_{EOL\_SS}, D_d, \rho_{d_j}, \alpha_d, 1\right)$

Figure 19a. Contour Plot of Best-Estimate Pressure Drop (psi) per 1000 ft of Pipe at Specified Flow Velocity (5 ft/s) (CS solid line, SS dashed line) vs.Particle Solids Density and Carrier Liquid Density - (Turian, Hsu, and Ma 1987).

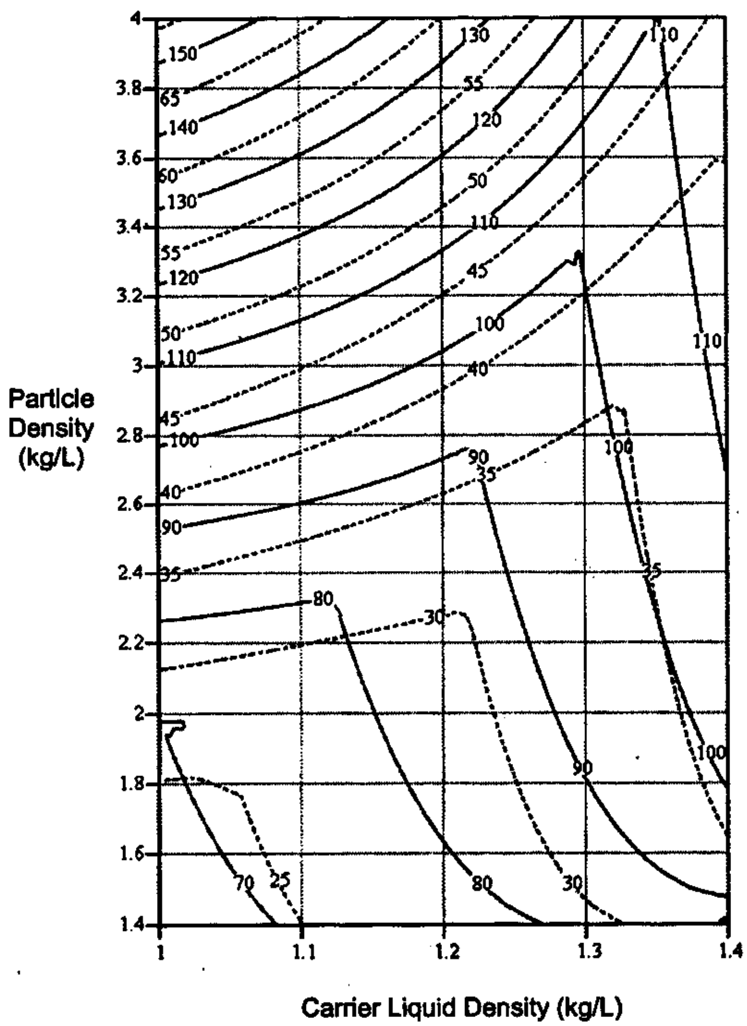
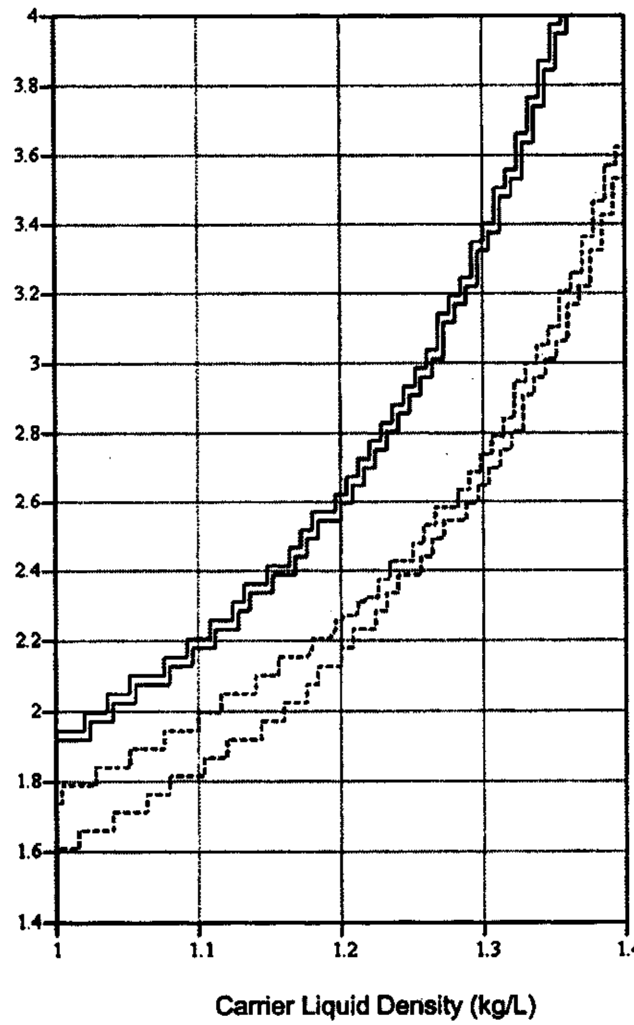


Figure 19b. Corresponding Flow Regime Contour Plot.

$R_{CS_{0,N}} = 0$ $R_{SS_{0,N}} = 0$ $R_{CS_{N,N}} = 3$ $R_{SS_{N,N}} = 1$

$R_{CS_{0,0}} = 3$ $R_{SS_{0,0}} = 3$ $R_{CS_{N,0}} = 3$ $R_{SS_{N,0}} = 3$



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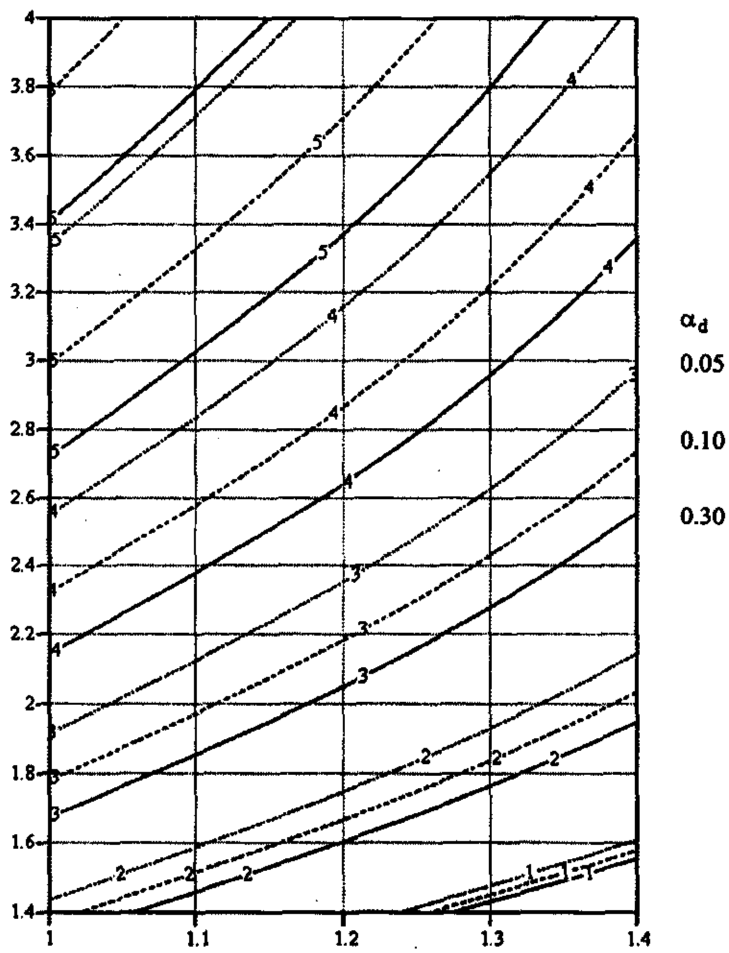
		Checked: 03/10/2000	By: T. C. Oten
Location:	200 Area - Hanford Site, Richland, Washington	Revised:	By:

$\kappa_{cv} = 1$ $\beta_{cv} = 1.2$ $T = 60$ °C $\boxed{D_d = 100\,\mu m}$ $D_{pipe} = 3.068\,in$

$v1_{crit_{i,j}} := v_{cr}\left(D_{pipe}, D_d, \rho_{d_j}, 0.30, \rho_{c_i}, \mu_{c_i}, \kappa_{cv}, \beta_{cv}\right)$

$v2_{crit_{i,j}} := v_{cr}\left(D_{pipe}, D_d, \rho_{d_j}, 0.10, \rho_{c_i}, \mu_{c_i}, \kappa_{cv}, \beta_{cv}\right)$ $v3_{crit_{i,j}} := v_{cr}\left(D_{pipe}, D_d, \rho_{d_j}, 0.05, \rho_{c_i}, \mu_{c_i}, \kappa_{cv}, \beta_{cv}\right)$

Figure 19c. Contour Plot of Best-Estimate Critical Velocity (ft/s) (Oroskar and Turian 1980) vs. Carrier Liquid Density and Particle Density for Selected Particle Volume Fractions.



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Subject: Critical Velocity and Pressure Drop Study in Support of Waste Tank Feed Transfer System
Location: 200 Area - Hanford Site, Richland, Washington

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Date: 03/08/2000 By: L. J. Julyk
Checked: 03/10/2000 By: T. C. Oten
Revised: By:

$\kappa_f = 1$ $T = 60$ °C $D_d := 40 \cdot \mu m$ $\alpha_d := 10 \cdot \%$ $D_{pipe} = 3.068\,in$ $L = 1000\,ft$ $\theta = 0\,deg$ $v_c := 5 \cdot \frac{ft}{sec}$

$\Delta p_{CS_{i,j}} := \Delta p\left(D_{pipe}, v_c, \rho_{c_i}, \mu_{c_i}, \varepsilon_{EOL\_CS}, D_d, \rho_{d_j}, \alpha_d, L, \beta_f, \kappa_f, \theta\right)$

$\Delta p_{SS_{i,j}} := \Delta p\left(D_{pipe}, v_c, \rho_{c_i}, \mu_{c_i}, \varepsilon_{EOL\_SS}, D_d, \rho_{d_j}, \alpha_d, L, \beta_f, \kappa_f, \theta\right)$

$R_{CS_{i,j}} := R_d\left(D_{pipe}, v_c, \rho_{c_i}, \mu_{c_i}, \varepsilon_{EOL\_CS}, D_d, \rho_{d_j}, \alpha_d, 1\right)$

$R_{SS_{i,j}} := R_d\left(D_{pipe}, v_c, \rho_{c_i}, \mu_{c_i}, \varepsilon_{EOL\_SS}, D_d, \rho_{d_j}, \alpha_d, 1\right)$

Figure 20a. Contour Plot of Best-Estimate Pressure Drop (psi) per 1000 ft of Pipe at Specified Flow Velocity (5 ft/s) (CS solid line, SS dashed line) vs.Particle Solids Density and Carrier Liquid Density - (Turian, Hsu, and Ma 1987).

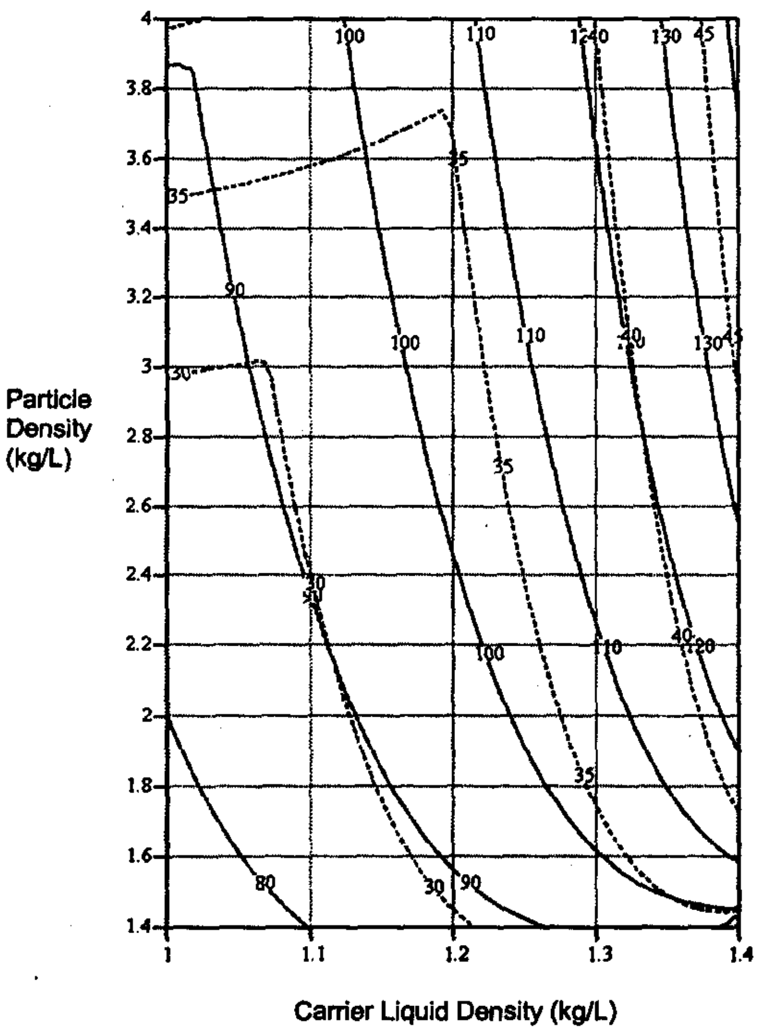
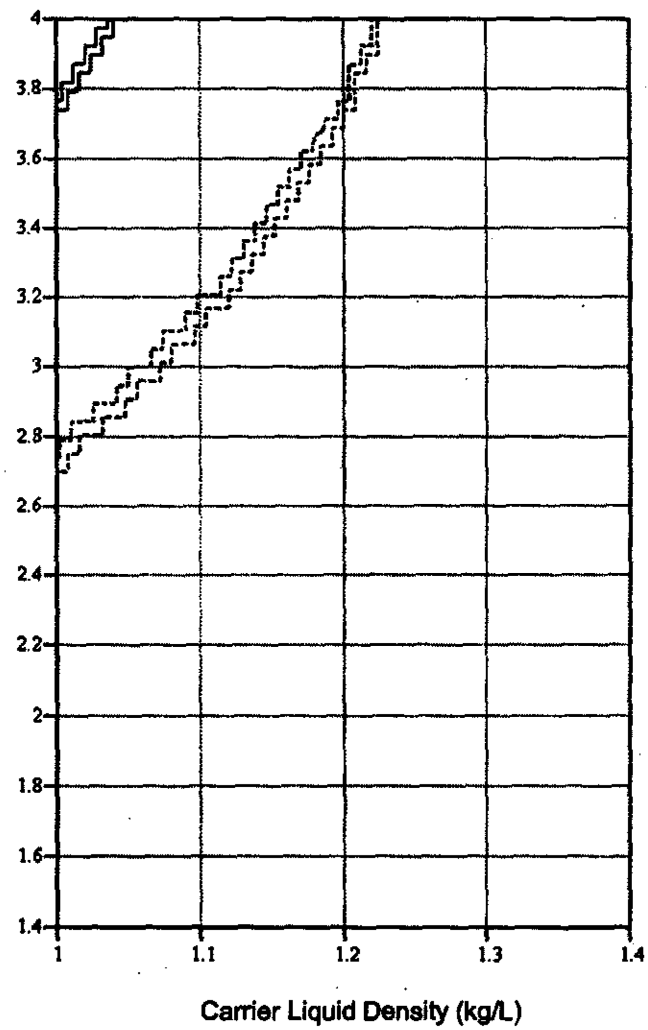


Figure 20b. Corresponding Flow Regime Contour Plot.

$R_{CS_{0,N}} = 0$ $R_{SS_{0,N}} = 0$ $R_{CS_{N,N}} = 3$ $R_{SS_{N,N}} = 3$

$R_{CS_{0,0}} = 3$ $R_{SS_{0,0}} = 3$ $R_{CS_{N,0}} = 3$ $R_{SS_{N,0}} = 3$



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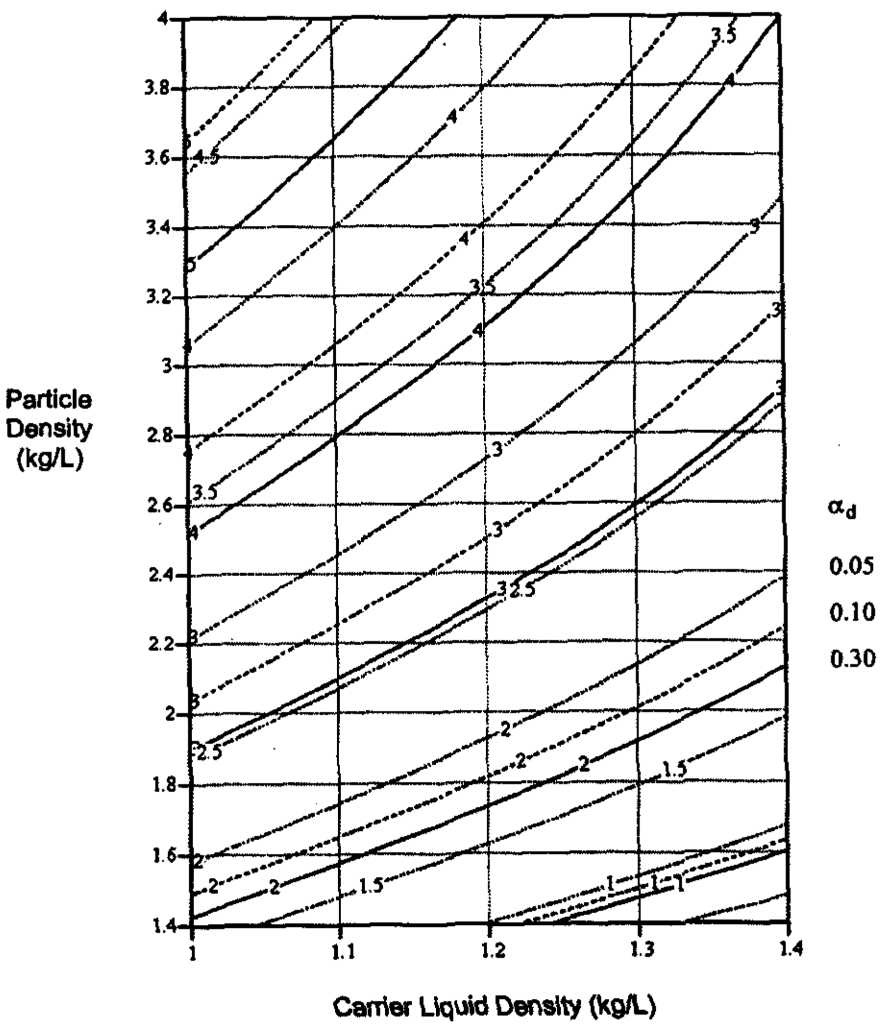
Subject:	Critical Velocity and Pressure Drop Study in Support of Waste Tank Feed Transfer System	Date: 03/08/2000	By: L. J. Julyk
		Checked: 03/10/2000	By: T. C. Oten
Location:	200 Area - Hanford Site, Richland, Washington	Revised:	By:

$\kappa_{cv} = 1$ $\beta_{cv} = 1.2$ $T = 60$ °C $\boxed{D_d = 40\,\mu m}$ $D_{pipe} = 3.068$ in

$$v1_{crit_{i,j}} := v_{cr}\left(D_{pipe}, D_d, \rho_{d_j}, 0.30, \rho_{c_i}, \mu_{c_i}, \kappa_{cv}, \beta_{cv}\right)$$

$$v2_{crit_{i,j}} := v_{cr}\left(D_{pipe}, D_d, \rho_{d_j}, 0.10, \rho_{c_i}, \mu_{c_i}, \kappa_{cv}, \beta_{cv}\right) \qquad v3_{crit_{i,j}} := v_{cr}\left(D_{pipe}, D_d, \rho_{d_j}, 0.05, \rho_{c_i}, \mu_{c_i}, \kappa_{cv}, \beta_{cv}\right)$$

Figure 20c. Contour Plot of Best-Estimate Critical Velocity (ft/s) (Oroskar and Turian 1980) vs. Carrier Liquid Density and Particle Density for Selected Particle Volume Fractions.



PIPE-OTpl.MCD

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Location: 200 Area - Hanford Site, Richland, Washington

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Date: 03/08/2000 By: L. J. Julyk
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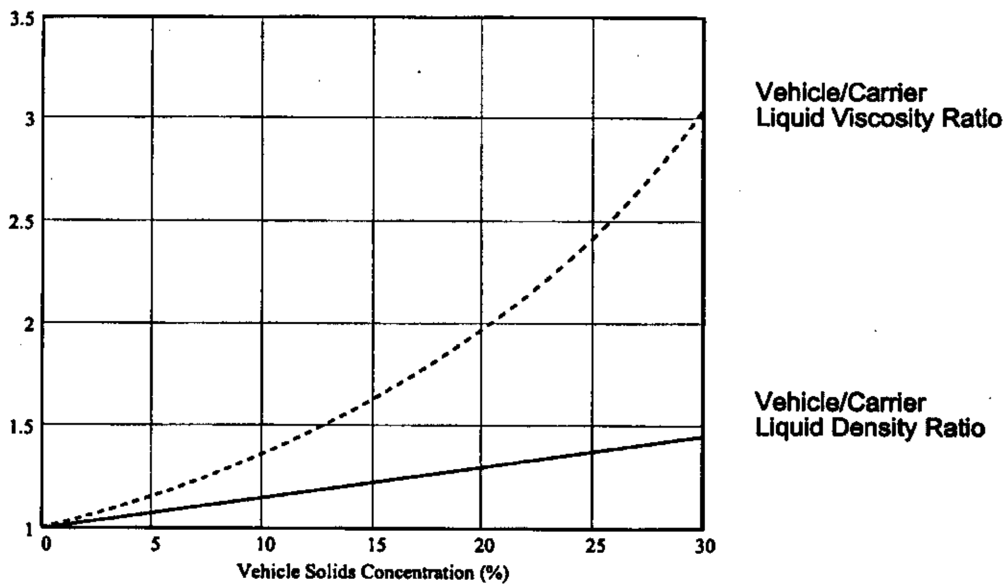
Figure F-21. Normalized "Vehicle" Liquid Density and Viscosity Relations vs. "Vehicle" Solids Concentration.

$$\mu_c(\mu_L, \Phi_v) := \mu_L \cdot \left(1 + 2.5 \cdot \Phi_v + 10.05 \cdot \Phi_v^2 + 0.00273 \cdot \exp(16.6 \cdot \Phi_v)\right)$$

$$\rho_c(\rho_s, \rho_L, \Phi_v) := \rho_s \cdot \Phi_v + \rho_L \cdot (1 - \Phi_v)$$

$T := 60\ ^oC$ $\quad \rho_L := 1.2 \cdot \dfrac{kg}{liter}$ $\quad \mu_L := \mu_{cL}(\rho_L, T)$ $\quad \mu_L = 0.771\,cP$ $\quad \rho_s := 3 \cdot \dfrac{kg}{liter}$



APPENDIX G

WASP MODEL VERIFICATION

Calculations contained herein were produced in Mathcad 2000 Professional (Mathcad is a registered trademark of MathSoft, Inc. of Cambridge, Massachusetts).

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CONVERSIONS

ft	feet = 0.3048 meter (m)
in.	inch = 2.54 centimeters (cm)
lbf/in^2	pounds per square inch = 0.06895 megapascals (MPa)
mils	0.001 in. = 0.0254 millimeter (mm)
gpm	0.0631 liter/second (L/s)
cP	centipose = 0.001 kilogram/meter-second (kg/m-s)

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EVALUATION ANALYSIS

Calc. No. RPP-LJJ-002
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Client: Numatec Hanford Corporation
Subject: Critical Velocity and Pressure Drop Study in Support of Waste Tank Feed Transfer System (Wasp Test Case)
Location: 200 Area - Hanford Site, Richland, Washington

WO/Job No. 110299 & 110300/BA10
Date: 03/08/2000 By: L. J. Julyk
Checked: 03/10/2000 By: T. C. Oten
Revised: By:

PROBLEM

Verification check of Wasp method against published example.

APPROACH

Compare results of Wasp et al. 1977, illustrative example, page 95, with results obtained through application of equations given in Appendix F. All necessary equations are copied from Appendix F with following modifications unique to the check problem:

1. The viscosity relation from Wasp et al. 1977, illustrative example, page 95 is used.
2. Stokes flow for the settling particles is assumed in accordance with the illustrative example.

CONCLUSION

Less than 0.2% error is shown between results obtained through application of equations given in Appendix F and results of Wasp et al. 1977, illustrative example, page 95. This validates the implementation of the Wasp method in Appendix F.

REFERENCES

Wasp, E. J., J. P. Kenny, and R. L. Gandhi, 1977, *Solid-Liquid Flow -- Slurry Pipeline Transportation*, Trans. Tech. Publ., Rockport, MA.

PRELIMINARIES

$TOL = 1 \times 10^{-7}$

$\mu m \equiv 10^{-6} \cdot m$

$cP \equiv 10^{-2} \cdot poise$

$\Delta\varepsilon := TOL \cdot 10^{-1} \quad \Delta\varepsilon = 1 \times 10^{-8}$

Return values of vector ϕ_p in accordance with nonzero values in vector $\phi_z > \Delta\varepsilon$

```
pack(φp, φz) := | J ← length(φz) − 1
                | k ← 0
                | for j ∈ 0..J
                |   if φz_j > Δε
                |     | φ_k ← φp_j
                |     | k ← k + 1
                | if k = 0
                |   | φ_0 ← Δε
                |   | φ_1 ← Δε
                | φ
```

Return d_β particle diameter that is βth percentile value by volumes

```
Dβ(dp, φcum, β) := | J ← length(φcum) − 1
                   | for k ∈ 0..J
                   |   break if φcum_k > β
                   | (dp_k − dp_{k−1}) / (φcum_k − φcum_{k−1}) · (β − φcum_{k−1}) + dp_{k−1}
```

$$D_\beta(d_p, \phi_{cum}, \beta) := \frac{d_{p_k} - d_{p_{k-1}}}{\phi_{cum_k} - \phi_{cum_{k-1}}} \cdot \left(\beta - \phi_{cum_{k-1}}\right) + d_{p_{k-1}}$$

The Reynolds Number for Newtonian flow is defined as

$$Re(D,v,\rho,\mu) := D\cdot v\cdot\frac{\rho}{\mu}$$

where D is a characteristic length, v is the flow velocity, ρ is the fluid density, and μ is the fluid viscosity.

The terminal settling velocity (v_∞) of spherical particle settling in a stagnant unbound liquid is given by the following:

For Stokes flow ($Re < 0.1$) the drag coefficient of a spherical particle is given by

$$C_D(D_d,v,\rho_c,\mu_c) := \frac{24}{Re(D_d,v,\rho_c,\mu_c)}$$

which leads the following explicit relation for v_∞

$$v_\infty(D_d,\rho_d,\rho_c,\mu_c) := g\cdot(\rho_d-\rho_c)\cdot(D_d)^2\cdot(18\cdot\mu_c)^{-1}$$

Note that the check problem assumes Stokes flow.

The approximation developed by Churchill in 1977 that includes the laminar and turbulent regimes as well as the transition regime between laminar and turbulent flow is used for the friction factor, i.e.;

$$f'_c(Re,\eta) := \left|\begin{array}{l} A \leftarrow \left[2.457\cdot\ln\left[\dfrac{1}{\left(\dfrac{7}{Re}\right)^{0.9}+(0.27\cdot\eta)}\right]\right]^{16} \\ B \leftarrow \left(\dfrac{37530}{Re}\right)^{16} \\ 8\cdot\left[\left(\dfrac{8}{Re}\right)^{12}+\left(\dfrac{1}{A+B}\right)^{\frac{3}{2}}\right]^{\frac{1}{12}} \end{array}\right.$$

or $f_c(D_{pipe},v_c,\rho_c,\mu_c,\varepsilon) := f'_c\left(Re(D_{pipe},v_c,\rho_c,\mu_c),\dfrac{\varepsilon}{D_{pipe}}\right)$

where v_c flow velocity of carrier liquid

Density of water as a function of temperature (°C)

$$\rho_{water}(T) := \left[999.7-0.10512\cdot(T-10)-0.005121\cdot(T-10)^2+0.00001329\cdot(T-10)^3\right]\cdot\frac{kg}{m^3}$$

mass density of water (5 °C < T <100 °C)

Viscosity of water as a function of temperature (°C)

$$\mu_{water}(T) := \left|\begin{array}{l} 100\cdot\exp\left[\ln(10)\cdot\left[\dfrac{1301}{998.333+8.1855\cdot(T-20)+0.00585\cdot(T-20)^2}-3.30233\right]\right]\cdot cP \text{ if } T\le 20 \\ (1.002)\cdot\exp\left[\ln(10)\cdot\left[\dfrac{1.3272\cdot(20-T)-0.001053\cdot(T-20)^2}{T+105}\right]\right]\cdot cP \text{ otherwise} \end{array}\right.$$

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Subject:	Critical Velocity and Pressure Drop Study in Support of Waste Tank Feed Transfer System (Wasp Test Case)	Date: 03/08/2000	By: L. J. Julyk
		Checked: 03/10/2000	By: T. C. Oten
Location:	200 Area - Hanford Site, Richland, Washington	Revised:	By:

$T_F(t_C) := \frac{9}{5} \cdot t_C + 32$ $\quad T_C(t_F) := \frac{5}{9}(t_F - 32)$ $\quad T_C(68) = 20$ $\quad \rho_L := \rho_{water}(T_C(68))$ $\quad \mu_L := \mu_{water}(T_C(68))$

$\rho_L = 0.998 \frac{kg}{liter}$ $\quad \mu_L = 1.002\,cP$

Liquid Density as a Function of Solids Concentration

$$\rho_c(\rho_s, \rho_L, \Phi_v) := \rho_s \cdot \Phi_v + \rho_L \cdot (1 - \Phi_v)$$

Viscosity as a function of solids concentration per

Wasp 1977, illustrative example, page 95

$i1 := 0..5$ $\quad v\phi_{1_{i1}} :=$ $\quad v\mu_{c1_{i1}} :=$

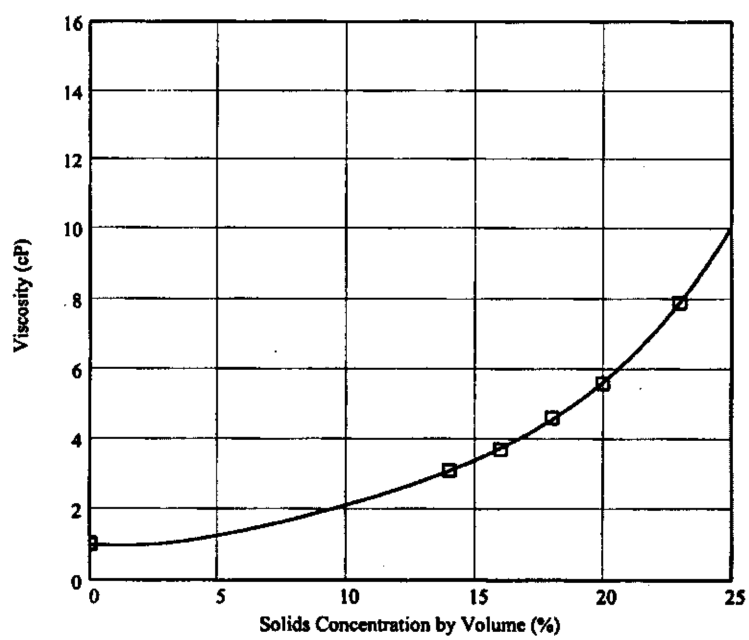
$v\phi_1$	$v\mu_{c1}$
0	1.002
14	3.1
16	3.7
18	4.6
20	5.6
23	7.9

$v\phi_1 := v\phi_1 \cdot \%$

$v\mu_{c1} := v\mu_{c1} \cdot cP$

$vs_1 := \text{regress}\left(v\phi_1, \frac{v\mu_{c1}}{cP}, 4\right)$ $\quad \mu_c(\mu_L, \Phi_v) := \text{interp}\left(vs_1, v\phi_1, \frac{v\mu_{c1}}{cP}, \Phi_v\right) \cdot cP$

Comparison of Viscosity Relations vs. "Vehicle" Solids Concentration.



Wasp et al. 1977, illustrative example, page 95

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		Checked: 03/10/2000	By: T. C. Oten
Location:	200 Area - Hanford Site, Richland, Washington	Revised:	By:

Wasp's Method for Pressure Drop Estimate (Wasp et al. 1977)

assume $\beta := 1 \qquad \kappa := 0.4$

$$\phi_v(v,\rho_L,\rho_c,\mu_c,d_p,\rho_s,\phi_s,f) := \phi_s \cdot 10^{\frac{-1.8}{\beta\cdot\kappa}\cdot\frac{v_\infty(d_p,\rho_s,\rho_c,\mu_c)}{v\cdot\sqrt{\frac{f\cdot\frac{\rho_L}{\rho_c}}{8}}}}$$

$$\Phi_c(v,\rho_L,\mu_L,d_p,\rho_s,\phi_s,f) := \left| \begin{array}{l} J \leftarrow \text{length}(d_p) - 1 \\ \Phi'_v \leftarrow 0.5\cdot\sum_{j=0}^{J} \phi_{s_j} \\ \text{root}\left(\Phi'_v - \sum_{j=0}^{J} \phi_v\left(v,\rho_L,\rho_c(\rho_s,\rho_L,\Phi'_v),\mu_c(\mu_L,\Phi'_v),d_{p_j},\rho_s,\phi_{s_j},f\right),\Phi'_v\right) \end{array}\right.$$

Durand friction factor correlation ($f_d = f - f_c$) using clear liquid density and viscosity properties of carrier liquid.

$$f_{dDurand}(D_{pipe},v,\rho_L,\mu_L,\varepsilon,D_d,\rho_d,\alpha_d,K_D) := K_D\cdot\alpha_d\cdot f_c(D_{pipe},v,\rho_L,\mu_L,\varepsilon)\cdot\left[\frac{v^2\cdot\sqrt{C_D(D_d,v_\infty(D_d,\rho_d,\rho_L,\mu_L),\rho_L,\mu_L)}}{g\cdot D_{pipe}\cdot\left(\frac{\rho_d}{\rho_L}-1\right)}\right]^{\frac{-3}{2}}$$

$$\Delta p_{Durand}(D_{pipe},v,\rho_L,\mu_L,\varepsilon,D_d,\rho_s,\alpha_d,L,\theta,K_D) := \rho_L\cdot g\cdot\left[\frac{L}{D_{pipe}}\cdot\frac{v^2}{2\cdot g}\cdot\left(\begin{array}{l} f_c(D_{pipe},v,\rho_L,\mu_L,\varepsilon)\ \ldots \\ +f_{dDurand}(D_{pipe},v,\rho_L,\mu_L,\varepsilon,D_d,\rho_s,\alpha_d,K_D)\cdot\cos(\theta)\end{array}\right)\ldots \\ +\left[\left(\frac{\rho_s}{\rho_L}-1\right)\cdot\alpha_d+1\right]\cdot L\cdot\sin(\theta)\right]$$

Wasp friction factor and pressure loss

$$f_{Wasp\_f}(D_{pipe},v,\rho_L,\mu_L,\varepsilon,d_p,\rho_s,\phi_s,\theta,f) := \left| \begin{array}{l} J \leftarrow \text{length}(d_p) - 1 \\ \Phi_v \leftarrow \Phi_c(v,\rho_L,\mu_L,d_p,\rho_s,\phi_s,f) \\ \rho_v \leftarrow \rho_c(\rho_s,\rho_L,\Phi_v) \\ \mu_v \leftarrow \mu_c(\mu_L,\Phi_v) \\ f_W \leftarrow f_c(D_{pipe},v,\rho_v,\mu_v,\varepsilon)\cdot\frac{\rho_v}{\rho_L} \\ \text{for } j\in 0..J \\ \quad \left| \begin{array}{l} \phi_{vj} \leftarrow \phi_v(v,\rho_L,\rho_v,\mu_v,d_{p_j},\rho_s,\phi_{s_j},f) \\ \phi_{aj} \leftarrow \phi_{s_j} - \phi_{vj} \\ f_W \leftarrow f_W + f_{dDurand}(D_{pipe},v,\rho_L,\mu_L,\varepsilon,d_{p_j},\rho_s,\phi_{aj},82)\cdot\cos(\theta) \end{array}\right. \\ f_W \end{array}\right.$$

vehicle friction contribution normalized to liquid

plus friction contribution from remaining heterogeneous particles using clear liquid properties

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EVALUATION ANALYSIS

Calc. No. RPP-LJJ-002
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Client: Numatec Hanford Corporation
Subject: Critical Velocity and Pressure Drop Study in Support of Waste Tank Feed Transfer System (Wasp Test Case)
Location: 200 Area - Hanford Site, Richland, Washington

WO/Job No. 110299 & 110300/BA10
Date: 03/08/2000 By: L. J. Julyk
Checked: 03/10/2000 By: T. C. Oten
Revised: By:

$f_f := 0.025$ initial guess

$$f_{Wasp}(D_{pipe}, v, \rho_L, \mu_L, \varepsilon, d_p, \rho_s, \phi_s, \theta) := \text{root}\left(f_f - f_{Wasp\_f}(D_{pipe}, v, \rho_L, \mu_L, \varepsilon, d_p, \rho_s, \phi_s, \theta, f_f), f_f\right)$$

$$\Delta p_{Wasp}(D_{pipe}, v, \rho_L, \mu_L, \varepsilon, d_p, \rho_s, \phi_s, L, \theta) := \left| \begin{array}{l} J \leftarrow \text{length}(d_p) - 1 \\ \Phi_s \leftarrow \sum_{j=0}^{J} \phi_{s_j} \\ \rho_L \cdot g \cdot \left[\frac{L}{D_{pipe}} \cdot \frac{v^2}{2 \cdot g} \cdot f_{Wasp}(D_{pipe}, v, \rho_L, \mu_L, \varepsilon, d_p, \rho_s, \phi_s, \theta) \ldots \atop + \left[\left(\frac{\rho_s}{\rho_L} - 1\right) \cdot \Phi_s + 1\right] \cdot L \cdot \sin(\theta) \right] \end{array} \right.$$

$$\Delta p_L(D_{pipe}, v, \rho_L, \mu_L, \varepsilon, L, \theta) := \rho_L \cdot g \cdot \left(\frac{L}{D_{pipe}} \cdot \frac{v^2}{2 \cdot g} \cdot f_c(D_{pipe}, v, \rho_L, \mu_L, \varepsilon) + L \cdot \sin(\theta) \right)$$ pressure drop for liquid only

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Wasp et al. 1977, illustrative example, page 95

$d_p := 0$ $\phi_s := 0$ $\phi_{cum} := 0$ $\theta := 0 \cdot deg$

Given solid particle size distribution

data :=

d_p (cm)	volume frequency (%)
0.0021	19.55
0.0059	2.3
0.0111	1.15

$d_p := data^{\langle 0 \rangle} \cdot cm$

$\phi_s := data^{\langle 1 \rangle} \cdot \%$

$$d_p = \begin{pmatrix} 21 \\ 59 \\ 111 \end{pmatrix} \mu m$$

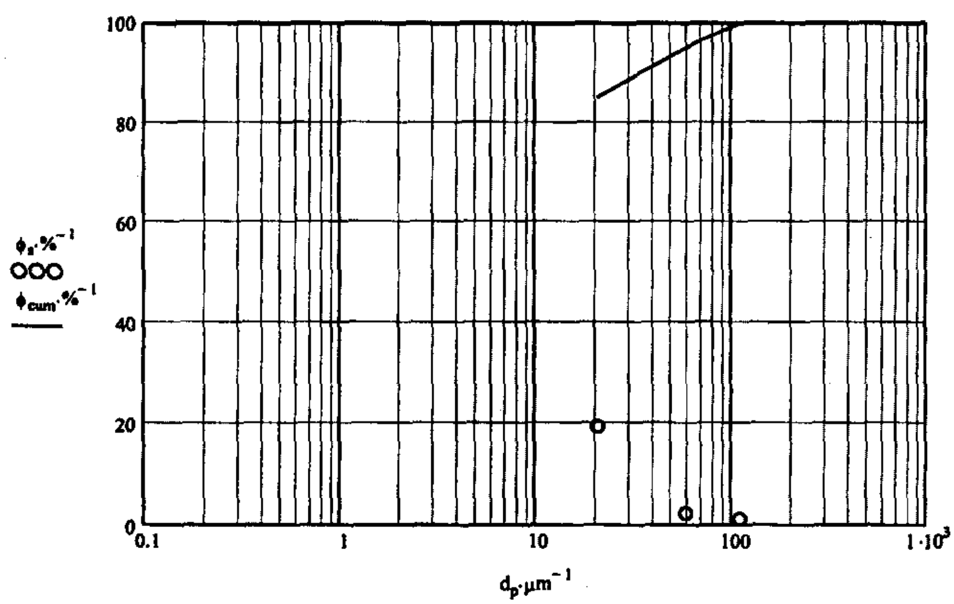
Given parameters

$\mu_L := \mu_{water}(T_C(68))$	Carrier liquid viscosity	$\mu_L = 1.002\,cP$
$\rho_L := \rho_{water}(T_C(68))$	Carrier liquid density	$\rho_L = 0.998 \frac{kg}{liter}$
$\rho_s := 5 \cdot \frac{kg}{liter}$	Average solids density	
$D_{pipe} := 12 \cdot in$	ID of pipe	
$\varepsilon := 0.002 \cdot in$	pipe roughness	
$v := 4.5 \cdot \frac{ft}{sec}$	flow velocity	
$L := 1 \cdot ft$	pipe unit length	

$J := length(\phi_s) - 1$ $J = 2$

$\Phi_s := \sum_{j=0}^{length(\phi_s)-1} \phi_{s_j}$ $\Phi_s = 0.23$ $j := 0 .. J$ $\phi_{cum_j} := \frac{1}{\Phi_s} \cdot \sum_{i=0}^{j} \phi_{s_i}$

Cumulative undersize volume distribution



Wasp-check.mcd

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$TOL = 1 \times 10^{-7}$

$f_W := f_{Wasp}(D_{pipe}, v, \rho_L, \mu_L, \varepsilon, d_p, \rho_s, \phi_s, \theta)$ $\quad f_W = 0.05282$

$\frac{\Delta p_{Wasp}(D_{pipe}, v, \rho_L, \mu_L, \varepsilon, d_p, \rho_s, \phi_s, L, \theta)}{\rho_L \cdot g} = 0.01662\,ft$ (ft of water/ft of pipe) **0.01659 ft water / ft of pipe reported in Wasp et al. 1977 as approximate answer**

$\frac{0.01662 - 0.01659}{0.01659} = 0.18\,\%$ error **Check OK**

$\Phi_v := \Phi_c(v, \rho_L, \mu_L, d_p, \rho_s, \phi_s, f_W)$ $\quad \Phi_v = 22.152\,\%$

$\rho_v := \rho_c(\rho_s, \rho_L, \Phi_v)$ $\quad \mu_v := \mu_c(\mu_L, \Phi_v)$

$\rho_v = 1.885\,\frac{kg}{liter}$ $\quad \mu_v = 7.154\,cP$

$\phi_{vv_j} := \phi_v(v, \rho_L, \rho_v, \mu_v, d_{p_j}, \rho_s, \phi_{s_j}, f_W)$

$\phi_{va_j} := \phi_{s_j} - \phi_{vv_j}$

$v_{t_j} := v_\infty(d_{p_j}, \rho_s, \rho_v, \mu_v)$

$j =$	$\frac{d_{p_j}}{\mu m} =$	$\frac{v_{t_j}}{\frac{ft}{sec}} =$	$Re(d_{p_j}, v_{t_j}, \rho_v, \mu_v) =$	$C_D(d_{p_j}, v_{t_j}, \rho_v, \mu_v) =$	$\phi_{vv_j} =$ (%)	$\phi_{va_j} =$ (%)	$j =$
0	21	0.00034	0.001	41469.3	19.29	0.26	0
1	59	0.00271	0.013	1869.9	2.07	0.23	1
2	111	0.00959	0.085	280.8	0.79	0.36	2

$\sum_{j=0}^{J} \phi_{vv_j} = 22.15\,\%$ $\quad \sum_{j=0}^{J} \phi_{va_j} = 0.85\,\%$

$v_{t_j} := v_\infty(d_{p_j}, \rho_s, \rho_L, \mu_L)$

$j =$	$\frac{d_{p_j}}{\mu m} =$	$\frac{v_{t_j}}{\frac{ft}{sec}} =$	$Re(d_{p_j}, v_{t_j}, \rho_L, \mu_L) =$	$C_D(d_{p_j}, v_{t_j}, \rho_L, \mu_L) =$
0	21	0.00315	0.020	1195.5
1	59	0.02485	0.445	53.9
2	111	0.08796	2.965	8.1

$\frac{\varepsilon}{D_{pipe}} = 0.00017$ $\quad Re(D_{pipe}, v, \rho_v, \mu_v) = 1.101 \times 10^5$ $\quad Re(D_{pipe}, v, \rho_L, \mu_L) = 4.165 \times 10^5$

Fanning friction factor $\quad \frac{f_c(D_{pipe}, v, \rho_v, \mu_v, \varepsilon)}{4} = 0.00463$ $\quad \frac{f_c(D_{pipe}, v, \rho_L, \mu_L, \varepsilon)}{4} = 0.00387$

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