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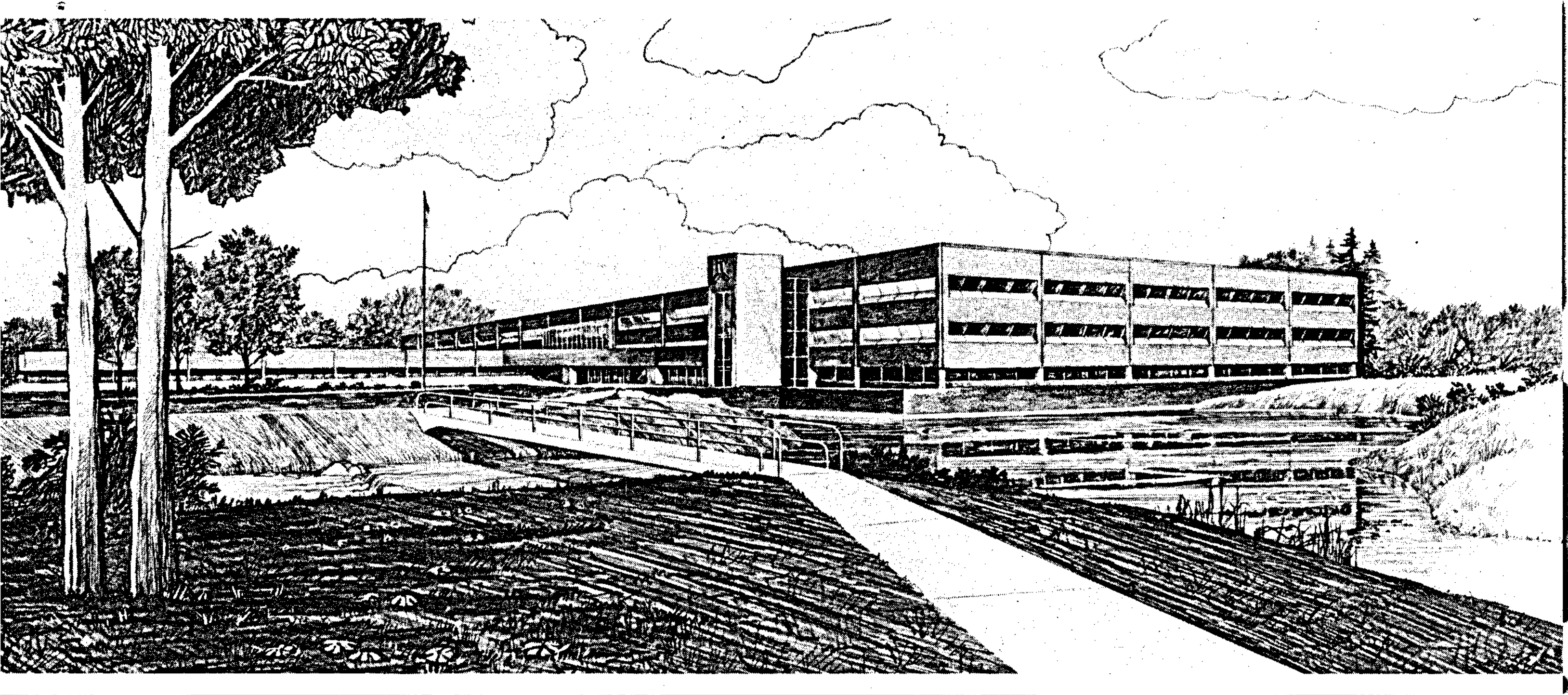
Pipe Selection Guide

MASTER

Ray D. Sanders

U.S. Department of Energy
Idaho Operations Office • Idaho National Engineering Laboratory



This is an informal report intended for use as a preliminary or working document

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EG&G Idaho

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EG&G Idaho, Inc.
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FOREWORD

The Geothermal Technical Assistance Program was developed under the premise that the majority of groups or individuals with available geothermal resources do not have the experience or manpower necessary to do a preliminary engineering and economic feasibility evaluation for geothermal energy projects. In order to disseminate technical information and to facilitate expanded use of geothermal energy resources, assistance was provided through FY-1981 in a consulting format on a first-come, staff-and-funds-available basis. Technical assistance can relate to conceptualization; engineering; economics; water chemistry implications for environmental, disposal, and material selection considerations; and planning and development strategies. This report is one of a series adapted from consultation provided to requesters either through in-house efforts or through limited efforts subcontracted to local engineering firms. The Geothermal Technical Assistance (GTA) reports in this series, which are listed below, will be available for purchase early in 1982 by those with interest in specific geothermal applications from the U.S. National Technical Information Service:

U.S. Department of Commerce
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GTA Report Number	EG&G Report Number	Title
1.	*EGG-GTH-5512	Aquaculture Facility Potential at Boulder Hot Springs, Boulder, Montana
2.	*EGG-GTH-5521	Preliminary Geothermal Disposal Considerations, State Health Laboratory, Boise, Idaho
3.	*EGG-GTH-5573	Geothermal Conversion at Veterans Hospital, Boise, Idaho

GTA Report Number	EG&G Report Number	Title
4.	*EGG-GTH-5574	Geothermal Applications for Highway Rest Areas
5.	*EGG-GTH-5575	Geothermal Applications for a Tannery
6.	*EGG-GTH-5599	Preliminary Conceptual Design for Geothermal Space Heating Conversion of School District 50 Joint Facilities at Pagosa Springs, Colorado
7.	EGG-GTH-5617	Selected Geothermal Technical Assistance Efforts (comprising short descriptions of ten space heating projects, five district heating projects, and three heat exchanger projects)
8.	*EGG-2137	Geothermal Source Potential and Utilization for Methane Generation and Alcohol Production (subcontractor report)
9.	*EGG-2138	Geothermal Source Potential and Utilization for Alcohol Production (subcontractor report)
10.	*EGG-2139	Potential Geothermal Energy Applications for Idaho Elks Rehabilitation Hospital (subcontractor report)
11.	*EGG-2144	Technical Assistance Report on a Geothermal Heating Utility for Lemmon, South Dakota (subcontractor report)
12.	*EGG-2145	Economic Analysis for Utilization of Geothermal Energy by North Dakota Concrete Products Company (subcontractor report)
13.	*EGG-2146	Geothermal Feasibility Analysis II for Polo School District No. 29-2, South Dakota (subcontractor report)
14.	*EGG-2147	Preliminary Feasibility Study of Heating and Cooling Alternatives for Nebraska Western College, Scottsbluff, Nebraska (subcontractor report)
15.	*EGG-2148	Inventory of Thermal Springs and Wells Within a One-Mile Radius of Yucca Lodge, Truth or Consequences, New Mexico (subcontractor report)

GTA Report Number	EG&G Report Number	Title
16.	EGG-2149	Utilization of Geothermal Energy, Feasibility Study--Ojo Caliente Mineral Springs Company, Ojo Caliente, New Mexico (subcontractor report)
17.	*EGG-2150	Geothermal Heated Office Building at Glenwood Springs, Colorado (subcontractor report)
18.	EGG-2151	Final Report--Dickinson Geothermal Study, Dickinson, North Dakota (subcontractor report)
19.	EGG-2152	CANCELLED
20.	EGG-2153	Comparison of Two Options for Supplying Geothermal Energy to the Veterans Administration Medical Center, Marlin, Texas (subcontractor report)
21.	EGG-2154	Geothermal Utilization at Castle Oaks Subdivision Castle Rock, Colorado (subcontractor report)
22.	EGG-2155	Space Heating for Twin Lakes School Near Gallup, New Mexico (subcontractor report)
23.	*EGG-2156	Pumping Tests of Well Campbell et al., No. 2, Gila Hot Springs, Grant County, New Mexico (subcontractor report)
24.	*EGG-GTH-5739	Geothermal Deicing of Highways and Bridge Structures
25.	*EGG-GTH-5740	Assessment of a Geothermal Application at Tucson, Arizona
26.	*EGG-GTH-5741	Heat Pump Systems for Spring Creek, Montana
27.	EGG-GTH-5779	Pipe Selection Guide
28.	EGG-GTH-5804	An Overview of Engineering and Agricultural Design Considerations of the Raft River Soil-Warming and Heat-Dissipation Experiment
29.	EGG-GTH-5812	Design of the Glenwood Springs Downhole Heat Exchanger

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CONTENTS

PIPE SELECTION GUIDE

PURPOSE

During preliminary evaluations of geothermal energy applications, it usually becomes necessary to select components and materials to be used in the system. This pipe selection guide is intended for persons not professionally trained in mechanical engineering who wish to make a preliminary selection of pipe for use in geothermal applications. The user is cautioned that this is not intended to be a final design guide and does not eliminate the need for sound engineering judgment. Pipe selections made with this guide should only be considered preliminary and should be confirmed later by a qualified design engineer.

In most instances, the piping system for a geothermal application will be under the jurisdiction of local or national codes. For example, geothermal steam and hot water piping is within the scope of ANSI B31.1 "Power Piping," which prescribes minimum requirements for design, materials, fabrication, erection, test, and inspection. Applicable codes should be determined early in the project so that pipe will be selected from those allowed by the code.

SCOPE

Only four parameters are used in this guide to define a particular pipe: inside diameter, wall thickness, material, and ends. For the purpose of this guide, the factors influencing pipe selection are limited to fluid pressure, temperature, chemistry, flow rate, and cost. Other pipe parameters and factors that influence pipe selection and design are mentioned, and, where appropriate, the user is warned that at some stage in the project these factors must be dealt with. It is assumed throughout this guide that the user's objective is the direct application of geothermal water at temperatures lower than 200°F and with 12-in. or smaller pipe. When considering friction losses for sizing purposes, only straight pipe is considered.

The preliminary nature of pipe selections made with this guide applies especially to selection of materials for resistance to corrosion and scaling. Because of the site-specific nature and complexity of the subject, this guide can only make very preliminary recommendations. Final selection should be made, or at least reviewed, by a qualified corrosion engineer after careful and thorough water anlaysis, and possibly after testing candidate materials in the geothermal fluid.

Costs discussed here are comparative costs of material relative to carbon steel. This approach is used to negate the effect of inflation somewhat, thereby extending the usefulness of the information. Accounting for the constantly fluctuating cost of individual metals must be left to the user.

A discussion of the characteristics and attributes of readily available pipe is included to aid the user in making a preliminary selection. Energy loss from buried pipe is considered in Appendix A.

PIPE SELECTION

General

For the purpose of this guide, the following parameters are sufficient to describe a particular pipe:

- Size and schedule, or inside and outside diameter, or one diameter and wall thickness.
- Material--must eventually be well specified, for example, not just carbon steel but ASTM A106 Gr B, etc.
- Threaded, plain, or welded ends.

A more detailed description could include method of manufacture, such as seamless or welded; length, such as random; testing; etc.

Material Selection

Selection Factors

The factors that will have the most influence on material selection are as follows:

Strength. The material must have sufficient strength at design temperature to allow the selection of pipe that will withstand the design pressure with a reasonable wall thickness.

Cost. Generally, cost will increase with material strength and corrosion resistance, and, to some degree, fabrication and assembly cost will depend on the material.

Corrosion and Scaling Resistance. The material selected should have sufficient corrosion and scaling resistance to ensure that the performance of the pipe is not impaired during the design lifetime. In a geothermal application, this may have the greatest influence on and be the most difficult and important part of pipe selection. The importance increases with the size or cost of the project. In the case of larger projects, the cost of extensive materials research and testing is usually well justified. On smaller projects where less money is being invested in piping and equipment, such thoroughness may not be warranted. It may be that material chosen on the basis of an educated guess, or because it is on hand or inexpensive, will perform satisfactorily and not be a large part of the overall cost, even if periodic replacement is required.

Selection Process

- In many cases, the source of water will already be in use or will be known to be similar to a source that is in use. If that is the case and existing piping has given satisfactory service, choose pipe of the same material.

- If the piping just described has not given satisfactory service, avoid similar material and select a material from those discussed below under "Types of Pipe." If temperature and pressure allow their use, one of the nonmetallic materials may be suitable. Except in extreme cases, plain carbon steel may give satisfactory service if the following precautions are taken:

    - Use a generous corrosion allowance
    - Limit fluid velocity to 5 to 7 fps
    - Avoid galvanic coupling
    - Prevent aeration of the fluid
    - Keep the fluid pressurized; this may reduce some forms of scaling.

  Because of their record of poor performance in geothermal applications (usually because of the presence of hydrogen sulfide), avoid copper-based alloys unless careful analysis shows that they can be used in the specific application under consideration.

- Depending on the size of the investment, it may be worthwhile to obtain the services of a corrosion engineer at this stage of the project.

Determining Inside Diameter

Selection Factors

Inside diameter selection is basically a cost consideration. The cost of pipe increases with diameter while, for a given flow rate, friction losses and therefore pump and pump power costs decrease. As diameter decreases, friction losses increase correspondingly, leading to increased pumping cost, to higher system or line pressure, and, possibly, to heavier walled, more costly pipe. A tradeoff between these costs will have to be made.

Several sources list reasonable fluid velocities in piping, ranging from 4 to 7 fps, for city and general service. However, before selecting a pipe size on the basis that it provides reasonable velocity at the given flow rate, the line length should also be considered since costly losses could result from long lines with "reasonable" velocities. If the source of water has a fixed head, as from artesian flow, gravity flow, or an existing pump, this would be especially important. In some instances, higher velocities are beneficial in that they prevent the settling out of solids and can provide a scouring or cleansing action. On the other hand, high velocities may cause erosion and objectionable noise.

Selection Process

For preliminary purposes, use the velocity rule-of-thumb and select an inside diameter, estimate pressure losses, and then estimate what these losses require in pump power.

- Inside Diameter. For a given flow rate and desired velocity:

$$d = 0.639\sqrt{\frac{Q}{V}}$$

where

d = inside diameter (in.)

Q = required flow rate (gpm)

and

V = mean velocity (fps)--in this case, the reasonable velocity chosen).

Find d and select a nominal pipe size reasonably close to d. (In the sizes of interest, nominal size is the approximate ID for wrought steel, iron, stainless, and some nonmetallics.)

- Friction Loss. For preliminary estimating purposes, ignore the temperature of the water and losses caused by fittings, valves, etc. These factors must be considered during system design, however. By Darcy's formula, head loss through a straight pipe is:

$$h_L = f \frac{L}{D} \frac{V^2}{2g}$$

where

h_L = head loss (ft of fluid)

f = friction factor (see Table 1)

L = length of pipe (ft)

D = internal diameter of pipe (ft)

V = mean velocity of fluid (fps)

and

g = acceleration of gravity = 32.2 ft/sec/sec.

Pipe friction data for clean commercial steel pipe with flow in a zone of complete turbulence are given in Table 1

TABLE 1. PIPE FRICTION DATA[a]

Nominal Size (in.)	Friction Factor
1/2	0.027
3/4	0.025
1	0.023
1 1/4	0.022
1 1/2	0.021
2	0.019
2 1/2, 3	0.018
4	0.017
5	0.016
6	0.015
8 to 10	0.014
12 to 16	0.013
18 to 24	0.012

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a. From Flow of Fluids Through Valves, Fittings, and Pipes, Crane Technical Paper No. 410.

- Pumping Power. The following formula can be used to calculate pumping power:

$$\text{bhp} = \frac{QH\,(\text{sp gr})}{3960\,\eta_p}$$

where

bhp = brake horsepower input to the pump shaft

sp gr = specific gravity of fluid = 1 for water at 68°F

Q = flow rate (gpm)

H = total head (ft of fluid)

and

η_p = pump efficiency (may be on the order of 70 to 80%).

To calculate the bhp required for friction losses only, replace H in the equation above with the h_L found in the previous calculation for friction loss. Neglect temperature effects and assume that sp gr = 1.

$$\text{bhp} = \frac{Qh_L}{3960\ \eta_p} .$$

To determine the actual power consumed, the motor or driver efficiency, η_d, must be considered. For an electric motor, full load efficiency will be 90% or better. Electric power input in kilowatts due to the head loss is:

$$\text{kW} = \frac{Qh_L}{3960 \times \eta_p \times \eta_d} \times 0.7457\ \frac{\text{kW}}{\text{hp}} .$$

As noted earlier, not only do friction losses consume power, but the increase in pump head required to compensate for the losses affects the initial cost of the pump and driver. Excessive friction loss can be reduced by selecting a larger diameter, more costly pipe.

Determining Wall Thickness

Codes such as ANSI B31.1, Power Piping, use a modified Barlow formula to determine minimum wall thickness of pipe. For the purposes of this guide, the formula for hoop stress in the pipe wall will do:

$$t = \frac{Pd}{2S}$$

where

t = wall thickness (in.)

P = internal fluid pressure (psi)

S = stress, psi (in this case, the allowable or design stress for the particular material at design temperature)

d = inside diameter, in.

Note that only pressure has been considered in determining the thickness. Mechanical strength to prevent damage, sagging, etc. has not been considered, nor has any allowance for corrosion, erosion, threading, etc. been added. Minimum wall thickness in sizes up to 6 in. should be that of Schedule 40 pipe, unless corrosion properties are well known and the pipe is protected from mechanical damage.

P, the design pressure, must not be less than the maximum fluid operating pressure expected. It should include elevation effects and, if a pump is in the system, the maximum pressure that the pump can exert, unless the piping is protected from such pressure, for instance by a relief valve. Although not necessary for the purpose of this guide, design pressure is often increased to compensate for water hammer. This would be an important consideration with brittle pipe material.

S, the allowable stress, is based on the strength of the material at design temperature. Codes such as ANSI B31.1 tabulate allowable stress for allowable materials at temperature. These values include joint efficiency factors for longitudinal welds, casting quality factors, and a large safety factor, which is included by allowing use of only 25% of the minimum tensile strength of the material. The tabulated values in the code cover hundreds of combinations of material specifications, grade or type, class, and method of manufacture such as seamless, furnace welded, etc.

Table 2 presents a range of values for carbon steel pipe at 200°F. Specific values for carbon steel or other materials, whether metallic or nonmetallic, should be obtained from codes or manufacturers.

When the pipe wall thickness has been determined, select a schedule for the inside diameter determined above that provides the required wall thickness. In the case of some nonmetallic pipe or pipe not sized by

TABLE 2. RANGE OF ALLOWABLE STRESSES[a]

Method of Manufacture	Range (psi)
Seamless pipe and tube	10,600 to 17,500
Furnace butt welded pipe	6,300 to 6,800
Electric resistance welded and electric flash welded pipe and tubes	9,000 to 15,000
Electric fusion welded pipe--filler metal added	7,700 to 20,000

a. From ANSI B31.1, 1980 edition.

schedule, available wall thickness may have to be obtained from the manufacturer or a vendor. If the schedule selected results in an inside diameter that is significantly different from that chosen in the calculation above, the resulting velocity and friction losses should be rechecked and adjustment made if required.

End Finish

Selection of end finish depends on the planned method of joining the pipe. Pipe is commonly furnished with threaded or plain ends. Plain ends may be square, beveled for welding, and in some cases deburred and finished to tolerance to accept mechanical couplings such as the Dresser coupling. Each length of threaded pipe will be furnished with a coupling. Several methods of joining pipe are discussed below, with comments on attributes that should be considered in making a selection.

Threaded Joints

Threaded joints are inexpensive and easily assembled and disassembled. ANSI B31.1 places certain limitation on their use. The only limits of concern here (for 200°F maximum water temperature) are that "Pipe with a wall thickness less than that of standard weight of ANSI B36.10 steel pipe shall not be threaded, regardless of service," and "threaded joints shall not be used where severe erosion, crevice corrosion, shock or vibration is expected to occur, . . ." Even if the piping is not under the jurisdiction of the code, these limits should be heeded.

Flanged Joints

Flanged joints can be used where components or equipment must be disassembled for maintenance work. They are often used for connections to valves and pumps. They are probably the most costly means of joining pipe. The following more common type of flanges differ mainly by the method of attachment to the pipe.

- Welding Neck. One of the more expensive methods, but best for severe service where high pressure, high temperature, and cyclic loading are involved.

- Slip-On. Lower initial cost, but the final installed cost is probably not much less than that of the welding neck. Strength is about 2/3 that of the welding neck, and fatigue life about 1/3. ANSI B31.1 limits this application to no higher than Class 300 primary pressure service rating.

- Lap Joint. When used with lap joint stub ends, the cost per joint is approximately 1/3 higher than a welding neck joint. Pressure retaining ability is comparable to a slip-on, and fatigue life is only about 1/10 that of welding necks. The main advantage of lap joints is the ability of flanges to rotate, which aids in alignment when frequent dismantling is required.

- Threaded. Unsuitable where cyclic loading or bending stress is involved. No welding is required for assembly. (Note code restrictions under "Threaded Joints," above.)

- Socket Welding. Slightly higher cost than slip-on, with about equal strength and better fatigue life when both types have internal welds. If crevice corrosion is of concern, an internal weld should be provided.

Proprietary Joints

This type of joint includes mechanical couplings such as the Dresser or Victaulic. Most provide ease and speed of assembly and disassembly. Some will accommodate a certain amount of thermal expansion, which can eliminate the need for expansion joints or loops. Cost of couplings and assembly is usually considerably less than for flanged joints. Most rely on an elastomer gasket, which should be selected with care.

Welded Joints

Properly made butt welds will provide a joint equal in strength to the material being joined. Welding is more costly than threading in the smaller sizes but is less costly than the other methods in larger sizes, especially in severe service.

TYPES OF PIPE

Carbon Steel

This is the most commonly used pipe material and is available in a wide variety of sizes, schedules, types, and method of manufacture. It is the least expensive of the wrought metallic pipes, has good strength at temperature, and is easily worked and joined. It can provide satisfactory service in geothermal applications if proper precautions are taken.

Low and Intermediate Alloy Steel

These materials have attributes similar to carbon steels. Strengths are generally higher, but so are costs. Corrosion resistance may be slightly better than carbon steel. Their advantages over carbon steel are probably not worth the increased cost.

Other Ferrous and Nonferrous Metals

This category includes the stainless steels, nickel and nickel alloys, copper and copper alloys, aluminum, and others too numerous to mention here. Many may be suitable for geothermal applications, but the cost is usually prohibitive. Do not assume that stainless steel or some other material that is normally considered corrosion resistant will do. Experience has shown that most of the materials just mentioned can sometimes be very adversely affected by geothermal fluids. If use of these materials is desirable, for instance copper for its superior thermal conductivity, it should be carefully investigated before making a final selection.

Plastic

Plastic pipe is generally available in standard iron-pipe sizes, ranging from 1/4 in. to 12 in. Fittings and some valves are available. Materials are available in two different groups, thermoplastic and thermosetting. Exposed, outdoor plastic pipe systems are subject to atmospheric effects such as ultraviolet deterioration, low-temperature brittleness, and hot sun softening. Pipe selection or system design may be affected by these factors.

Thermoplastics

This group includes polyvinyl chloride (PVC), chlorinated polyvinyl chloride (CPVC), polyethylene (PE), acrylonitrile-butadiene-styrene (ABS), cellulose-acetate-butyrate (CAB), polypropylene (PP), and polyvinylidene fluoride (PVDF). There are others, and with continuing development still more will become available.

These materials have excellent chemical resistance and may be suitable for geothermal applications. Because of the smooth inside surface, the friction factor will be low, resulting in lower friction losses, and these losses should remain low because the materials tend to resist scaling. Maximum service temperatures range from approximately 140°F to well over 200°F, depending on the material. Cost increases with service temperature. Since the strength decreases rapidly with increasing temperature, the manufacturer's data for the particular material should be used when selecting these materials.

Pressure ratings of plastic pipe vary according to schedule type or class, material, diameter, service temperature, and type of end fittings. Special joining procedures such as back welding may be required for maximum pressure rating, and service life may be significantly reduced for operation near the maximum allowable service temperature. Representative service pressure-temperature data for 2-in. diameter pipe are shown in Table 3; pressure ratings for larger diameters will be lower.

TABLE 3. TYPICAL PLASTIC PIPE PRESSURE RATINGS (2-in. diameter)

Pipe Material	Maximum Operating Temperature (°F)	Pressure Rating at Maximum Operating Temperature (psi)	Pressure Rating at ∿75°F Operating Temperature (psi)
PVC	140	110	200
CPVC	210	52	280
PE	120	32	50
PP	170	52	200
ABS	170	40	75
CAB	150	55	110
PVDF	280	53	275

Thermoplastic pipe can be joined by threading, flanges, solvent welding, or thermal welding. One of the easist and most common joining methods is solvent welding using plastic socket weld fittings.

Thermal conductivity of the thermoplastics is much lower than that of metals, which is an advantage in most cases. Their coefficient of thermal expansion, however, is much higher than that of the metals--2 to 10 times that of steel in some materials. This can cause serious problems, even from normal temperature fluctuations during installation, and must be considered in the design.

Thermosetting Plastics

Two major resins are used, epoxy and polyesters. The pipe is generally reinforced with fibers such as glass or asbestos and will have higher strength and somewhat higher service temperatures than the thermoplastics. Other features are similar to those of thermoplastics except that their coefficient of thermal expansion is generally lower, ranging from slightly above to two times that of carbon steel. As with the thermoplastics, a wide range of material properties are available, and the manufacture's data should be used for selection and design. Cost is somewhat higher than for the thermoplastics.

Asbestos-Cement

Asbestos-cement pipe is readily available, in several classes, with diameters ranging from 4 to 16 in. in 2-in. increments. Some vendors may supply insulated asbestos-cement pipe in diameters to 30 in. Temperatures to 300°F or so can be accommodated. Reduced cost and reduced corrosion, expansion, and friction effects are selection considerations. Potential cost reduction can be attributed to

- Shorter assembly time than for welded joint steel pipe
- Expansion absorbed in the couplings, reducing or eliminating the need for large expansion loops
- Bare pipe cost is less than that of steel
- Friction losses are less than in standard Schedule 40 steel, tending to reduce pump and operational costs--in some cases, the reduced friction loss may allow specification of smaller diameter pipe, further reducing the cost.

Proper design, installation, and operation are necessary to avoid pipeline failure from

- Thermal or mechanical shock, causing wall fracture
- Installation of low temperature gaskets in the couplings
- Rolling the gaskets when the couplings are installed, allowing the coupling to leak
- Use of improper Dresser couplings (steel-to-asbestos-cement pipe couplings), which could move under thermal cycling, resulting in ratcheting and, ultimately, detachment from the pipe.

The following suggestions, where appropriate, can aid in securing satisfactory costs and performance for buried or surface piping:

- Obtain a contractor experienced or knowledgeable in the installation of asbestos-cement pipe.
- Install asbestos-cement pipe over a carefully prepared trench bottom, with rocky material covered or removed.
- Inspect pipe for damage before and after installation.
- Use 1 to 2 in. of polyurethane, sprayed in place after installation, to thermally insulate and cushion the pipe and reduce the likelihood of externally induced shock.
- Use backfill that is free of rocks larger than 1-in. diameter.
- Cross irrigation ditches and streams with an "overpass," if possible, to minimize water seepage into the soil around the pipe.
- Use steel-to-asbestos-cement couplings as recommended by manufacturer.

- Inspect and verify that all seals used in the line are designed for the designated operating temperature.

- Verify correct pipe penetration into the collars so that "designed-in" expansion is not inhibited.

- Operate the pipeline in accordance with appropriate procedures to avoid thermal and mechanical shock.

Other Nonmetallic Pipe

Included in this category are concrete, polymer concrete, and clay pipe. Some of these materials have been used or tested in geothermal applications with varying success. In some applications such as outfall lines, they may provide suitable service and would be less costly than steel or plastic. Because of the wide variety of properties and the limited experience with these materials in geothermal applications, however, selection of this type of pipe should be based on careful study of the application or on appropriate testing.

RELATIVE COST OF MATERIALS

Table 4 presents the relative costs of 8-in. pipe of different materials for service at 150°F and 120 psig. These are 1981 costs relative to carbon steel. Relative costs of 1-in. NPS pipe are given in Table 5 to illustrate the effect of size. The carbon and stainless costs were based on Schedule 40, but the cost ratio should be approximately the same between the two regardless of schedule.

TABLE 4. RELATIVE COSTS OF DIFFERENT 8-IN. PIPE MATERIALS FOR SERVICE AT 150°F AND 120 PSIG

Material	Relative Cost
Furnace butt-welded ASTM A120 8 NPS x 0.188-in. wall[a]	1.00
Electric fusion welded, no filler added, ASTM A312, Type 304L, 8NPS Sch 5S	2.81
Bondstrand 8-in. Series 1600	1.29
Bondstrand 8-in. Series 6000	1.89
Type IV CPVC, 8 NPS Sch 80	5.33
Asbestos-Cement 8-in. Class 150 with coupling and gasket	0.86

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a. 0.188-in. wall includes 1/10 in. corrosion allowance.

TABLE 5. RELATIVE COSTS OF 1-IN. NPS PIPE

Material	Relative Cost
Welded ASTM A120, Black carbon steel, plain ends, 1-in. Sch 40	1.00
Welded ASTM A312 Type 304, 1-in. Sch 40	3.50
Type I PVC, 1-in. Sch 80	0.70
Type II CPVC, 1-in. Sch 80	1.48
PVDF, 1-in. Sch 80	7.93
Seamless copper tube ASTM B88, Type K, 1.125-in. O.D. x 0.065-in. wall	1.33

APPENDIX A

ENERGY LOSS FROM BURIED PIPE

APPENDIX A

ENERGY LOSS FROM BURIED PIPE

A preliminary estimate of energy loss from a buried, parallel pipe grid operating under steady-state conditions can be made using the Kendrick and Havens formula:

$$Q = \frac{2\pi k \Delta T}{\ln\left(\frac{2\ d-r}{r}\right) + \sum_{n=1}^{N} \ln\left[\frac{(nl)^2 + (2\ d-r)^2}{(nl)^2 + r^2}\right]}$$

where

Q = rate of heat loss/unit length of pipe (Btu/hr/ft)

r = pipe diameter (ft)

l = spacing of parallel pipes (ft)

d = depth of grid (ft)

k = soil thermal conductivity (Btu/hr/ft/°F)

ΔT = temperature difference between the pipe surface and soil surface (°F)

N = number of parallel pipes on each side of center pipe (let $N = 0$ for single pipe).

The following simplifying assumptions are employed in the Kendrick and Havens formulation:

- Constant, uniform soil conductivity
- Pipe wall temperature equal to water temperature

- Both pipe and water without temperature gradients
- Constant, uniform soil temperature
- Steady-state operation with constant surface temperature
- Heat transfer in soil only by conduction
- Heat transfer only in radial direction.

These assumptions do not seriously affect the use of the equation for initial calculations, because a parametric study can be employed to investigate the major effect of deviation from steady-state conditions.

The formulation can be used to estimate the steady state heat rate produced by a buried parallel pipe-grid, transmission line heat loss, and fluid temperature drop across the pipe system. Mass flow rate and average temperature difference between the pipe surface and the soil surface must be known. The effect of pipe material selection and insulation can be investiqated by appropriate variation of the pipe-soil surface temperature difference on the basis of vendor specification or the physical and thermal characteristics of selected materials.