DESIGN OF IN-MOLD DECORATION MOLD FOR COMPLEX THIN-WALLED PARTS

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Abstract. In order to address the issues of warping deformation and long-term production of complex thin-walled parts during In-Mold Decoration (IMD) production, the structure design of the IMD mold was carried out with the humidifier top cover as the production object. To ensure the flow characteristics of molten plastic in the mold during the injection molding process, based on the technical contradiction analysis of TRIZ theory, the hot runner mold is improved to mix cold and hot runner, that is, the sprue is set as a hot runner, the branch runner is set as a cold runner, and use a multi-point injection cold gate solution. And construct a complex structure numbering method to arrange and design various complex structure undercut-forming side insert mechanism, design of special structure lifters along the same direction of motion the two inverted buckle at the same time undercut-forming. The lifter mechanisms are used to complete the molding, parting, demolding and ejection of plastic parts, multiple uses for one mechanism. In order to optimize product quality and improve production efficiency, providing theoretical and empirical support for the production of complex thin-walled parts with IMD molds. Then design the cooling system and demolding mechanism separately. Finally, based on Moldflow software, the final flow of plastic part warpage analyzed. The maximum warping deformation of the product is 0.7055mm, while the maximum warping deformation of the traditional cold runner mold is 0.8519mm, reducing the warping deformation of the humidifier top cover.

1 INTRODUCTION

The development trend of "replacing steel with plastic" and "replacing wood with plastic" in many industries[1-3]. The application of injection molds accounts for more than 50% of the production of the plastics industry. And injection molds are moving towards large-scale, high-precision, information technology, multi-functional development[4, 5].

As early as in the 1950s and 1960s, Canada MOLD-MASTERS, the United States DME company has developed a more complete range of hot runner products. Hot runner technology has significant savings in the amount of plastic, improve product surface quality, and do not need to use the three-plate mold frame can be used in the form of point gating and other advantages, based on the development of hot runner molds, injection molds, new technology research and development and application of a wider range[6, 7]. The basic properties of each type of injection mold are shown in Table 1.

Table 1: Comparison of basic performance of three types of molds

	Two-plate mold	Three-plate mold	Hot runner mold
Sprue gate form	Side gate	Point gate	Point gate
Filling temperature	Higher	Higher	Lower
Scope of application	No gate at the top	No gate at the side	No limit
Solidifying plastics of gating systems	Exist	Exist	None or very little

In the process of injection molds developing, a new type of process has arisen: In-Mold Decoration (IMD) , Which is widely used in home appliances, instruments, medical equipment and other industries, it’s a brand new plastic decorative process[8]. It can be applied to most of the plastic parts that need to be decorated on the surface, such as printing stickers, trademarks, etc., so that the product has both functionality and decorative properties[9-11].

The process will be plastic film sheet for the pattern of screen printing and coating 3M adhesive. The film sheet, ink layer and 3M adhesive three layers of compaction and cut edges into the mold for injection molding can be completed IMD production. IMD process in the United States, Japan, Germany and other countries more in-depth research, more widely used. Jan-Christoph Zarges[12] in 2023 used PP as the substrate, and added short particles of natural plant fibers into the substrate to strengthen the product strength. Through the more mature hot runner technology to control the injection temperature below 200 ℃ to avoid overheating and deterioration of natural plant fibers, to achieve low-temperature injection molding and injection molded products to further lightweight; Japan's Nissha and Germany's Kurz manufacturers[13], they use the IMD process in addition to the above process, but also developed a thermal transfer technology, that is, first printed on the PET film carrier and then in the injection molding, the printed on the film printed on the surface of the plastic parts. The two IMD processes can be taken according to the product demand, the development is more mature.

This paper takes a humidifier top cover as the production object, using ABS for injection molding production, the IMD mold redesign, under the premise of ensuring product quality to improve production efficiency. Humidifier top cover development requirements for static mechanical properties require no deformation under a load of 10kg, precision class IT6.

The thickness of the diaphragm is 0.2mm, and the pattern is shown on the upper surface of the product. In order to ensure a smooth demolding process, the fixed cavity draft angel is 3°, and the movable cavity draft angle is 1° to ensure that plastic part does not sticking the fixed core[14]. Before starting a production cycle, the film sheet needs to be placed inside the mold, and then complete the process of mold closing, filling, packing, cooling, mold opening, and demold[15]. The physical copy of the produced humidifier top cover is shown in Figure 1.

In order to optimize product quality, improve production efficiency, and provide design ideas for in-mold injection molds for thin-walled parts with complex structures, this paper redesigns the IMD mold. Taking the humidifier top cover as a complex structure thin-walled parts design case. Combined with TRIZ theory to design the runner system. We also analyze the complex structure of the humidifier top cover, and design the undercut-forming side insert mechanism to reduce the number of lifters, avoid structural interference, and improve the reliability of the ejector process. The IMD mold is also subjected to Moldflow-based finite element analysis of the injection molding process and trial mold verification.

Figure 1: Structure of the humidifier top cover

After the comprehensive design, the use of Creo software modeling to obtain the mold explosion diagram shown in Figure 2.

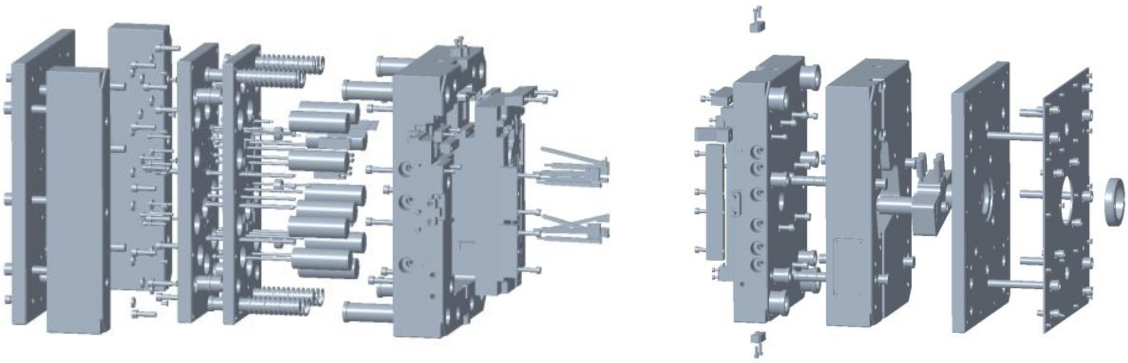


Figure 2: Humidifier top cover IMD mold explosion diagram

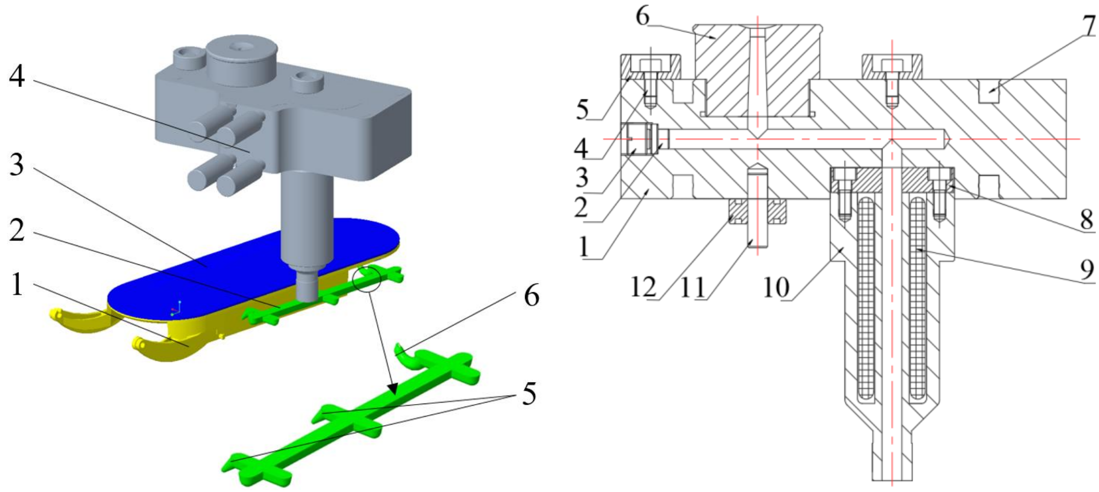
2 IMD MOLD STRUCTURE DESIGN

2.1 Runner system design

The injection mold gating and runner solutions are mutually constraining each other. Due to the requirement of improving product quality and manufacturing efficiency, there are some difficulties in developing the program for this IMD production. And due to the diaphragm barrier, unable to choose three-plate mold. And in order to ensure the synchronization of the mold filling process, the edges gate multi-point pouring scheme is adopted.

After determining the gating program, the following problems exist in the runner design: the traditional cold runner two-plate mold structure is simple, standardized design and easy to assemble, but there are problems such as long production cycle and low product quality; if hot runner is used, the molten plastic to obtain the best mobility, to improve the adhesion between the diaphragm and plastic part, to reduce production cycle and warpage[16-18]. However, the size of the hot nozzle is large, and it is difficult to arrange it in the end of the fixed mold. Moreover, the gate types of hot runner mold are mostly pinpoint gates, which are not in line with the desired solution. There is a contradiction between the two technical solutions[19-23].

Using the separation principle of TRIZ theory, the two-plate cold runner mold and the hot runner mold were split and recombined to have the advantages of the two sets of molds. After analysis, it was found that there are two shortcomings of using hot runner molds: insufficient layout space and the limitation of gate types. To solve the above problems, a spacer plate was added to the two-plate mold, and the sprue is temperature controlled by a complete hot runner system. The end of the hot nozzle does not directly act as a gate to connect the cavity, but plays a transitional role between the sprue and branch runner. The hot nozzle injects the molten plastic into the branch runner, and three side gates are set by the branch runner to complete the design of the combination of the hot and cold runner molds. The diameter of the sprue is designed for 8mm, the branch runner adopts a modified trapezoidal runner, the width of the lower bottom is 8mm, the draft angel is 5 °, the gates use two routine 45 °submarine gates and a horn submarine gate, the gates' size are 1mm^2 and 1.2 mm^2 separately. The runner system as shown in figure 3.



1-Plastic part 2-Branch runner 3- Diaphragm 4-Hot runner system 5- 45° Submarine gates 6- Horn gate

（a） Gating system Three-dimensional model

1-Hot manifold 2-"T" pin 3-Screw plug 4- Screw 5-Riser pad 6-Sprue bushing7-Band heater 8-Hot nozzle cover9-Ring heater 10-Hot nozzle 11-Cylindrical pin 12-Center support pad

（b） Hot runner system assembly drawing

Figure 3: Runner system

2.2 Design of inward undercut-forming side insert mechanism

Due to the design of holes and convex structure in the humidifier top cover is not consistent with the mold opening direction it is necessary to add side insert and other mold structures to complete the molding and demolding[24-26].

Due to the humidifier top cover has more internal undercut structures, inward undercut-forming not only requires the core distance to meet the requirements, but also to meet the various parts of the undercut-forming side insert mechanism does not have interference. Considering that the undercut structures are small and the product is thin-walled, it is easy to be destroyed by the ejector pin extrusion during demolding. This design adopts the double roller type lifter to produce the internal undercut and help ejector process. The complex structure inside the humidifier top cover is tried as shown in Figure 4 for subsequent analysis.

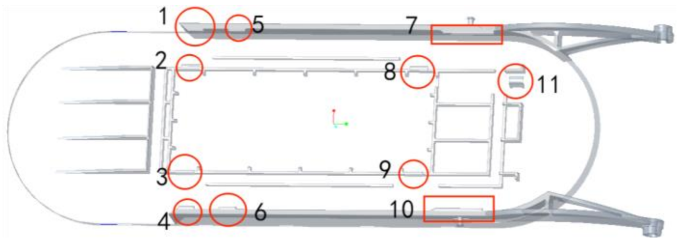


Figure 4: Complex structure numbering schematic

Due to the large number of complex structures inside the molded part, which should not be deleted, and the proximity of some of the complex structures, the arrangement of the lifter, the direction of movement and the angle of inclination need to be analyzed and determined.

After measuring the Creo model, the No. 1 and 2 undercuts are 11mm apart, and the No. 3 and 4 undercuts are 17mm apart, so the design of these two lifters should be considered emphatically. For the No. 1 and 2, doing undercut-forming along the width direction of the product is not desirable. Therefore, try to innovate the design of thicker lifter along the length of the two undercut at the same time to the left side of the undercut-forming. As No. 1, 2 need to undercut-forming to the left, if No. 5 lifter downward, the lifters will produce mechanical motion interference. So the design of the No. 5 lifter along the length of the direction of the undercut-forming to the right, can avoid No.1 and 2 lifters. Design No. 3 downward, No. 4 upward, and the two lifters thinner to avoid motion interfering. No. 4 and 6 are in the same plane and have the same thickness, so the same lifter is also used for undercut-forming. No. 7, 8, 9, 10 undercut to the width direction, respectively, upward and downward and leftward undercut-forming can be. Lifter movement program schematic is shown in Figure 5.

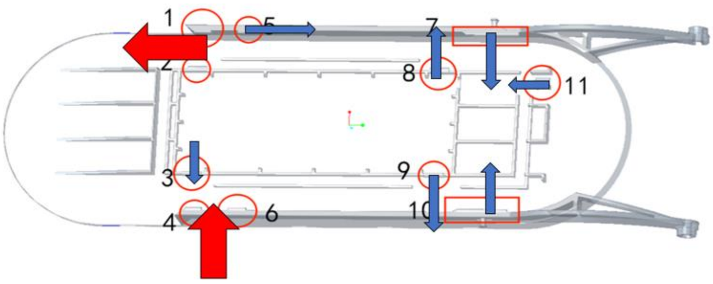


Figure 5: Undercut-forming solutions for complex structures

Determination of the parameters of the lifter according to the requirements of the undercut-forming movement.

1. Undercut-forming extraction distance S

$$S = S' + K \tag{1}$$

In the equation: S' is the distance at which the insert pin is completely free from the mold part, and K is undercut-forming safety coefficient, it range from 2 to 3. According to the product design, the measurements of the undercut-forming side inserts were carried out and the undercut-forming extraction distance was taken, the results are shown in Table 2.

Table 2: Undercut-forming extraction distance at various complex structures

Complex structure	1	2	3	4	5	6	7	8	9	10	11
S' (mm)	7.8	8	1.2	1.2	8	1.2	1.2	1.2	1.2	1.2	6
S (mm)	10.5	10.5	3.2	3.2	10.5	3.2	3.2	3.2	3.2	3.2	8.5

2. Lifter dip angle α

Usually, the lifter dip angle should be 5 °~8 °, and the maximum value should not exceed 15 ° for special conditions. According to the following formula to take the lifter dip angle.

$$h \tan\alpha > S \quad (2)$$

In the equation: h is ejection platen movement range, which designed for 40 mm, α is the lifter dip angle. After calculation, α of each lifter are obtained in turn. The actual undercut-forming extraction distance S_R from the lifter dip angle is calculated by the following equation:

$$S_R = h \tan\alpha \quad (3)$$

The resulting design is shown in Table 3.

Table 3: Lifter design parameters

Complex structure	1 and 2	3	4 and 6	5	7	8	9	10	11
α (°)	15	5	5	15	5	5	5	5	12
S_R (mm)	10.72	3.5	3.5	10.72	3.5	3.5	3.5	3.5	8.5

According to the analysis of the undercut-forming direction in Figure 5 and the design data in Table 3, the design of the lifter mechanism is completed.The three-dimensional model of the relationship between the position of the lifter, lifter base and plastic part is shown in Figure 6.

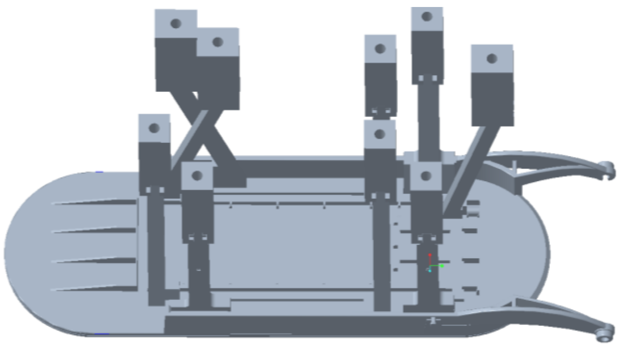


Figure 6: Positioning of the lifter, lifter base and moulded parts

2.3 Design of other structures

1. Design of outward undercut-forming side insert mechanism

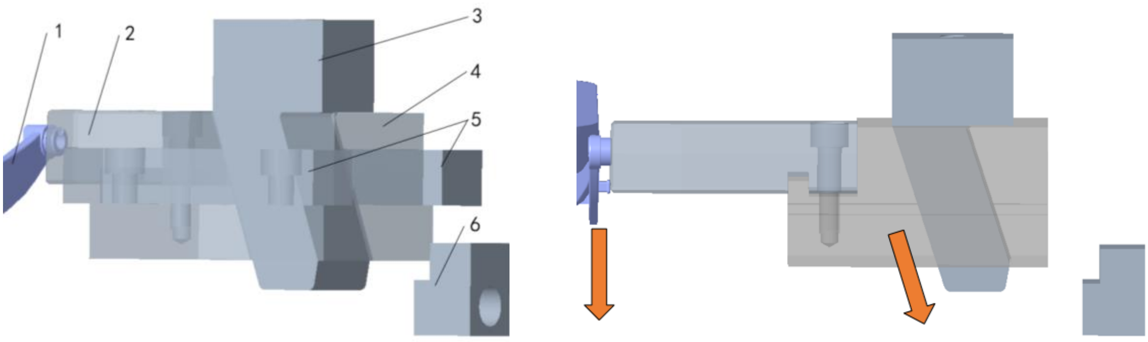
The outward undercut-forming side insert mechanism is similar to the inward one in terms of parameter design[27]. The humidifier top cover has only two inward undercuts., so two guide bar with slider mechanisms are used. Designed for the undercut-forming extraction distance

S=11mm, the guide bar dip angle α=18°, length of the guide bar L_z=71mm. Considering the lightweight design of the side insert, the undercut-forming side insert part is designed as two parts: a side insert and a movable slide, connected by a screw. And design limit segments.

The guide bars are fixed to the fixed platen by screw, and the rest of the pieces are connected to the movable platen. Side inserts are involved in molding during injection, and the movable mold end pieces are synchronized with the sub-movement in mold opening direction. Among them, the plastic part, gib and limit segment are no motion in other direction, but the side insert and moveable slide have a sub-movement in the direction perpendicular to mold opening. The displacements ratio of plastic part and side insert is the cosine of the guide bar dip angle, i.e.:

$$\frac{x_{plastic}}{x_{insert}} = \frac{v_{plastic}}{v_{insert}} = \cos\alpha \qquad (4)$$

The undercuts can be gradually separated from the side insert to complete the undercut-forming when mold opening. The guide bar with slider mechanism is shown in Figure 7.



1-Plastic part 2-Side insert 3-Guide bar 4-Moveable slide 5-Gib 6-Limit segment
(a) Guide bar with slider mechanism

(b) Absolute motion vectors of the side insert and the humidifier top cover during the mold opening stage

Figure 7: Guide bar with slider outward undercut-forming mechanism

2. Design and modeling of cooling channels

The sprue is set as a hot runner, so no need to consider the sprue cooling, which can reduce the difficulty of cooling waterway design. This mold design mold frame is CI-3550-A70-B100-C110 Chinese standard mold frame, according to the cooling channel design experience, choose its diameter is 8mm. the general arrangement of the cooling channel is shown in Figure 8.

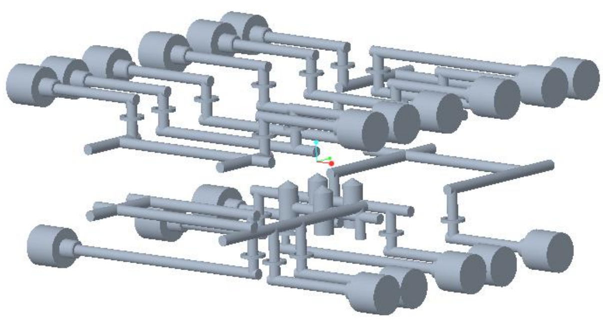


Figure 8: General arrangement of cooling channel

3. Design and arrangement of ejection system

The ejection system consists of ejector pins, ejector bars, ejector blads, lifter mechanisms and two ejection platens. In the ejection stage, the hydraulic press pushes the ejector platen, the ejector pins, lifters, etc. assembled on the ejector platen are pushed forward together, so that the humidifier top cover and the residual material move in the mold closing direction. In addition to the previously designed lifters, a total of 24 ejectors were designed, of which 7 ejectors were designed in the branch runner to prevent residual material from tearing and sticking to the branch runner. The arrangement of the ejector elements in relation to the humidifier top cover is shown in Figure 9.

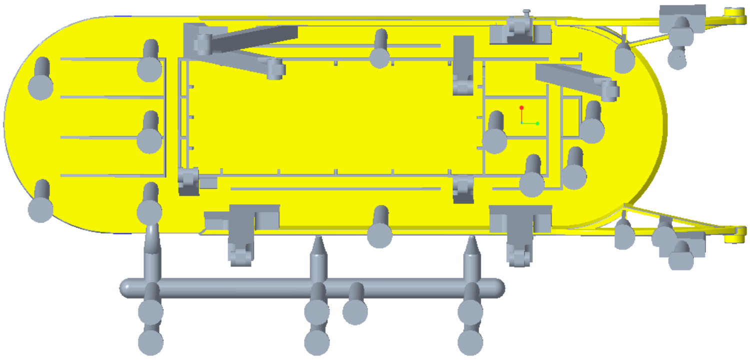


Figure 9: Layout relationship between the ejector elements and the humidifier top cover

3 COMPARATIVE ANALYSIS OF INJECTION MOLDING QUALITY

Each process within the IMD production process is not independent of the other processes, so each process has a non-negligible impact on the quality of the final injection molded part. The following is a quality analysis of this IMD mold redesign through Moldflow software and trial mold production. Based on the above analysis and orthogonal experiment, the process parameters of this IMD mold are set as shown in Table 4.

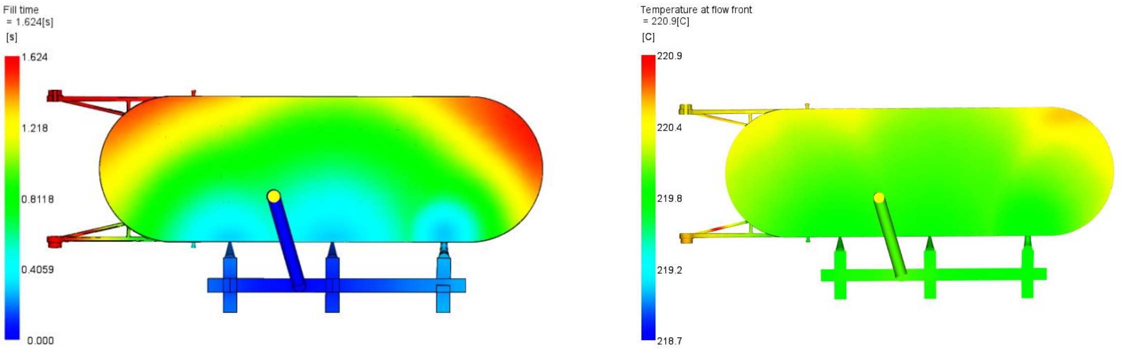
Table 4: Production process parameter setting

Project	Setting
Filling pressure	80MPa
Packing pressure	80MPa
Filling time	1.5s
V/P convert	99%
Filling temperature	220℃
Mold temperature	60℃
Cooling mode	General waterway
Coolant temperature	25℃
Ejection temperature	70℃
Mold opening time	5s

The model of the plastic part is input into Moldflow software, and the previously designed gate, cooling channel, sprue and branch runner, etc. are modeled and meshed in Moldflow, doing finite element calculation is carried out, and the results of simulation are as follows.

3.1 Filling and packing effect analysis

The actual filling took 1.624s, and there was no short shot phenomenon after checking, and the mold filling is balanced, the molten plastic can basically reach the end of the cavity at the same time. The filling and pressure maintaining aspects meet the production requirements. The pressure maintaining time is determined according to the orthogonal test. The design is qualified. The filling effect is shown in Figure 10.

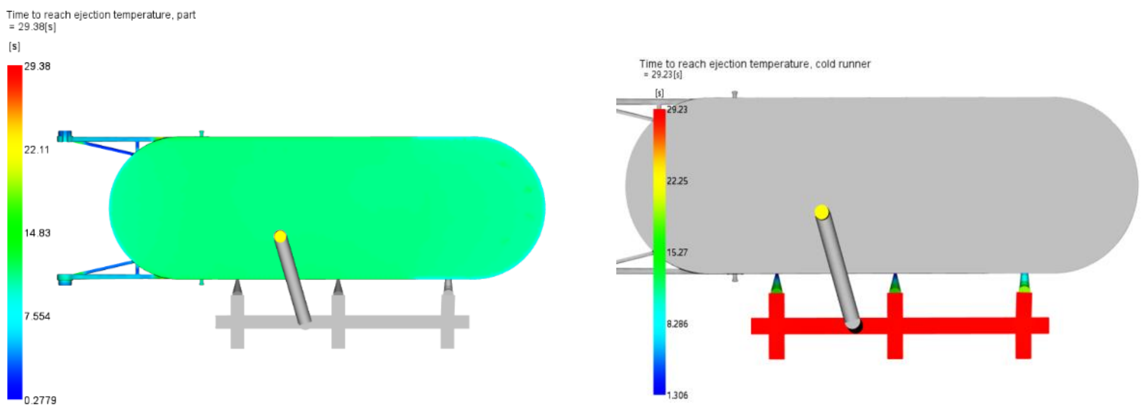


(a) Fill time (b) Temperature at flow front

Figure 10: Hot and cold runner mold filling effect analysis

3.2 Cooling effect analysis

Cooling simulation of hot and cold runner mold through Moldflow, the cooling time of the cavity and cold runner of the IMD mold are all in the vicinity of 30s, The Humidifier top cover have some connection structure, whose wall thickness is larger, The humidifier top cover have some connection structures, whose wall thickness is larger, there are a small number of "hot spots" cooling slower, The residual material of branch runner is discarded and recycled after demolding, which has lower cooling requirements and can produce a certain limit of plastic deformation. So the cooling time is set to 30s. After the trial mold to verify that the cooling time is set reasonably. The cooling time of the plastic part and cold runner in hot and cold runner IMD mold are shown in Figure 11.

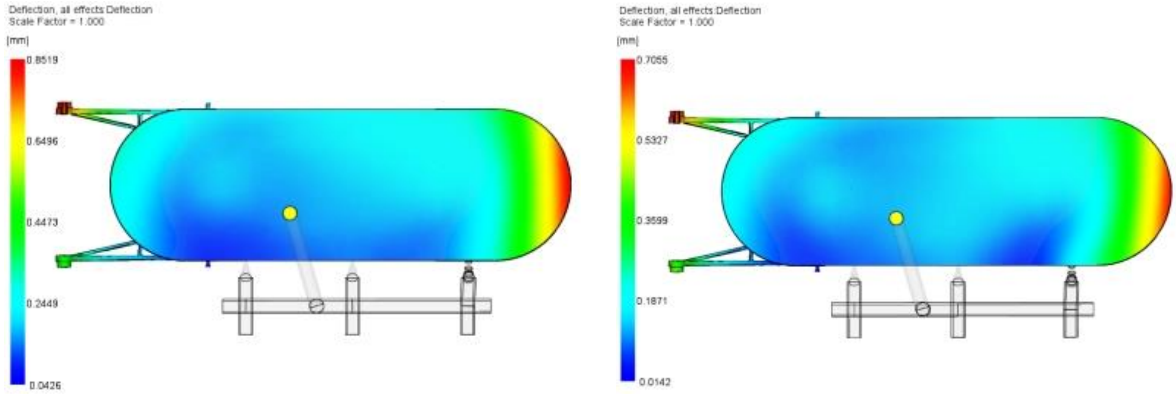


(a) Time for part to reach ejection temperature (b) Time for residual material to reach ejection temperature

Figure 11: Hot and cold runner cooling effect analysis

3.3 Warpage effect analysis

The warping deformation of plastic parts is the result of the superposition of three factors: uneven cooling, uneven in-mold shrinkage, and fiber orientation effect[28-30]. The warpage comparison of hot and cold runner mold and cold runner mold are shown in Figures 12.



(a) Warpage effect of cold runner mold (b) Warpage effect of hot and cold runner mold

Figure 12: Warpage comparison of hot and cold runner IMD mold and cold runner IMD mold

The overall warpage is small, the mold process parameters are selected reasonably, and the maximum warpage occurs at the end of the plastic part. Comparative analysis found that the maximum warpage of cold runner mold is 0.8519mm, while the maximum warpage of hot and cold runner mold is 0.7055mm, which effectively improves the product quality. Analysis of the reasons for: hot and cold runner mold for each production cycle of the injection start position in the junction of the sprue and branch runner, that is, the hot nozzle out of the injection port, and the sprue of the runner wall does not exist in the residual layer, the filling pressure loss relative to cold runner mold is smaller, the transfer and control of filling and packing pressure more accurately.

As verified by Moldflow analysis and trial mold, the hot and cold runner IMD mold designed in this paper for the humidifier top cover is able to complete the production normally, and its production cycle, including applying the diaphragm, mold closing, filling, packing, cooling, mold opening, and demolding take a total of 60s, which is shortened by 12s compared to the 72s of the cold runner mold before the improvement.

4 SUMMARY

4.1 Main headings

The design of the main sprue diameter is 8mm, using buried hot manifold and hot nozzle. The branch runner adopts a modified trapezoidal cold runner, the width of the lower bottom is 8mm, the draft angle is 5 °, two 1mm^2 45 °submerged gates and a 1.2mm^2 horn submarine gate are used to complete the pouring. For the complex structure numbering of the humidifier top cover, a local database was established for the design of the inward undercut-forming side insert mechanism, and only 9 sets of lifter mechanisms were used to complete the molding of 11 undercuts. And completed the design and modeling of the two outward undercut-forming side insert mechanisms, cooling channel and ejection system.

Based on Moldflow analysis to confirm the IMD process parameters and to verify the effect of redesign. Compare the Moldflow simulation results, it can be seen that the warpage of the part is reduced from 0.8519mm to 0.7055mm, which completes the optimization of warpage. At the same time, based on the test mold, it is found that the injection production cycle is reduced from 72s to 60s, and the replacement of the hot and cold runner molds completes the improvement of production efficiency.

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