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가스사출시 가스흐름방향의 예측 및 제어

서 영 수
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Control of Gas Direction in Gas Assisted Injection Molding

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요 약

가스사출시 두개이상의 가스흐름가능방향이 존재 할 때 가스는 선택적인 방향으로 흐르게는데 여기에서는 이가스흐름 방향을 예측 하는 방법을 제시하였다. 지금까지는 가스흐름방향은 가스의 하류에 있는 수지의 저항값, 즉 압력손실필요량을 비교하여 예측 되어 왔는데 이방법은 대부분의 경우에 정확한 예측력을 가지고 있었다. 그러나 수지의 저항값 또는 압력손실필요량을을 비교 하는 방법이 실제에는 경우에따라 맞지 아니하였다. 이 연구에서는 수지속도비교가 압력손실필요량비교 보다 한단계위의 판단기준(criterion) 이 되는 것을 설명하고 그예를 들어 증명 하고 있다. 압력손실필요량비교 대신 수지속도비교방법을 쓰면 예외없이 모든 경우 정확하게 가스흐름방향을 예측을 할수 있다.

Abstract–An improved method to predict preferred direction of gas in gas assisted injection molding processes is introduced. Resistance of resin flow is defined and this resistance of resin flow is not directly related to the resistance of gas flow. Pressure drop requirement was believed to be proportional to the resistance to gas flow in our previous work. Instead of using the pressure drop requirement, velocity of resin should be compared to predict the gas flow direction. This method predicts the gas flow direction from the knowledge of process variables such as resin flow length, cross section area of cavity, melt temperature, and short shot. A simulation package was used to confirm the method.
Keywords–Gas assisted injection molding, Preferred direction of gas, Velocity difference

1. Introduction

In the gas assisted injection molding process, an inert gas is injected into the center of the flow of resin[1-5]. The lower viscosity of the hotter molten material in the center of thicker sections, such as gas channel, confines the gas to form hollow spaces.

To design molds in which the gas cores out all the thick sections and not the thin walls, one needs to predict and understand the preferred direction of gas in the process. In this paper, we use a method to relate the preferred gas direction with the process variables. The method requires a knowledge on the relations between resistance for the gas flow and process variables such as resin flow length, cross section area of cavity, melt temperature, and existence of short shot. A simulation package was used to confirm the method.

Commercial packages simulate the flow of gas. At a mold design stage, the commercial package plays a very important role to prevent blow through or fingering phenomena by simulating the gas flow. At the pilot production or first mold trial stage, the package also plays an important role to make perfect parts. If, however, the packages are not available at the molding shop or instant solution to prevent blow-through or fingering is necessary at the mold trial stage, then the methods in this paper will be very useful to treat the troubles. When a trouble shooting engineer modifies the virgin mold without a flow analysis package, initially he needs qualitative information described in the method, not quantitative. After qualitative questions are answered, the quantitative solution comes from trial and error. For example, if the theory tells that the channel size be enlarged, the shop mold maintenance technician will enlarge the channel diameter a little and try the molding cycle. This channel enlargement step is repeated until satisfactory parts come out of the mold.

It is well known that a prerequisite condition for gas flow is the existence of an unfilled region or a short shot at the moment of gas injection. "Gas goes to the direction of the last resin fill area" is a very common sentence to many gas assisted injection molding engineers and mold/part designers. Once this unfilled region exists, gas goes to that direction.

When there exists more than one unfilled region and these paths are competing for the direction of gas, it was believed that the gas prefers the direction of less resistance. "Gas goes to the direction of least resistance" is another common sentence to gas assisted injection molding technicians.

In our previous papers[6,7], we suggested that the degree of resistance of gas flow is proportional to the pressure drop requirement in equation[1] through[4]. This suggestion was correct to a certain extent. However this suggestion became inapplicable when certain situations were encountered.

Yang and Huang[9] defined resistance of the flow and used it as resistance for the gas flow. In this paper, we show how the resistance is useful yet has limitations in prediction of gas flow. Furthermore, this paper shows how velocity difference comparison gives perfect solutions for the prediction and control of gas flow direction.

2. Theory

Although the process is an unsteady state, steady state flow equations may be used. The equation for the steady state flow of a Newtonian fluid between infinite parallel flat plates is[8]

$$\Delta P = \frac{12\mu \bar{V} L}{a^2} \tag{1-1}$$

where

L = length of plate in direction of flow

a = distance between plates

ΔP = pressure drop across the distance

$\bar{V}$ = average velocity

neglecting end effects.

This equation can be rewritten as

$$\Delta P = \frac{12\mu Q L}{b a^3} \tag{1-2}$$

where

Q = flow rate

b = width of plate

The equation for the steady state flow of pseudo plastic liquids between infinite parallel flat plates is given by

$$\frac{\Delta P}{2L} = \left(\frac{Q(3n+1)}{\pi n}\right)^n \left(\frac{m}{a^{(3n+1)}}\right) \tag{2}$$

where

m, n=power law indices

The steady state flow of a Newtonian liquid through conduit with diameter D is given by (1)

$$\Delta P = \frac{32\mu \bar{V} L}{D^2} \tag{3-1}$$

or

$$\Delta P = \frac{128\mu L Q}{\pi D^4} \tag{3-2}$$

The steady state flow of pseudo plastic liquids through conduit with radius R is given by

$$\frac{\Delta P}{2L} = \left(\frac{Q(3n+1)}{\pi n}\right)^n \left(\frac{m}{R^{(3n+1)}}\right) \tag{4}$$

When one predicts the preferred gas direction, equations (1-1), (1-2) and (3) were used. These equations were easier than equations (2) and (4) to use, and these are as correct as equations (2) and (4) for high shear flow like injection molding process.

Theoretically, there exist pressure drops both along the gas phase and along the polymer melt phase. However viscosity of gas is less than 0.1% of apparent viscosity of polymer resin and the pressure drop along the gas phase can be considered negligible. Thus the pressure of the gas may be considered the same for all regions of gas not only in the stage of stationary packing mode, which comes from fluid statics, and but also in the phase of first filling mode. Hence, only the pressure drop of the resin is necessary for the discussion of the degree of the resistance.

2.1. Definition of resistance

Equation (3-2) can be rewritten as

$$\Delta P = Q\frac{128\mu L}{\pi D^4} \tag{5}$$

Resistance r is (4)

$$r = \frac{128\mu L}{\pi D^4} \tag{6}$$

The resistance increases with the increase of viscosity, path length between gas front and melt front, and decreases with the increase of cross section area. The cross section area here excludes the frozen layer of the mold cavity. Equation (6) can be reorganized into

$$\Delta P = Qr \tag{7}$$

2.2. Total resistance of two pipes connected in series

Consider Fig. 1 where two pipes are connected in series.

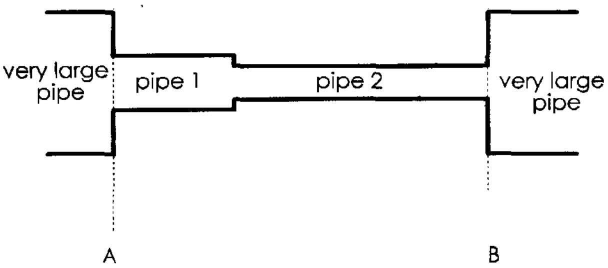

Fig. 1. Two pipes connected in series.

For pipe 1, pressure drop ΔP_1 is

$$\Delta P_1 = Q_1\frac{128\mu L_1}{\pi D_1^4} \tag{8}$$

And for pipe 2, pressure drop ΔP_2 is

$$\Delta P_2 = Q_2\frac{128\mu L_2}{\pi D_2^4} \tag{9}$$

Since

$$\Delta P = \Delta P_1 + \Delta P_2 \tag{10}$$

and flow rate is same in a steady state for both pipes connected in series,

$$\Delta P = Q\left(\frac{128\mu L_1}{\pi D_1^4} + \frac{128\mu L_2}{\pi D_2^4}\right) \tag{11}$$

This equation can be rewritten into

$$\Delta P = Q(r_1 + r_2) \tag{12}$$

$$r_t = r_1 + r_2 \tag{13}$$

where r_t is total resistance across point A and point B. For the pipes connected in series, the total resistance is the sum of each resistance.

2.3. Resistance of two pipes connected in parallel

In Fig. 2, pipe 1 and pipe 2 with different diameters are positioned in parallel configuration. Consider a case where a fluid is flowing from left to right in a steady state. For pipes connected in parallel as in Fig. 2,

$$\Delta P_1 = Q_1\frac{128\mu L_1}{\pi D_1^4} = Q_1 r_1 \tag{14}$$

$$\Delta P_2 = Q_2\frac{128\mu L_2}{\pi D_2^4} = Q_2 r_2 \tag{15}$$

Since

$$\Delta P = \Delta P_1 = \Delta P_2 \tag{16}$$

$$(Q_1 + Q_2)r_t = Q_1 r_1 = Q_2 r_2 \tag{17}$$

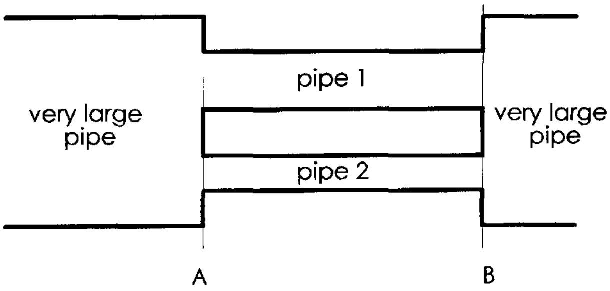

Fig. 2. Two pipes positioned in parallel configuration.

By rearranging this equation

$$\frac{1}{r_t} = \frac{Q_1 + Q_2}{Q_1 r_1} = \frac{Q_1}{Q_1 r_1} + \frac{Q_2}{Q_2 r_2} = \frac{1}{r_1} + \frac{1}{r_2} \tag{18}$$

Total resistance can be obtained from this expression.

2.4. Q_1/Q_2 and D_1/D_2 for two pipes connected in parallel

Consider Fig. 2. By substituting equation (14) and (15) into equation (16),

$$\frac{Q_1}{Q_2} = \frac{L_2 D_1^4}{L_1 D_2^4} \tag{19}$$

or

$$\frac{\overline{V}_1}{\overline{V}_2} = \frac{L_2 D_1^2}{L_1 D_2^2} \tag{20}$$

At a steady state, equation (19) expresses the ratio of resin flow rate between pipe 1 and pipe 2. Equation (20) expresses the linear velocity ratio.

3. Results and Discussions

3.1. Which equation to use to compare the resistance

Consider a case shown in Fig. 3. In our previous work (1)(2), the preferred direction of gas was predicted assuming that the pressure drop requirement is directly proportional to the resistance of gas flow. In that work, equation (3-1) which include average velocity, not the flow rate, was used. We did not use equation (3-2), as this equation is not an appropriate one to use for the purpose. The reason why equation (3-2) should not be used was not explicitly described in our previous paper. It is indeed very possible for someone to use equation (3-2) to compare the resistance. In this case study, we will show why equation (3-1) should be used and why equation (3-2) is not an appropriate equation to use.

The resistance of gas flow to the left hand side is proportional to

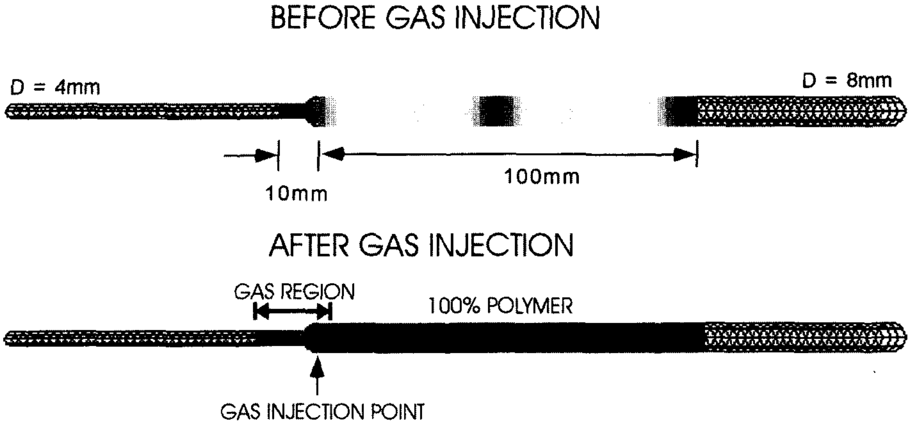

Fig. 3. Gas direction in pipes

$$(\Delta P)_L = \frac{32\mu\bar{V}_L L_L}{D_L^2} \text{ or } (\Delta P)_L = 32\mu\bar{V}_L(10/16) \tag{21}$$

and the resistance of gas flow to the right hand side is proportional to

$$(\Delta P)_R = \frac{32\mu\bar{V}_R L_R}{D_R^2} \text{ or } (\Delta P)_R = 32\mu\bar{V}_R(100/64) \tag{22}$$

$\bar{V}_L$ is velocity along the left hand side path and $\bar{V}_R$ is velocity along the right hand side path. Assuming the same velocity at both sides, $(\Delta P)_L$ is smaller than $(\Delta P)_R$, and our previous work concluded that the resistance of the flow to the right hand side direction is greater. The left hand side direction is the preferred direction of gas flow. Mold Flow simulation result in Fig. 3 confirmed the case.

Instead of equation (3-1), one may be mislead to use equation (3-2). We will show how this choice of equation gives wrong conclusion.

With the equation (3-2), one can calculate that the pressure drop requirement to the left hand side is proportional to

$$(\Delta P)_L = \frac{8\mu Q_L L_L}{\pi R_L^4} \text{ or } (\Delta P)_L = \frac{8\mu Q_L(10)}{\pi(4)^4} \tag{23}$$

and the pressure drop requirement to the right hand side is proportional to

$$(\Delta P)_R = \frac{8\mu Q_R L_R}{\pi R_R^4} \text{ or } (\Delta P)_R = \frac{8\mu Q_R(100)}{\pi(8)^4} \tag{24}$$

where Q_L is the flow rate along the left hand side path and Q_R is the flow rate along the right hand side path.

In this calculation, the pressure drop requirement to the left hand side, $(\Delta P)_L = (0.3125)\frac{\mu Q_L}{\pi}$, seems to be larger than the right hand side, $(\Delta P)_R = (0.1953)\frac{\mu Q_R}{\pi}$. Thus one may erroneously conclude that flow goes to the right hand side, which is contradictory to the above conclusion using equation (3-1). This is not true because this method compares pressure drop requirement to keep the flow rate constant for both directions. The pressure drop requirement to keep flow rate constant is not related to the resistance to gas direction.

If one want to use pressure drop requirement as a variable for resistance for gas direction, one should realize that "resistance of gas flow is proportional to pressure drop requirement to keep velocity constant." Thus, equation (3-1) not equation (3-2) should be used.

3.2. Better and best way of prediction : Comparison of velocity

Consider the case shown in Fig. 3 again. Since pressure at the connection point of two pipes is the driving force for both directions of flow,

$$(\Delta P)_L = (\Delta P)_R \tag{25}$$

assuming both ends are open to atmospheric pressure, as is the case in most of well-maintained mold. If we substitute equations (23) and (24) into (25), or from equation (19)

$$\frac{Q_L}{Q_R} = 0.625 \tag{26}$$

The calculation shows that more volume of liquid flows through the right hand side. However a higher flow rate does not necessarily mean a lower resistance to gas flow. By correlating the average velocity with flow rate, the equation (26) can be modified to show

$$\frac{\bar{V}_L}{\bar{V}_R} = 2.5 \tag{27}$$

This result is also obtained by using equation (20). The calculation results implys that the average linear velocity of resin fluid is 2.5 times faster along the left hand side path compared to the right hand side path. When the gas enters, the gas chooses a direction of higher resin fluid velocity, not the higher flow rate. Once the gas chooses this dirction, the resistance of the flow drastically decreases in the direction. The preferred direction is chosen at the beginning stage of gas flow and the preferred direcion can never be reversed afterwards.

Direction with higher flow rate may or may not have higher average velocity. In this case direction with higher flow rate did not have higher average velocity. It is very important to compare the velocity, not the flow rate when one need to predict the preferred direction of gas. Remember here againthat simulation result showed that gas flows to the left hand side in the figure.

In this case, equation (3-2) can not be used in the prediction of gas path, and equation (3-1) can be used. Furthermore, method of velocity comparison is the better method in the prediction of gas path.

Consider a second case shown in Fig. 4.

In this case, the upper side is composed of two pipes. The first pipe with a diameter of 4 mm and a length of 50 mm is connected in series with a second pipe with a diameter of 8 mm and a length of 50 mm. At the lower side, the same pipes as the upper side are connected but flipped horizontally. At the left hand side and the right hand side of these pipes, very thick pipes are attached as shown in the figure.

Resin fluid is injected into the very large pipe at the left hand side as shown in the Fig. 4, and gas is injected at the same location when 80% of the cavity is filled with resin. At this moment, a very large pipe at the right hand side is 50% filled. To predict the preferred direc-tion of gas in this situation, pressure drop requirement may be compared between the upper side and the lower side. In this case, resistance at the upper side is the same as the lower side. Pressure drop requirements (to keep same flow rate) are the same for both sides. Thus one may erroneously conclude that gas may enter both sides simultaneously.

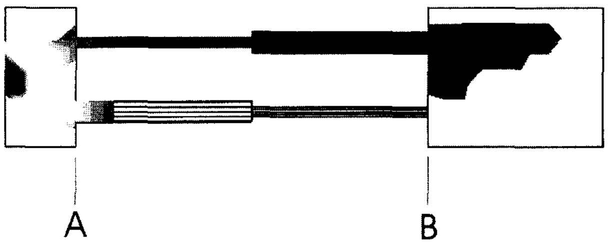

Fig. 4. Preferred direction of gas through two path with same total resistance. Gas exists partially at dark area. Each contour shows time when gas has reached.

At a second attempt to predict the preferred direction of gas, pressure drop requirement to keep the same velocity may be compared between the upper side and the lower side. This approach is acceptable. However, with the kind of complex situation as this case, one can get easily lost in the process of reasoning.

Since the pressure drop and total resistance of the upper side is the same as the lower side,

$$Q_U = Q_L \tag{28}$$

at the entrance to the upper and lower pipes.

Here subscript U denotes the upper side and L denotes the lower side.

$$Q_U = \frac{\bar{V}_{UU}\pi D_{UU}^2}{4} \tag{29}$$

$$Q_L = \frac{\bar{V}_{LU}\pi D_{LU}^2}{4} \tag{30}$$

Here first subscript U denotes the upper side and first subscript L denotes the lower side. Second subscript U denotes the upstream near region A. Substituting these equations at the entrance into equation (28)

$$\frac{\bar{V}_{UU}}{\bar{V}_{LU}} = \frac{D_{LU}^2}{D_{UU}^2} \tag{31}$$

Here we need to know what happens at upstream. D_{UU} is the pipe diameter of the upper pipe at the upstream region A and D_{LU} is the pipe diameter of the lower pipe at upstream region A. D_{UU}=4 mm and D_{LU}=8 mm. By substituting these numbers into equation (31), $\bar{V}_{UU}$ is 4 times larger than $\bar{V}_{LU}$ at the entrance. Since $\bar{V}_{UU}$, velocity at the upper side in the entrance region, is higher during the resin filling stage, entering gas at the upper side moves faster. Once this occurs, velocity increases with time. Simulation results confirms that gas prefers the upper side. In this case, the upper side has the same resistance as the lower side. The upper side has the same flow rate as the lower side. Only the velocity differs, depending on the diameter of the pipe at upstream. Since the upper side of the pipe has a thinner pipe at upstream, the gas enters the upper side first.

In this case, neither equation (3-1) or equation (3-2) was proved to be practical to use in the prediction of gas path. Only the method of velocity comparison may be used in the prediction of gas path.

4. Conclusion

When one uses pressure drop requirement as a mean for the prediction of the resistance to gas flow, equation (3-1) should be used. Wrong choices sometimes lead to a contradictory conclusion of gas direction. Furthermore, instead of using the pressure drop requirement or the concept of resistance of flow, one should compare the velocity of fluid in the prediction of gas direction. Comparison of the velocity of fluid is especially important for more complex situations. Comparison of the fluid velocity is the correct way in the prediction of gas direction in any situation.

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