Development of transient-integrated gas flow model and its evaluation in gas assisted injection molding

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INTRODUCTION

For such conditions that $(\frac{H}{R_0})^2$ is replaced by ε (that is the order of 10-1) and $\hat{\theta}^2$ is the order of one, the rule of thumb containing an approximated flow model was previously introduced to show, in qualitative way, whether the resistance of the relatively thick cavity of two square plates may affect the gas direction in GAIM under the fore-said geometry.[Lim, 2004] Subsequently various simulations were performed using Moldflow (version of MPI 4.0) under the conditions that all dimensions of cavity of two square plates and pipes were fixed except for the diameters of pipes and the results of simulation were compared with the results of rule of thumb (RT1) containing the approximated flow model as well as those of another rule of thumb (RT2) without the resistence of the relatively thick cavity of two square plates. There were some exceptional cases that RT1 or RT2 were not consistent with the simulation results (i.e., flow directions). Thus such a developed model as time-dependent model is required to describe transient behavior of the interface between gas phase and resin phase instead of comparison of initial velocities in upper side and lower side of the configuration, which shall be proposed and shall be utilized to compare with the results of Moldflow in this paper. In addition time-dependent model shall be also established and shall be used to compare with the results of Moldflow when cavities of pipes and runners were involved in configuration.

METHODS

1. Theory

1.1. Flow model through pipes

It is suggested that a pseudo-plastic fluid through conduit may be treated as a Newtonian fluid in such a qualitative approach as the rule of thumb to determine gas direction in GAIM. The expression of pressure drop of the steady state flow of a Newtonian liquid through a conduit with diameter of D is given in terms of average velocity V as Eq. (1) by McCabe et al.

$$\Delta P = \frac{32\mu VL}{D^2} \tag{1}$$

Assuming that Eq. (1) may be in the condition of quasi-steady state and neglecting coated layer on the surface of molds, the length of resin (L) may be described as:

$$L^2(0) - L^2(t) = \frac{\Delta P D^2 t}{16\mu} \tag{2}$$

1.2. Flow model when cavities of pipes and thick plates are involved in configuration

Since pipes are located in serial and parallel position as in Fig. 1 the section of pipes may be divided into upper part and lower part of the proposed geometry. When the combined geometry of pipes and a cavity between two SFP is considered as in Fig. 1 the model-predictions of gas penetration length may be categorized in two regions, i.e., the cavity between two SFP and the pipe. Then one may consider the case that a gas leading front (i. e, the interface between gas and melt resin) exists in the region of the cavity between two SFP as well as the case that a gas leading front exists in the region of a pipe.

1.2.1. Gas penetration in the upper part

For the former case (0≦t≦Δt) the length of gas penetration may be evaluated as below.

$$\Delta Pt = \frac{6\mu}{H^2} \ln R_0 \left(R_1^{\,2}(t) - R_1^{\,2}(0) \right) - \frac{3\mu}{H^2} \left\{ R_1^{\,2}(t) \ln R_1^{\,2}(t) - R_1^{\,2}(0) \ln R_1^{\,2}(0) - (R_1^{\,2}(t) - R_1^{\,2}(0)) \right\} + \hat{\theta} H \frac{32\mu}{\pi} \frac{L_1(0)}{D_1^{\,4}} \left(R_1^{\,2}(t) - R_1^{\,2}(0) \right) \tag{3}$$

for $t < \Delta t$:

$$\Delta t = [\frac{6\mu}{H^2} \ln R_0 \left(R_0^{\,2} - R_1^{\,2}(0) \right) - \frac{3\mu}{H^2} \left\{ R_0^{\,2} \ln R_0^{\,2} - R_1^{\,2}(0) \ln R_1^{\,2}(0) - (R_0^{\,2} - R_1^{\,2}(0)) \right\} + \hat{\theta} H \frac{32\mu}{\pi} \frac{L_1(0)}{D_1^{\,4}} (R_0^{\,2} - R_1^{\,2}(0))] / \Delta P \tag{4}$$

For the latter case (t≧Δt) the time-dependent length of remaining resin in the upper pipe may be described as below.

$$\left[\frac{L_1^{\,2}(0) - L_1(t)^2}{D_1^{\,2}} \right] = \frac{\Delta P}{16\mu} (t - \Delta t) \tag{5}$$

1.2.2. Gas penetration in the lower part

For the former case the length of gas penetration may be evaluated as below.

$$\Delta Pt = \frac{6\mu}{H^2} \ln R_0 \left(R_1'^{\,2}(t) - R_1^{\,2}(0) \right) - \frac{3\mu}{H^2} \left\{ R_1'^{\,2}(t) \ln R_1'^{\,2}(t) - R_1^{\,2}(0) \ln R_1^{\,2}(0) - (R_1'^{\,2}(t) - R_1^{\,2}(0)) \right\} + \hat{\theta} H \frac{32\mu}{\pi} \left(\frac{L_{21}(0)}{D_{21}^{\,4}} + \frac{L_{22}(0)}{D_{22}^{\,4}} \right) \left(R_1'^{\,2}(t) - R_1^{\,2}(0) \right) \tag{6}$$

for $t < \Delta t$:

$$\Delta t = [\frac{6\mu}{H^2} \ln R_0 \left(R_0^{\,2} - R_1^{\,2}(0) \right) - \frac{3\mu}{H^2} \left\{ R_0^{\,2} \ln R_0^{\,2} - R_1^{\,2}(0) \ln R_1^{\,2}(0) - (R_0^{\,2} - R_1^{\,2}(0)) \right\} + \hat{\theta} H \frac{32\mu}{\pi} \left(\frac{L_{21}(0)}{D_{21}^{\,4}} + \frac{L_{22}(0)}{D_{22}^{\,4}} \right) \left(R_0^{\,2} - R_1^{\,2}(0) \right)] / \Delta P \tag{7}$$

where the prime(') denotes the lower side of fan-shaped gas penetration in the cavity between two SFP.
For the latter case the time-dependent length of remaining resin in the lower pipe may be described as below.
1) When a gas-leading front exists in pipe21 the length of remaining resin in a pipe becomes the sum of $L_{21}(t)$ and $L_{22}(0)$. The dynamic behavior of $L_{21}(t)$ may be expressed as

$$\frac{L_{21}{}^2(0) - L_{21}{}^2(t)}{2D_{21}{}^2} + \frac{L_{22}(0)D_{21}{}^2(L_{21}(0) - L_{21}(t))}{D_{22}{}^4} = \frac{\Delta P}{32\,\mu}(t - \Delta t) \qquad (8)$$

for $\Delta t < t < \Delta t + \Delta t_1$

$$\text{where} \quad \frac{L_{21}{}^2(0)}{2D_{21}{}^2} + \frac{L_{22}(0)D_{21}{}^2 L_{21}(0)}{D_{22}{}^4} = \frac{\Delta P}{32\,\mu}\Delta t_1 \qquad (9)$$

2) When a gas-leading front exists in pipe22 the dynamic behavior of $L_{22}(t)$ becomes

$$\frac{L_{22}{}^2(0) - L_{22}{}^2(t)}{D_{22}{}^2} = \frac{\Delta P}{16\,\mu}(t - \Delta t - \Delta t_1) \qquad (10)$$

for $t > \Delta t + \Delta t_1$

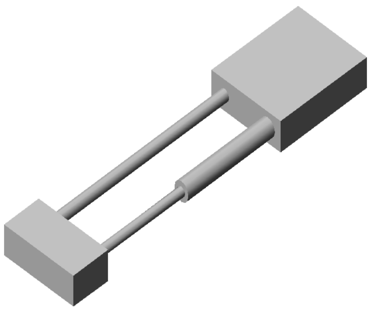


Fig. 1

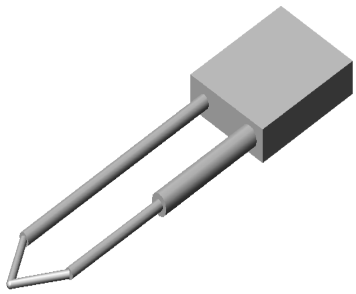


Fig. 2

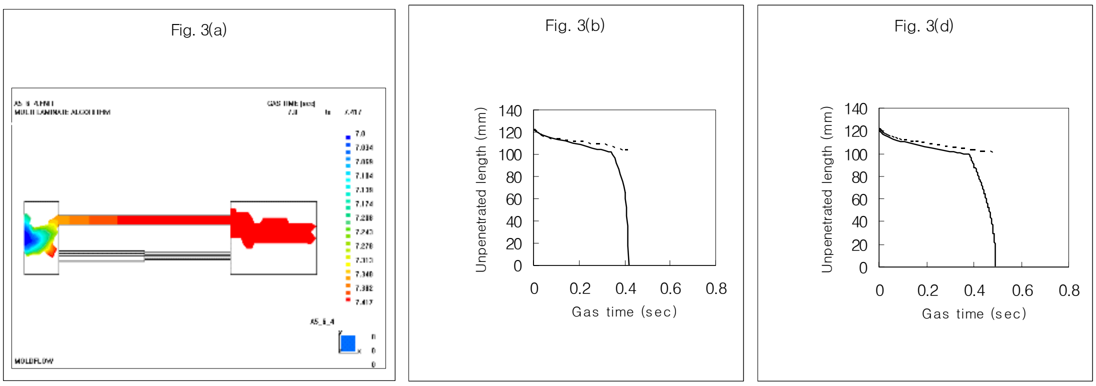
2. Simulations and Model-predictions

The simulation and model-prediction were performed under the geometry composed of two pipes (pipe1 and pipe2) connected in parallel as well as two relatively thick cavities between two SFP attached to each side of them as shown in Fig. 1. The vertex angle ($\hat{\theta}$) of fan-shaped cavity was initially π and it remained at this value at the incipient stage of gas penetration. However the vertex angle ($\hat{\theta}$) became smaller when the interface between gas and resin existed in the cavity between two SFP and it reached the value of 0.93 radian of a triangle formed connecting a gas nozzle and two junctions between SFP and pipes when the interface between gas and melt resin approached the junctions between SFP and pipes. The value of the vertex angle ($\hat{\theta}$) was chosen $\frac{2}{3}\pi$, in average, as control to apply to the proposed flow model. The values of the vertex angle ($\hat{\theta}$) were also adopted 0.93 and π as reference-vertex angles. Finite element method (FEM) was adopted to simulate the center (a pipe) and the left and right hand sides (SFP), modeled with line-elements and triangle elements respectively, of Fig. 1 in the environment of MOLDFLOW (version of MPI 4.01). In the similar manner, as in Fig. 2, finite element method (FEM) was adopted to simulate the center (a pipe), the left (runner) and the right hand side (SFP), modeled with line-elements, line elements and triangle-elements, respectively.

RESULTS AND DISCUSSION

1. Situation when cavities of pipes and thick plates are involved in configuration

The predictions of developed flow model were so quite consistent to the results of simulation that the proposed time-dependent flow model may be referred to describe very well the transient behavior of the movement of the interface of gas and melt-resin in the cavities. The predicted results were better when the value of $\hat{\theta}$ was applied as $\frac{2}{3}\pi$ radian than when the value of $\hat{\theta}$ was applied as 0.93 radian or π radian as in Figs. 3a and 3b(simulation) and Fig. 3c(model-prediction with $\hat{\theta}$ of $\frac{2}{3}\pi$ radian).



2. Situation when cavities of pipes and runners are involved in configuration

The predictions of developed flow model were also so quite consistent to the results of simulation that the proposed time-dependent flow model may be referred to describe very well the transient behavior of the movement of the interface of gas and melt-resin in the cavities. The effect of CRT was possibly expected so greater than that of RT, whose value is close to unity, in the result of simulation that the directiuon of gas flow would be finally changed to the other side of the cavity in the geometry. It is reminded that CRT was advised, in part 1 of the paper, to use as adapted rule of thumb specially when the vale of RT was so close to unity. However there was no idea which one finally prevails in the other case in part 1 of the paper, which may be treated successfully in the proposed developed model. It is amazing that the proposed developed model was able to predict exactly the cross-over between the trajectories of interface of upper and lower side.

CONCLUSION

The predictions of developed flow model were so quite consistent to the results of simulation that the proposed time-dependent flow model may be referred to describe very well the transient behavior of the movement of the interface of gas and melt-resin in the cavities.

REFERENCES

Lim, K. H., "Flow directions in gas assisted injection molding when cavities of square flat plates and pipes are involved: 1. Theory of flow model and its criterion," Korean Journal of Chemical Engineering, In print, (2004)