Simulation of the glass melt flowing during the slit down draw process

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Abstract. The three-dimensional numerical simulation of the glass melt flowing out from the slit was conducted by Semi-Implicit Method for Pressure Linked (SIMPLE) and volume of fluid (VOF) method with the software FLUENT. In this work, the effect of liquid level of glass melt, viscosity of glass melt, width and height of the slit on flow rate was investigated. The simulation results showed that the flow of glass melt was proportional to the height of the liquid surface and the square of the slit width, and inversely proportional to the viscosity of the glass melt and the height of the slit. It was concluded that high liquid level and low viscosity should be adopted in the drawing process of the flexible glass sheet.

1. Introduction

The flexible glass is a new type substrate material that is flexible, high transparent and resistant to high temperature and degradation. It will enhance the properties of flexible monitors [1-4], touching sensor [5] and solar cell board [6-9] with the substrates changing from high polymer to flexible glass. Recent years, lots of researches are focused on the forming process of flexible glass sheet. Slit down draw method is one of the basic forming methods in which the homogeneous glass metal made into sheets by flowing through a Pt alloy silt and then drawn by a gripping roller [10,11]. EGLASS Pt Technology Company in German has obtained a kind of flexible glass with 50um thickness by slit down draw method, at the same time, the Corning Company in America has produced Grade 7059 glass with the same technology. Since commercial reasons, all firms keep the process parameters secret strictly [12].

The most essential technology parameter in slit down draw method is the flow of glass melt which dominates the quality of flexible glass products [13]. The simulation software FLUENT was used to simulate the process of glass melt flowing through the Pt slit, and the influences of height of liquid surface, viscosity of glass melt, width and height of the slit on flow rate was investigated in this paper. Consequently, the effects of factors on glass melt outlet flow will conduct the manufacture of flexible glasses.

2. The method of simulation

2.1. Modelling

Fig. 1 shows the model of the slot. The platinum slot model is constructed on the three-dimensional coordinate system of X, Y and Z. The upper and lower surfaces are on the X-Y plane, which the height h is in the Z direction. Besides, lower half of the model is the inverted triangle shape and the sidewall angle is 60°. And set a slot on the base, which the height of the slot displayed as l and the width drew as w. The inlet of the molten glass is located at the center of the upper surface, while the outlet is located at the lower surface, which is Z=0. To ensure the balance of air pressure, we set the position for air in and air out. Both the parameter of model and materials are listed in the table 1, 2.
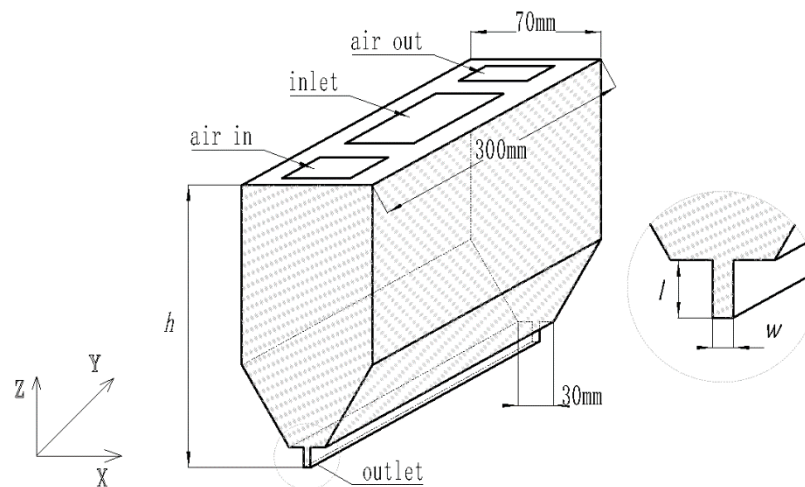
Fig. 1 Model of the slot

2.2. Meshing and boundary conditions

The modelling and mapped meshing are used to be calculated by the GAMBIT, which the model ratio is 1:1 and the coordinate unit is mm. Besides, the average volume of hexahedral mesh is 1.5mm^3 and the quantity was about 30 ~ 600000.

The fluid is divided into three parts, molten glass phase, air phase and mixture phases, in the simulation process. The inlet is set as the velocity-inlet of the glass phase, while the outlet is set as the free pressure-outlet. All the other walls are set to no-slip walls.

2.3. Calculation

Using the software FLUENT to simulation, the pressure coupling semi-implicit (SIMPLE) method was adopted during the calculating process. Both the air and the molten glass are adopted by the VOF method.

Make the following assumptions before simulating:

a. The molten glass with high viscosity had low Reynolds numbers, assuming that the fluid flow was a laminar flow motion.

b. The molten glass was stable without component unevenness, chemical reaction, bubbles, stones and so on.

c. The molten glass was a uniform incompressible Newtonian fluid.

d. The temperature of the molten glass was considered as a constant without heat transfer, that is, the thermal conductivity C_p was 0.

e. Some physical properties of the molten glass were constant, including approximately coefficient of expansion.

Table 1. Parameters of simulation

	h(mm)	η(Pa·s)	w(mm)	l(mm)
Model 1	100, 150, 200, 250, 300	50	2	3
Model 2	300	50, 100, 150, 200, 300, 400, 600	2	3
Model 3	300	50	1, 1.5, 2, 2.5, 3	3
Model 4	300	50	1	2, 3, 4, 5, 6

Table 2. Materials properties.

Materials	Physical property	Value
Molten glass	Density	2500 kg/m^3
	Viscosity	2000 Pa·s
	Surface tension	300 dyne/cm
	Contact angle	45°
Air	Density	1.225 kg/m^3
	Viscosity	1.784×10^{-5} Pa·s

3. Simulation results and discussion

The relationship between the outlet flow Q of the molten glass and the parameters is based on the simulation of all the model parameters in Table 1. The results are shown in Fig. 2. Fig. 2 (a) shows the relationship between outlet flow and glass surface height, (b) is the relationship between the outlet flow and the viscosity of the glass melt, (c) is the relationship between the outlet flow and the slit width, and (d) is the relationship between the outlet flow and the slit height.
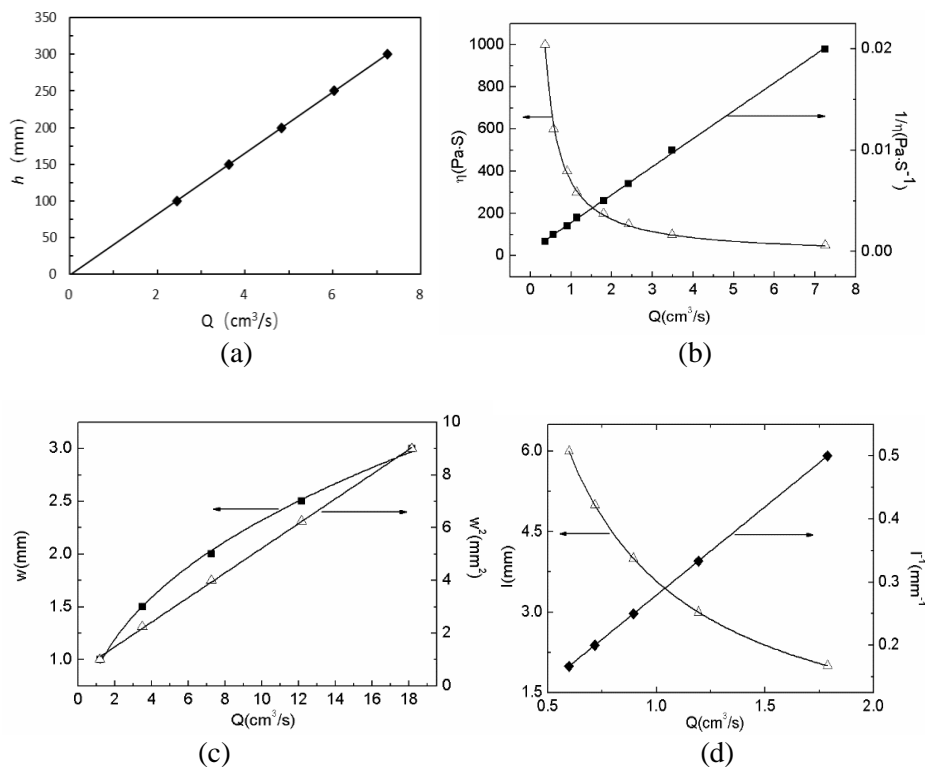
Fig. 2 Relationships between the outlet flow and the height of liquid surface, viscosity of glass melt, width and height of the slit.

From the results shown in the Fig. 2, the glass flow rate Q is proportional to the height of the liquid surface h and the square of the width w of the slit, and proportional to the reciprocal of the slit height l and the reciprocal of the glass melt viscosity η. The relationship between the outlet flow of glass melt and the parameters can be made into a formula:

$$Q = K \frac{hw^2}{l\eta}$$

Which, K is the coefficient in the formula. The K value varies only with the slit width w in the liquid level from 100 to 300 mm, glass viscosity from 50 to 600 Pa • s and slit height of 2 to 6 mm range (As shown in Table 3). The results showed that the K values increased with the slit width increasing.

Table 3. Relationship between the slit width and K values

Slit width w(mm)	K
1	0.59653
1.5	0.77579
2	0.90554
2.5	0.97213
3	1.00772

4. Conclusion

According to the modelling, calculation and analysis above, some conclusions could be certain. In the slit down draw process, the slit outlet flow can be calculated according to the formula: $Q = K \frac{hw^2}{l\eta}$. The formula shows that the outlet flow of the glass melt is proportional to the height of the glass and width of the slit, and inversely proportional to the height of the slit and the viscosity of the glass melt. The coefficient value of the formula is only related to the width of the slit.

Acknowledgments

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