

# The Investigation of Flow Behavior of Polymeric Melts in the Water Assisted Injection Molding

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## Abstract

Water assisted injection molding (WAIM) is a pretty new way to fabricate hollow or more complicated parts. Basically, the process of WAIM is similar to gas assisted molding. If it is controlled correctly, WAIM can yield thinner, more uniform part walls. However, to obtain better products, a number of questions, regarding to the material properties and process conditions, need to be fully understood. In this study, the complex flow behavior of melts under the assistance of injected water is conducted by examining the coupling effects of the process conditions and the material properties numerically. Further, the verification is performed experimentally as well.

## Introduction

During the past decades, people have been tried several media as the assistant for injection molding. Among them, water and gas are more famous and successful. Water is chosen because of its low cost. Further, water has significant thermal conductivity that can provide more effective cooling effect to reduce the cycle time of the process. In addition, it is similar to gas assist that water also can provide packing/holding effect to reduce the shrinkage and warpage to yield good quality products. Hence, several suppliers have involved to this class of techniques and equipments [1-3]. However, to obtain better products, a number of questions, regarding to the material properties and process conditions, need to be fully understood. In this study, the complex flow behavior of melts under the assistance of injected water is conducted by examining the coupling effects of the process conditions and the material properties numerically. Further, the verification is performed experimentally as well.

## Theory and Assumption

Theoretically, the water-assisted injection molding process is a three-dimensional, transient, two-phase problem with moving front and water-melt interface. To

simplify the mathematical model of this complicated problem, this work assumes that the flow in the polymer melt phase is governed by the generalized Hele-Shaw flow model [4] for the inelastic non-Newtonian fluids under non-isothermal condition. That is,

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{u}) = 0 \quad (1)$$

$$\frac{\partial}{\partial z} \left( \eta \frac{\partial \mathbf{u}}{\partial z} \right) - \nabla p = 0 \quad (2)$$

$$\rho C_p \left( \frac{\partial T}{\partial t} + \mathbf{u} \cdot \nabla T \right) = \frac{\partial}{\partial z} \left( k \frac{\partial T}{\partial z} \right) + \eta \dot{\gamma}^2 \quad (3)$$

where  $\rho, C_p, k, \eta$  denote the density, specific heat, thermal conductivity, and viscosity of the molding compound, respectively. The velocity vector in the Hele-Shaw flow model is assumed to be  $\mathbf{u} = (u_x, u_y, 0)$ .

$T$  represents the polymer temperature. The symbol  $z$  denotes the gapwise coordinate.  $\dot{\gamma}$  stands for shear rate.

In the water phase region, a constant pressure condition is assumed and the variation of water properties is ignored in this work. Also, the heat transfer effect from injected water is ignored. A special numerical technique based on flux continuity is developed to track the water/polymer interface position. The hybrid finite-difference/control volume finite element method is used to solve the governing equation numerically. Selection of time step in the time-marching procedure is crucial for a stable numerical computation. A special technique of determining time step has been developed in order to balance the efficiency and accuracy of the computation.

## Case Study

**Geometrical Modeling:** A geometry model of the product is shown in Fig.1. The rectangular dimension is 50mm X 205mm. The lower and upper sections of the trapezoid are 32mm and 20mm, respectively. Besides, the water injection location is in the runner near the gate of melts.

**Material Modeling:** Generalized Newtonian fluid (GNF)

model, (in this case, the modified Cross model), is used to model the viscosity of polymer melt as functions of pressure, temperature, and shear rate. To examine the material effect, PP and PS are applied as the testing materials theoretically. Furthermore, to confirm the accuracy of numerical results, PP 1080E-43325 (Yeong-Jia) is used as the melted material experimentally.

**Processing Conditions:** The fill time is specified to be 1.0 sec. Melt temperature at sprue entrance is specified as 230°C. Injection pressure is specified as 100 MPa. Mold temperature is 50 °C. Pre-filled percentage of melt short-shot has important effect on the process dynamics and product quality. In this case, priori CAE analysis suggests a value of 75% is suitable for this case. water injection time is specified as 0.6 sec, with a water pressure of 7 MPa. Delay time is specified around 0.6 sec.

## Results and Discussions

Dealing with the complicated water assisted injection molding process, simulation technique can provide a good direction for operation. To verify the accuracy of numerical results, first we have tried to measure the filling/packing of melts through the short shot experiments shown in Fig. 2 and Fig. 3. Obviously, at the short shot of 50% and 78%, the numerical computation can catch the flow front of melts quantitatively.

Further, the operation conditions regarding to this process are very huge. It has to be considered not only for the injection of melts but also the injection of water, especially, the design of the location of the injection location of water, the material effect, and others. Fig. 4 shows the effect of materials, where (a) is PP with MFI = 2.06 (230°C) and (b) is PS with MFI = 2.84 (225°C). As both cases are executed under the same process conditions including water assisted condition setting. It could be found that the water flow is more compact in PS case. But the flow behaviors of both cases look similar. Moreover, the symmetrical feature of this class flow has been studied as well. From Fig. 5 (a), when PP melts fill the cavity with water assisted, the symmetrical feature is clear even under the poor cored situation. In addition, when PS is applied as the testing material, this symmetrical characteristic is still valid. Obviously, water assisted injection molding could provide the symmetrical flow behavior.

To further verify our simulation result, we also

have studied this class of flow experimentally, shown in Fig.6. The operating conditions of water injection for this part include: water pressure 7 to 18 MPa, delay time 0.8 sec, short shot around 80%, water temperature 25 °C. To simulate this case, several conditions have been set up to compute this flow behavior which shown in Fig. 7. Clearly, comparing to the real part, simulated result shows the similar flow pattern as that of the real experiments. However, the skin layer between water and plastic looks a little different. It could be due to the cooling effect of the injected water inside of the part that we haven't considered into our numerical calculation yet.

## Conclusion

In this paper, we have examined the melts flow behavior under water assisted injection molding. To verify the accuracy of our numerical results, melt flows either with or without water assisted has been conducted both theoretically and experimentally. Indeed, they are in a good agreement. In addition, water assisted injection molding provide symmetrical flow behavior. It could be easier for people to apply for certain symmetrical parts fabrication. Finally, to obtain more strict results, it is necessary to consider about the cooling effect of injected water for this class of flows.

## References

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## Key Words

water assisted injection molding (WAIM), Hele-Shaw flow model, Generalized Newtonian fluid (GNF)

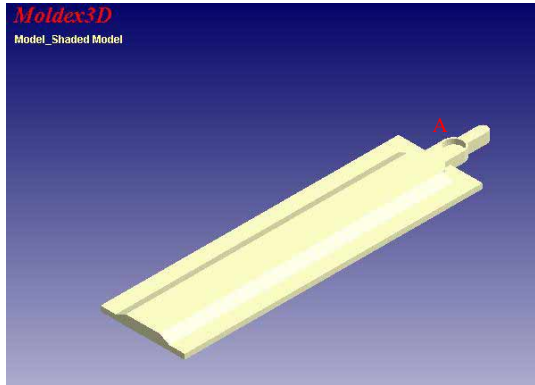


Figure 1. The study case: the thickness of parts is from 3 mm to 6mm, where A is the water injection location.

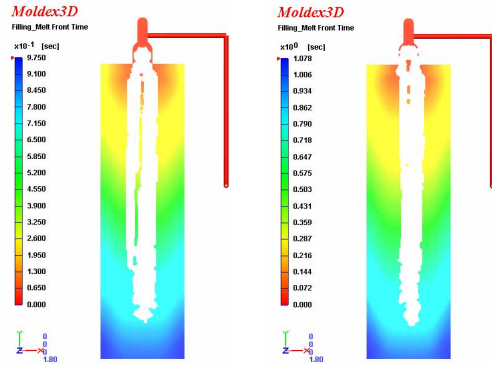


Figure 4. The material effect: (a) PP, (b) PS

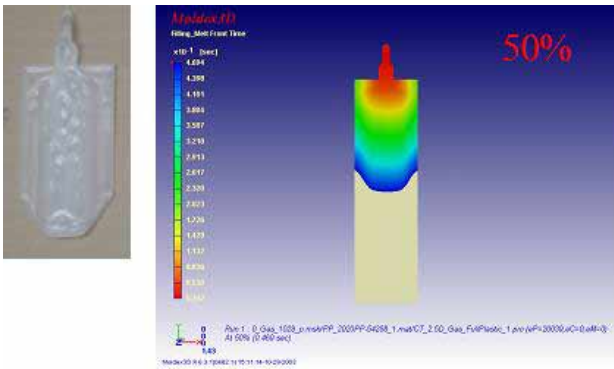
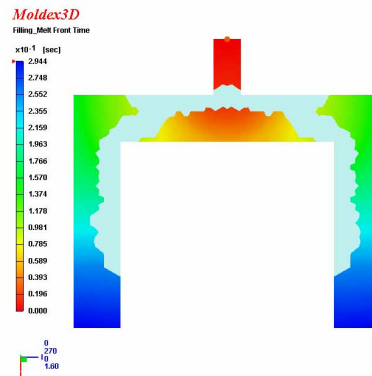


Figure 2. The verification of filling/packaging through short shot experiments.



(a)

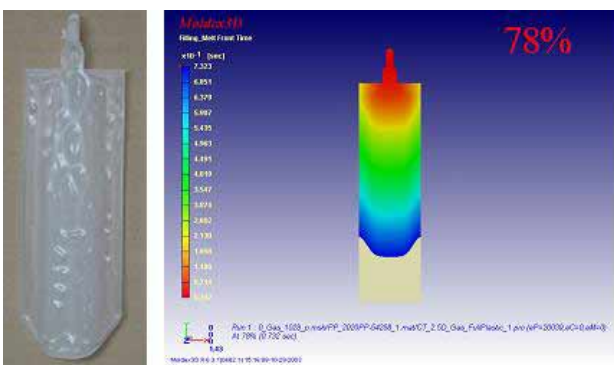
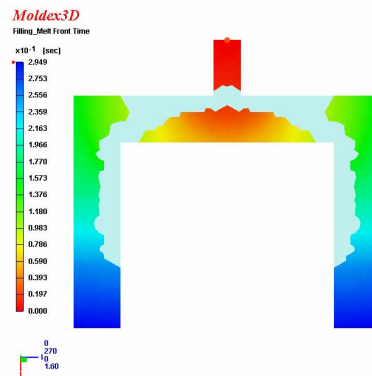


Figure 3. The verification of filling/packaging through short shot experiments.



(b)

Figure 5. Examining the symmetrical behavior of water assisted injection molding: (a) PP, (b) PS



Figure 6. The molded part after the water assisted injection molding.

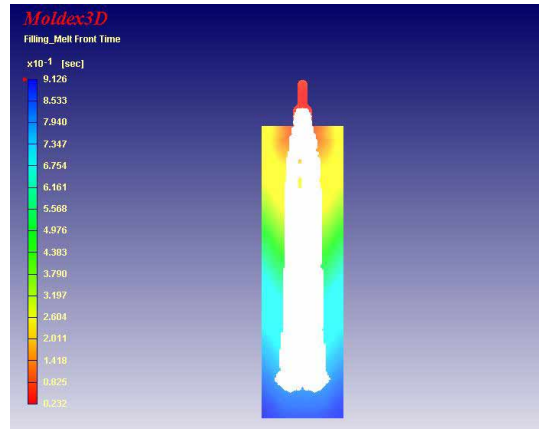


Figure 7. Using the simulation with water assisted injection molding, the flow behavior could be caught under certain operating parameters.