# True 3D CAE visualization of filling imbalance in geometry-balanced runners

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## Abstract

The filling imbalance in geometrically balanced runner system of multi-cavities is always difficult to handle in injection molding. Previous researchers revealed that the flow imbalance problem is related to the three-dimensional thermal history and shear rate distribution of melt flow in the runner, and accordingly proposed a novel apparatus to overturn the melt to avoid this problem. However, the design parameter of this apparatus is different to realize, and it is only performed by trial-and-error. In this paper, we have proposed a new methodology to analyze this injection process. Firstly, a flexible meshing methodology comprising different element topologies is proposed to provide high-resolution mesh for the runner system and cavity. Further, to demonstrate and verify our idea, the comparison between simulation and experiments has been performed. From the numerical experiments, we have proven that the proposed methodology is a highly valuable tool to help understand and further optimize the melt flipping apparatus.

## Introduction

The filling imbalance in geometrically balanced runner system of multi-cavities is always difficult to handle in injection molding. Previously, it has been proven that this imbalance results from non-symmetrical temperature and shear rate distribution. This phenomenon is always complicated by integration of the runner layout, runner geometry size, material, and process conditions. Fortunately, one of the commercial techniques, MeltFlipper$^{TM}$, provides a solution to balance the filling between cavities. Basically, it applies an overturn apparatus in runner system, and thus overcomes the non-symmetrical temperature and shear rate distribution problem shown in Fig.1 [5][6]. Obviously it is a great device, but for most people, it is too difficult to understand why and how it works?

Hence, in this study, we provide a professional tool from CAE viewpoint. We can know how the imbalance flow happened, and how the melt overturn apparatus works from the visualization of CAE analysis result.

## New Methodology and Simulation Approach

### FVM Technology for 3D analysis

It has adopted the newly developed FVM technology to provide real three-dimensional substantial analysis. This supports analyzing real conditions such as inertia effect, non-isothermal flow, and so on. Besides, it excels in its speedy and accurate calculating ability. This makes the analysis results approach reality and economizes working hours; moreover, it supports mesh analysis for over a million elements!

The polymer melt is assumed to behave as Generalized Newtonian Fluid (GNF). Hence the non-isothermal 3D flow motion can be mathematically described by the followings:

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

$$\frac{\partial}{\partial t}(\rho \mathbf{u}) + \nabla \cdot (\rho \mathbf{u}\mathbf{u} - \boldsymbol{\sigma}) = \rho \mathbf{g} \tag{2}$$

$$\boldsymbol{\sigma} = -p\mathbf{I} + \eta(\nabla \mathbf{u} + \nabla \mathbf{u}^T) \tag{3}$$

$$\rho C_P \left( \frac{\partial T}{\partial t} + \mathbf{u} \cdot \nabla T \right) = \nabla(\mathbf{k} \nabla T) + \eta \dot{\gamma}^2 \tag{4}$$

where $\mathbf{u}$ is the velocity vector, $T$ the temperature, t the time, $p$ the pressure, $\sigma$ the total stress tensor, $\rho$ the density, $\eta$ the viscosity, k the thermal conductivity, $C_p$ the specific heat and $\dot{\gamma}$ the shear rate. In this work, the Modified-Cross model with Arrhenius temperature dependence is employed to describe the viscosity of polymer melt:

$$\eta(T, \dot{\gamma}) = \frac{\eta_o(T)}{1 + (\eta_o \dot{\gamma} / \tau^*)^{1-n}} \tag{5}$$

with

$$\eta_o(T) = BExp\left( \frac{T_b}{T} \right) \tag{6}$$

where n is the power law index, $\eta_o$ the zero shear viscosity, $\tau^*$ is the parameter that describes the transition region between zero shear rate and the power law region of the viscosity curve. A volume fraction function f is introduced to track the evolution of the melt front. Here, f=0 is defined as the air phase, f=1 as the polymer melt phase, and then the melt front is located within cells with 0<f<1. The advancement of f over time is governed by the following transport equation:

$$\frac{\partial f}{\partial t} + \nabla \cdot (\mathbf{u} f) = 0 \tag{7}$$

The flow rate or injection pressure is prescribed at mold inlet. No slip is assumed at mold wall. Note that only inlet boundary condition is necessary for the hyperbolic transport equation of volume fraction function. [1-4]

**Hybrid mesh for true 3D Injection Molding Simulation**

In general, to obtain reasonable simulation result, for the pre-processing, it needs to tune up the resolution of meshing for numerical simulation. However, it's hard to achieve followed the traditional method. In traditional way, people have to create the geometry model in CAD software, and then generate the surface/solid mesh based on a given characteristic mesh size. By doing this way, it is very difficult to control the quality and quantity of meshing and elements. It will further increase the computation loading and provides the incorrect results.

To avoid this problem, here we proposed a new methodology to handle this pre-processing issue shown in Fig. 3. In this way, users only need to draw lines to represent the runner layout, and set the parameters of the runner geometry. Then, the runner solid mesh can be generated automatically. Indeed, the hybrid mesh is feature of this method; shown in Fig 2 and Fig.3. Through this way, people can flexibly tune up the resolution of element layer and also retain the quality and quantity of elements. It can further enhance the efficiency of the computation and provide more reasonable results.

## Results and Discussion

In order to illustrate how to handle the filling imbalance using this new methodology, we are going to apply two models. One is original design, and the other is revised design shown as following.

In the original design, the model has 314865 elements with hybrid solid meshes, including 62640 hexa elements, 93312 prism elements, 600 pyramid elements, and 158313 tetrahedral elements (Fig. 4). The element layer count is more than six at most regions.

Based on the original design, Fig.5 to Fig.7 are the visualized CAE analysis results. Fig. 5 shows when the melt flow passed through the first divergence, melt property of the shear rate, temperature and the viscosity produced imbalance distribution. In Fig. 6., the hotter melt near outer ring in the primary runner flow along the right side in the secondary runner A, and the colder melt near middle in the primary runner flow along the left side in the secondary runner A. Similarly, in another side, the hotter melt near outer ring in the primary runner flow along the right side in the secondary runner B, and the colder melt near middle in the primary runner flow along the left side in the secondary runner B. It results in the melt temperatures in secondary runner with one side higher and one side lower. Obviously, it is the reason when the melt flow passed through tertiary runner; the flow imbalance between cavities was created (Fig.6). This imbalance flow simulation has been compared with experimental result in a good agreement shown in Fig. 7. Specifically, when melt fills the cavities on the right hand side closer to the primary runner, its melt temperature is higher. So it is easier to fill the cavities with lower viscosity and lower flow resistance compared with the cavities on the left hand side.

In the revised design, to overcome the fill imbalance, it applies a melt overturn apparatus in runner system shown in Fig.8. Also, the geometrical system with hybrid meshes is demonstrated.

The simulation results are listed in Fig. 9 to Fig. 11. After melt passes through the overturn apparatus and enters the first divergence, the original left-right imbalanced temperature distribution turns to top-button imbalanced distribution (Fig 9). Further, when the melt passes through the second divergence, the flow imbalance between cavities was disappeared (Fig 10). This is because the runner imbalanced temperature distribution through the runner system is removed. Now the flow behavior is balanced from the runner to the cavities. (Fig 11)

## Conclusions

In this study, we have proposed a new methodology to analyze the flow imbalance from runner system to cavities. Obviously, compared both simulation and experimental results, it demonstrates the reason why the filling imbalance happened in geometry-balanced runners. Furthermore, our CAE tool can greatly help us to visualize the novel apparatus, which is used to overturn the melt in runner, and realize how it works. The melt overturn apparatus design parameter directly affects the thermal history and shear rate distribution, and this is the key point of the device. However, the control of this device is the crucial. When the melt turns over if the design parameter is inappropriate shown in Fig.12, the imbalance situation will still happen. Hence, in the assistance of the suitable CAE tool, people can realize and handle these phenomena easily and effectively.

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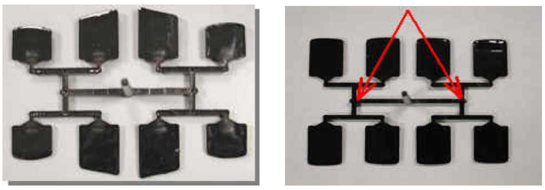
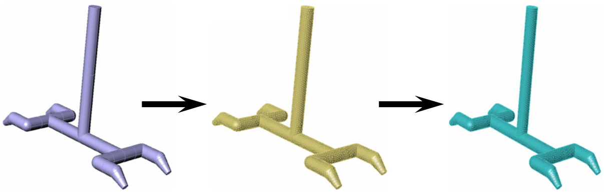
## Key Words

CAE, FEM, FVM, Mesh, Injection Molding



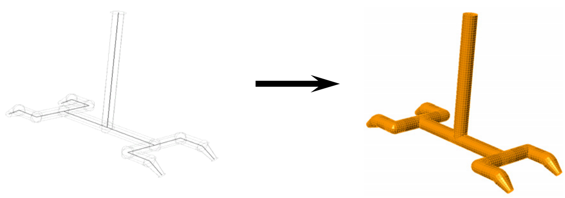
(a) (b)

**Figure 1.** True filling result from MeltFlipper™ (a) Original (b)Revised (MeltFlipper™)

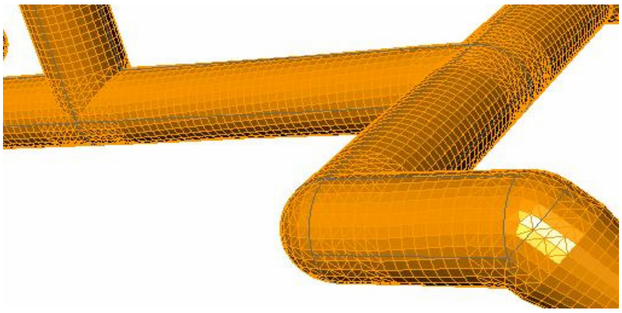


(a) (b) (c)

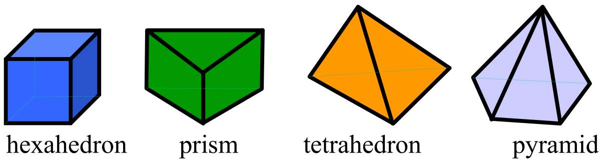
**Figure 2.** Create mesh flow path (traditional) (a) build geometrical of model (b) create surface mesh (c) generate the solid mesh



(a) (b)



(c)




(d)

**Figure 3.** Create mesh flow path (New) (a) Use line to build geometrical of model (b) Create solid mesh (c) Hybrid solid mesh (d) Different solid element

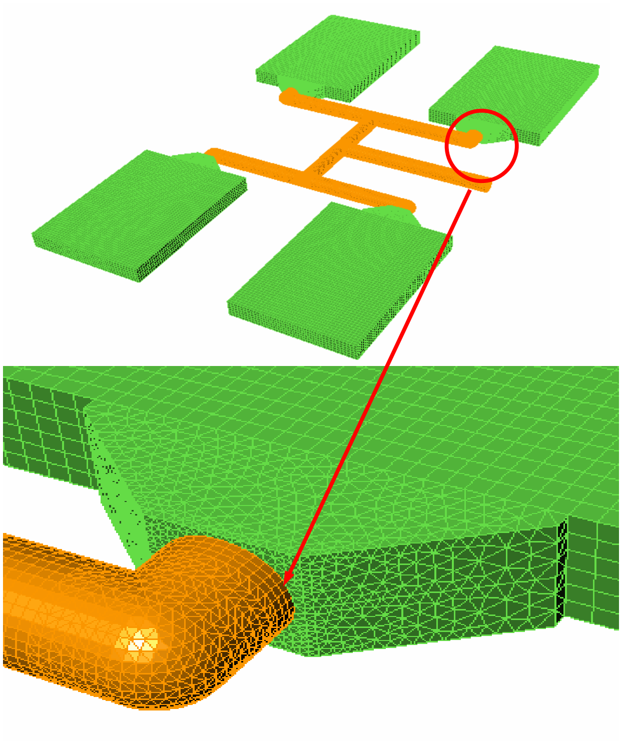


**Figure 4.** The original design: runners enter the cavity

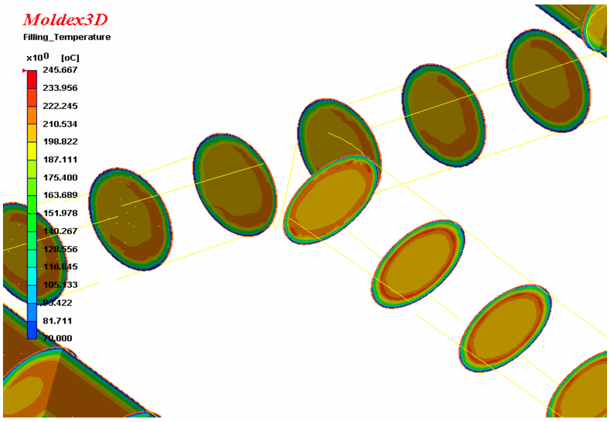



**Figure 5.** **X-Y** direction Profile at the first divergence (Original design)

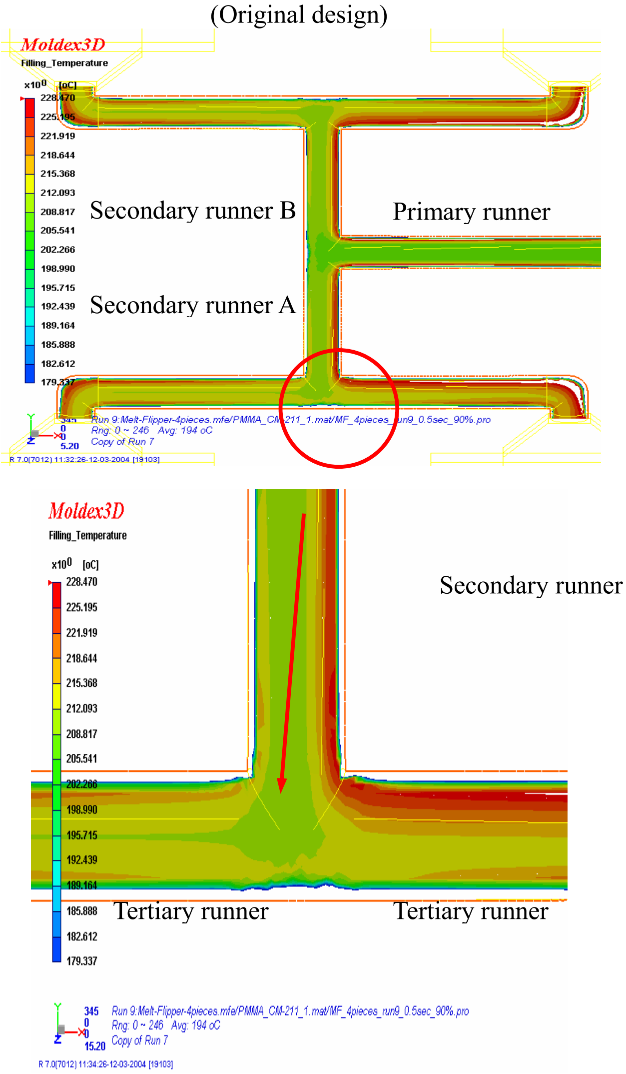



**Figure 6.** **Z** direction Profile at the second divergence (Original design)

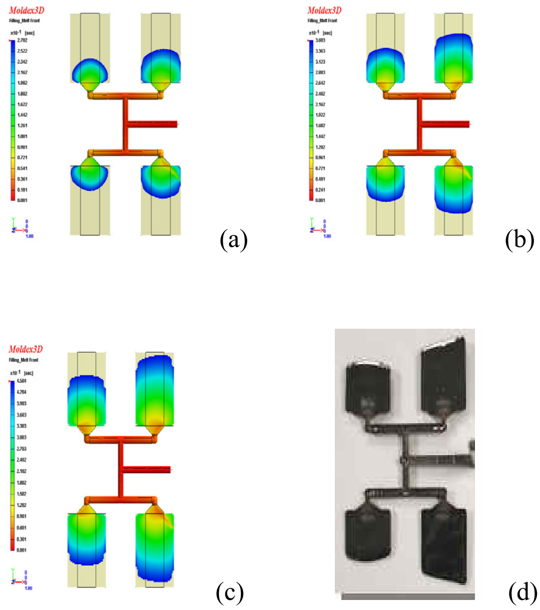



**Figure 7.** The comparison between simulation and experimental without overturn apparatus. Melt front (a)40%, (b)60%, (c)80%, (d) Experiment result of original design (MeltFlipper™)

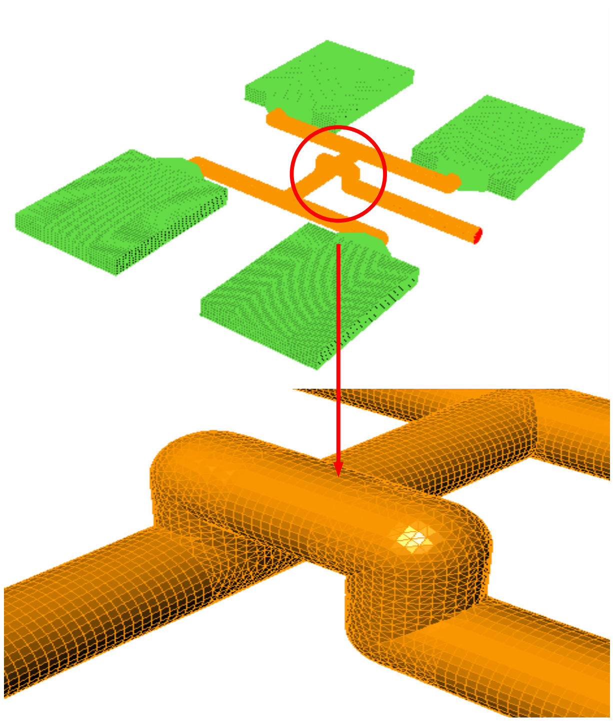


**Figure 8.** Revised design: runner system has been modified.

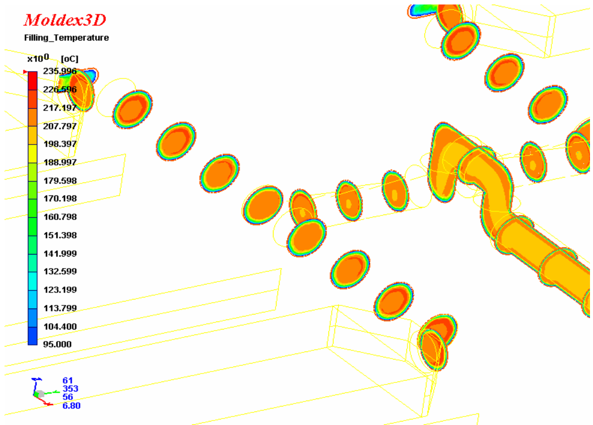



**Figure 9.** Runner profile in revised design.

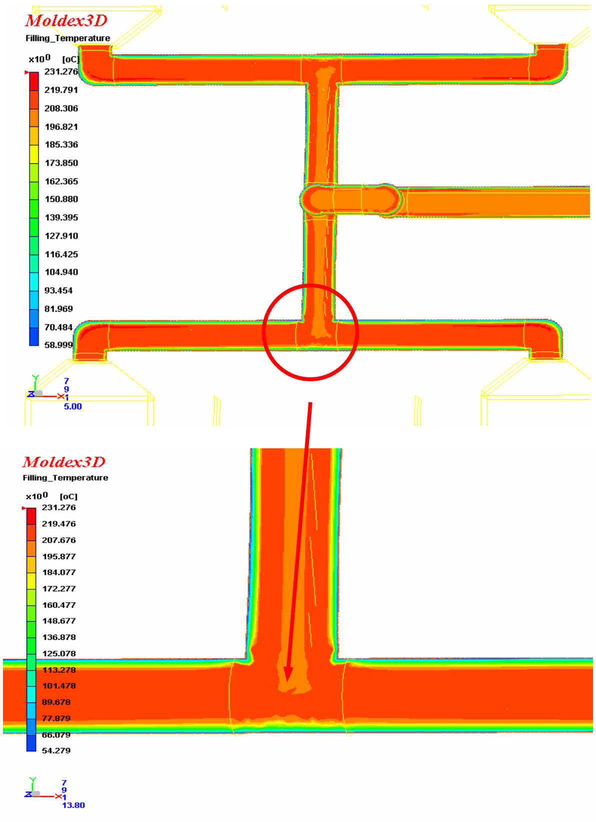



**Figure 10. Z** direction Profile at the second divergence (Revised design)

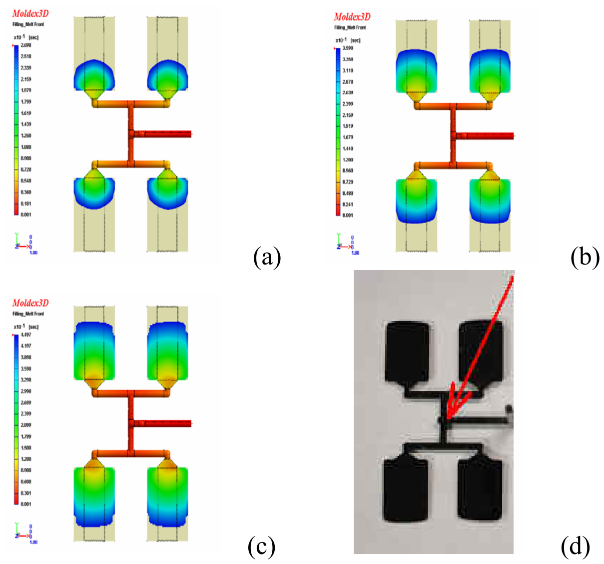



**Figure 11.** The comparison between simulation and experimental without overturn apparatus. Melt front (a)40%, (b)60%, (c)80%, (d) Experiment result of revised design (MeltFlipper$^{TM}$)

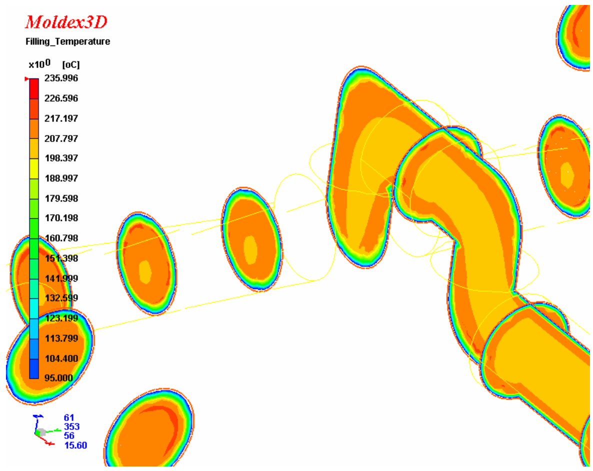



**Figure 12. X-Y** direction Profile at the first divergence (Revised design)