euspen's 20th International Conference &
Exhibition, Geneva, CH, June 2020
www.euspen.eu

# A three-dimensional flow analysis of film/ sheet extrusion dies coupled with die body deflection analysis

Dastan Igali[1], Asma Perveen[1], Dongming Wei[2] & Dichuan Zhang[3]

[1]*Department of Mechanical and Aerospace Engineering, School of Engineering and Digital Sciences, Nazarbayev University, Nur-Sultan city 010000, Republic of Kazakhstan*
[2]*Department of Mathematics, School of Sciences and Humanities, Nazarbayev University, Nur-Sultan city 010000, Republic of Kazakhstan*
[3]*Department of Civil and Environmental Engineering, School of Engineering and Digital Sciences, Nazarbayev University, Nur-Sultan city 010000, Republic of Kazakhstan*

*dastan.igali@nu.edu.kz*

**Abstract**
The coat-hanger dies are widely used in the plastic film and sheet extrusion industry. The quality of the product and power requirements of the extrusion machine depend on the flow homogeneity at the exit and pressure drop, respectively. For die manufacturers, designing the die capable of providing uniform flow at the die outlet and low pressure drop is particularly challenging. However, many numerical studies conducted on the analysis of the die pressure drop and exit flow homogeneity do not consider the deformation of the die body. This study revealed how very small displacement of the die slit may distort the flow homogeneity and increase the pressure drop. The two-way coupled fluid-structure interaction approach was proposed using the Ansys Fluent and Ansys Static-Structural software programs to study the flow behaviour in the die subjected to deformation.

Coat-hanger die, polymer extrusion, die deformation, flow homogeneity, pressure drop, fluid-structure interaction

## 1. Introduction

The coat-hanger dies are widely used in the polymer processing industry for the production of plastic films and sheets. The quality of the extruded product primarily depends on the homogeneity of the flow inside the die, while the power requirements of the equipment and tool life are governed by pressure drop [1]. The computer simulation is a powerful approach for predicting the optimal design of a die capable of providing the uniform flow and minimum pressure drop since it eliminates the need for costly material waste and time when manufacturing the die. There are several studies of the extrusion dies proposing the design methodologies based on the computational fluid dynamics (CFD) simulations [1-6]. However, only few of them [1] consider the die body deformation when calculating the polymer melt velocity and pressure drop. High internal pressures within the viscous polymer melt can cause significant die deformation which distorts the flow uniformity and increase the pressure drop.

This study is aimed to show the importance of considering die body deformation when determining the flow velocity and pressure drop within the coat-hanger die. A three-dimensional two-way coupled fluid-structure interaction (FSI) approach was carried out to represent the effect of the deformation of the solid die body on the fluid uniformity and pressure drop. Then, the results obtained will be compared with the rigid body FSI results assuming the die body to be undeformable.

## 2. Computational model

### *2.1. Material properties*

High density polyethylene (HDPE) with a melt density of 850 kg/m$^3$ at 170$^o$ C was used as example resin for the extrusion simulation. The viscosity of the polymer melt is modelled based on the Carreau model [4]:

$$\eta = \eta_0[1 + (\lambda\dot{\gamma})^2]^{\frac{n-1}{2}} \tag{1}$$

where $\eta_0$ is the viscosity at zero shear rate, $\lambda$ is a time constant obtained from the viscosity curve of the material, $\dot{\gamma}$ is the rate-of-strain tensor, $n$ is the power-law index. For HDPE: $\eta_0 = 8920$ Pa s, $\lambda = 1.58$ s, $n = 0.496$.

The die body is assumed to be constructed of tool steel with Young's modulus of $E = 2.09 \times 10^{11}$ Pa and Poisson's ratio of $\nu = 0.29$.

### *2.2. Geometry*

The geometry used for the numerical simulations consists of the following domains: solid die body and polymer melt. Die body is of the 85 mm thick, 180 mm width (distance between inlet and outlet), 750 mm long, and has an entrance of 20 mm diameter. The dimensions of the extruded product are 720 mm long and 3 mm thick. Due to the symmetric feature of the coat-hanger die, only a quarter of the die body was simulated. This reduces overall computation time.

### *2.3. Boundary conditions*

The following assumptions were made when simulating the polymer through a die: (1) the polymer melt is incompressible non-Newtonian fluid; (2) the polymer melt flow is assumed to be isothermal, laminar, and fully-developed; (3) no-slip condition between die wall and polymer melt.

The boundary conditions for the solid and fluid domains were defined based on the schematics shown in Figure 2.

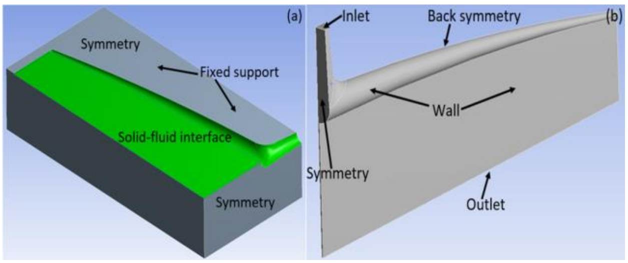

Figure 1. (a) solid domain and (b) fluid domain

For the solid part, there are two symmetrical planes and solid-fluid interface as shown in Figure 1a. Ansys Static-Structural was used for the computation of the die body deformation. It is assumed that the upper symmetry of the solid domain is fixed as in reality this face of the die is bolted. The FSI coupling data exchange between the fluid flow and solid structure appears at the solid-fluid interface.

The fluid domain was simulated using Ansys Fluent. At the inlet, the flow is assumed to be fully-developed with the mass flow rate of $\dot{m} = 0.0115$ kg/s. For the die wall, the no-slip boundary condition was applied. This implies zero normal and tangential velocities at the wall. Along the symmetrical planes, zero normal velocities and zero shear rates are applied. The outlet boundary conditions were defined as zero normal and tangential forces (Figure 1b).

## 3. Results and discussion

After conducting FSI study, the maximum deformation was determined to be $3.22{\times}10^{-5}$ m at the central region of the die outlet (Figure 2). This value is very small compared to the total die body thickness which is $8.5{\times}10^{-2}$ m. However, this displacement of the die slit caused noticeable variation in the flow rate at the outlet. The Figure 3 represents the outlet velocity distribution across the die width for both cases: (a) die body is subjected to the deflection due to high internal pressures and (b) when the die body assumed to be totally rigid.

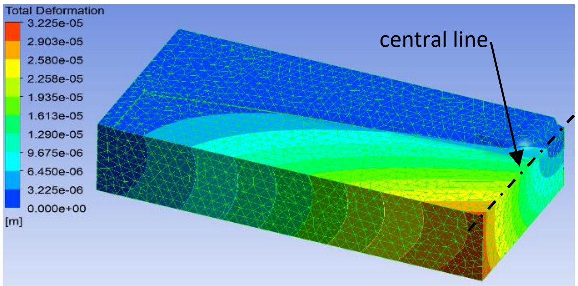

Figure 2. The total deformation of the solid die

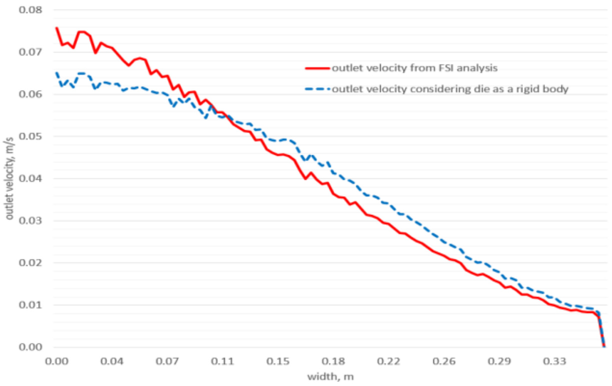

Figure 3. Outlet velocity distribution (m/s)

It can be seen from the graph that due to deflection the melt velocity is much higher at the centre and lower as it gets closer to the side wall of the die compared to the melt velocity of the rigid die. In addition, the pressure drops for deformed die and rigid die are 6.363 MPa and 6.138 MPa, respectively. Pressure contour plots are shown in Figure 4.

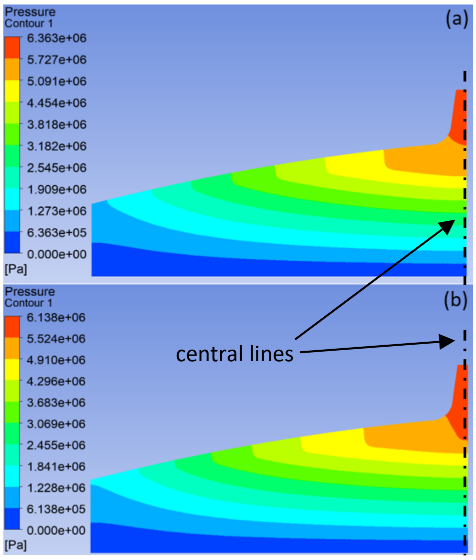

Figure 4. Pressure distribution for (a) FSI study (b) Rigid die body study

## 4. Conclusion

The FSI approach was applied by using the system coupling of Ansys Fluent and Ansys Static-Strucrual software programs. The results obtained from FSI study are different compared to the simple CFD analysis assuming the die body to be rigid. The calculated maximum deformation of the die body was only $3.22{\times}10^{-5}$ m. However, this caused totally different velocity profile at the outlet and higher pressure drop compared to the rigid body CFD analysis. The possible reason for that will be the expansion of the outlet slit particularly at the center, which causes increased flow rate and higher pressure drop at the central region. Thus, it can be concluded that the consideration of the die deflection when analysing the flow behaviour of the melt is crucial since even small displacement of the die slit may cause considerable outlet flow variation and different pressure drop. In addition, there is no work experimentally validating FSI analysis of the fluid flow through coat-hanger dies. Thus, one of the future objectives of this study will be to experimentally validate the velocity and pressure results obtained.

## References

[1] Wang Q and Smith D E 2007 Analysis of the fluid-structure interaction in the optimization-based design of polymer sheeting dies *Journal of applied polymer science* **103** 3994-4004

[2] Smith D E and Wang Q 2005 Optimization-based design of polymer sheeting dies using generalized Newtonian fluid models *J. Polymer Engineering & Science* **45** 953-965

[3] Köpplmayr T, Aigner M and Miethlinger J 2012 A Comparative Study of Viscous Flow in Slit-exit Cross-section Dies Using Network Analysis *J. Plast Techn.* **8** 53-74

[4] Huang Y, Gentle C R and Hull J B 2004 A comprehensive 3-D analysis of polymer melt flow in slit extrusion dies *J. Advances in Polymer Technology: Journal of the Polymer Processing Institute* **23** 111-124

[5] Vlachopoulos J, Polychronopoulos N, Tanifuji S and Müller J P 2012 Flat Film and Sheet Dies

[6] Meng K, Wang X and Huang X 2008 Numerical analysis of the stagnation phenomenon in the coat-hanger die of melt blowing process *Journal of applied polymer science* **108** 2523-2527