MACHINES AND EQUIPMENT

EFFECT OF THE GAP BETWEEN THE CROWN OF THE SCREW THREAD AND BODY IN OPERATION OF EXTRUDERS

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There is always a radial space between the crown of the screw thread and the inner surface of the body in extruders or helical pumps (Fig. 1). This space can vary from 0.1 to 1 mm and more as a function of the purpose of the equipment, screw diameter, and duration of operation of the extrusion unit. The existence of this radial space decreases the efficiency of the extruder due to the onset of flow of leaks.

Mohr and Mollouk proposed in [1] a method for taking into consideration the flow rate of leaks of a Newtonian liquid through the gap for an isometric task, considering flow through a plane normal to the axis of an endless screw (Fig. 2). The analytical expression obtained can be used to account for the effect of leaks on operation of the extruder in a given pressure gradient regime and their effect on the pressure gradient in a given flow regime. However, the model has important drawbacks: the effect of pressure differentials in the screw channel and in the gap on the magnitude of the leak flow rate, anomaly of the liquid, and nonisothermal character of the process are not considered.

Further improvements in the model in [1] did not eliminate these drawbacks.

The model in [1] was significantly developed in [2], where the pressure differential in the gap in the direction of axis x was considered. Nevertheless, the question of the liquid anomaly, flow rate of the liquid over the crown of the screw along axis z, and heat release in the gap remained open.

In the study described here, further improvements in this approach are proposed: flow in the gap is considered as nonisothermal flow of a non-Newtonian liquid with consideration of the pressure differential in the gap. In addition, a method for considering dissipative heat release in the gap between the crown of the screw thread and the inner wall of the body in the overall heat balance is reported.

We will make the following assumptions for describing flow of a polymer melt in the channel of an extruder with consideration of the gap. The temperature of the polymer melt along the height of the gap is constant and equal to the temperature of the body. We will consider movement of the polymer melt in the gap as movement of a pseudoplastic liquid between two infinite plates, one immobile and the other moving at rate \( v_0 \), equal to the circumferential velocity of the screw directed at angle \( \varphi \) to coordinate z. Flow in the gap is caused both by the movement of the plate and the pressure differential. The movement of the polymer melt in the gap between the crown of the screw thread and wall of the cylinder can thus be described by a system of differential equations of the following type:

\[
\frac{\partial}{\partial y} \left( \mu_e \frac{\partial v_{1x}}{\partial y} \right) = \frac{\partial P_{1x}}{\partial x}
\]

(1)

\[
\frac{\partial}{\partial y} \left( \mu_e \frac{\partial v_{1x}}{\partial y} \right) = \frac{\partial P_{1x}}{\partial z}
\]

(2)

where \( \frac{\partial P_{1x}}{\partial x} \) is the pressure gradient in the gap in the direction of axis x; \( \frac{\partial P_{1x}}{\partial z} \) is the pressure gradient in the gap in the direction of axis z; \( v_{1x} \) is the constituent of the velocity in the gap in the direction of axis x; \( v_{1z} \) is the constituent of the velocity in the gap in the direction of axis z; \( \mu_e \) is the effective viscosity, which is a function of the shear rate and temperature.
Fig. 1. Diagram of the extruder screw channel.

Fig. 2. Scan of the channel for calculating leaks.

The mass flow rate through a plane normal to the axis of the screw (plane AA' in Fig. 2) is equal to the assigned mass flow rate $G_0$. This holds for any section along the length of the screw channel during operation in the steady-state regime.

The efficiency of a screw extruder in some arbitrary section with consideration of flow of a polymer melt through the radial gap can be determined with the equation (in Fig. 3: flow through closed region 1):

$$G_0 = G_z - G_u,$$

where $G_z$ is the mass flow rate in the direction of axis $z$ (flow through closed region 2 in Fig. 3); $G_u$ is the mass flow rate of leaks (flow through closed region 3 in Fig. 3).

To determine the mass flow rate through closed region 2 in Fig. 2, we will divide it into two constituents: flow through region AB and flow through region BC. The mass flow rate in the direction of axis $z$ is thus defined as

$$G_z = G_{AB} + G_{BC},$$

Flow $G_{BC}$ over the crown of the thread through the gap in the direction of axis $z$ and flow $G_{AB}$ in most of the channel in the same direction are found with the equations

$$G_{BC} = \rho \int \frac{H}{H_0} v_z dy,$$

$$G_{AB} = \rho \int \frac{H}{H_0} v_x dx dy.$$