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PARAMETRIC STUDY & ANALYSIS OF SPIRAL DIE MANDREL

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Abstract— An analysis of flow in spiral mandrel die is presented. The analysis is applied to study the effect of various die design parameters on the flow distribution at the end of the spiral mandrel section. Three variables that have a very strong effect on the flow distribution are the number of grooves, the initial clearance, and the groove helix angle. The distribution is improved by increasing the number of grooves, by using a non-zero initial clearance, and a relatively small helix angle. Two more variables that have a significant effect on the flow. Distribution are the taper angle and the initial groove depth.

Keywords- Spiral Die, Spiral Mandrel, Extruder Die, Flow analysis, Die Flow

1. INTRODUCTION

Spiral mandrel distributors have been used initially for the extrusion of blown film, and then have been adopted for the extrusion of tubes and pipes. In recent years, spiral mandrels have replaced the coat hanger and fish tail type of distributors in side-fed wire and cable covering and coating dies, because of their superiority in fine distribution of the melt around the circumference. The spiral mandrel die is used to form the polymer melt into an annulus without the formation of the type of “weld lines,” which are inherent in other types of die designs. These weld lines are due to the splitting and subsequent recombining of the polymer melt as it flows past some obstruction (necessary mechanical support). Even though weld lines may not be visible, they are a weak point in the product and increase the potential for failure [1]. Figure 1 is a cutaway view of a typical spiral mandrel distribution system

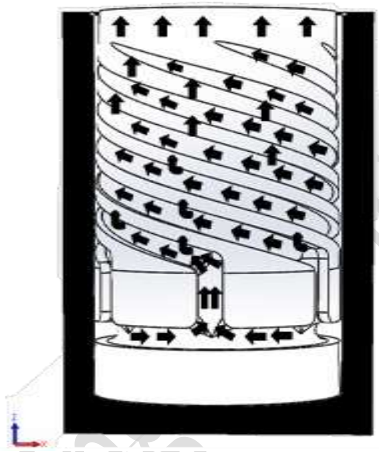

Figure 1: spiral mandrel distribution (cut way view)

The polymer melt enters the die from the bottom and flows through radial holes (ports) to the surface of the mandrel. The ports feed the spirals, which are helical grooves cut into the surface of the mandrel. A gap between the land and the body allows the polymer to leak out of the spiral channel, thereby creating the annular flow[7]. The smearing effect of this design is advantageous because it helps distribute any inhomogeneities in the polymer melt, resulting in a product with more uniform properties and essentially no weld lines.

1.1 SPIRAL MANDREL

Dies for the extrusion of melt strands with an annular cross section are used for the extrusion of pipes, hoses, tubular film, and tubular parisons, for extrusion blow molding as well as for cable and pipe jacketing. Extrusion of pipes and nonreinforced hoses is done mainly with straight dies. For the extrusion of tubular films, reinforced hoses, and prisons as well as for jacketing, the extruder is at an angle—most often 90°—to the direction of the extrudate. Mainly the die types are, 1) Mandrel support die 2) Screen pack die 3) Side Feed Die 4) Die with spiral distributor [4].

In this parametric study we are using Die with spiral distributor with side feed input. Three

Different types of spirals are taken for experimental studies which are 4-star, 5-star & 6-star spiral mandrel as shown in fig 2, 3 & 4.

Figure 2: 6-Groove Spiral (side view**)**

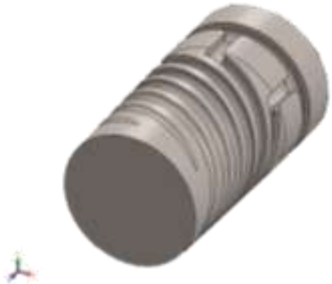

Figure 3: 6-Groove Spiral (Trimetric view)

Figure 4: 5-Groove Spiral (Trimetric view)

Figure 5: 4-Groove Spiral (Trimetric view)

The stream of melt delivered by the extruder is first divided by a primary distributor into individual flows with which the spiral of the secondary distributor is fed. In the simplest case, the primary distributor consists of radially symmetrical bores, a so-called star distributor, as was selected for the design described here.

In the spiral section, the channel depth decreases steadily, and the gap between the mandrel and the outer part of the die (die housing) usually increases steadily in the direction of extrusion. In this way, the melt stream flowing through one spiral divides itself into two streams. The first stream flows axially over a land formed between two spirals; the other continues to follow the course of the spiral. As a result, every point around the annular discharge gap receives melt formed by the superposition of the tangential melt streams from all channels of the spiral distribution system. Since there are no weld lines with this arrangement, good thermal homogeneity (i. e., a uniform melt temperature) is achieved in addition to the desired physical homogeneity[4]. The complete elimination of weld lines and flow marks is one of the greatest benefits of this melt distribution system. The channel depth decreases toward the center so that the melt, which initially flows only in the channel, is gradually forced over the land. The melt is finally redirected toward the die outlet and, if desired, can be combined with additional melt layers.

1.2 EXTRUDER

Basically extrusion consists of transporting the solid polymer in an extruder by means of a rotating screw, melting the solid, homogenizing the melt, and forcing the melt through a die. The extruder screw of a conventional plasticating extruder has three geometrically different zones (Fig.5), whose functions can be described as follows:

Feed zone: Transport and preheating of the solid material.

Transition zone: Compression and plastication of the polymer.

Metering zone: Melt conveying; melt mixing and pumping of the melt to the die [3].

Extruder output is depending on the type of extruder, the output is determined either by the geometry of the solids feeding zone alone, as in the case of a grooved extruder, or by the solids and melt zones to be found in a smooth barrel extruder.

2. CALCULATION

A good estimate of the solids flow rate can be obtained from Eq. (1) as a function of the conveying efficiency and the feed depth. The desired output can be found by simulating the effect of these factors on the flow rate by means of Eq. (1)

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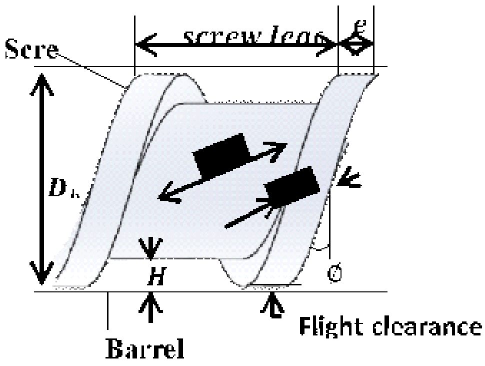

Figure 6: Screw cross-section

$$G = 60 * \rho_0 * N * n_f * \pi^2 * H * D_b(D_b - H)\frac{W}{W+W_{FLT}} * \sin\emptyset * \cos\emptyset \quad [2] \tag{1}$$

The pressure generating due to rotation of screw is calculated by,

Pressure (ΔP):

$$\Delta P = \frac{6\pi\Delta L N\eta}{H^2 \tan\emptyset} \tag{2}$$

The conveying capacity of the melt zone must correspond to the amount of melt created by plastication, in order to ensure stable melt flow without surging. This quantity can be estimated by means of the Eq. (3).

$$\dot{Q}_p = \frac{-\pi D_b \cdot H^3\left(1-\frac{v\cdot e}{s}\right)\cdot \sin\varphi^2 \cdot \Delta p \cdot 10^{-4}}{12\eta_a \cdot L} \quad [8] \tag{3}$$

Mass Flow Rate $\dot{m}_p$:

$$\dot{m}_p = 3600 * 1000 * \dot{Q}_p * \rho_m \tag{4}$$

The melt conveying rate of the metering zone can be calculated from

$$\dot{m} = 3 \cdot 10^{-5} \cdot \pi^2 \cdot {D_b}^2 \cdot N \cdot H \cdot \left(1 - \frac{v \cdot e}{s}\right) \cdot \rho_m \cdot \sin\varphi \cdot \cos\varphi \cdot (1 - a_{d-J}) \tag{5}$$

Where $a_d = -\dot{m}_p/\dot{m}_d$ and $J = \delta_{FLT}/H$

The average shear rate in the metering channel is calculated as

$$\dot{\gamma}_a = \pi \cdot D_b \cdot N/60 \cdot H \quad [9] \tag{6}$$

Melt Pressure: For a screw zone of constant depth the melt or stock pressure can be obtained generally from the pressure flow by means of Eq.(7),

$$|\Delta p| = \frac{F_1 \cdot 2 \cdot \eta_p \cdot \Delta l}{\sin\emptyset\,(H_{out} + \delta_{FLT})}\left[\frac{|\dot{Q}_p|(2\eta_R + 1}{W(H_{out}}\right. \cdot 10^{-5} \tag{7}$$

Where, $\eta_p = \frac{\eta_\sigma}{\gamma^{n_R-1}}$ [9], $\eta_\sigma = K_R * \exp(-\beta * T)\gamma^{n_R-1}$, $\beta = \frac{10^{-6}*{\delta_{FLT}}^2*N}{240*a}$, $a = \frac{\lambda_m}{10^6*c_m*\rho_m}$

For a circular channel the shear rate is calculated from Eq. (8). For an annulus, which represents the pipe cross-section it is given by

$$\dot{\gamma}_{annulus} = \frac{6\dot{Q}}{\pi(R_0+R_i)(R_0-R_i)^2} \quad [9] \tag{8}$$

The pressure drop is,

$$\Delta P = \frac{\dot{Q}^{\frac{1}{n}}}{K^{\frac{1}{n}} * G} \tag{9}$$

Where G, the die constant follows from

$$G_{circle} = \left(\frac{\pi}{6}\right)^{\frac{1}{n}} * \frac{R^{\frac{1}{n}+1}}{2L} \quad [6] \tag{10}$$

$$G_{slit} = \left(\frac{W}{6}\right)^{\frac{1}{n}} * \frac{H^{\frac{2}{n}+1}}{2L} \tag{11}$$

$G_{annulus}$ Follows as,

$$G_{annulus} = \left(\frac{\pi}{6}\right)^{\frac{1}{n}} * \frac{(R_0+R_i)^{\frac{1}{n}} * (R_0-R_i)^{\frac{2}{n}+1}}{2L} \tag{12}$$

Table 1: Calculation Data

Temperature (℃)	Speed (rpm)	Mass flow rate (Kg/h)	Pressure (bar)	Melt Pressure(bar)	Pressure Drop(bar)
190	47	6.06	37.4	180.4	5.21
190	35	4.85	40	336.6	9.95
190	20	2.57	26.74	202.9	20.2
200	47	6.04	35.25	155.3	5.21
200	35	4.44	37.84	301	9.95
200	20	2.57	25.21	189.7	20.2
210	47	6.04	33.45	132.7	5.21
210	35	4.86	35.89	266.2	9.95
210	20	2.57	23.66	177.4	20.2

Table 2: Spiral Data

Numbers of spiral Grooves	Speed (rpm)	Time (s)
4	47	124
4	35	169
4	20	292
5	47	145

5	35	197
5	20	341
6	47	166
6	35	226
6	20	391

***Note: Data is calculated according to above equations.**

3. DESIGN & FLOW SIMULATION

Fig. 7 shows design of screw and barrel & fig. 8 shows flow simulation of material in barrel. Fig. 9 shows Die body and spiral where fig. 10, 11, 12 shows flow simulation in different spirals.

Figure 7: screw & barrel

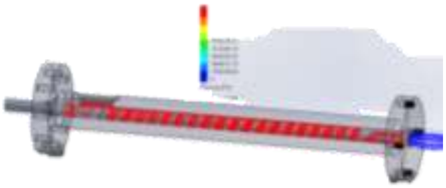

Figure 8: screw & barrel (Flow simulation)

Figure 9: Die body & Spiral

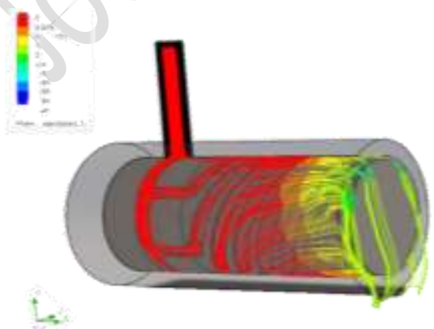

Figure 10: 6-Spiral mandrel flow Simulation

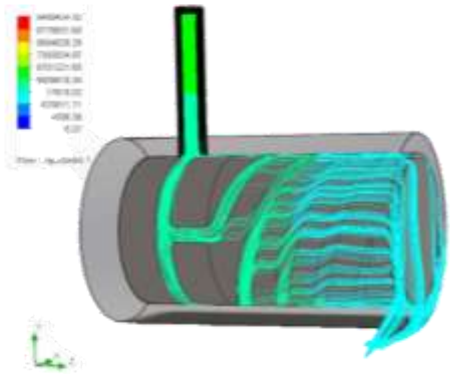

Figure 11: 5-Spiral mandrel flow simulation

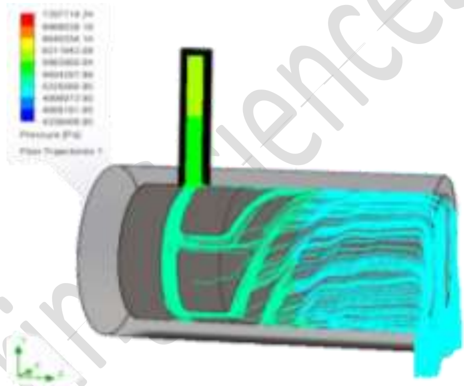

Figure 10: 4-Spiral mandrel flow simulation

4. CONCLUSION

An analysis of flow of a power law fluid in a spiral mandrel die is presented. The analysis is applied to study the effect of various die design parameters on the flow distribution at the end of the spiral mandrel section. Three variables that have a very strong effect on the flow distribution are the number of grooves, the initial clearance, and the groove helix angle. The distribution is improved by increasing the number of grooves, by using a non-zero initial clearance, and a relatively small helix angle. Two more variables that have a significant effect on the flow distribution are the taper angle and the initial groove depth. The distribution uniformity improves with the initial groove depth, while the pressure drop reduces at the same time. The pressure inside the barrel is increasing due to change in rotation of the screw; due to this the melt pressure is also varying. There are no effect on pressure drop due to varying temperature, because this pressure drop is depend upon spiral geometry and spiral's width & depth, so for all temperature pressure drop remain same.

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