Optimization of the Maddock & Egan Thermomechanical Homogeneisation Zones

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Analysing the Maddock and Egan dispersive zones, their thermal homogeneisation effect and their role in dispersing agglomerated particles within the melt, resulted a correlation between the barrier zone slit height, h_3 and the length of the barrier zone, L_{02} assuring the dispersing of the agglomerated particles within the melt. Given the role the Maddock and Egan zones have, based on the obtained relations, their dimensions (h_3, B_3, L_{02}, φ) can be calculated.

Keywords: Maddock and Egan, thermal homogeneisation, in dispersing, barrier zone

The flowrate over the barrier flight *f* results from the superposition of drag flow, $G_{m,d}$ with pressure flow corresponding to pressure variation, Δp_{12}, between channels c_1 and c_2 [1]. Similar superpositions of drag and pressure flows are taken place into the channels c_1 and c_2, respectively.

To obtain a relationship for the necessary barrier zone slit height h_3 one uses the correlations for pressure variation along the homogeneisation zone, given in literature [2; 3].

For the flow over the barrier flight, based on relationships obtained in [3] (fig.1):

$$\Delta p_{12} = 2K_3 \cdot \frac{B_3}{h_3^{2\nu_3+1}} \cdot \left| \frac{2\left(\frac{1}{\nu_3}+2\right)\cdot\left(G_{m1}-G_{md3}\right)}{\rho_3 \cdot L_2} \right|^{\nu_3} \cdot \mathrm{sgn}\Delta G_m \qquad (1)$$

where:

p_1 - pressure at slit entry;
p_2 - pressure at slit exit;
$\Delta p_2 = p_1 - p_2$;
K_3; ν_3 - rheological constants at temperature in the slit;
ρ_3 - melt density inside slit;
D - screw diameter; $L_2 = L_{02} / \sin\varphi$ [3];
φ - helical barrier flight angle [3];
L_{02} - length of channels in the serw axis direction;
$G_{m1} = \frac{G_m}{n_z}$ - flowrate at entry into channel c_1;

$$G_{md,3} = \frac{\pi}{120} \cdot k_w \cdot \rho_3 \cdot \left(D - h_3\right) \cdot \left(h_3 - 0{,}5 \cdot \delta\right) \cdot L_{02} \cdot n \qquad (2)$$

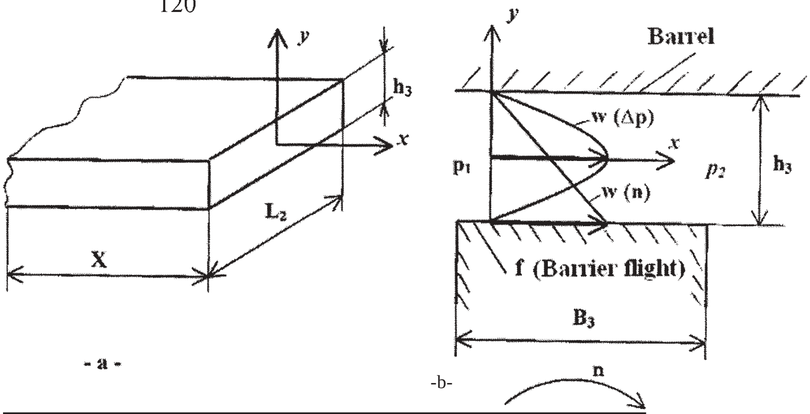

Fig. 1. Melt flow inside the slit:
a - geometerical dimensions of the slit;
b-velocity profiles of flow inside the slit

$G_{md,3}$ – drag flow inside the slit;
k_w - coefficient (generally equal to 0.7-1.0);
n - screw rotational speed, rot/min;

$$\mathrm{sgn}\,\Delta G_m = \begin{cases} 1, & \text{if} \quad G_{m1} > G_{md,3}; \\ -1, & \text{if} \quad G_{m1} < G_{md,3}. \end{cases}$$

Using Δp_{12} calculated with relationship (1) a correlation for the necessary height of the slit h_3 is inferred. Pressure variation Δp_{12} determines the effective shear, τ_{ef}, when moving through the slit h_3. This shear must fulfil the condition:

$$\tau_{ef} \geq \tau_{\min}, \qquad (3)$$

where $\tau_{\min}$ is the minimum shear that assures the destroying of solid particles agglomerates. Its value depends on the nature of particles that need to be dispersed [4; 5]. By example, for carbon black $\tau_{\min}$ is about 60 kPa [4].

On the other hand, when flowing through the slit of height h_3, the shear tension at the wall is:

$$\tau_w = \frac{h_3 \cdot \Delta p_{12}}{2B_3} \qquad (4)$$

From relationships (3) and (4) results:

$$\frac{h_3}{B_3} \geq \frac{2 \cdot \tau_{\min}}{\Delta p_{12}} \qquad (5)$$

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which together with relationship (1), gives the final condition (*minimum shear condition*):

$$h_3 \le \left(\frac{C_2}{L_{02}}\right)^{0,5} \qquad (6)$$

where:

$$C_2 = \frac{2\left(\frac{1}{\nu_3}+2\right)}{\rho_3 \cdot \dot{\gamma}_{\min}} \cdot \left|G_{m1} - G_{md3}\right| \cdot \sin\varphi$$

and Δp_{12} is a pressure drop, therefore $\operatorname{sgn}\Delta G_m = 1$ and $\Delta p_{12} > 0$.

The minimum shear rate was noted:

$$\dot{\gamma}_{\min} = \left(\frac{\tau_{\min}}{K_3}\right)^{\frac{1}{\nu_3}} \qquad (7)$$

representing the minimum value resulting from the necessary condition for the initiation of particles' dispersion.

If $\Delta p_{12} < 0$ (pressure increase inside the slit), the zone has a meager effect in particles' dispersing. Dependency $h_3(L_{02})$ is hiperbolique, as results from relationship (6).

In paper [1] was determined a relationship for the efficiency of thermal homogeneisation that is strongly dependent on the homogeneisation zone geometry, as can also be seen from paper [6].

For example, for a screw of diameter D=63.5 mm that processes a HDPE with a flowrate of 84 kg/h at a rotation of 100 rot/min, the dependency of the efficiency of thermal homogeneisation, η_{ht}, function of h_3 and the barrier flight width, B_3 was represented in figure 2, whereas figure 3 shows the dependency of the thermal homogeneisation efficiency, η_{ht} with the angle of allignment φ of the barrier flight *f* and its length L_{02}.

Analysing figures 2 and 3 results the necessary geometry for an optimum homogeneisation, which is for η_{ht}=1.

In the example discussed above, if the width of the barrier flight is chosen B_3 = 0.15 . D then we must have $h_3 \approx$ 0.46 mm, whereas if we choose B_3 = 0.1 . D then $h_3 \approx$ 0.36 mm (fig. 2).

To have η_{ht} = 1, for a length of the homogeneisation zone of L_{02} = 4D we must have $\varphi \approx 38^o$ (fig. 3).

Also, the condition for the dispersion of particles' agglomerates (5) depends of the pressure drop Δp_{12} and the geometry of the Maddock and Egan zones has a direct influence on the variation of the melt pressure [6-9].

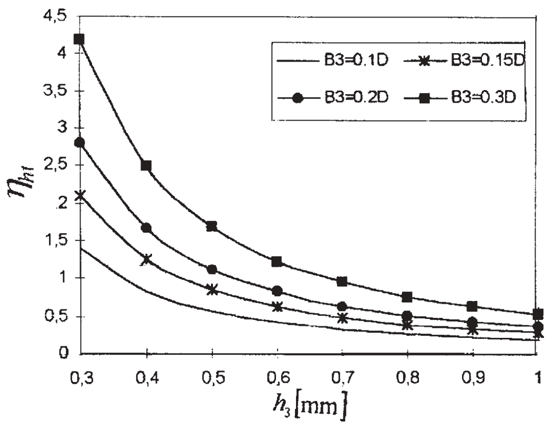

Fig. 2. Variation of the thermal homogeneity, η_{ht}, with h_3 at various values of barrier flight width, B_3

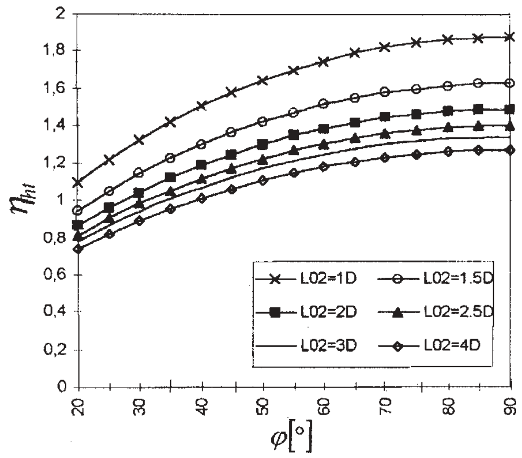

Fig. 3. Variation of the thermal homogeneity, η_{ht}, with φ [°] for various lenght of the homogeneisation zone, L_{02}

Practical application

Considering a screw with a thermal homogeneisation zone, having the following geometrical dimensions:

D=63.5 mm;

δ = 0.08 mm – slit between screw flight and barrel;

L_{02} =2D=127 mm;

φ=45o;

B_3=0.15D;

n_z=3;

h_3=0.5 mm.

The flowrate is G_m=84 kg/h at a screw rotational speed of n=100 rot/min.

At the entry into the homogeneisation zone, the melt temperature is $T2$ = 190°C, and the minimum temperature is T_1=170°C.

The processed polymer is HDPE (ρ=960 kg/m³), having the following characteristics at processing temperature:

ρ=770 kg/m³;

c_p=2604 J/(kg . K);

ν_3 = 0.5;

K_o = 4.754 . 10⁵ Pa . s;

b_T = 0.01093 K⁻¹.

With these data it can be determined the homogeneisation zone geometry (6). With n_z=3; φ=45°. If T_1=190°C and τ_{min}=60kPa, in (7):

$$\dot{\gamma}_{\min} = \left(\frac{\tau_{\min}}{K_3}\right)^{\frac{1}{\nu_3}} = \left[\frac{60\times10^3}{4{,}754\times10^5\times\exp(-0{,}01093\times463)}\right]^{\frac{1}{0,5}} =$$

$$= \left(\frac{60000}{3014{,}9}\right)^2 = 396{,}06\ \mathrm{s^{-1}}$$

The drag-flow inside the slit of height h_3, is given by (2):

$$G_{md,3} = \frac{\pi}{120}\times0{,}8\times770\times(63{,}5-0{,}5)\times(0{,}5-0{,}5\times0{,}08)\times10^{-6}$$
$$\times0{,}127\times100 = 5935{,}4\times10^{-6}\ \frac{\mathrm{m^3}}{s} \qquad (9)$$

and the flowrate through a channel c_1:

$$G_{m,1} = \frac{G_m}{n_z} = \frac{84}{3600\times3} = 7{,}778\times10^{-3}\ \frac{}{\mathrm{s}} \qquad (10)$$

The constant in the right-hand term of (6) becomes:

$$C_2 = \frac{2 \cdot \left(\frac{1}{0,5} + 2 \right)}{770 \times 396,06} \cdot \left| 7,778 - 5,935 \right| \times 10^{-3} \cdot \sin 45^0 = 0,3418 \times 10^{-7}$$

thus

$$h_3 \leq \left(\frac{0,3418 \times 10^{-7}}{L_{02}} \right)^{0,5}$$

With L_{02} = 127 mm, results:

$$h_3 \leq \left(\frac{0,3418 \times 10^{-7}}{0,127} \right)^{0,5} = \left(0,29914 \times 10^{-6} \right)^{0,5} = 0,51878 \times 10^{-3} \text{ m.}$$

Therefore, it is necessary that $h_3 \leq 0,51878$ mm**.**

Often, in practice, it is chosen h_3 = 0.5 mm, which corresponds to the condition obtained theoretically, i.e. $h_3 \leq$ 0.51878mm.

Conclusions

From the undertaken analysis, the correlation between the barrier zone slit height, h_3 and the length of the barrier zone, L_{02} can be calculated (6) assuring the dispersing of the agglomerated particles within the melt. If particles of a diameter larger than a given value $d_{p,o}$ need to be retained by the barrier zone, then $h_3 < d_{p,0}$.

Given the role the Maddock and Egan zones have, based on relations 1,2, 6 and 7, the thermal homogeneisation zones dimensions (h_3, B_3, L_{02}, φ) can be calculated.

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