DETERMINATION OF THE FRICTION COEFFICIENT BETWEEN THE POLYMERIC GRANULAR MATERIAL AND THE METALLIC SURFACES OF THE GROOVES SPECIFIC TO EXTRUDERS' FEEDING ZONES

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Debitul în zona de alimentare a unui extruder monomelc depinde, prin intermediul coeficientului de debit, de valorile coeficientilor de frecare dintre materialul granular şi melc şi respectiv dintre materialul granular şi cilindru, pe cele două direcţii, paralela cu spira melcului şi perpendiculara pe aceasta.

În teoriile de până acum la calculul debitului s-a utilizat un singur coeficient de frecare în raport cu cilindrul. Deoarece debitul depinde atât de coeficientul de frecare la deplasarea pe direcţia axei x, cât şi de cel corespunzător deplasării pe direcţia axei z a spirei melcului, se va determina în continuare dependenţa coeficientului de frecare de 1) unghiul de deplasare al materialului granular în raport cu canelurile din zona de alimentare şi 2) de forma şi dimensiunile canelurilor.

The flowrate in the feeding zone of a single screw extruder depends through the flowrate coefficient on the values of the friction coefficients between the granular material and the screw, and between the granular material and the barrel, on two directions, parallel with the screw flight and perpendicular to it, respectively.

In the previous theories calculating the flowrate, considered only the friction coefficient between the granular material and the barrel. As far as the flowrate depends on the values of the friction coefficients on two directions (parallel to and perpendicular on the screw flight direction), the dependence of the friction coefficient on the angle of movement of the granular material with respect to the allignment of grooves, and the form and dimensions of the grooves, will be further determined.

Keywords: single screw extruder, feeding zone, friction coefficients, angle of movement, grooves, flowrate.

1. Introduction

Analysing the material motion over the length of a screw flight (Fig. 1), it can be noticed that the material is pushed by the screw flight on x direction with the speed w_x. At a full screw rotation, the material moves over [1]:

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- distance AC, ideally, without backpressure and friction between material and barrel, and between material and screw;

- distance AC_1, in a real situation, because the friction between material and screw, material and barrel, and the backpressure. On the z direction of the hellicoidal channel, the material travels over distance OC_1 instead OC in the ideal case.

From the relationship of the feeding zone flowrate the flowrate coefficient k_G depends on the angle β (Fig. 1) between the direction of movement of the material and the x axis (perpendicular on the screw flight), through its components, k_{w1} (rel. 1) and k_{w2} (rel. 2) [1].

$$k_{w1} = \frac{\cos\varphi_s \cdot \cos(\beta + \varphi_s)}{\cos\beta} \tag{1}$$

$$k_{w2} \approx 0{,}5\left[1 + \frac{\cos\varphi_e}{\cos\varphi_s} \cdot \frac{\cos(\varphi_e + \beta)}{\cos(\varphi_s + \beta)}\right]. \tag{2}$$

At its turn, angle β depends on the friction coefficients between the processed material and screw, f_m, and between the material and barrel, (f_{cx} and f_{cz}) according to relationship (3) [1]

$$\tan\beta = \frac{K_2 \cdot h_1 \cdot \dfrac{\mathrm{d}\overline{p}_z}{\mathrm{d}z} - p_{yc}\left(f_{cz} + k_s \cdot K_3 \cdot K_4 \cdot f_m\right)}{K_1 \cdot h_1 \cdot \dfrac{\mathrm{d}\overline{p}_x}{\mathrm{d}x} - p_{yc} \cdot f_{cx}}. \tag{3}$$

To verify the accuracy of the k_G relationship, and through it of the feeding zone flowrate, it is necessary to know the mentioned friction coefficients.

The up to date theories [2-4] use for the flowrate calculation one friction coefficient only, f_c - friction coefficient with respect to the barrel. For example, in paper [5] the friction coefficients between the granular material and grooved plates of varied profiles have been determined.

Because the angle β depends on both the friction coefficient for the motion on the x axis, as well as on the one with respect to the movement on the z axis, with respect to the internal grooved surface of the barrel, the dependence of the friction coefficient f_c will be determined, with respect to the angle of movement and the form and dimensions of the grooves.

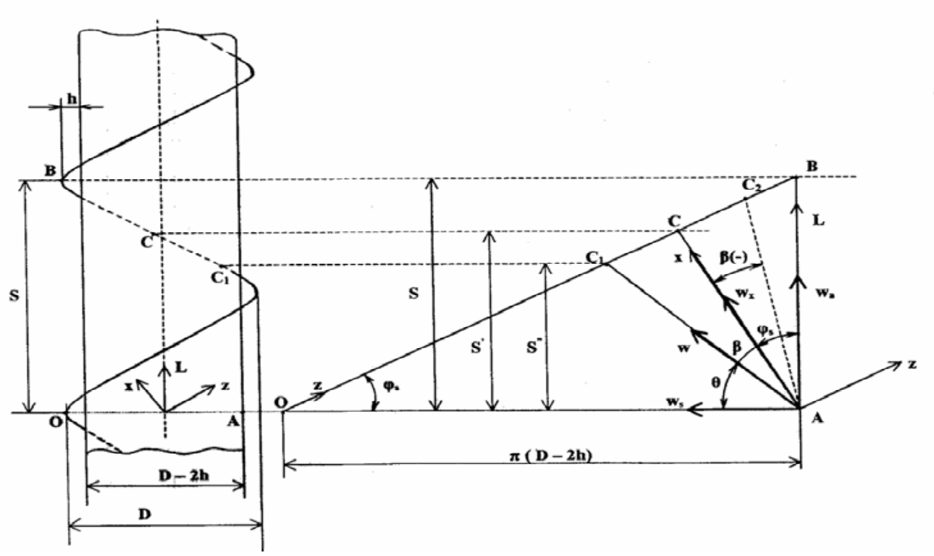


Fig. 1. Length of a screw flight, S.

2. Experimental installation

The experimental set-up is represented in Fig. 2: it consists of a grooved plate, 1, on which the movement frame, 2 is set. On this frame run the wheels, 3 (bearings) of the basket without bottom, 4. In 4, the granular polymeric material 5 is introduced. The basket on the wheels is pulled by a thread, 6, over 7, by the force generated by the mass, 8, sitting on a plate, 9.

Metallic balls are set on the plate 9 until the basket on wheels, 4 begins to move. Then, we remove the metallic balls, one at a time, until the basket stops, a.s.o. After a few try-outs, the final mass on 9, m_t is weighed.

This corresponds to the start of the movement and determines the thrust force $F = m_t \cdot g$. By definition, the friction coefficient is given by the ratio between the friction force, F_f, and the normal force, N,

$$f = \frac{F_f}{N}. \tag{4}$$

Because in this case $N = m_c \cdot g$ and $F_f = F$, where g is the gravitational acceleration, and m_c – the mass of polymeric granules in the basket, the relation results:

$$f(\gamma) = \frac{m_t}{m_c} \tag{5}$$

The movement frame, 2 is positioned under various angles γ, which allows the experimental determination of the friction coefficient f as a function of γ. The picture of the experimental set-up is represented in Fig. 3. The try-outs were done for granules of high density polyethylene (HDPE) and polypropylene (PP). The form and the limit sizes of the tested granules are given in Table 1.

Table 1.

Size of the tested granules

Granular polymeric material	Granules' form	Limit size, mm		Material density at 20^{0}C, kg/m^3
		d_{max}	d_{min}	
HDPE	cylindrical	3,45	1,942	962
PP	lenticular	4,29	2,93	900

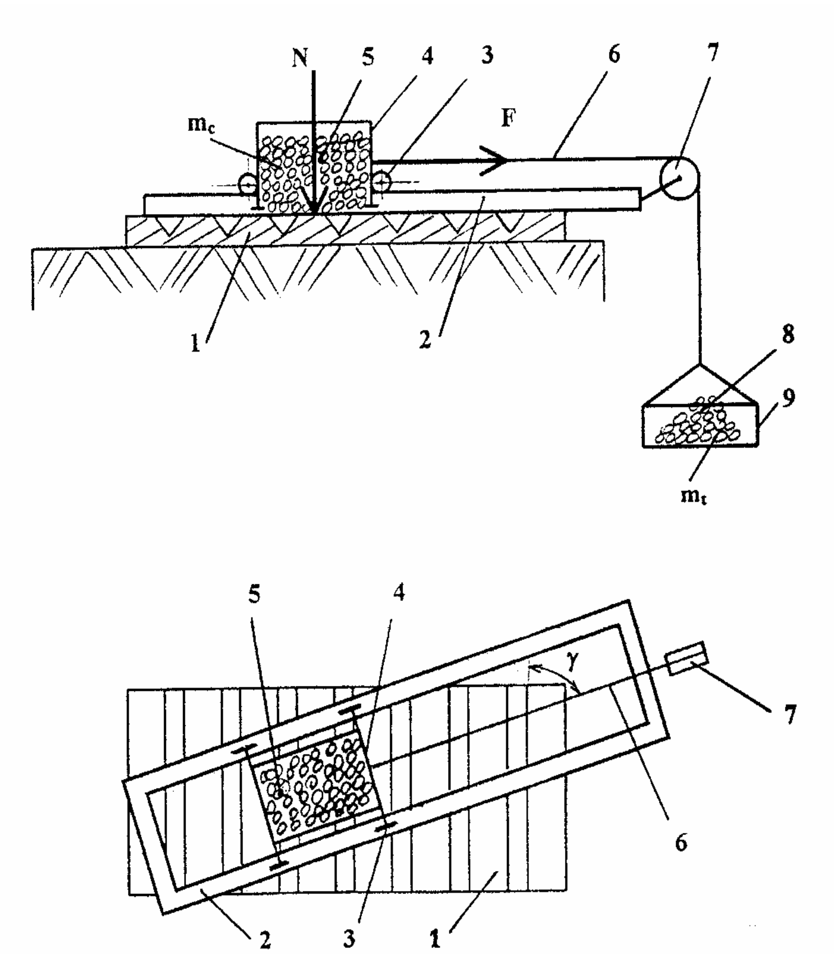


Fig. 2. Set up for the determination of the friction coefficient of the granular material on grooved plates

Fig. 3. Experimental set-up

3. Results

Table 2 contains the experimental values for the friction coefficient as a function of the path angle, γ. The grooved plates used are represented in Table 3. The experimental determinations were performed at room temperature, using granules of HDPE and PP.

Table 2.

Friction coefficients values $f(\gamma)$ function of the movement angle γ.

Granular material	Grooved plate:		γ, grade				
			0	30	45	60	90
HDPE	semicircular	ps1	0,28	0,674	0,76	0,775	0,82
		ps2	0,28	0,60	0,64	0,65	0,66
PP		ps1	0,36	0,56	0,64	0,66	0,68
		ps2	0,36	0,48	0,52	0,60	0,67
HDPE	equilateral triangles	pt1	0,28	0,51	0,60	0,67	0,71
		pt2	0,28	0,56	0,60	0,65	0,66
PP		pt1	0,32	0,32	0,36	0,48	0,57
		pt2	0,32	0,43	0,52	0,61	0,67
HDPE	isosceles triangles	pt3	0,238	0,265	0,254	0,276	0,300

Analysing the results in Table 2 as represented in figures 4 and 5, one obtains:

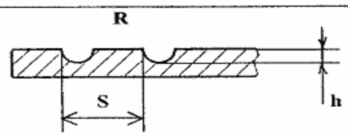
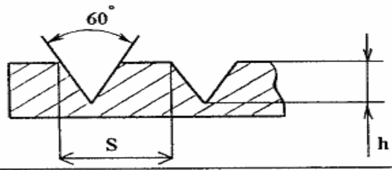
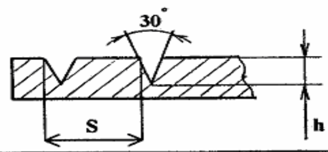
- the friction coefficients for both HDPE and PP increase with the increase of angle γ and attain a maximum at $\gamma = 90^0$;
- friction coefficients between the granules of HDPE and the grooved plates are in general higher than those of the PP granules;
- channel depth influence the value of the friction coefficient. At a bigger depth of the semicircular channels (plate ps2 –Fig. 4) the friction coefficients are lower than at smaller depth (plate ps1) for the tested granules.

When analysing the grooved plates with equilateral triangles the influence of the grooves' depth proves different: for HDPE the friction coefficients values are very close for the two grooved plates (Table 3 and Fig. 5), whereas, friction coefficients values for the PP granules for the plate with bigger depth grooves (pt2) are higher than for the plate with smaller depth grooves (pt1);

For the plate with isosceles triangles grooves (pt3), and the width of the grooves lower than the granules'sizes, the granules will not get „anchored" in the grooves, which result in smaller values for the friction coefficients as compared to the other cases analysed.

Table 3

Grooved plates used

<table>
<tr><td></td><td>Grooved plate</td><td>Plate length , mm L = 500;
Plate width , mm l = 195.</td></tr>
<tr><td>1</td><td>Semicircular</td><td>
<table><tr><td></td><td>S</td><td>R</td><td>h</td></tr><tr><td>ps1</td><td>8</td><td>1,5</td><td>1,6</td></tr><tr><td>ps2</td><td>15</td><td>3,5</td><td>3,5</td></tr></table></td></tr>
<tr><td>2</td><td>Equilateral triangles</td><td>
<table><tr><td></td><td>S</td><td>h</td></tr><tr><td>pt1</td><td>8</td><td>1,5</td></tr><tr><td>pt2</td><td>15</td><td>3,5</td></tr></table></td></tr>
<tr><td>3</td><td>Isoscel triangles</td><td>
<table><tr><td></td><td>S</td><td>h</td></tr><tr><td>pt3</td><td>8</td><td>0,5</td></tr></table></td></tr>
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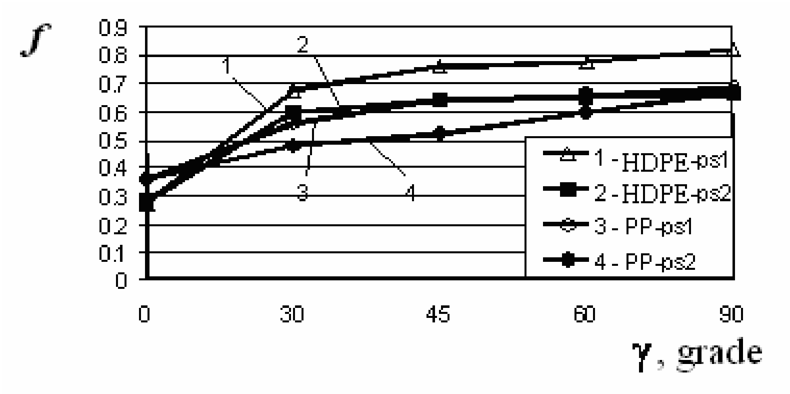

Fig. 4. Dependence of the friction coefficient on the direction of movement (given by angle γ) for plates with semicircular grooves (ps).

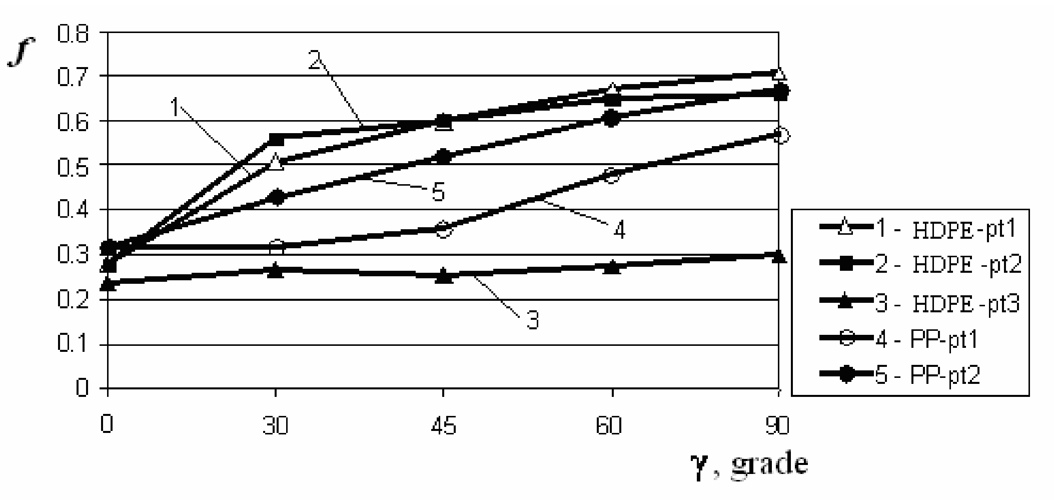

Fig. 5. Dependence of the friction coefficient on the direction of movement (given by angle γ) for plates with triangular grooves (pt).

4. Conclusions

For the barrel with axial grooves, z axis direction (direction of the screw flight) makes with the direction of the grooves the angle $\gamma = 90 - \varphi$, so that $f_{cz} = f_c(90 - \varphi)$. The direction of x axis, perpendicular on the screw flight, and therefore perpendicular on z axis, is at an angle $\gamma = \varphi$ with the grooves' direction, so that $f_{cx} = f(\varphi)$.

The friction coefficients values, $f_{cz} = f_c(90-\varphi)$ and $f_{cx} = f(\varphi)$, respectively, are introduced in the relationship calculating the angle β (rel. 3), and have a direct influence on the flowrate coefficient, k_G through the coefficients k_{w1} (rel. 1) and k_{w2} (rel. 2).

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