Twin Screw Extruders Optimization

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The paper presents the corotating twin screw extruder optimization, taking into account the quality of final product. Thus it was established the optimum screws configuration, the optimum screw speeds and the optimum flow rates.

Keywords: twin screw extruder, quality, flow rate, screw

The corotating twin screw extruders are only available commercially in the fully intermeshing mode and are used widely in the polymer processing industry for compounding, blending, reactive processing etc. The versatility of the machine to some extent arises from the modular nature of the extruder since a number of machinery producers offer corotating twin screw extruders with interchangeable barrel and screw sections. Thus, in the age of flexible manufacturing where manufacturers are urged to move from one product line to another, using the same capital equipment, the versatile twin screw extrusion technology plays a significant role. However, each time a new screw and barrel configuration is assembled the extruder becomes a new machine. Therefore, optimization and scale-up continue to remain significant issues for most companies.

Some researches regarding the twin screw optimization

Previous experimental and numerical investigations were performed in several contributions in the literature, regarding the optimization of twin screw extruder [1 ÷ 6].

The problem of setting the best operating conditions of a co-rotating twin screw extruder was solved, using an optimization approach based on Genetic Algorithms [7]. They considered two possibilities: i) the maximization of an objective function that takes into account the relevant performance to the process (criteria or objectives) and their relative importance to the process; ii) the simultaneous optimization of the individual criteria and the use of Pareto plots. The flow conditions inside the machine were simulated using the Ludovic software. These techniques were applied to different extruders (Leistritz LSM 30.34 and Clextral BC 45) using various screws configurations and two distinct polymers (a Polypropylene Homopolymer and a Linear Density Polyethylene). Six criteria were considered: flow rate, average strain, melt temperature at die exit, maximum melt temperature, power and average residence time. The flow rate and the average strain were maximized, while the power and the average residence time were minimized. The optimal operating conditions were obtained for both extruders. Clextral extruder can reach higher flow rates at lower screw speeds.

The effect of the screw configuration of a closely intermeshing corotating twin screw extruder on residence time and mixing efficiency was studied for an uncompatibilized immiscible PA6/PP (80:20) blend, [8] . Alternative screw configurations were investigated systematically. The residence time distribution and holdback value were poor indicators of total mixing efficiency. The mixing intensity function derived from the shape of residence time distribution was of great assistance in evaluating the flow characteristics and mixing efficiency. As the number of mixing elements was increased, better transverse mixing was achieved, indicated by increasing positive slope of the intensity function, changing the flow character of the extruder to be more plug-like. It could be concluded that each mixing section acted like an ideal mixer applied to the screw.

They found that high shear stresses in the melting section were of great importance in achieving good dispersion in the immiscible blend. Long residence time and high fill ratio in the high shear melting zone also improved the dispersion.

The quality of the dispersion was not only defined by the screw configuration but by the character of the downstream flow.

The main features of adopting concurrent engineering design were described [9]. The designer has great responsibility to ensure that the product will conform to customer requirements, comply with specification, meet cost targets and ensure quality in every aspect of the product, including its manufacture and assembly. The plasticizing system has the most decisive influence on throughput and quality of the extruded products (fig. 1). All the influential parameters concerning quality of the extruded products are strongly interdependent.

Author considers that the effectiveness of a plasticizing system means the ability of this system to extrude products of good quality with as high throughput as possible, combined with high energy efficiency. Evaluation of the

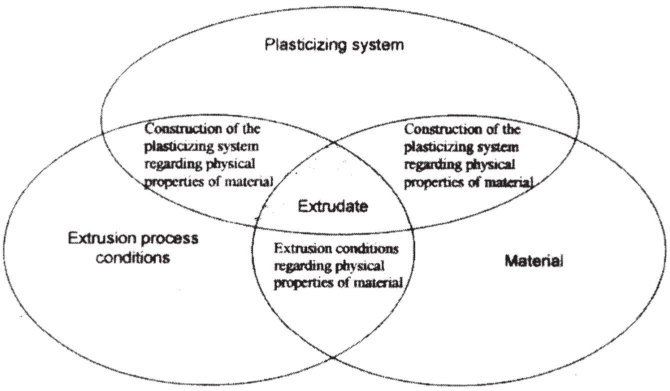

Fig. 1. Quality of extruded product is a result of complex dependence between the engineering design of the plasticizing system, materials and extrusion conditions [9]

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effectiveness of the extrusion process can be carried out according to three groups of criterions: quantitative (extrusion throughput, the degree of plasticization, the energy efficiency), qualitative (heat homogenization, degree of mixing, quality of dispersion, stability of extruder throughput, structural changes – degradation, quality of the extrudate – appearance, physical properties) and exploitation criterion (length of service life, production versatility, automation of extrusion process).

Experimental part

The fully intermeshing corotating twin screw extruder, Clextral BC 21, Firminy, France was used. The diameter of screw was 25 mm, the centreline distance was 21 mm, and the channel depth was 4 mm.

The effective screw length was 600 mm. The screws of the extruder were assembled from individual screw elements. There were tested several screw configurations. The 1st screw configuration resulted from tests, through the change of direct and reverse flight sections from the third and ninth zones at the beginning of screw (fig. 2, a). The 2nd screw configuration had the first six identical modules with the 1st screw configuration. It resulted through the change of the angle of kneading discs (the seventh module) and the next modules until the complete screw (fig. 2, b).

The material tested was low density polyethylene (HDPE 5810 G, manufactured by Dow Chemical Co.). The density was 0.919 g/cm^3 and melt index was 9 g/10 min. A pressure transducer Dynisco was used for measurements of pressure at the entrance (pos. 1, fig.1) and exit (pos. 2, fig. 2) of mixing zone. Four flow rates (1.3, 3 , 6, 9 kg/h) and three screw speeds (205, 340, 420 rpm) were used.

After each flow rate and screw speed of screws, the extruder was stopped, the temperature of barrel was decreased for the opening of the extruder. Photos of mixing zone for both screw configurations were taken with a camera.

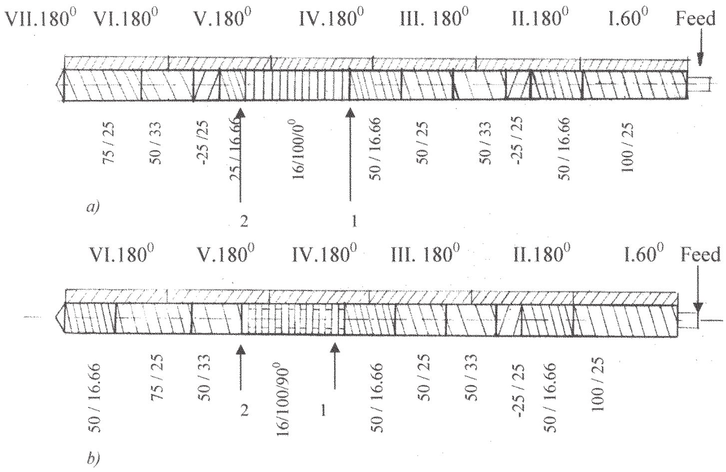
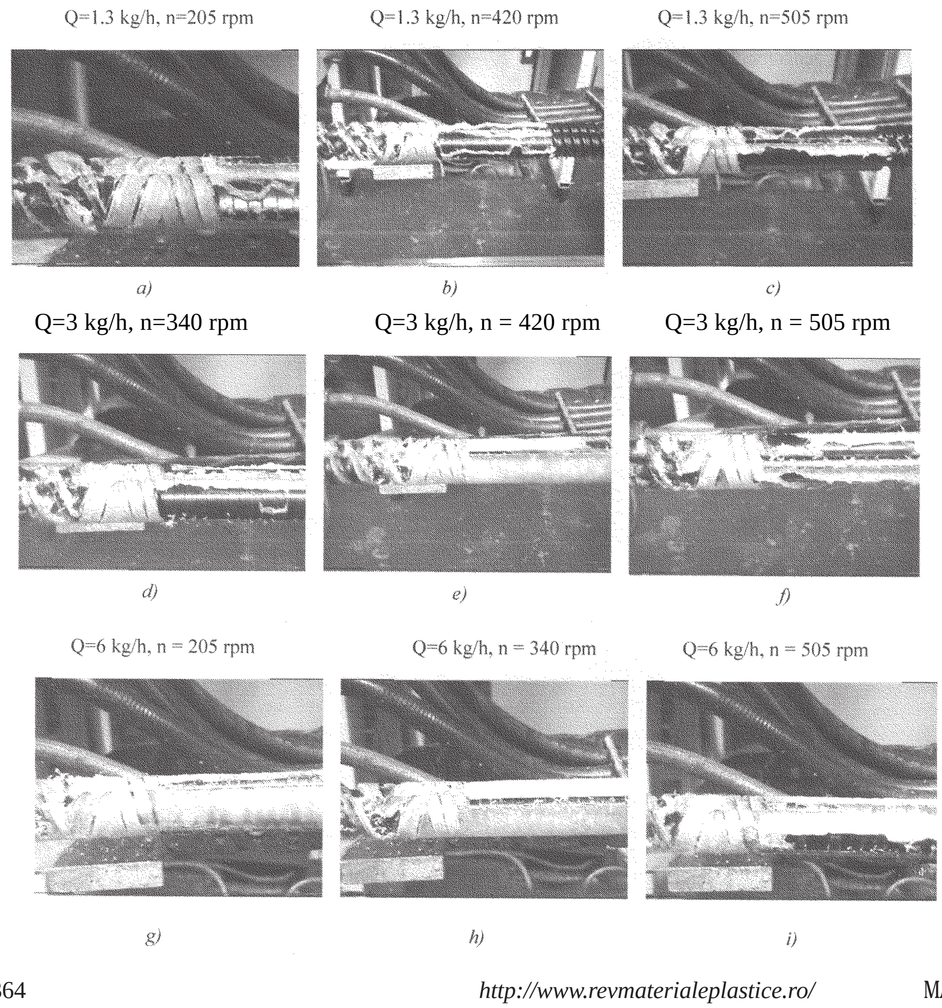
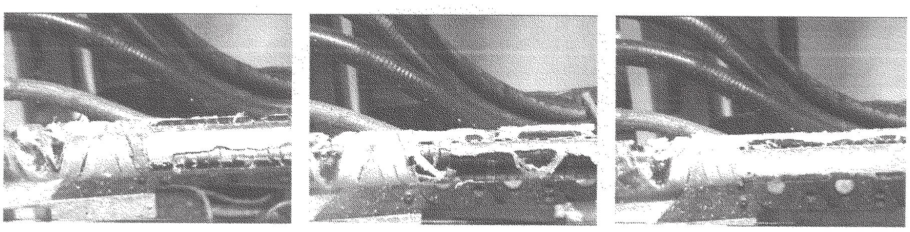


Fig. 2.Screw configurations
a) 1st screw configuration;
b) 2nd screw configuration



Q=9 kg/h, n = 205 rpm | Q=9 kg/h, n = 420 rpm | Q=9 kg/h, n = 505 rpm



j) k) l)

Fig. 3. The mixing zone at different screw speeds and flow rates, for the 1st configuration (a-l)

Results and discussion

In figure 3 and 4 are represented the pictures taken in the mixing zone, for the degree of fill visualization.

The pressure drop is defined as:

$$\Delta_p = p_i - p_f \quad (1)$$

where:

p_i is the pressure at the entrance of mixing zone;

p_f - the pressure at the exit of mixing zone.

The pressure gradient was established from flow rate relation of corotating twin screw extruder, for a Newtonian melt [10, 11]:

$$\bar{p}_L = \frac{\eta}{F_\beta \cdot \beta_1}\left[F_\alpha \cdot \alpha_1 \cdot n - \frac{Q_m}{\rho\left(2 \cdot n_S - 1 + \frac{\alpha_t \cdot n_S}{\pi}\right)} \cdot \delta(\alpha_i)\right] \cdot \delta(\alpha_i) \quad (2)$$

where:

η is the shear viscosity;

n - screw speed;

Q_m - flow rate;

α_t - helix angle of the screw at the tip of the flights;

α_1, β_1 - geometrical factors;

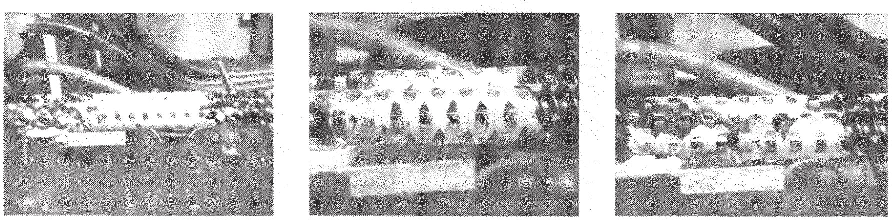
α_i - angle of intermesh;

n_s - number of flight starts;

F_α - F_β - correction factors that include the curvature of channel, the leak through the gap between the flight and the barrel wall, the channel width bigger than channel depth;

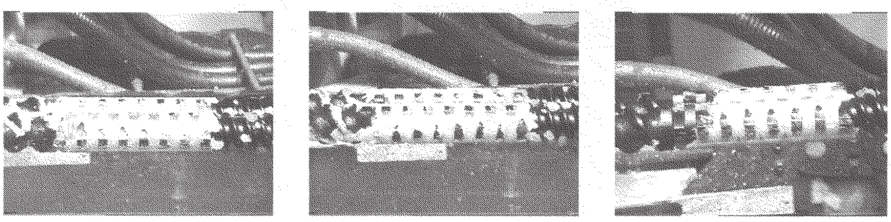
$$\delta(\alpha_i) = \begin{cases} 1, & \text{for direct flight} \\ -1, & \text{for reverse flight} \end{cases}$$

Q=1.3 kg/h, n = 205 rpm | Q=1.3 kg/h, n = 420 rpm | Q=1.3 kg/h, n = 505 rpm



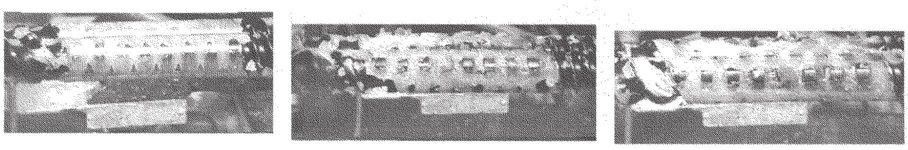
a) b) c)

Q=3 kg/h, n = 205 rpm | Q=3 kg/h, n = 420 rpm | Q=3 kg/h, n = 505 rpm



d) e) f)

Q=6 kg/h, n = 205 rpm | Q=6 kg/h, n = 420rpm | Q=6 kg/h, n = 505 rpm



g) h) i)

Q=9 kg/h, n = 205 rot/min | Q=9 kg/h, n = 420 rot/min | Q=9 kg/h, n = 505 rot/min

j) k) l)

Fig.4. The mixing zone at different screw speeds and flow rates, for the 2nd configuration

The dependence of pressure versus flow rate at constant screw speed, at the entrance of mixing zone is represented in figure 5 and the pressure drop versus flow rate, in figure 6.

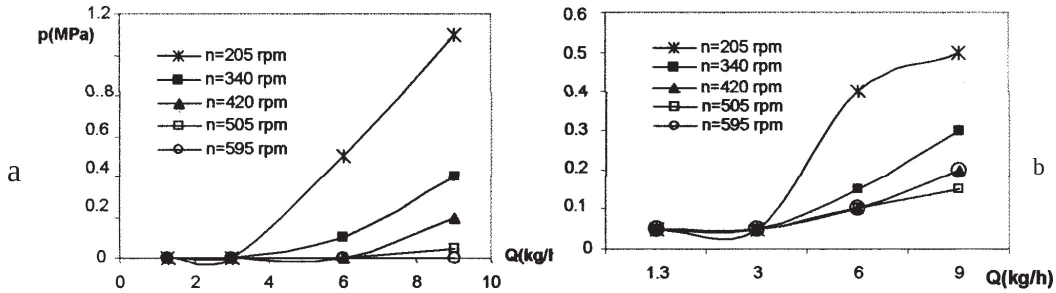


Fig. 5. Dependence of pressure versus flow rate at the entrance of mixing zone, at constant screw speed. a) – the 1st screw configuration; b) – the 2nd screw configuration

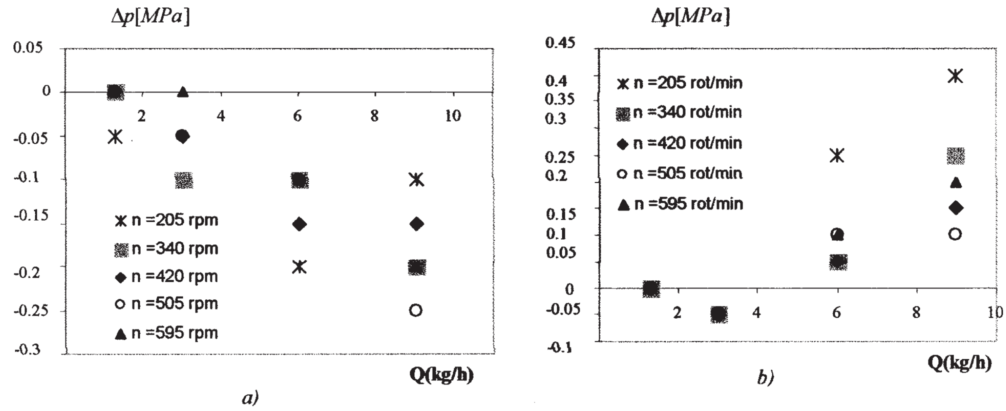


Fig. 6. Δp versus flow rate, at constant screw speed
a) – the 1st screw configuration; b) – the 2nd screw configuration

From analysis of the experiments, the conclusions referring to mechanics of twin screw extrusion and to the quality of final product can be drawn.

The case of the 1st screw configuration

a) For low flow rates (1.3 kg/h):

- below the screw speed of 205 rpm and small flow rate, the quality of process is affected because the time of process increases and therefore the productivity is low, the degree of fill in the channel is below 1 (meaning that the material from the channel includes the air holes, in detriments of its quality – fig. 3, a). In the same time, when the screw speed increases, the degree of fill decreases, at constant flow rate (fig. 3, b, c);
- the small values of screw speed and flow rate do not affect the value of the pressure in channel of mixing zone.

b) For high flow rates (9 kg/h):

- when the screw speed increases, the degree of fill in the mixing zone decreases (fig. 3, j, k, l), but more than for low flow rates. The quality of material is the same as for the case of low flow rates; the difference is only from the point of view of productivity;
- the reduction of the degree of fill is correlated with the reduction of pressure in material, so that the biggest pressure (1.1 MPa) is at the low screw speeds.

It is recommended the avoiding of low and high flow rates (lower than 1.3 kg/h and over 9 kg/h), to maintain the quality of the product.

At the same flow rate, in case of low screw speeds, the residence time is high. The utilization of easy damaging materials is not recommended; thus it is affected not only the quality of product through local burnings, but also the adherence of material on the active flights of screws. In these situations, the screws have a short lifetime, and the productivity of extruder decreases.

c) For medium flow rates (3 – 6 kg/h):

- when the screw speed decreases, the degree of fill in mixing zone increases (fig. 3, d ÷ i); the quality of extrudate is the best for this configuration the material does not present inclusions, burnt material or the adhesion of material on screws);
- the pressure in material has a maximum at minimum screw speed and constant average flow rate (fig. 5, a); justifying the previous affirmation related to increasing of degree of fill;
- when the flow rate increases from 3 kg/h to 6 kg/h it is noticed that the highest pressure drop is at the low screw speed (fig. 6, a);
- the optimum values of screw speeds, for which it was found out an adequate flow of material (a high degree of fill and an insured quality), are 420 rpm in the case of 3 kg/h (fig. 3, e) and 340 rpm in the case of 6 kg/h (fig. 3, h).

The case of the 2nd screw configuration

a) For small flow rates

- the channel doesnot fill; there is a dispersion of material on the length of screws. When the screw speed increases, the dispersion is higher and higher;
- the pressure drop at low flow rates is null (fig. 6, b), regardless of screws speed. This means that the generated pressure by the two screws is the same with the used pressure energy for the drive of screw;
- it was found out that at this configuration, as for the 1st configuration, the pressure is higher at small screws speeds and high flow rates, at the entrance of mixing zone;
- the pressure increases when the flow rate increases, maintaining screw speed constantly (fig. 4 a, d, g, j);
- the degree of fill increases with the growth of the flow rate;
- at this configuration including kneading discs with a stagger angle of 90^0 , the pressure is not null for low flow rate, as opposed to the 1st configuration (including kneading

discs with a stagger angle of 0^0), for which the pressure is null at low flow rate;

- the efficiency of kneading discs with a stagger angle of 90^0 results from here. These elements represent an optimized geometry of screws configuration.

b) For high flow rates:

- the degree of fill maintains tendency of growth with the reduction of screw speed (fig. 4, j, h, l), but the product has an improper quality (the fractures in material are presented);
- the pressure drop is positive (fig. 6, b), indicating a consumption of pressure energy;
- the material almost fully fills the screw channel.

c) For medium flow rates:

- the pressure increases with the growth of flow and the reduction of screw speed (fig. 5 b), for the range of medium flow rate, (3,6) kg/h;
- the degree of fill is better (fig. 4 d ÷ i) than it is at low and high flow rates (fig. 4 a÷ c, j÷ h), were occurs the fractures in material;
- the values of flow rates and screw speeds - for which the degree of fill and the characteristics of material are optimum – are those in the middle of ranges (fig. 4e, h);
- the pressure drops have different values for medium flow rates:
- at 3 kg/h, $\Delta p < 0$ (fig. 6b), so that the pressure is generated; the material spreads on the length of screw with the growth of screw speed (fig. 4, d ÷ f), what is different from one screw extruder.
- at 6 kg/h, $\Delta p > 0$ (fig. 6b), so that there is a consumption of pressure energy; the material almost fully fills the screw channel (fig. 4g ÷ i).

The data obtained experimentally, lead to the utilization of the 2nd screw configuration.

The quality of extrudate is insured if the material is homogeneous, it has the thermal and dimensional stability (the section is uniform, without twisting and longitudinal bending), inclusions (air or particles that are not melt) or burnt surfaces [12].

In this study , the observance of quality conditions is estimated through indexes between 1 and 10, the last value is associated with the best quality criteria.

The correlation between flow rate and quality is represented in figures 7 and 8.

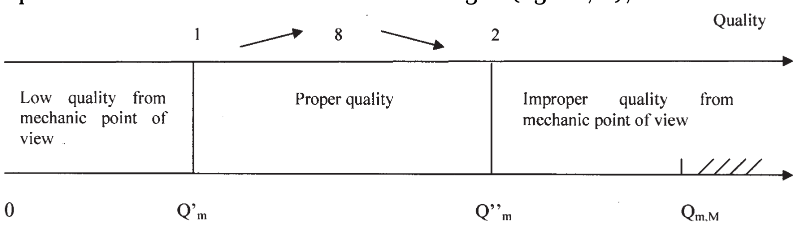


Fig. 7. The correlation between flow rate and quality for the 1st screw configuration

For the 1st screw configuration are recommended the following flow rates, in the case of polymeric materials:

$$Q'_m = 3 \text{ kg/h}; \qquad Q''_m = 6 \text{ kg/h}.$$

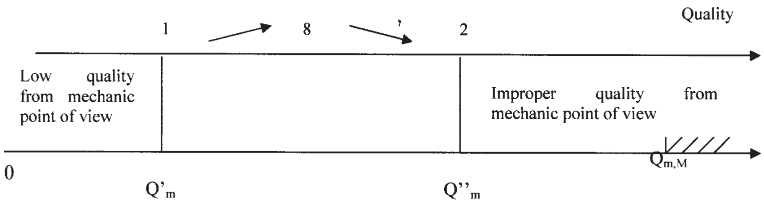


Fig. 8. The correlation between flow rate and quality for the 2ndscrew configuration

Conclusions

The quality of extrudate resulted from processing on the corotating twin screw extruder was studied. The structural modifications of extrudate (homogeneity, thermo stability, the absence of the inclusions, external aspect) were taking into account, through using the pictures taken by a camera. The degree of fill was studied through the analysis of the pictures.

The optimum screw configuration was established through persistent tests, from the viewpoint of extrudate quality. The optimization of process parameters was done taking the quality of product, as starting base.

Qualitative, geometrical and process parameters optimization leads to the following values:

- modular screw with 16 kneading discs with a stagger angles of 90^0 ;
- medium screw speed, 340 ÷ 420 rpm;
- medium flow rates, 3 ÷ 6 kg/h.

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