# EXTRUDER SCREW FUNCTIONAL CHARACTERISTIC CHANGING IN POLYMERIC MATERIALS REPROCESSING

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**Abstract**. Polymeric materials reprocessing leads to modification of polymeric materials flow properties. In this paper there are summarized the correlations $\eta-\dot{\gamma}$ (obtained from previous experimental research), for several types of virgin and reprocessed polymeric materials, comparatively presented. Models and simulations were performed for the extruding polymeric materials reprocessing, the screw functional feature $Q(\Delta p)$ – with and without considering the leaks over the screw helix flight tip – to assess changes in the performances.

**Keywords**: polymeric materials, recycling, flow properties, extruder screw, functional extruding performances changes

## 1. INTRODUCTION

Romania needs to recycle far more wastes than it is done today. So it is very important to do the researches that can help to accomplish this aim. In the polymeric materials products domain the quantities recycled are far from enough too, so it is necessary to do more, from the point of view of the recycling technologies. Many recent papers deals with such topic, among them we cite especially our previous researches [1–10].

It is essential to give attention to: collection, sorting, transporting, treatment, recycling and reuse, as it can be seen from Figure 1.

The research for the recycling phase must comprise: the knowledge of the recycled polymer rheological behavior compared with the virgin one to know how to change the process parameters as the number of the recycling is higher; setting if can be use the same equipment or something different, taking into account the economic aspect, the environmental problems during recycling (including the amount of energy needed, the material deterioration by thermal or mechanical destructions), the assessment of the recycling limits and the of the real benefactor effects.

Here it is studied the extruding process, in which it is used as raw material the recycled polymeric material. It was aimed to determine the modifications of the recycled polymeric materials flow properties (due to a different number of recycling operations) and than, it is established the influence of these modifications on the screw functional feature (as flow rate-pressure drop correlation), which can give a view of the process parameters modifications needed during reprocessing.

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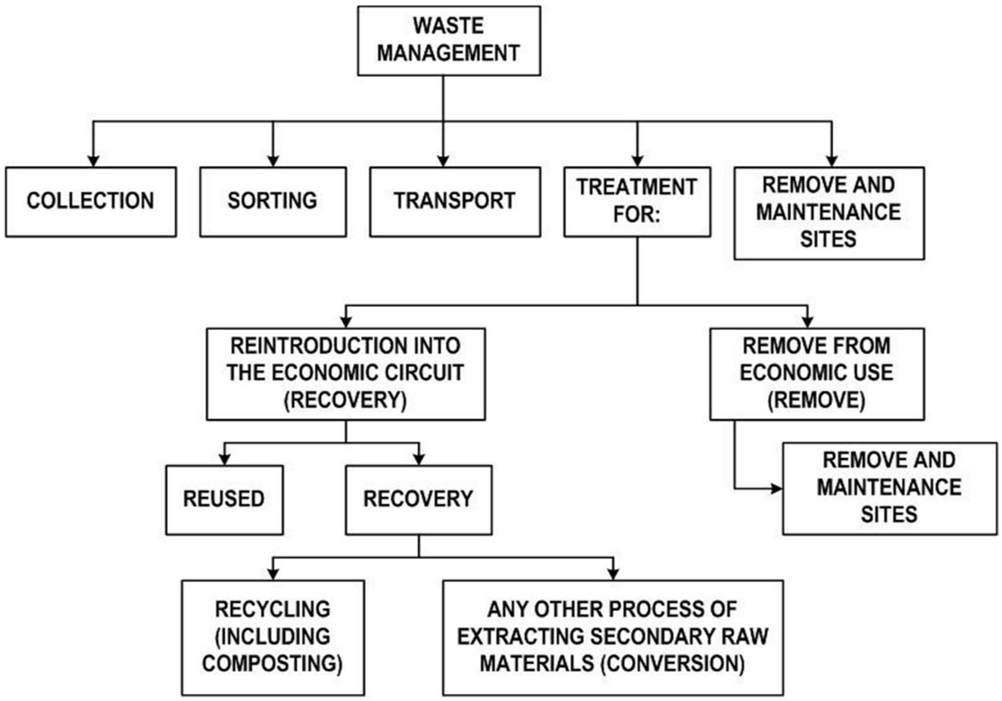


Fig. 1. The waste management essential elements.

## 2. STUDY OF THE FLOW PROPERTIES CHANGING WITH THE NUMBER OF THE RECYCLING

An experimental research was done with the aid of a capillary rheometer. The experimental device and the procedures were presented in previous papers [7–11].

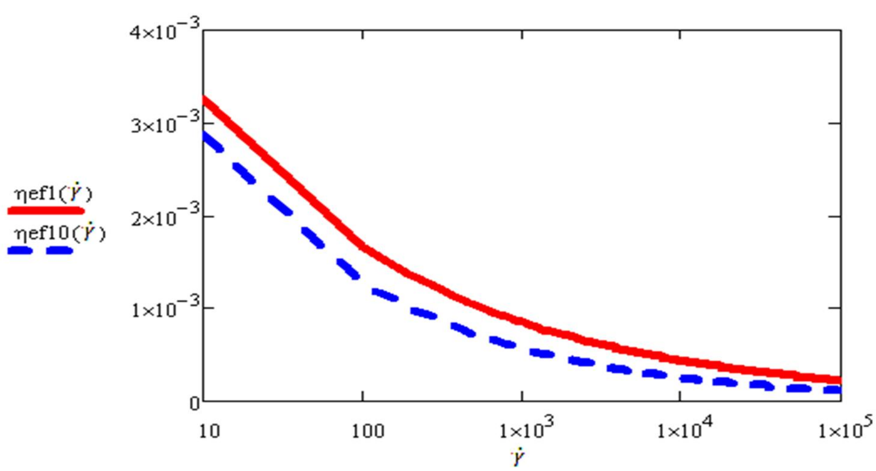


Fig. 2. Viscosity versus shear rate ($\eta - \dot{\gamma}$), for LDPE, the first and the 10th pass.

Here there are presented only the results in terms of rheograms ($\eta - \dot{\gamma}$, correlations) in Figures 2 and 3, for two different polymeric materials (LDPE at 180 ºC and PP at 200 ºC, both of them virgin and 10 times recycled). The rheograms are needed further to evaluate the influence on the screw functional feature. It can be seen that the two materials shows quite different rheological behavior: LDPE rheological constants/viscosity are less influenced by the number of the recycling compared with PP ones.

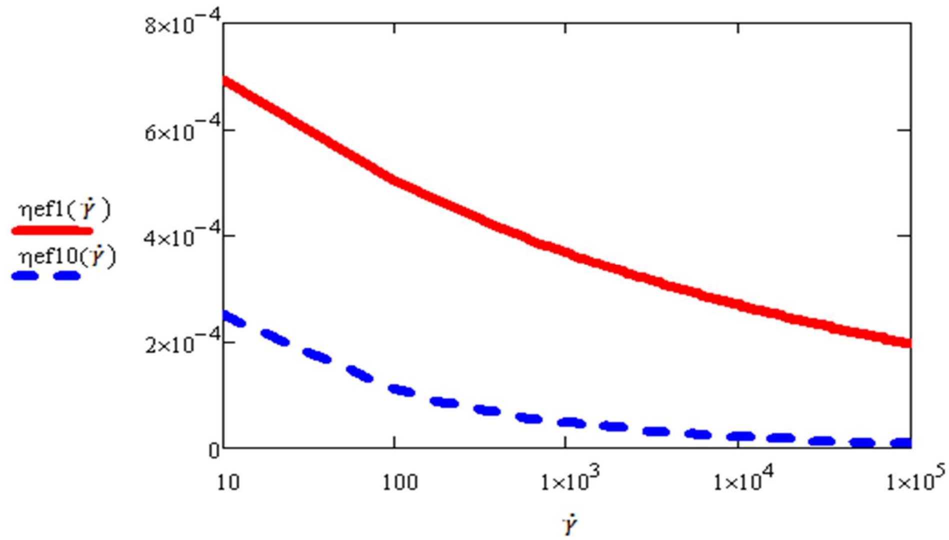


Fig. 3. Viscosity versus shear rate ($\eta - \dot{\gamma}$), for PP, the first and the 10th pass.

## 3. SIMULATIONS

There were done simulations for an extruding machine with one screw, in the case of pressure generation $\left(\frac{\partial p}{\partial z} > 0\right)$ or pressure consumption $\left(\frac{\partial p}{\partial z} < 0\right)$ in the metering zone, for virgin polymeric materials and 10 times recycled.

In the Figure 4 it is presented the functional feature for the screw, Q(Δp), for PP at $200°$ C, function of the rotation speed and the number of the recycling compared with the virgin material, in the case of the flow model without leaks between the screw flight tip and the cylinder and the pressure variation along the channel is $\frac{\partial p}{\partial z} > 0$ (pressure generation – the worst situation from flow rate point of view, when pressure flow rate opposes drag flow). The mathematical model used for the flow rate is very simple, for Newtonian fluids rheological behavior, but corrected with the actual value of the shear viscosity, determined based on the nonNewtonian rheological behavior of the polymeric melt. The flow rate is obtained as a sum between drag flow (it was used the hypothesis of the flow between parallel palates – the upper plate – the cylinder, the lower plate- the screw; it was used the lubrication approximation, so the upper plate – the cylinder rotates and the screw is motionless) and the pressure flow; the reduction influence of the flights is introduced by the coefficients $F_a$ and $F_p$ [12].

$$Q = i\frac{v_{c,z} \cdot W \cdot h_{p,3}}{2} F_a + i\frac{W \cdot h_{p,3}^3}{12\eta_{ef}}\left(-\frac{\partial p}{\partial z}\right)F_p \tag{1}$$

where the $\eta_{ef}$ is the effective viscosity of the polymer melt flowing in the screw channel, given by:

$$\eta_{ef} = m \cdot \nu \left(\frac{v_{c,z}}{h_{p,3}}\right)^{\nu - 1} \tag{2}$$

where $m$ and $\nu$ are rheological constants (from Ostwald de Waele rheological model $\tau = m\dot{\gamma}^{\nu}$).

In the relations (1) and (2), $v_{c,z}$ is the cylinder velocity in z direction (towards the discharge of the melt into the extrusion head), *i* – number of flights in parallel, $h_{p,3}$– the metering zone depth.

The simulations were done for a screw having the geometry: the diameter $D$ = 110 mm, channel width $W$ = 99 mm, square pitch flight, $h_{p,3}$ = 3 mm, width of the screw flight, $e$ = 11 mm, $\delta_s$ is the gap between screw flight tip and the barrel and it varies with the screw wear (0.2 - 1.6 mm). The rheological constants of the materials are presented in Table 1.

Table 1. Rheological constants (experimental resulted).

| Material | PP | | LDPE | |
|---|---|---|---|---|
| Consts. Pass | m [MPa·s$^{\nu}$] | ν | m [MPa·s$^{\nu}$] | ν |
| The first | 0.0011 | 0.8628 | 0.009 | 0.709 |
| The 10 th | 0.0009 | 0.6404 | 0.01 | 0.648 |

The influence of the leaks is important as the screw wears, so it can be used the next mathematical model [12]:

$$Q = i\frac{v_{c,z} \cdot w \cdot h_{p,3}}{2} \cdot F_a + i\frac{w \cdot h_{p,3}^3}{12\eta_{ef}}\left(-\frac{\partial p}{\partial z}\right) \cdot F_p - E_s\frac{\pi D_c \cdot \delta_s^3 \cdot \Delta P_s}{12\eta_{ef,g} \cdot e} \quad (3)$$

where $\eta_{ef,g}$ is the melt's effective viscosity in the gap between screw tip flight and the barrel, given by

$$\eta_{ef,g} = m \cdot \nu \cdot \left(\frac{v_{c,x}}{\delta_s}\right)^{\nu-1} \quad (4)$$

The symbols used in relations (3) and (4) are: $v_{c,x}$ is the velocity of the cylinder in x direction (perpendicular on *z*, backwards over the helical screw flight), $\Delta P_s$ – the pressure drop along one pitch of the screw, $\Delta P_s = \frac{\Delta P}{n_p}$, $\Delta P$ – total pressure drop, $n_p$ - number of turns, $E_s$ – coefficient (for the entire screw $E_s$ = 1.2). The flow rate must fulfill the condition: $Q \geq 0$ – resulting limitations for certain parameters (limitation values for rotation speed, pressure and gap between screw flight tip and the barrel – due to wear).

In the followings there are presented in the figures the simulations results only for PP. The results for LDPE are presented only as comments.

From the Figure 4, it can be seen that for the 10th time recycled material the pressure flow rate became higher than the drag flow so, at high pressure values, the recycled material needs to be extruded at higher rotation speeds. For example, to obtain the same flow rate of ~110 kg/h, at the same pressure value of 12 MPa, the virgin material processing can be done at 60 rpm and the 10 times recycled needs to be processed at 90rpm. The differences increase as the pressure is higher. But this is the case only for the PP at 200° C; for LDPE at 180° C it is obtained only a slightly difference for the screw functional feature for the virgin and the 10 times recycled polymer (this is also due to the different processing temperature, not only caused by the polymeric materials change in flow properties), for example at $\Delta p$ =25 MPa, the difference between the flow rate for the virgin and that of 10 times recycled LDPE is less than 1 % at 30 rpm it remains the same for the higher rotation speed.

In Figure 5 it can be seen the influence of the leak over the flight for PP virgin and 10 times recycled – resulted that at low rotation speed the flow rate is zero (obtained, for example, for 30 rpm or less, for all pressure domain).

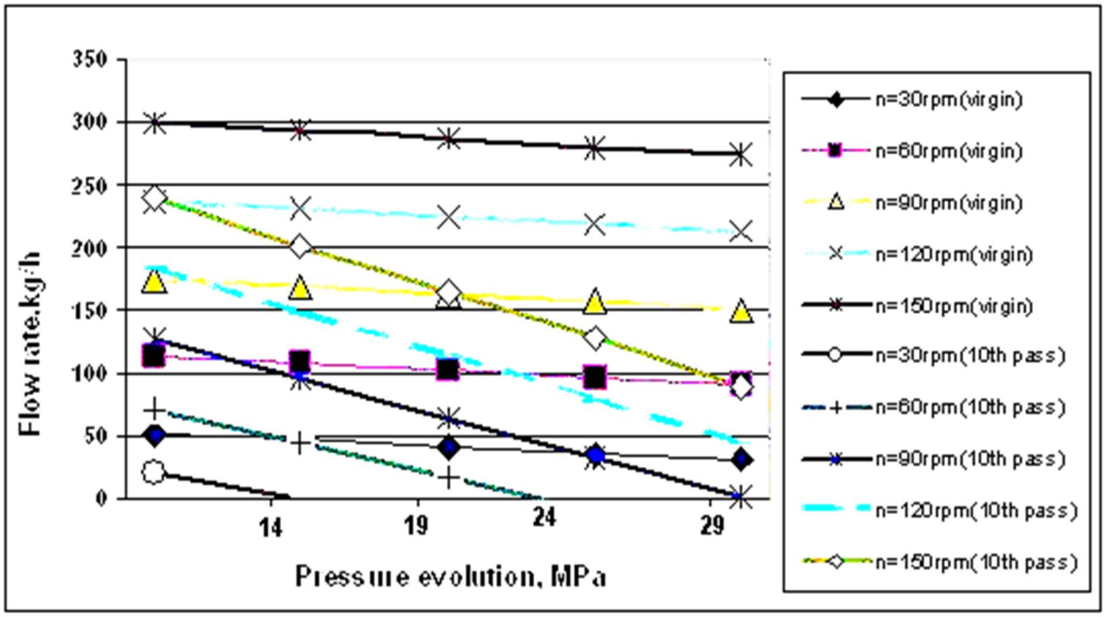


Fig. 4. Screw functional feature $Q(\Delta p)$ without leaks, for PP at 200 ºC.

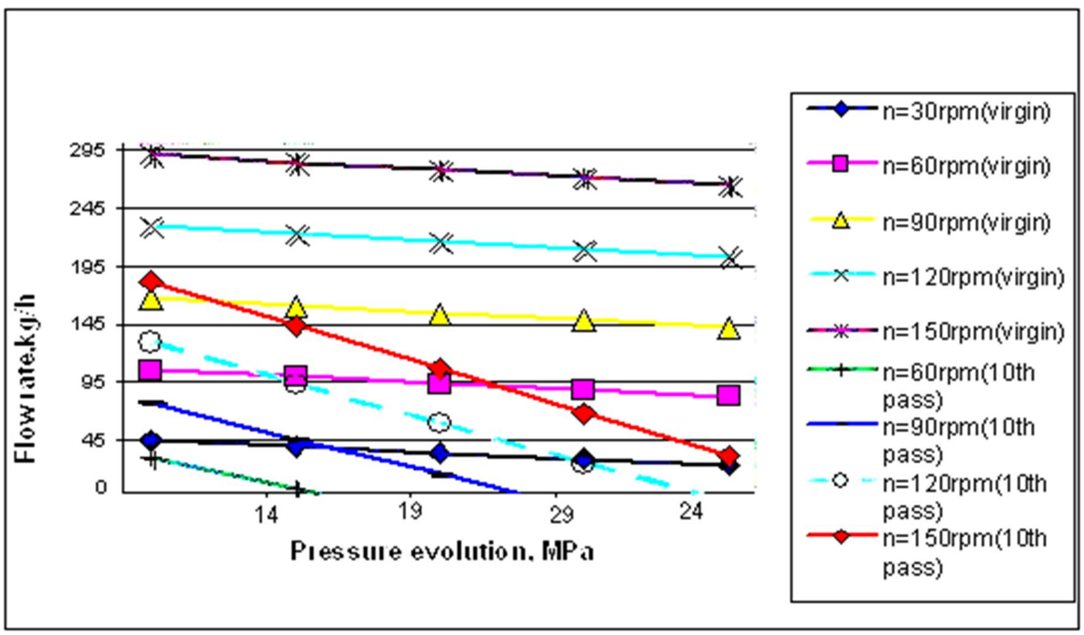


Fig. 5. Screw functional feature $Q(\Delta p)$ with leaks, for PP at 200 ºC.

As the screw wears, the flow rate decreases and the influence of the recycling on the pressure flow increases, far more than in the case of new screw (Figure 4), so to compensate this influence higher screw rotation speed is needed. To obtain the same flow rate (~160 Kg/h) at the same value of the pressure (12 MPa), for the 10 times recycled material one has to increase the rotational speed from 90 rpm to 150 rpm. The influence of the recycling material increases whereas the pressure growths. For LDPE the differences are not so obviously – the difference between the flow rates for the virgin and the 10 times recycled LDPE is less than 1 %.

## 4. CONCLUSIONS

The experimental research gives valuable data on the rheological behavior changes due to polymer recycling. These data are badly needed as the number of recycling increases, so it was taken into account the $10^{th}$ recycling. The research was done on several polymeric materials, here there were presented the results for only two materials. It was compared the rheological behavior of PP at 200 ºC (the recommended extruding temperature), virgin and 10 times recycled with LDPE rheological behavior at 180ºC (the recommended extruding temperature), also virgin and 10 times recycled. The results were quite different.

So one concludes:
– Experimental researches are to be done to know how the flow properties are changing during reprocessing;
– Simulations ought to be performed to evaluate the influence of the flow properties changing on the performances of the screw;
– From experimental research shows quite different rheological behavior and processing performances for the two materials;
– These kinds of data are seldom find in literature;
– The simulations reveal how to change processing parameters for a feedstock made of a material many times recycled (for example the rotation speed must be increased as the materials is many times reprocessed). For some materials it is compulsory to work at high screw rotation speed in the case of many times reprocessed polymeric material.

It is further to establish the rheological behavior changing and its influence on the screw performances in the case of the use in the feedstock virgin and an amount (different percentages) of recycled polymers.

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