International Journal of Trend in Scientific Research and Development (IJTSRD)
International Open Access Journal
ISSN No: 2456 - 6470 | www.ijtsrd.com | Volume - 2 | Issue – 1

# Dynamical Modelling and Control in the Polymer Extrusion Process

**Bekir Cirak**
Karamanoglu Mehmet Bey University, Engineering
Faculty, Department of Mechanical Engineering,
Yunus Emre Campus, Karaman, Turkey

## ABSTRACT

In this paper, the results of experimental investigation are using PVC molten is used as the coating material in a extrusion unit at different extruder temperatures, extruder speeds and shear rate value.The quality of extrusion is emphasis the extruded plastics material viscosity as first indicator parameters in polymer extrusion. Also parameter which primarily determines of the viscosity is shear rate.The other parameters are extruder temperature, and single screw rotation speed. This nümerical model to evaluate the viscosities of thermoplastic polymers in the extrusion process for quality control proposed in this article. PVC was used in this study to test the effectiveness of the model. Comparing the available results, it was found that the viscosities obtained with the nümerical model are in agreement with those obtained by using an in line rheometer. The result shows that the this method can be applied to control the polymer extrusion process. The topic of this paper is the design and experimental testing of a PID control system for the desired of the barrel temperature, extruder pressure and shear rate in a polymer single single screw extruder. Simulations of PID Control algorithms for coating process have been made and the results of these simulations was observed. There are a comparison of PID Controller and nümerical results and there are comments about this comparison in these studies. The simulations of the algorithms are done in MATLAB 2010 a packaged program environment.

***Keywords:*** *Barrel temperature; Extruder; PID control; Shear rate; Viscosity*

## 1. INTRODUCTION

At present, Moulding process is used in almost every area especially in the electrical and electronic industry. Extrusion is a process which utilizes a variety of complex equipment. This consists of a plasticating extruder fitted with a wire coating die through which the wire is continuously drawn. Polymer extruder is a general concept and a sample plant which changes product name with construction of die in it. Besides pass to through of funnel and enter of extruder which the changes of polimer as for important as this design.A continuously increasing number of commercial products are produced by polymer extrusion using plasticating extruders, which are among the most widely used equipments in polymer process industry.The extrusion process has a standard setup includinga feeding section, a barrel and a head with a die for shaping. In the feeding section, the solid polymer is fed into the extruder through a hopper in the form of pellets or irregular small bits. Then, the polymer is transported along the barrel by means of a rotating single screw.

The plasticating extruder is one of the main pieces of equipment used in the polymer processing industries. As plastics is found more uses, with more stringent quality specifications, the methods of increasing polymer production while improving product quality are needed. Extrusıon molding is the most widely used process in manufacturing plastic products. Since the quality of extrusıon coated plastic parts are mostly influenced by process conditions, how to determine the optimum process conditions becomes the key to improving the part quality.

In the early studies concerning contrary to thermoplastics, little attention has been paid until now to the pvc extrusion. Recently, different research programs have been developed to remedy this lack [1]. Experimental and theoretical works on single stage extruders have been pub published [2] and experimentations on single and theoretical approaches of the two stage extrusion process have been developed in the case of thermoplastic materials, but always for isothermal flow [3]. the viscosity control strategy, Researcher [4] reported that the viscosity characterises the flow behaviour of the plastified polymer. Because it is difficult to directly measure the state of the melt viscosity while an extruder is in operation, it is only possible to keep a check on the barrel wall temperature or on the stock temperature and pressure as indicators of the state of the melt.

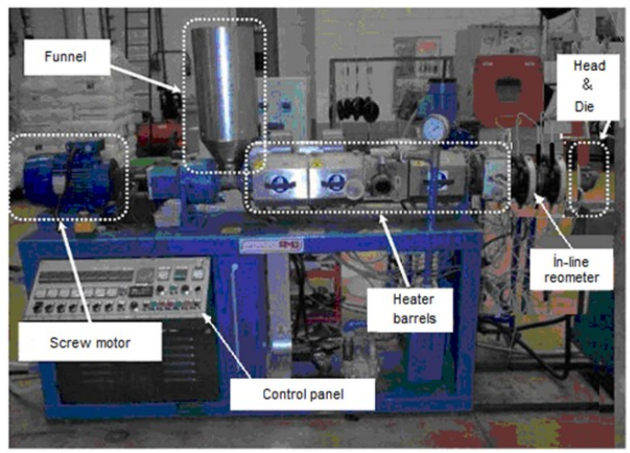
Researches [5] used a measuring device to measure the torque of the plastified polymer at the single screw tip. Researches [6] designed a controller using an in line wedge rheometer as the sensor to control the extrusion of PVC with desired viscosity. Researches developed a fuzzy controller using an in line viscometer to control the melt viscosity during extrusion processing [7]. It is most effective to maintain product quality utilising viscosity control, because a polymers viscosity correlates with its composition and molecular distribution [8], and hence the characteristic of the material. In view of this, more and more researches are aimed at using viscosity measuring instruments as sensors to control the quality of the products.

The rheological properties are generally temperaturesensitive, and it is not possible to control the temperature of the material while the rheological measurement is being made. A rheometer generally requires two extra pressure transducers, temperature compensation devices, if necessary, and special care in design taken to ensure that the main flow and the rheological measurement do not interfere with each other. Therefore the total cost of the rheometer increases the initial investment costs involved in the manufacture [9].

## 2. Material and experimental equipment

The polymer granules are filled in the hopper and the hopper is connected to the body of extruder. The PVC compound was prepared using a proprietary formula which includes PVC resin, foaming (blowing) agent, heat stabilizer, lubricant, process aid, pigment and filler.The extrusion process parameters; i.e. barrel heater zones' temperatures and single screw speed were varied systematically and in random order to vary of the extruded parts.

The available extruder incorporated five heating zones along the barrel and two independent heater zones at the die sections. In order to maintain a constant heat profile in the barrel, the ratio between the five heater zones was fixed during all experiments while varying the temperatures of all five heater zones accordingly. The die heater zones were maintained at the same temperature, which was also varied during the experiments. The polymer material used for coating the cover is PVC. The other words, the coating material PVC shear rate via viscosity and extrusion of an industry example, shown in Fig.1 was studied.




The SSE OMP T35 L / D 24 at the EGE PLASTİC CO. İzmir - TURKEY

**Fig. 1. Polymer extruder and parts**

Polymer extruder is a general concept and a sample plant which changes product name with construction of die in it. Besides pass to through of funnel and enter of extruder which the changes of polimer as for important as this design [10]. Rheometer with to investigate fluid characteristics of coating material in Figure 1. To measure the viscosity and shear rate, each sample was measured at five different positions along its length by a in line rheometer. In this study, plastic material was used as test material. The material was supplied from EGE PLASTİC CO. (İzmir / Turkey). The experimental value and data is given from this company. The die heating zones was maintained at the same temperature, which was also varied during the experiments. Some of temperatures for each heating zone (barrel), the different single screw speeds, shear rates and viscosity values are shown in Table 1

**Table 1. Collected of experimental process parameters**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | Experimental data values | | : Manuel from process | | | |
| | | Experimental name | | : Extrusion | | | |
| | | Extrusion material | | : EP 58 PVC | | | |
| | | Time interval | | : 5 min. | | | |
| **No.** | **Screw Speed ( rpm )** | **1 . Barrel Temperature (°C)** | **2.Barrel Temperature (°C)** | **3 . Barrel Temperature (°C)** | **Shear Rate (1 / s)** | | **Viscosity (Pa.s.)** |
| **1** | 5 | 475 | 525 | 575 | 25 | | 1500 |
| **2** | 15 | 480 | 550 | 580 | 150 | | 875 |
| **3** | 25 | 495 | 560 | 590 | 45 | | 550 |
| **4** | 20 | 505 | 570 | 595 | 250 | | 450 |
| **5** | 40 | 485 | 565 | 585 | 350 | | 245 |
| **6** | 30 | 490 | 530 | 575 | 25 | | 150 |
| ------ | | | | | | | |
| **154** | 35 | 500 | 545 | 595 | 150 | | 755 |
| **155** | 30 | 515 | 540 | 580 | 250 | | 600 |
| **156** | 20 | 505 | 535 | 590 | 45 | | 500 |
| **157** | 15 | 510 | 555 | 575 | 350 | | 350 |
| **158** | 5 | 490 | 560 | 585 | 25 | | 250 |
| **159** | 10 | 475 | 570 | 580 | 150 | | 1250 |
| **160** | 45 | 520 | 525 | 590 | 250 | | 1485 |

The in line rheometer has a 2.5 cm inside diameter and two pressure transducers installed at a distance of 10 cm, similar to the capillary rheometer. This in line rheometer was equipped to measure the viscosity of the polymer melt based on the pressure drop and flow rate.The measurements were carried out on a capillary rheometer (monsanto M.P.T). The results are indicated in the range of shear rates and temperatures in extrusion process (typically betwen 25 and 350 s-1 and between 475 and 575 °C). The material used in this study for both in the laboratory and in line measurements was PVC, which was manufactured by Ege Plastic. with melt flow index: 1.98 g /5 min and density: 0.901 g/ cc. The off line rheological measurement for PVC was carried out by using a cone rhemometer (Instron 3250). The test temperatures of PVC were between 475 and 575 K. The shear rates were chosen between 25 and 350 1/s, as the measured ranges encountered in most polymer extrusion processing [11].

The polymer extrusion experiment was carried out at five screw speeds 5, 10, 15, 20, 25, 30, 35, 40 and 45 r.p.m. for three different melt temperatures 475, 525 and 575 K. The pressure drops for analysing the in line viscosity data and single screw speeds for the proposed model were written to the hard disk every second. The flow rates at various screw speeds and temperatures were individually investigated in advance for evaluating the in line viscosity data. The experimental equipment was a single single screw extruder with maximum 45 mm single screw shaft diameter, 50 mm of single screw housing, 42 mm single screw pitch, and an in line viscometer at the exit end. The machine was a laboratory extruder capable of a maximum throughput of about 100 kg/h. A reasonable explanation for the differences is that the orifice diameter of the in line viscometer is around 5–10 times of that of a laboratory rheometer. The pressure drop in the in line rheometer is much lower than that of the laboratory rheometer.

Among these control strategies, perhaps the most popular type used in industrial practice is control of the melt temperature. In this approach, setting the temperatures of the heating zones regulates the melt temperature. PID controllers are usually used to maintain a constant melt temperature in the heating zones. The aim of the temperature control is to keep the temperature at different points in the extruder as close as possible to the desired values. In pressure control, the melt pressure can be maintained by adjusting the single screw speed at predetermined limits [12]. The PID controllers controlled the temperatures of three heating zones. These controllers could automatically control the temperature profile and read the melting temperature at the single screw tip, when connected to a PC.

## 2.Equation Model

In the literature, many efforts have been made to establish the relationship between viscosity, temperature and shear rate. Andrade's equation. In published papers of Z.-L. Chen, P.-Y. Chao, S.-H. Chiu was assumed that the relationship between viscosity and shear rate is described by the (1), (2), (3) and (4) equations [1]. They used model this equation. So the equation model of viscosity control system in the polymer extrusion process.

Where, $\dot{\gamma}$ = Shear Rate ( 1/s ), $\omega$ = Screw speed (r. p. m.) , $T$ = Melt Temperature ( K) and $\eta$ = Viscosity (Pa.s.)

$$\dot{\gamma} = 1.025\,\omega \qquad (1)$$

$$\dot{\gamma} = (0.3172T^3 + 0.5054T^2 + 0.5293T + 0.5562)\,\omega + (0.0435T^3 - 0.8835T^2 + 0.6264T + 0.2932) \qquad (2)$$

$$\eta = 814090865.35\, e^{-0.02427.T}\,(1.025\,\omega)^{0.003279\,T-2.16386} \qquad (3)$$

$$\eta = 814090865.35\, e^{-0.02427.T}\,[(0.3172\,T^3 + 0.5054\,T^2 + 0.5293\,T + 0.5562)\,\omega + (0.0435\,T^3 - 0.8835\,T^2 + 0.6264\,T + 0.2932)]^{0.003279\,T-2.16386} \qquad (4)$$

Where, $T$ = 475 ~ 575 K values with $\omega$ = 5 ~ 45 r.p.m. values put in the (4) equation. So becoming Table 1.

Fig. 2 shows the Equation model of viscosity control system in the polymer extrusion process, where the inputs are screw speed ($\omega$) and barrel zone temperature profiles ( $T_b$ ) and the viscosity ($\eta$ ).

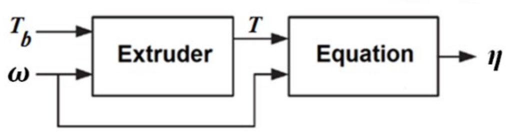



**Fig. 2. Equation model**

Table 2 shows the measured viscosities of PVC in the laboratory at various temperatures and shear rates in the selected ranges [13].

**Table 2. Measured viscosity values**

| $\dot{\gamma}$ (s-1) | η ( Pa.s.) | | | | |
|---|---|---|---|---|---|
| | T = 475 K | T = 500 K | T = 525 K | T = 550 K | T = 575 K |
| 25 | 1.502.540 | 1.264.370 | 856.111 | 832.900 | 451.932 |
| 45 | 997.648 | 894.854 | 595.099 | 657.213 | 387.555 |
| 150 | 579.771 | 501.047 | 405.400 | 365.980 | 295.121 |
| 250 | 394.660 | 399.080 | 275.823 | 400.001 | 197.004 |
| 350 | 265.552 | 200.008 | 195.012 | 162.222 | 122.098 |

**Fig. 3 shows variation of ln $\eta$ against ln $\dot{\gamma}$ at between 475 via 575 K values the PVC temperatures.**

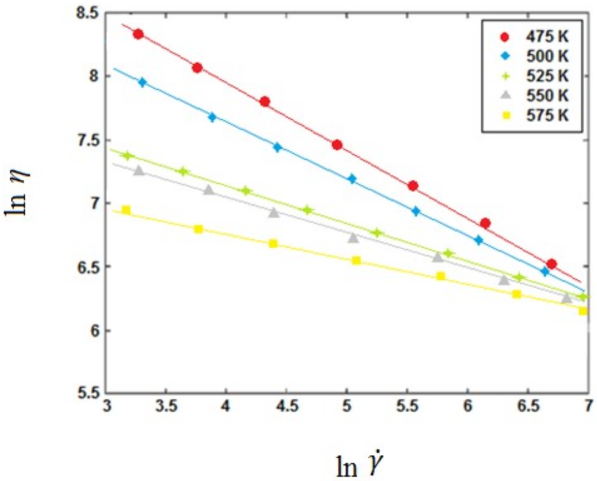



**Fig. 3. Ln $\eta$ against ln $\dot{\gamma}$ for PVC at 475 ~ 575 K values the temperatures**

The shear rates by eqs. (1) and (2) in Fig. 4. The shear rate values calculated by Eq. (1) are higher than those calculated by Eq. (2).The shear rate values calculated by Eq. (2) are increased with the increase of temperature.

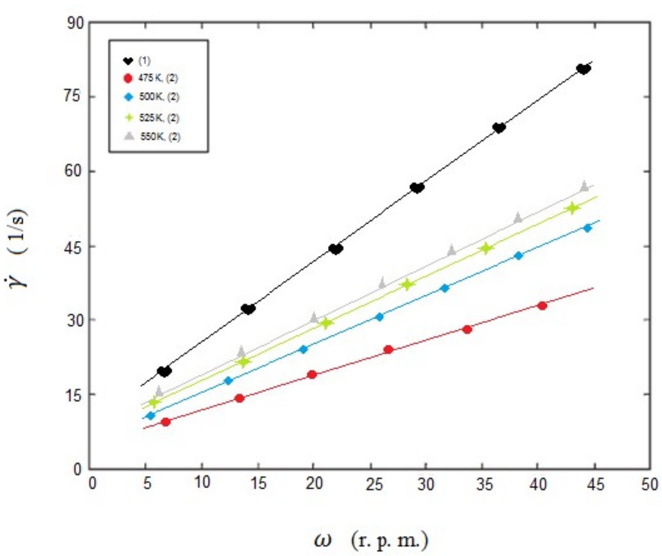



**Fig. 4. Shear rates vs. screw speed at various temperatures.**

Fig. 5 shows calculated by equations (3) and (4) that puts T= 500 K, 525 K and 550 K in (3) equation with (4) equation. Therefore $\eta$ against $\omega$ change value.

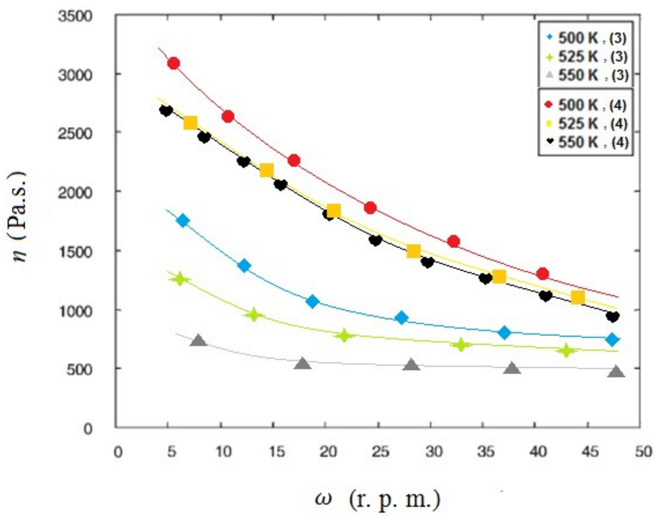



**Fig.5. Calculated viscosities with screw speed at various temperatures.**

Fig. 6 shows the averaged viscosity values collected by the in line rheometer for each temperature at various screw speeds. Comparing viscosity values calculated by eqs. (3) and (4) (Fig. 5) and those evaluated by the in line rheometer (Fig. 6), that the in line viscosities are very much less than those calculated by the equation model.

However, when compared the shapes of curves in Figs. 5 and 6, we found that they are quite similar. If we linearly magnify a whole set of in line viscosity values for the same temperature by shifting upward (different distances for each different temperatures), that these viscosity values fitted the curves plotted by eqs. (3) and (4) very well.

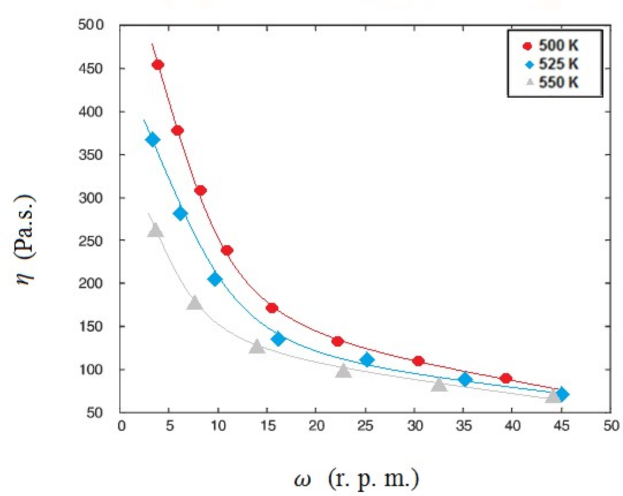



**Fig. 6. Collected viscosities with screw speed at various temperatures.**

The comparisons of modified in line viscosities and those obtained by Eq. (3) in Fig. 7

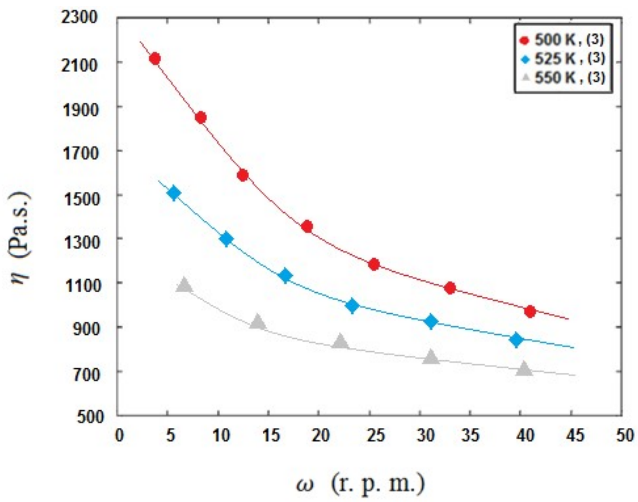



**Fig. 7. Relation of between viscosities and screw speed at various temperatures**

The comparisons of modified in line viscosities and those obtained by Eq. (4) in Fig. 8

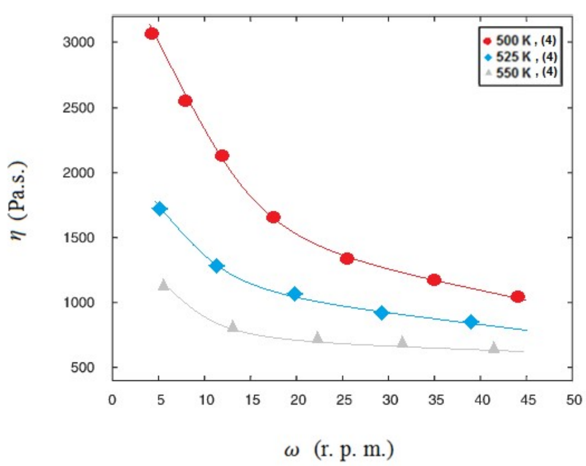



**Fig. 8. Relation of between viscosities and screw speed at various temperatures**

## 5. CONCLUSİON

Experimentations on a single screw, in particular single screw pulling experiments, have permit to observe the flow conditions in the single screw sections. The computation method which has been developed leads to the description of the pressure and temperature evolutions in the single screw and to the filling rate of the single screw stage. Except fort he pressure at the end of the stage, the theoretical results are in good agreement with the experimental ones.

This type of computation permits to beter understand the extrusion process. It may be used in order to optimize the single screw geometry study is going on by testing different pvc polimers and other single screw geometries.

The viscosity control models that can be used in extrusion control have been proved to be generally in good agreement with the modified data analysed by the in line rheometer. The models were built based on the empirical material model investigated in advance in the laboratory. The proposed models can be applied to the product quality control using viscosity as the main control parameter in the polymer extrusion process without imbedding an in line rheometer, which will influence the throughput of the product.

## Nomenclature

**SSE** Single single screw Extruder
**PVC** Polyvinyl chloride
**PID** Proportional Derivative Integral Control
**PC** Personal computer

## Acknowledgment

In this study, PVC extrusion plastic material was used as test material. This work was supported by EGE PLASTİC CO. in İzmir, Turkey. The experimental value and data is given from this company.

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