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NON-NEWTONIAN MELT FLOW OF THERMOPLASTIC MATRIALS IN EXTRUDER

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Abstract: Thermoplastics are plastics that melt and flow as a thick fluid when heated above a certain temperature. In this state, the material is often referred to as a plastics melt. It is also in this state that the material is usually formed or shaped into a product. In plastics, the viscosity changes when the shear rate change, a fluid that behaves that way is called a non-Newtonian or non-linear fluid. Non-Newtonian fluids are of great scientific interest due to their range of physical properties, which arise from the characteristic shear stress-shear rate relation for each fluid. The applications of non-Newtonian fluids are widespread and occur in many industries. In order to understand how a plastic behaves during processing it is necessary to know how thermoplastics melt flows. So this research work is devoted to the development of mathematical models for the simulation of the flow of polymer melts through the metering and die regions of single screw extruders. The set of the governing equations in flow are solved, to determine the large deviation of Newtonian behavior then study the Newtonian and non-Newtonian behavior in this research. These models are used not only to study the effects of various process conditions and geometry variations on the performance of the process but also to predict the operating point of the extruder machine. The power- law model was used to describe the non-Newtonian behavior of the fluid, this model has proven useful for calculating the velocity and shear rate distribution for tube flow of shear thinning fluids, and Carreau correlations are used to predict the low strain rate in the region of Newtonian and non-Newtonian fluid flow. Tube flow of shear thinning fluids, and Carreau correlation are used to predict the low strain rate in the region of Newtonian and non-Newtonian fluid flow displaying the inter dependence of stress, strain and time by means of creep curves, in this research mathematical models representing the creep curves are achieved. When the screw speed increased by 100% the output doubled and also approximately the operating pressure to be doubled, according to the Newtonian fluid method however, this does not apply to polymers that have non- Newtonian behavior with increasing shear rates, the operating pressure is found to increase about 21% according to the power-law fluid method.

I. Introduction

Many mathematical of varying complexity and forms have been proposed in the literature to model shear-thinning characteristics, some of these are straight forward attempts at curve fitting, giving empirical relationships for the shear stress (or apparent viscosity) shear rate curves for example, while others have some theoretical basis in statistical mechanics- as an extension of the application of the kinetic theory to the liquid state or the theory of rate processes[1,2] Figure1 and Figure2 represents a conventional extruder linked to die and the metering zone where pumping occurs.

Objectives:

- The primary objective of this work is to study NON-Newtonian behavior in single screw extruder suitable for extrusion of the thermoplastic materials.
- Use the Mathematical modeling for the simulation of the polymer melts flow through the metering and die regions of single screw extruders.
- Used the engineering relationships that enable the plant to calculate the necessary calculations of the flow of thermoplastic materials.

- Predict the operating point of the extruder machine.
- Determining the performance of single screw extruder with increasing screw speed.
- Determining the extent of the deviation between Newtonian and NON-Newtonian behavior.

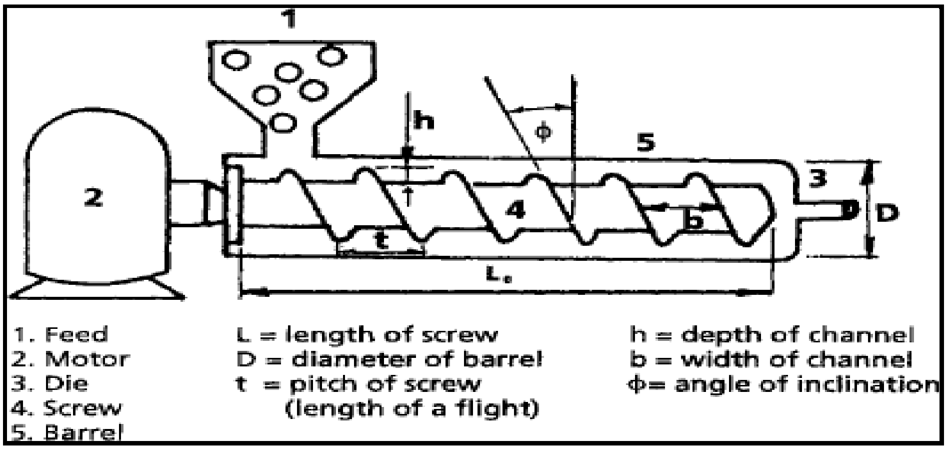

Figure1: single extruder with a die.

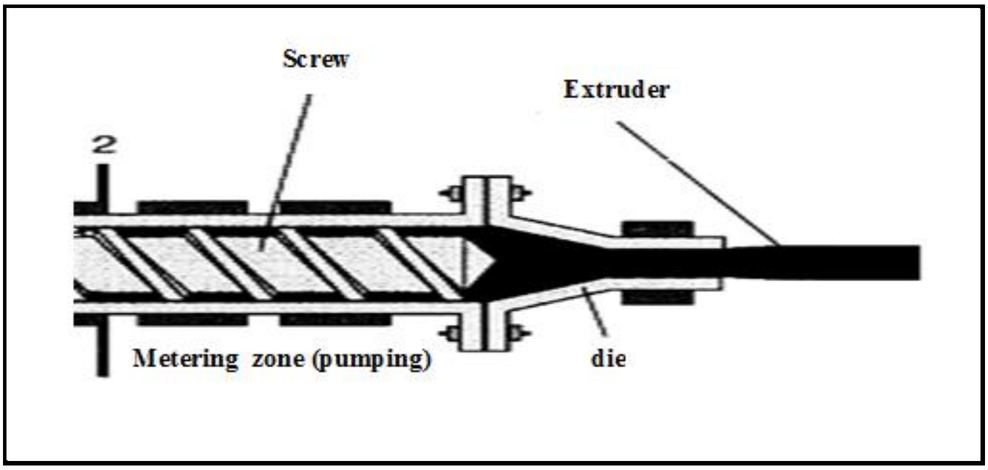

Figure 2: Single extruder metering zone.

II. Melt Flow Properties Extruder Screw Metering zone (pumping)

To understand the extrusion process, it is not enough just to know the hardware aspects of the machine. To fully understand the entire process, one also has to know and appreciate the properties of the material being extruded. The characteristics of the polymer determine, to a large extent, the proper design of the machine and the behavior of the process. There are two main classes of properties important in the extrusion process: the rheological properties and the thermal properties. The rheological properties describe how the material deforms when a certain stress is applied [3,4]. Figure3 represents the creep curve of pp where the experimental data is used in this study.

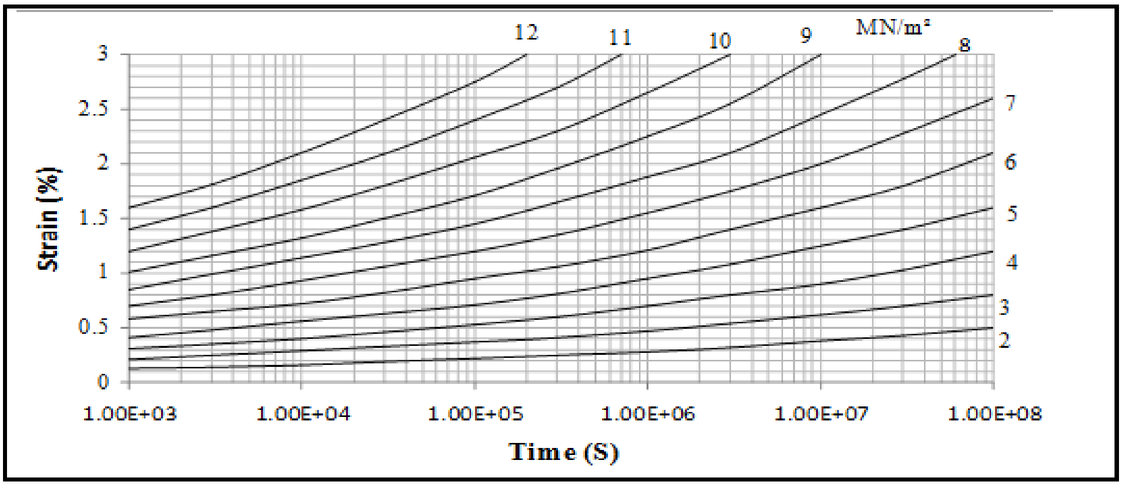

Figure 3: Creep curve of Polypropylene.

Where: Strain = 1 %, At 1 Year, Stress = 4 MPa.

III. Extruder and die characteristics

The cooperation of the screw and the die can be presented in way in a diagram Showing the relationship between the output of the screw and the pressure it must produce to overcome the resistance of flow in the die (characteristics of a screw) and the relationship between die output and pressure produced by the screw (characteristics of die).Figure 4 represents the operating point for isothermal extension process for Newtonian melt flour.

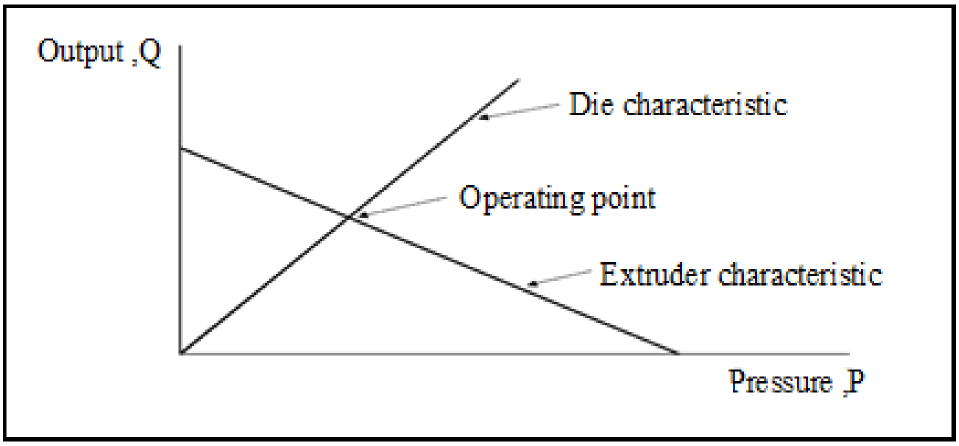

Figure 4: Operating diagram for isothermal extrusion of a Newtonian melt.

IV. Calculation and Results

Power Law Fluids Oswald - de Waele model is used in the calculation to represent the non-Newtonian case[5,6].

$$\tau = k\left(-\frac{du}{dr}\right)^{n} = [k\left(\frac{du}{dr}\right)^{n-1}](-\frac{du}{dr})$$

Where: k = Flow Consistency Index.

n = Flow Behavior Index. The Carreau Equation Model:

$$\frac{\eta_a}{\eta_o} = a_T(1 + a_T(A_T.\gamma^0)^2)^{\frac{n-1}{2}}$$

Typically, the shift factor, may be obtained from:

$$\log a_T = \frac{C_1(T_1 - T_g)}{C_2 + (T_1 + T_g)} - \frac{C_1(T_2 - T_g)}{C_2 + (T_2 - T_g)}$$

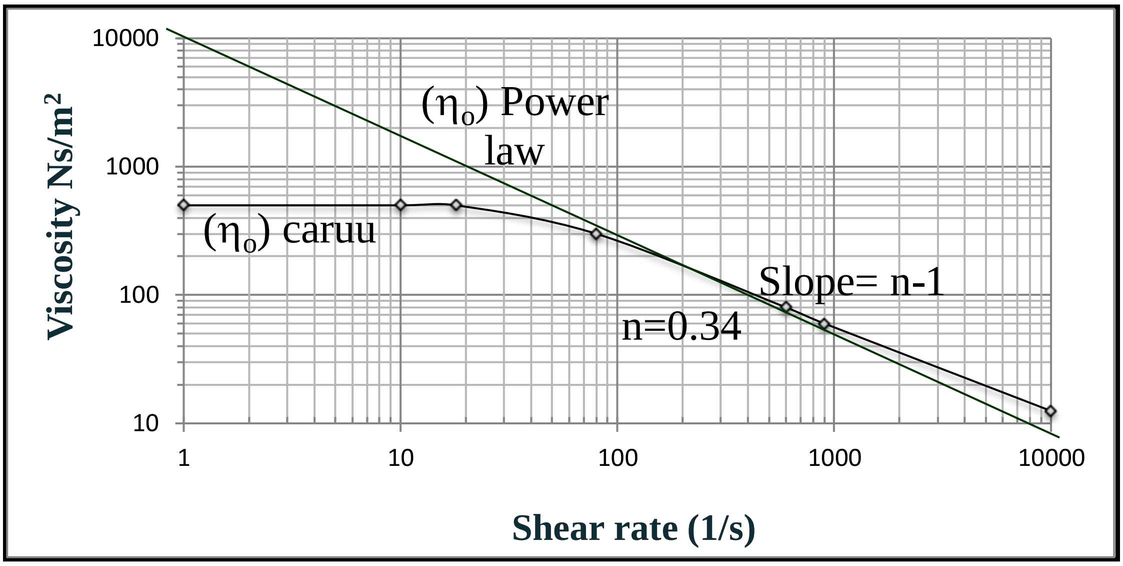

Figure 5: Shear rate vs Viscosity.

The shear rate Viscosity are established using power law and Caruu correlations and shear in Figure5.

Table 1: Power-law model parameters for pp.

Power law index	0.34
Power law constant (pa-s^2)	7000
Reference Temperature (C^0)	250

Table 2: Carreau-Yasuda parameters for PP.

Zero-shear viscosity (pa-s)	500
Temperature T (C^0)	250
Glass Transition Temperature (C^0)	190
The shift Factor at T	0.2055
The pseudo-plastic(a shear-thinning) index n	0.34
Material Constant	0.05
C1 & C2	17.4 & 51.6

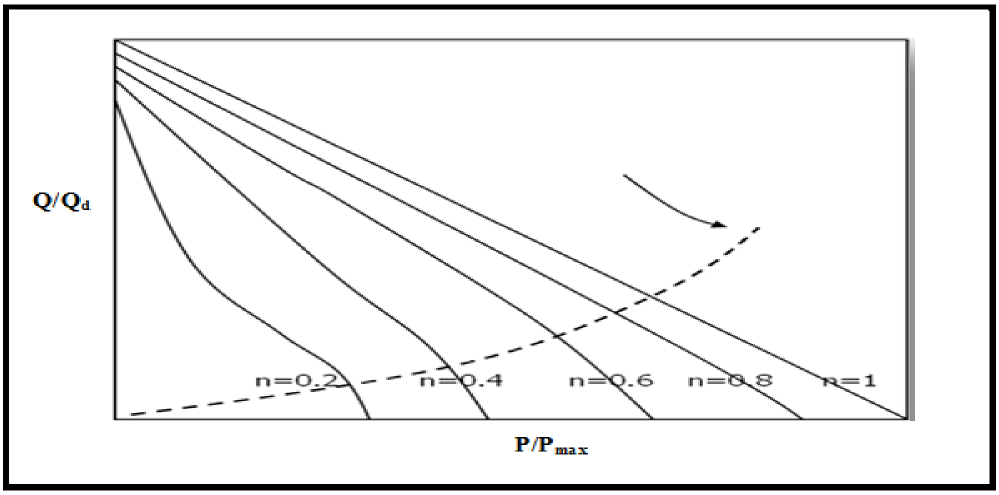

Figure 6: Normalized characteristic screw and die curves in

Non-Newtonian fluids.

Table 3: Extruder / die characteristic at different screw speed.

Parameter	Value
Extruder Cannel Depth (H)	2 mm
Screw Diameter (D)	25 mm
Screw Speed (N)	100 rev/min
	150 rev/min
	200 rev/min
Screw Length (L)	500 mm
Die Length (L)	40 mm
Die Diameter (D)	5 mm
R	2.5 mm
Flight angle	17.7

Table 4: Drag flow, Pressure flow Total flow rate.

Speed (rev/min)	Q_d (m^3/s)	Q_p (m^3/s)	Q (m^3/s)
100	2.97E-06	7.739E-06	2.83E-06
150	4.46E-06	7.739E-06	4.38E-06
200	5.95E-06	7.739E-06	5.87E-06

Newtonian and Non Newtonian models available in literature are used to calculate dependency of operating point of the extruder in several parameters including the hard ware of the extruder and die are illustrated in table1 to table 4. Rheological and thermal properties effect on the operating point of the extruder is illustrated in Figure 6 to Figure 8. Comparison of the fitted results are shown in Figure 9 for both Newtonian and Non Newtonian models[7,8]. The results indicate that the operating pressure is found to increase about 21% according to the power law non Newtonian fluid. The screw speed of the extruder has a significant effect for both Newtonian and non-Newtonian models.

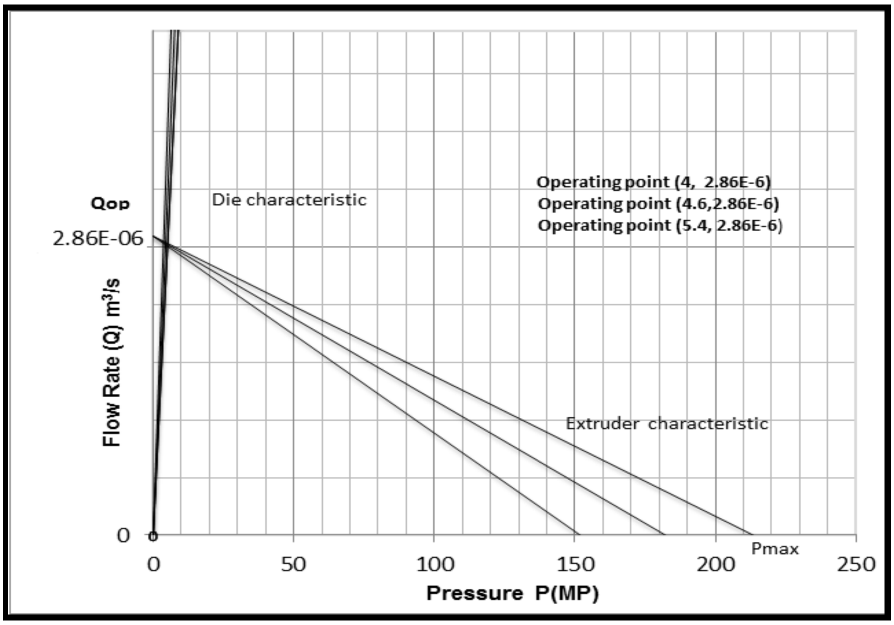

Figure 7: dependency of flow rate to pressure in extruder.

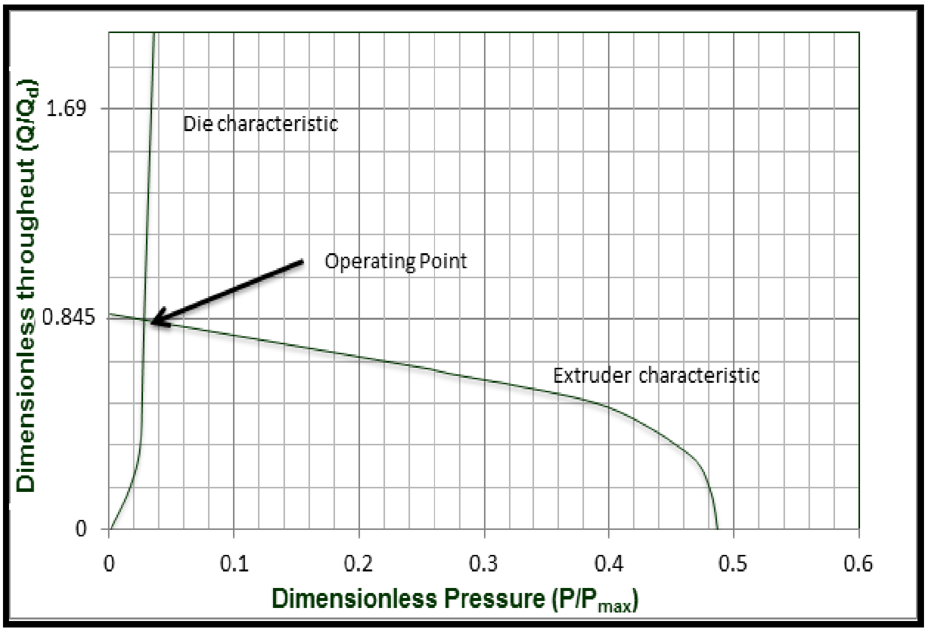

Figure 8: determination of the operating point of the extruder.

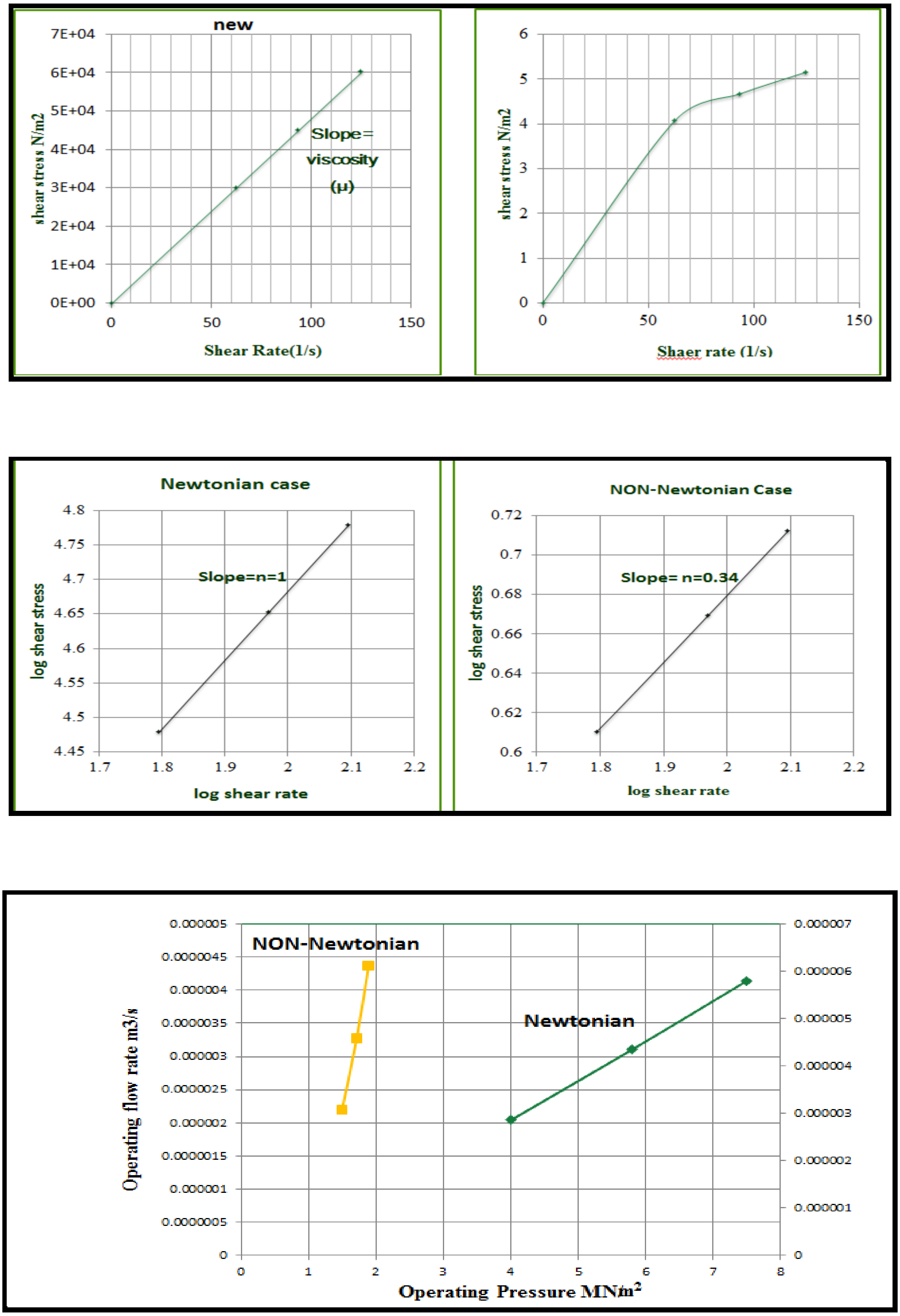

Figure 9: Comparison between Newtonian non Newtonian flow behaviors.

V. Conclusion

The polymer melt flow properties determine to a large extent the characteristics of the extrusion process.

Any given extrusion die can produce a specific shape with only a relatively narrow range of polymers. That's because polymers are non-Newtonian in behavior; they have different viscosity-thinning characteristics at increasing shear rates.

The assumption of a constant viscosity, at shear rates corresponding to those found in an extruder, is not valid even for polymers with relatively little shear rate dependence. The power law index of a polymer melt, to a large extent, will determine its extrusion behavior.

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