

SINGLE-SCREW EXTRUDER EXPERIMENT

1. Introduction.

Extrusion is a widely used method of forming certain polymeric materials into useful shapes. Extrusion involves transport and melting of the feed and pressure build-up and transport of the melt. It is applied to thermoplastic polymers: those which deform when heated and resume their earlier "no-flow" properties when cooled.

The material, usually in the form of small pellets about 5 to 10 mm in size, is fed from a hopper by gravity into the extruder. The extruder is comprised of a hollow chamber with heating zones outside and a threaded shaft (the screw) which can rotate along the center-line inside. The shaft is narrow at the feeder end with the diameter increasing along the length, reaching its maximum near the other end and tapering off at the extruder tip [see Fig 1]. In addition to the changing diameter, screw flights also change along the length of the shaft. The extruder is designed to: (a) ensure steady transport from the feeder to the melting zone; (b) allow for reduction in volume occurring as the pellets melt; (c) build up pressure; and finally, (d) transport the melt through the die attached to the extruder tip. Dies for extrusion are designed to produce the final desired form of the polymer. Depending on the desired shape and number of layers of extrudate required, dies can be machined into complicated shapes. For this experiment, the die is a simple cylindrical tube (Fig. 2).

The behavior of a polymer melt changes with the operating conditions, namely, shear rate, temperature and pressure. The fluid viscosity is not constant, but varies with the shear rate as well as with temperature. This property is important in terms of processing and design. References on fundamentals of viscoelastic behavior are **Transport Phenomena** by Bird, Stewart, and Lightfoot (ch. 2-3) and **Process Fluid Mechanics** by Denn (ch. 2, 8, 19), as well as any ChE Polymers textbook.

2. Theory.

For a non-Newtonian, viscoelastic fluid, the shear stress is a function of the shear rate, and viscosity is dependent on both temperature and shear rate. Several models exist which are applicable to such fluids. The flow behavior of polymer melts is sometimes described by a Power Law model, which in cylindrical coordinates is:

$$\tau_{rz} = -m \left| \frac{dV_z}{dr} \right|^{n-1} \frac{dV_z}{dr}$$

The model contains two empirical constants, m , the modulus of viscosity, and n , the Power Law index. The above relation holds for a given temperature. The parameter m is a strong function of temperature. The parameter n may vary with temperature. The parameters can also vary with shear rate, and for the range of shear rates developed in this experiment they may not be true constants. Note that for $n=1$, the Power Law model reduces to Newton's Law where m is exactly the same as the viscosity of the fluid.

3. Operator's Manual

The extruder assembly consists of a screw pump equipped with a motor and a die, with instrumentation to control and measure temperature and pressure. The pump (SIESCOR) is a single screw, 3/4" diameter with a L/D ratio of 20. It is driven by a 1/4 HP DC motor (MINARIK). The motor is provided with a single reduction worm gear reducer with a ratio of 31:1.

Familiarize yourself with the extruder and its instrumentation before proceeding. The hopper feeds the pellets into zone 1 of the extruder; zone 2 is further along the screw. The die, a cylindrical hole of 2 mm diameter and 12.5 mm length, is attached to the extruder tip. Temperature and pressure of the melt at the die are sensed by the transducer located at the top of the die. Some safety precautions: The die is hot and should not be touched. The exhaust fans for the lab should be ON.

There are two heaters, one for each zone. Zone 1, zone 2 and die temperatures, and the die pressure, are displayed on the front panel. Temperatures are set by the operator; refer to the handout for appropriate values. The panel also displays the speed in rpm of the screw. Speed is controlled by a rheostat -- turning the dial from 0-100%.

Start-up Procedure

1. Turn the exhausts (top and bottom) ON when you are ready to power up the extruder.
2. Make sure that the motor switch is OFF. Then turn the main switch ON.

3. Set the required temperature profile.
4. After the temperatures of all the settings reach their set points, wait for a minimum of one hour to melt the polymer inside the extruder. This is called the "heat-soak"; it is important because any solid left in the melt will exert undesirable high pressure on the die and foul up pressure readings. This procedure should be performed prior to class if possible.
5. After the heat-soak, you are ready to make a run.
6. Fill the hopper with polymer pellets and switch the motor ON. There are 2 switches. Run for 10-15 minutes before collecting data so that fresh polymer comes through the die. Periodically check the hopper.
7. Measure the flow rate by cutting and weighing the extrudate mass exiting between measured time intervals.

Shutdown Procedure

1. After collecting your data turn OFF the extruder motor switches.
2. Next turn OFF the main switch. BE SURE TO TURN OFF THE MOTOR SWITCH FIRST BEFORE TURNING THE MAIN SWITCH OFF.

Troubleshooting

(a) Pressure build-up : You don't want the die pressure to rise above 2500 psi under normal operating conditions. If you observe pressures above 2500 psi turn the speed control down somewhat. If this condition persists even at low speeds (<50 RPM, e.g.), check if the temperatures are set too low. Report to the lab instructor unusual pressure build-ups.

(b) Pellets in extruder discharge : You should get polymer melt discharge from the die. If you observe pellets as a whole being pushed from the die, **stop the motor immediately**. You may not have allowed for sufficient heat-soak, or the die may require insulation.

(c) Degradation : If the polymer stands at elevated temperature for a long time it will degrade. The color will turn yellow. The melting point and viscosity will be lowered. To get consistent readings don't keep the polymer at elevated temperatures while not running the extruder (except for heat-soak).

4. Assignment

For this experiment, a typical thermoplastic polymer such as polypropylene (PP), high-density polyethylene (HDPE), low-density polyethylene (LDPE) or linear low-density polyethylene (LLDPE) is used. The operating temperature for the die and zone temperatures (zone 1 and zone 2) of the extruder depend on the material. Typical die temperatures are: PP, 180-220°C; LDPE, 150-210°C; LLDPE, 170-210°C, HDPE, similar to LDPE; HDPE copolymer, 220-250°C. The zone 1 temperature should be ~5-20°C above the polymer melting temperature; zone 2 temperature is set between zone 1 and the die temperatures. Melting points and other properties for polymers can be found in *Modern Plastics Encyclopedia, Polymer Handbook* (3rd ed., Brandrup and Immergut, 1989, or earlier editions), or any standard handbook on polymers. I have also provided typical properties in the “spreadsheet for extrusion calculations” on my website at:

http://www.che.lsu.edu/faculty/dooley/polymers_class.htm .

Part I

Determine the values of m and n that best characterize the material. Given the above discussion, n may be a constant (determine yes/no), and m a function of temperature. Assuming that the extruder near the die may be approximated as a cylinder of uniform radius R , and the polymer melt maintains a constant fluid density, a differential momentum balance yields Eq. 2:

$$Q = \left(\frac{n \pi R^3}{1+3n} \right) \left(\frac{\Delta P R}{2 m L} \right)^{1/n} \quad (2)$$

Q is the volumetric flow rate of extrudate, L the length of the die, and ΔP the pressure drop in the die.

The data you collect should consist of volumetric flow rates and die pressure drop for varying values of die temperature (at least 3 different T's) and screw RPM (from the lowest measurable RPM to the highest). You should critically examine your data to see how well they are fitted by the power-law model, and whether portions of the data are in fact even consistent with the model. You should use both linear regression (as in my spreadsheet) and nonlinear regression and compare the results. Be sure to show the relevant equations in your report and explain them. From the linear regression results estimate the one-sigma confidence limits on m and n at each temperature. Report the goodness of your fits (all of them) in terms of the average percent relative deviations. Major deviations from the model should be explained. You should also compare your results to results for a similar polymer from the vast literature on polymer rheology.

Part II

Another aspect of the experiment is to examine the flow/displacement behavior of the screw extruder. The amount of polymer melt delivered per rotation (the flow rate Q) varies with the operating conditions; the screw does not function as a constant discharge device. Using Q vs. screw RPM data, this relationship can be examined. Since the polymer is virtually incompressible, a deviation from the correct relationship will provide a measure of the degree of slippage and back-mixing in the extruder. Explain why the amount of slippage varies in the manner observed.

Part III

Compare the diameter of the extrudate with the die diameter (the ratio is the "die swell ratio") at the lowest temperature you use. Is there correlation between operating conditions (e.g., shear stress at wall) and the *die swell ratio*? Does the character (shape, texture) of the extrudate change at high shear rates? What do you think are the reasons for these changes, if any?

Need help with statistics and experimental design? See:

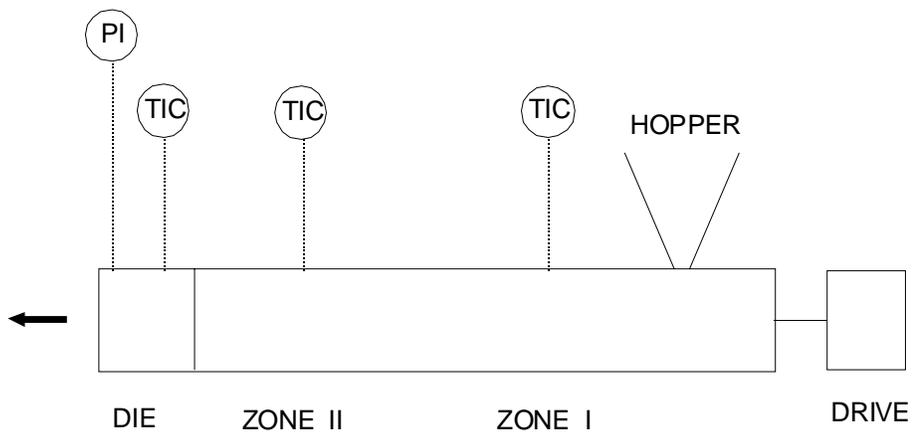


Fig. 1 Schematic of the extruder assembly

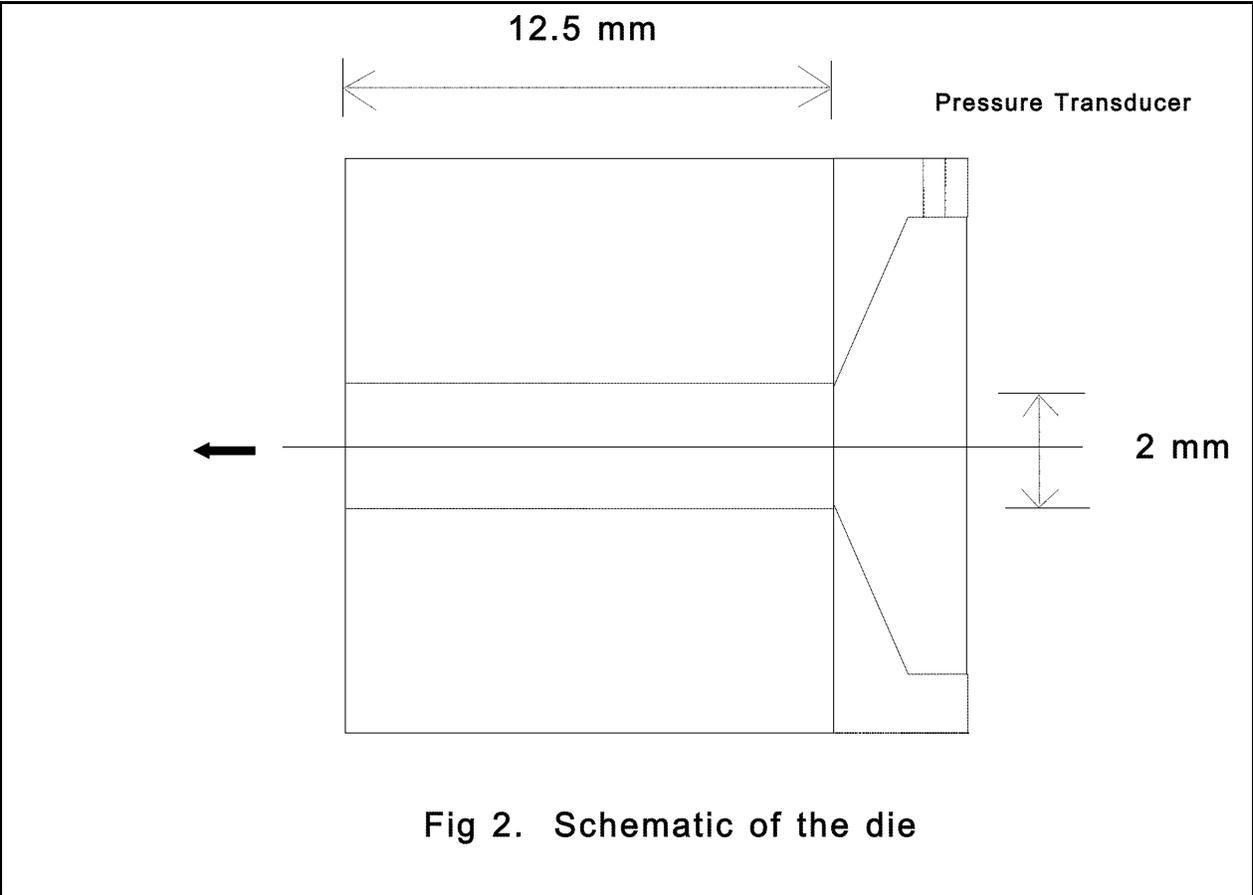


Fig 2. Schematic of the die