2018 Powerlaw Lab
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2

THE UNIVERSITY OF TEXAS AT AUSTIN
DEPARTMENT OF CHEMICAL ENGINEERING
CHE 395E

EXTRUSION OF POLYPROPYLENE: DETERMINATION OF CONSTANTS IN THE POWER LAW RHEOLOGICAL EQUATIONS

I.Object

The object of this experiment is to use the extruder equipped with a cylindrical die for studying the rheological properties of polypropylene melt.

II. References

I. Transport Phenomena, Chapter 2.

2. Polymer Processing by McKelvey, pages 65-71.

3. Modern Plastics Encyclopedia, section on extrusion.

III. Equipment and Supplies

I. One inch, 30:1, Killian plasticizing extruder equipped with a 3" x 1/8" I.D. extrusion die with pressure tap.

2. Triple beam balance

3. Electric stopwatch or equivalent

4. 600 cc beaker

5. Polypropylene material

6. Micrometer or calibers (may be borrowed from shop)

IV. Preliminary Work

The preliminary work for this experiment includes the following:

I. Mathematical derivation of the power law viscosity analogue to the Hagen-Poiseville equation.

2. Set up of extruder

V. Extruder Starting Procedure

I. Turn on hopper and bearing cooling water. This should be on at least 15 minutes prior to adding material to the hopper. Water flow rate should be adjusted so that bearing and hopper are cool to finger touch when barrel heaters are on.

2. Pump grease into Zerk fitting on the Bourdon gage stem. To avoid over pressuring the gage be sure to open plug at stem top prior to pumping grease into stem bottom. Replace top plug as soon as grease is pumped through the fitting.

3. Turn on barrel and die heaters and set to desired level. For extrusion of polypropylene, suggested starting levels are:

Rear Zone (Zone 1) 360°F
Center Zone (Zone 2) 450°F
Front Zone (Zone 3) 450°F
Die (Zone 4) 450ºF

4. Allow heaters to heat to control temperature. After the temperatures are reached (but not before), allow an extra 10 minutes after reaching control point to be sure. The resin may be placed in the hopper and the screw turned on.

a. Screw speed control should be set at zero prior to initially starting motor and should be slowly adjusted to desired speed (10 rpm initially).

b. The screw motor ammeter should be continuously watched. If the current exceeds five amps, decrease the screw speed or stop and wait for the polymer to melt.

c. BE SURE THAT POLYMER IS MELTED BEFORE TURNING ON MOTOR. The screw may break if the motor is turned on while solid polymer is in the extrusion barrel.

VI. Data Taking Procedure

I. Determination of throughput. Set the screw speed at desired value after start up procedure above.

2. Allow machine to run for several minutes before taking data.

3. Run the melted plastic into a tared beaker and using a stop watch determine the run time. At the end of a run, the screw motor is stopped, the run time noted and the beaker weighed to give the mass rate of flow.

4. Use the published density of polypropylene to estimate the volume throughput.

5. The die pressure is read simultaneously with each throughput calibration and recorded.

6. Extrudate samples are taken at each screw speed setting and their diameters measured.

7. The procedure above (steps 1-6) are repeated at one other and, if time permits, two other die temperatures. Suggested heater settings for the two runs are:

ZONE	RUN 2	RUN 3
1	360°F	400°F
2	400°F	500°F
3	400°F	500°F
4	400°F	500°F

VII. Theory Development

l. For isothermal, laminar flow of a power law fluid in a tube, one may assume the viscosity to be of the form

$$\eta = m(\frac{\partial V_z}{\partial r})^{n-1} \qquad \text{(n, m are constants)}$$

Show that the shear stress, τ_{rz}, is then

$$\tau_{rz} = -m(\frac{\partial V_z}{\partial r})^{n} \qquad \text{(a)}$$

Using equation (a) as a starting point, along with the boundary condition, $V_z(R) = 0$, show that the power law analogue to the Hagen-Poiseville relationship is:

$$Q = \pi(\frac{\Delta P}{2Lm})(\frac{n}{3n+1})R^{\frac{3n+1}{n}} \qquad \text{(b)}$$

Where,

L = where length of tube

R = radius of tube

Q = volumetric throughput

ΔP = Pressure drop across tube

m, n = constants

3. From the various steps in the development, show that the shear stress at the wall is

$$\tau_w = \frac{R\Delta P}{2L} \qquad \text{(c)}$$

and that the shear strain at the wall is

$$\dot{\gamma}_w = (\frac{\partial V_z}{\partial r})_{r=R} = -(\frac{3n+1}{n})\frac{Q}{\pi R^3} \qquad \text{(d)}$$

4. Show then that the polymer viscosity at the wall is

$$\eta_w = \frac{\Delta P}{2L}\frac{\pi R^4 n}{(3n+1)Q} \qquad \text{(e)}$$

5. From experimental information on Q, ΔP, and tube dimensions one can thus determine the constants m and n.

VIII. Data Analysis and Questions

l. Plot ln(Q) versus ln ΔP and determine the slope 1/n for the two die temperatures.

2. Determine the rheological equation for polypropylene for the two die temperatures.

3. Are n and m really constants? Determine a logical expression for the temperature dependencies of these constants if necessary.

4. Comment on the accuracy of determining n and m in the manner outline above. Would you be willing to predict, for example, the pressure drop through a die twice as long, using the results obtained here?

5. Plot $V_z / \langle V_z \rangle$ versus r/R to obtain the velocity profile of polypropylene melt in the die. For comparison purposes, include the plot which would result if the flow were Newtonian. Comment.

6. Compare the measured diameters of the extended rod with the actual die hole diameter. What causes the difference?

7. Using the values of n and m calculated in (2) above, plot η_w versus $(\frac{\partial V_z}{\partial r})_{r=R}$ Comment on this and indicate how such a plot would appear for a Newtonian Fluid.

8. Comment on the temperature dependencies of n. How does this affect the analysis?