Single-Screw Extrusion

THE EXTRUDER CHARACTERISTIC

A. W. Birley, B. Haworth and J. Batchelor, Physics of Plastics: Processing, Properties and Materials Engineering, Hanser (1992) Chapter 4.

(on reserve in Deike Library)

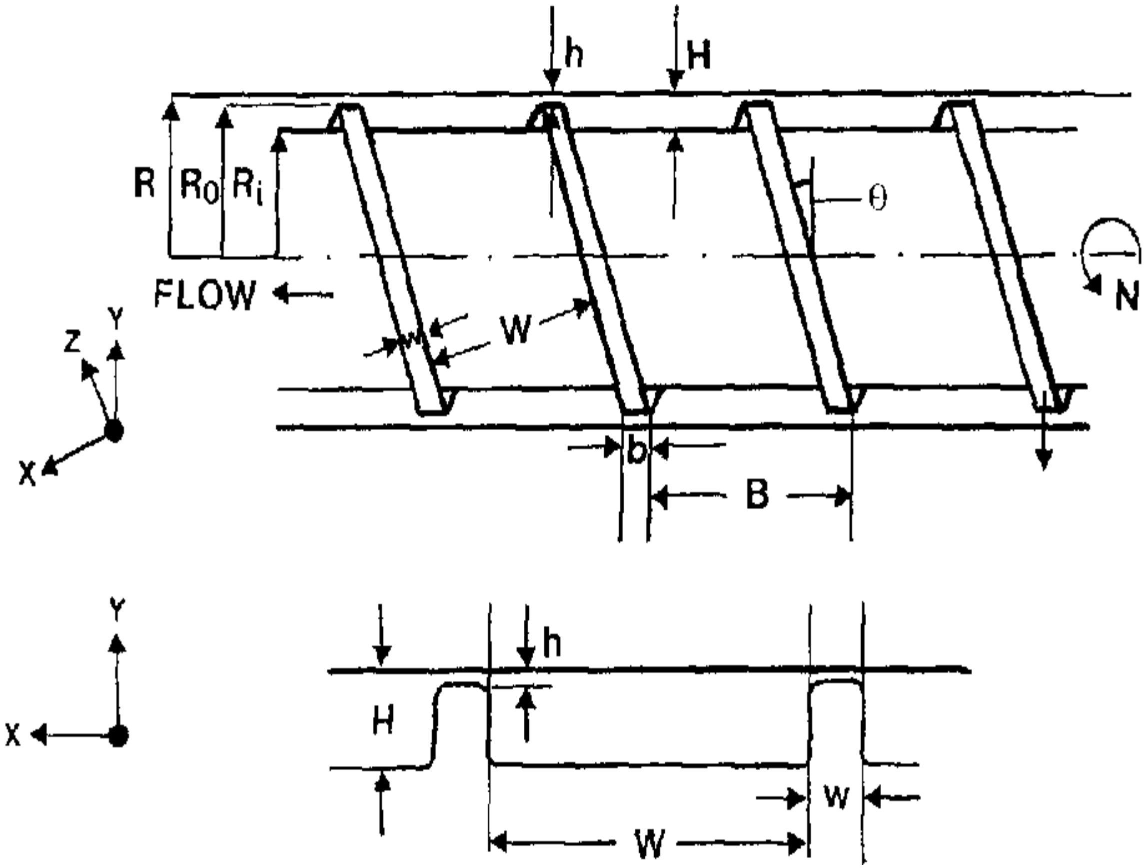

Figure 1: Definitions of Symbols

Barrel Diameter $D = 2R$	Channel Depth $H = R - R_i$
Screw Helix Angle θ	Screw Clearance $h = R - R_o$
Screw Pitch $B + b$	Channel Width W
Screw Rotation Speed N (RPM)	Flight Width w

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DRAG FLOW — the Couette flow between the rotating screw and the stationary barrel

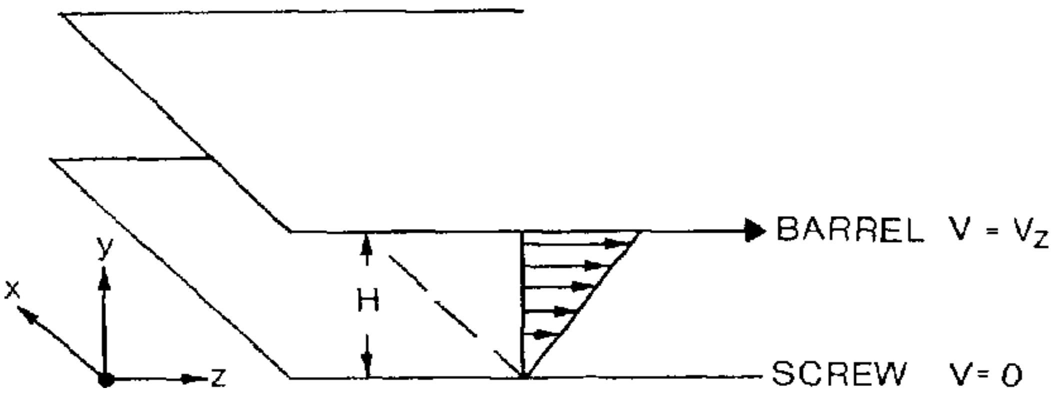

Figure 2: Drag Flow Mechanism

Down Channel Velocity Component $$V_z = V\cos\theta \quad (4.1)$$

Volumetric Flow Rate from Drag $$Q_D = W\int_0^H v(y)dy \quad (4.2)$$

For a Newtonian fluid, the velocity profile is linear:

$$v(y) = V_z\frac{y}{H}$$

$$Q_D = \frac{WV_z}{H}\int_0^H ydy = \frac{WV_z}{H}\frac{H^2}{2} = \frac{WV_zH}{2} \quad (4.3)$$

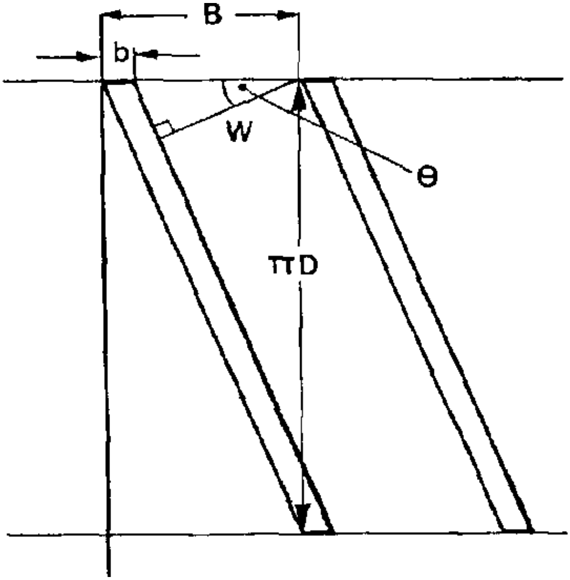

Figure 3: Unrolled Single Turn of the Extruder Screw Helix

The tangential velocity at the barrel surface is determined from the rotation speed of the screw:

$$V = \pi D N \tag{4.4}$$

Down Channel Velocity Component $\quad V_z = \pi D N \cos\theta \quad (4.5)$

$$Q_D = \frac{\pi}{2} W H D N \cos\theta \equiv \alpha N \tag{4.6}$$

The drag flow effectively pumps the polymer through the extruder.

Q_D is proportional to the rotation speed N.

Proportionality constant α only depends on screw geometry.

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PRESSURE FLOW — the Poiseuille flow suppressing flow through the extruder

Extruders usually have some FLOW RESTRICTION (like a die) at the end of the extruder. This creates a pressure gradient along the screw that works against the flow through the screw:

$$Q_P = -\frac{WH^3}{12\mu}\frac{\Delta P}{L} \equiv -\frac{\beta}{\mu}\Delta P \tag{4.7}$$

Again, the proportionality constant β only depends on screw geometry.

The NET VOLUMETRIC FLOW RATE is the sum:

$$Q = Q_D + Q_P \tag{4.8}$$

Example 1: OPEN DISCHARGE
No flow restriction at the end of the extruder (remove die)

$$Q_P = 0 \qquad \text{and} \qquad Q = Q_D$$

Example 2: CLOSED DISCHARGE
No flow out of the extruder (plug die)

$$Q = 0 \qquad , \qquad Q_P = Q_D \qquad \text{and} \qquad \Delta P = \alpha\mu N/\beta$$

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In general the die restricts the flow somewhat, but not completely. Combining equations 4.6, 4.7, and 4.8, we get the EXTRUDER CHARACTERISTIC:

$$Q = \alpha N - \frac{\beta}{\mu}\Delta P \tag{4.13}$$

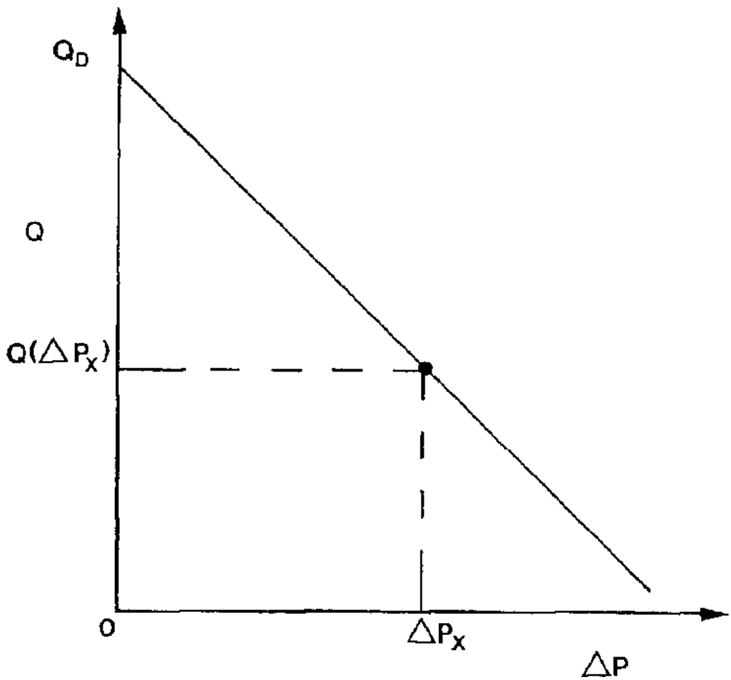

Figure 4: The Extruder Characteristic for a Newtonian Fluid is a linear relation between Q and ΔP.

y-axis intercept ⇒ OPEN DISCHARGE ($\Delta P = 0$)
x-axis intercept ⇒ CLOSED DISCHARGE ($Q = 0$)

More Flow Restriction ⇒
Larger Pressure (larger ΔP) ⇒
Smaller Throughput (lower Q)

Single-Screw Extrusion
THE DIE CHARACTERISTIC

There is a simple relation between pressure drop and volumetric flow rate in the die.

$$Q = K\frac{\Delta P}{\mu} \tag{4.21}$$

Circular Die: $K = \frac{\pi R^4}{8L}$ Hagen-Poiseuille Law

Slit Die: $K = \frac{WH^3}{12L}$

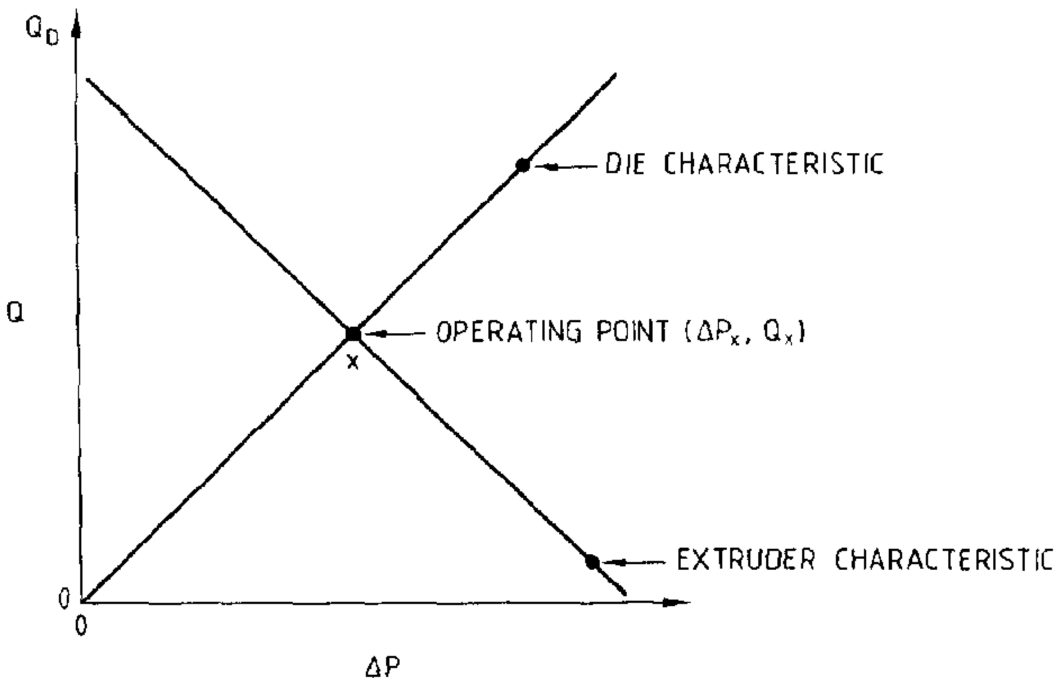

Figure 5: The Operating Point is the Intersection of the Extruder Characteristic and the Die Characteristic.

Single-Screw Extrusion
EFFECT OF PROCESS VARIABLES

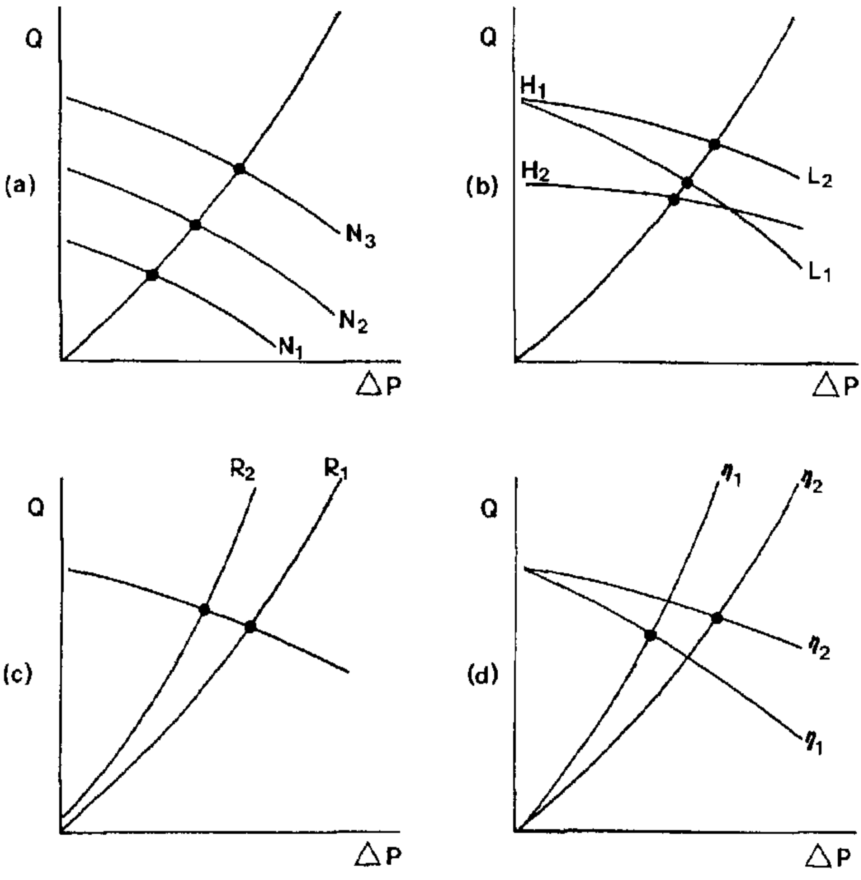

Figure 6: (a) Effect of Screw Speed ($N_3 > N_2 > N_1$).
(b) Effect of Screw Channel Depth ($H_1 > H_2$)
and Metering Section Length ($L_2 > L_1$).
(c) Effect of Die Radius ($R_2 > R_1$).
(d) Effect of Viscosity ($\eta_2 > \eta_1$).