Comments on a Proposed Mechanism of the Departure from Steady Laminar Flow in Molten Polymers

It has been suggested[1] that the departure from steady laminar flow in the extrusion of molten polymers at high stress may not be the result of melt fracture as is now widely believed[2-4] but might, rather, arise from a tendency of flow at high stress to leave a stagnant layer of finite thickness at the tube wall, which periodically breaks down. This stagnant layer is supposed to form when the condition

$$(\partial F_D/\partial D)_{Q_D} \geqslant 0$$

is met, where F_D is the extruding force per unit length of tube impressed within diameter D, at constant Q_D, the throughput inside the diameter D. The condition that F_D decreases with decreasing diameter is met in steady laminar flow when $n(\tau_D) = [d \ln (32Q_D/\pi_D{}^3)/(d \ln \tau_D)] \geqslant 3$, where $\tau_D = F_D/\pi D$ is the shear stress at diameter D. In fact, $n(\tau_D)$ does appear to be approaching 3 as the stress is raised toward the onset of the nonsteady flow in the few systems for which published data exist.

We wish to point out that the change in sign of $(\partial F_D/\partial_D)_{Q_D}$ at $n = 3$ is not accompanied in steady laminar flow by any singular behavior of the pressure drop per unit length, P, which always rises with decreasing diameter at constant throughput. Thus, $(\partial P/\partial_D)_{Q_D} = (P/D)[\partial \ln (4\pi_D/D)/(\partial \ln D)]_{Q_D} = -(P/D)[1 + 3/n(\tau_D)] < 0$ for all positive n, where $P = 4F_D/\pi D^2 = 4\tau_D/D$. As a direct consequence, both the rate of energy dissipation in the flowing polymer per unit length, $\dot{E}_D = PQ_D$, and the shear stress on the fluid in the proposed stagnant layer would be greater than in a steady laminar flow with the same throughput, utilizing the entire cross section of the tube. We can see no reason to suppose that flow involving a finite stagnant layer would tend to establish itself in the face of these opposing factors and suggest that the explanation of the breakdown of steady laminar flow must be sought elsewhere, e.g. in melt fracture.

References

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