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

In a previous Note Tordella and Wilkins[1] commented on a criterion for unstable flow of non-Newtonian liquids published in this journal.[2]

We stated that a stationary laminar flow through a circular tube becomes unstable when the total driving force per unit length F required for a volumetric flow rate Q decreases in consequence of a reduction of the tube radius R; that is, when

$$(\partial F/\partial R)_Q \geqslant 0 \tag{1}$$

Experiments made by Bagley with linear and branched polyethylene confirm the criterion rather well, as we showed.[2]

Tordella and Wilkins point out that a stagnant liquid layer of finite thickness at the wall, suggested by the illustration in our paper,[2] is improbable, if not impossible.

We agree with this view.

However, such a stagnant layer is not a necessary consequence of our stability criterion—nor was it meant to be more than an illustration (apparently incorrect) of what might happen if inequality (1) were fulfilled.

We believe that the basic idea, that of proposing a stability criterion that at least seems logical and leads to results that are acceptable, still has value as a working hypothesis, so long as it is not disproved.

In my opinion the main feature of the criterion is that it suggests a macroscopic instability and not an instability in a point in space.

The extreme regularity of the extrudate distortions suggests that the flow as a whole is unstable but that there remains complete order in the extrudate. In other words, the flow in the capillary remains laminar, but the flow lines are not straight. We have made flow lines visible in an extremely regularly waved polystyrene extrudate. The colored lines in the extrudate were smoothly waved, and no interruptions were noticed.

I should like to point out that flow disturbances that can be traced to entrance effects and that cause highly irregularly shaped extrudates must be considered separate from the instability initiated in the capillary, viz. the type of instability which Tordella called "land fracture."[3]

As long as the flow is steady and laminar, the sign of $(\partial F/\partial R)_Q$ can be determined from the measurements. As soon as the flow becomes nonsteady, this is not possible any more, because the assumptions on which the calculations are based are not fulfilled any more.

These assumptions are the conditions defining steady laminar flow: the velocity vector V remains constant in every point in space and over the boundary, or

$$\partial V/\partial t = 0 \tag{2}$$

The rheological properties of the liquid and the boundary condition determine the velocity profile in steady laminar flow.

Let it be supposed that for every type of flow, steady and nonsteady, the following always holds:

$$(\partial F/\partial R)_Q < 0 \tag{3}$$

Then, as soon as the rheological properties are such that for steady laminar flow a positive value of $(\partial F/\partial R)_Q$ is calculated, conditions (2) and (3) cannot be reconciled any longer. So, as a necessary consequence, condition (2) has to be dispensed with in order to comply with the prevailing condition (3).

Admittedly this is a step beyond our first statement, inequality (1), but if the onset of a nonsteady flow of polymer melts means a deviation from condition (2), we can expect circular movements, axial velocity pulsations, and nonsteady boundary conditions, i.e., slip-stick effects. Nobody would be surprised to find that such phenomena could account for what is now known as melt fracture.

On the other hand, the strictly regular character that is often observed can hardly be reconciled with the notion of fracture, which is a notoriously irregular phenomenon.

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References

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2. W. S. Overdiep and D. W. van Krevelen, *J. Appl. Polymer Sci.*, **9**, 2779 (1965).
3. J. P. Tordella, *J. Appl. Polymer Sci.*, **7**, 215 (1963).

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