COMMUNICATIONS TO THE EDITOR

On Further Correlations of Exit Pressure with Die Swell Ratio

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The purpose of this paper is to present a new correlation between the exist pressure and the die swell by the use of recent experimental data. The correlation fortifies the author's earlier contention (*1, 2*) that the exit pressure is a manifestation of the elastic behavior of viscoelastic fluids.

It has been believed for a long time that the die swell phenomenon is a manifestation of the elastic behavior which is typical of viscoelastic fluids. Many researchers (*3* to *8*) have attempted to correlate die swell measurements with other elastic properties, for instance, with the normal stress difference (*3, 4*). It has also been reported in the literature (*4, 6*) that die swell ratio decreases as the melt temperature is increased. This implies that elastic behavior of melts becomes less pronounced as the melt temperature is increased.

Now, the plots of the exit pressure vs. shear rate are made at different temperatures, as shown in Figure 1 for high density polyethylene and in Figure 2 for polypropylene. It is seen that the exit pressure decreases as the melt temperature is increased, for both polyethylene and polypropylene melts. This result is indeed as expected, based on the author's earlier contention (*1, 2*). It is to be noted that the measurements were taken with a capillary length-to-diameter (L/D) ratio of 20, the capillary diameter being 0.125 in. The L/D ratio of 20 is believed to be sufficiently large for the attainment of fully developed flow, at least for the materials investigated (*7*).

Several years ago Vinogradov and Prozoroskaya (*8*) reported that the plots of die swell ratio vs. shear stress for polypropylene melts yielded a single curve, independent of melt temperature. Recently, Graessley et al. (*9*) also reported that they obtained a similar correlation from their die swell measurements of polystyrene melts.

At this point, a natural attempt would be to plot the exit pressure against shear stress. In Figure 3 are shown the plots of the exit pressure vs. shear stress for poly-

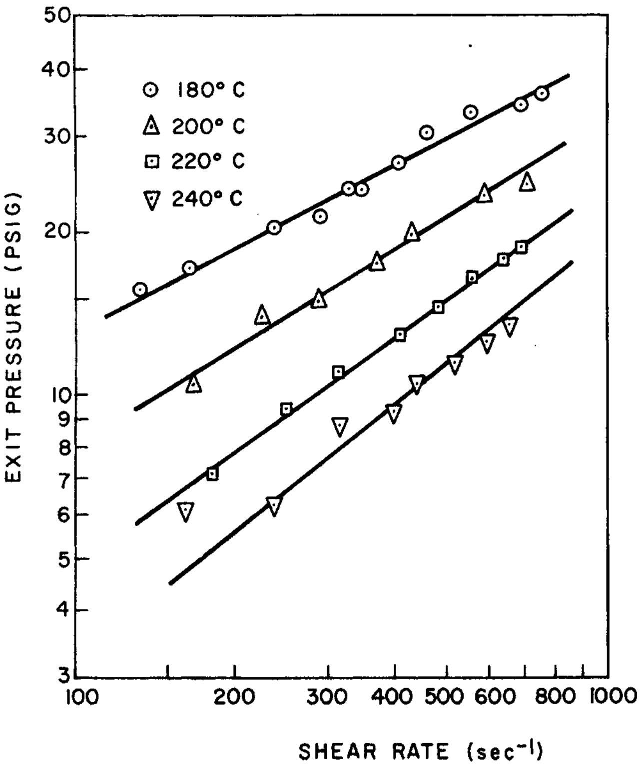

Fig. 1. Exit pressure vs. shear rate for high density polyethylene at temperatures 180°, 200°, 220°, and 240°C.

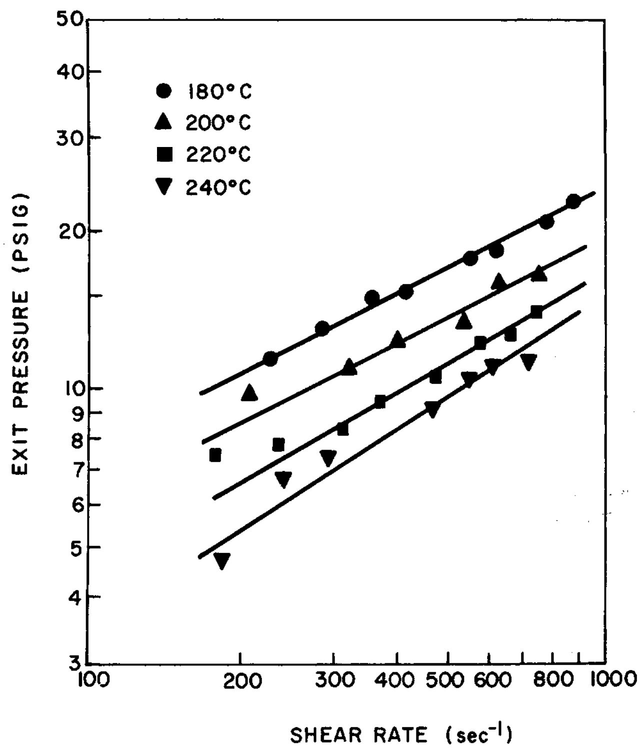

Fig. 2. Exit pressure vs. shear rate for polypropylene at temperatures 180°, 200°, 220°, and 240°C.

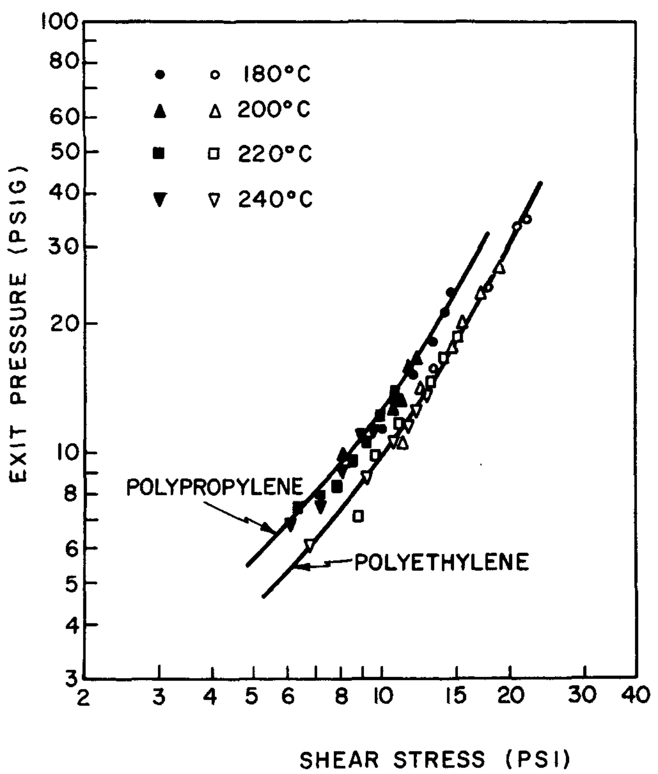

Fig. 3. Exit pressure vs. shear stress for high density polyethylene and polypropylene, respectively, at temperatures 180°, 200°, 220°, and 240°C.

ethylene and polypropylene melts, at four different temperatures. A closer examination of the plot in Figure 3 yields some very interesting observations: the exit pressures of polypropylene melts are consistently higher than those of polyethylene melts in the whole range of shear stresses investigated, and the ratio of the polypropylene exit pressures to the polyethylene exit pressures is about 1.28, which is independent of shear stress and melt temperature as well. Since the exit pressure is approximately equal to the primary normal stress difference (*1, 2*), at least in the case of polymer melts, one might say from the results in Figure 3 that the polypropylene melt is about 28% more elastic than the polyethylene melt.

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Experimental Measurements of Loss Coefficients in the Entrance Region of a Pipe for Viscous Power Law and Viscoelastic Fluids

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When a viscous fluid enters a pipe through an abrupt contraction, its velocity profile undergoes a change from its initial entrance form, usually assumed to be flat, to that of a fully developed profile at an axial position far downstream. The development of the boundary layer in the entrance region causes the acceleration of the central core of the fluid, and the high velocity gradient at the pipe wall results in a greater viscous dissipation than in the fully developed region. The losses in the entrance region are usually reported as a loss coefficient which is the sum of the increase in kinetic energy of the fluid and the increase in viscous frictional losses in excess of the losses that would have existed for fully developed flow. This loss coefficient, expressed as an equivalent number of velocity heads, is a function of the axial distance from the tube entrance and reaches an asymptotic value as the flow becomes fully developed.

Application of the mechanical energy balance for a viscous power law fluid between a station 1, immediately downstream of the contraction where the velocity profile is assumed to be flat, and a station 2, in the fully developed region (Figure 1) yields

$$\frac{p_1 - p_2}{\frac{\rho V^2}{2}} = \frac{32\ X/R}{N_{Re'}} + C \tag{1}$$

where

$$N_{Re'} = \frac{D^n\ V^{2-n}\ \rho}{k\ 8^{n-1}\left(\frac{3n+1}{4n}\right)^n} \tag{2}$$

$$C = \frac{\Delta p_{EX}}{\frac{\rho V^2}{2}} + \frac{3(3n+1)^2}{(2n+1)(5n+3)} - 1 \tag{3}$$

and Δp_{EX} is the frictional loss over and above the fully developed loss. Schmidt and Zelden (*1*) have summarized the theoretical and experimental values of C obtained by different investigators for Newtonian fluids. Astarita and Greco (*2*) have suggested a value of $C = 4.48$ for a Newtonian fluid in the entrance of a pipe from an abrupt contraction. This value is far greater than any of the previously published values which range from 1.0 to 1.41.

Theoretical values for C as a function of n for power law fluids have been presented by Bogue (*3*) and Collins and Schowalter (*4*). Both analyses assumed a flat entry profile in solution of the boundary-layer equations, and both compared their pressure drop predictions with the data of Dodge (*4*). Good agreement was obtained, yet the available experimental data for C as a function of n as summarized by Skelland (*5*) do not agree with either the predicted results of Bogue or of Collins and Schowalter.

For a viscoelastic fluid, the influence of the deviatoric