Turbulent Drag Reduction in Fiber-Polymer Systems: Specificity Considerations

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Several unusual drag reduction effects were recently reported by Lee, Vaseleski, and Metzner (1974) in systems containing both suspended fibers and dissolved polymer: unusually high levels of drag reduction (up to 95%), an apparently decreased sensitivity to polymer degradation and, most importantly, a shift in the drag reduction—friction velocity curves in that high levels of drag reduction were obtained at far lower values of the friction velocity than typical of systems containing polymer alone. This last fact is of primary importance in almost all industrial applications involving internal flows in systems of large scale since these take place at far lower levels of velocity than those usually studied in laboratory experiments. This first presentation of results for mixed systems was limited to a small number of polymer-fiber combinations and the generality of the results observed was therefore left uncertain. This note provides for an incremental addition to the previous results.

EXPERIMENT

Nylon fibers having an aspect ratio of 350 and a length of 2 mm were suspended in a 0.25% aqueous solution of aerosol OT, surfactant. A fiber concentration of 800 ppm. by weight was employed. The polymer used was WSR-301 polyethylene oxide at a concentration level of 100 ppm. Viscometric properties of the test fluids used as obtained with a capillary tube viscometer are given in Table 1. The density of all systems was essentially that of water. The test loop used and the experimental procedure was the same as reported before by Vaseleski (1973).

TABLE 1. VISCOUS PROPERTIES OF FLUIDS

	Fluid	Viscosity, centipoise
(i)	Water, 66°F.	1.01
(ii)	Aerosol solution, 73°F.	1.08
(iii)	Polymer solution, 78°F.	1.00
(iv)	Nylon fiber suspension, 78°F.	1.31
(v)	Mixed system, 78°F.	1.33

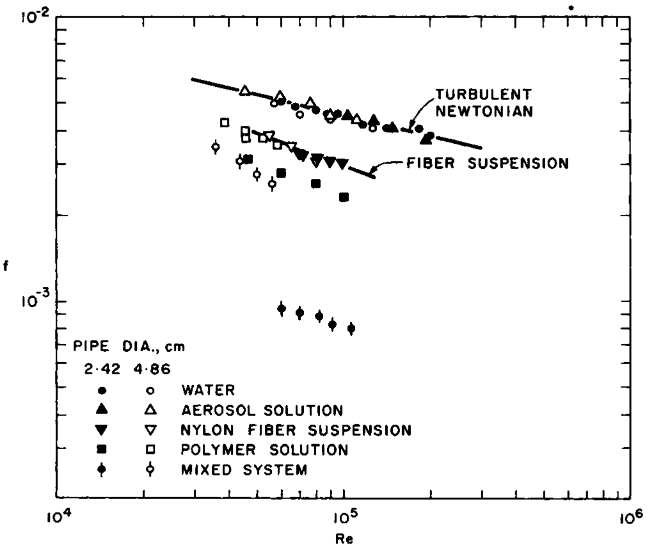

Fig. 1. Friction factor-Reynolds number results for all systems studied. "Mixed system" refers to 800 ppm of fibers with surfactant suspended in a 100 ppm polymer solution.

RESULTS

Figure 1 shows, as noted by Vaseleski and Metzner (1974), that there are no discernable diameter effects exhibited by the suspension of fibers although the usual strong dependence is present in the polymeric system. Figure 2 shows the actual percentage reduction in drag or pressure drop, at a given flow rate, plotted versus the friction velocity of the additive-free system.

These results are generally similar to those reported earlier for the other mixed systems studied. In total we now have results for two polymeric species (polyethylene oxide and polyacrylamide—the latter both with and without added surfactant, the former with surfactant) and two different fiber compositions having four aspect ratios: nylon fibers having aspect ratios of 100 (no surfactant) and 350 (with surfactant) and asbestos fibers, (with surfactant) having approximate aspect ratios of 10^3 and 4×10^4. We conclude, therefore, that the unusual and superior drag reduction characteristics of mixed polymer-fiber systems are not merely specific to one or two fortuitous formulations but represent a general phenomenon.

ACKNOWLEDGMENT

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NOTATION

D = internal diameter of pipe

f = Fanning friction factor defined as $\tau_w \Big/ \frac{1}{2}\rho u^2$

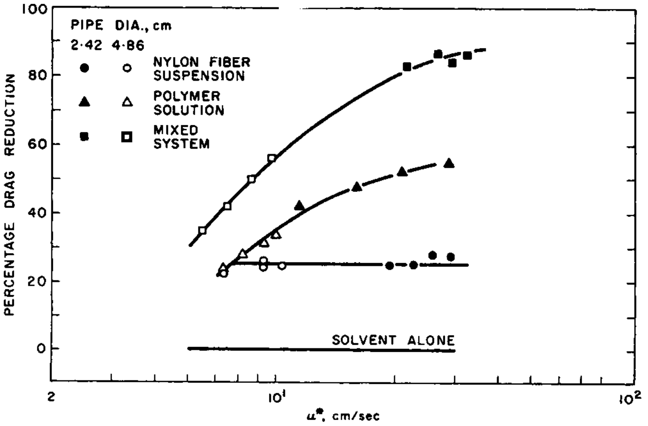

Fig. 2. Drag reduction as a function of friction velocity (flow rate).

$\Delta P/L$ = pressure drop per unit length
Re = Reynolds number defined as $Du\rho/\mu$
τ_w = wall shear stress defined as $\dfrac{D\Delta p}{4L}$
u = average velocity
u^* = friction velocity $\sqrt{\tau_w/\rho}$
ρ = density of the fluid mixture
μ = viscosity of the fluid mixture

LITERATURE CITED

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On Size-Dependent Crystal Growth Rates

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Several recent papers (Canning and Randolph, 1967; Abegg et al., 1968; Estrin et al., 1969) have contained expressions for size-dependent crystal growth rate which are used to describe the particle size distributions produced in a continuous mixed-suspension, mixed-product-removal (CMSMPR) crystallizer operating at steady state. These studies involved the use of population balance methods (Randolph and Larson, 1962) to treat experimental distributions which were not in accord with growth behavior suggested by McCabe's ΔL law (McCabe and Stevens, 1951). The paper by Abegg et al. (1968) lists the conditions necessary for the incorporation of a number of growth models into the population balance equation. These empirical growth rate expressions, however, are not related to specific crystal growth mechanisms.

In a suspension crystallizer, crystal growth is generally considered to involve three basic steps (Hixson and Knox, 1951), namely, diffusion of solute to the solid-liquid interface, followed by surface integration at the crystal surface and diffusion of heat of crystallization away from the interface. The effects of the third step on the overall growth processes are considered to be small in most systems exhibiting relatively low heats of crystallization. Lieb and Osmers (1973) recently studied the effects of diffusion and surface integration on the crystal size distribution in a CMSMPR crystallizer. They developed several mathematical growth rate models which reflect different mechanisms of diffusion and interfacial kinetics. The functional form of the growth rate expression was constrained by the requirement that the third moment of the distribution must converge. Their results showed that, under certain conditions, the size distribution may be greatly altered from the classic straight-line plot of logarithm of the particle density function versus particle size. In particular, a maximum exists in the distribution at a finite particle size when diffusion is dominant.

Recently, a rather unusual type of growth behavior has been obtained experimentally for ammonium sulfate and potassium sulfate crystals (Randolph and Cise, 1972; Youngquist and Randolph, 1972) which indicates that the growth rate of very tiny crystals is small but increases rapidly with size. Sikdar and Randolph (1974) observed the same phenomenon for magnesium sulfate heptahydrate crystals and indicated that such a size-dependent growth behavior for very tiny crystals cannot be described meaningfully by a slip velocity model as suggested by Rosen (1974). Neither can this behavior be explained by conventional diffusion and/or interfacial kinetics mechanisms (Lieb and Osmers, 1973). However, work by Wey and Estrin (1972), which takes into account the surface curvature effect (change of solubility with particle size), shows that the growth rate of small particles may indeed be a strongly increasing function of size. In this note, we (1) present a growth rate expression which includes the influence of surface curvature as well as those of diffusion and interfacial kinetics, and (2) study the effects of surface curvature on the behavior of the crystal size distribution in a CMSMPR crystallizer.

A description of the growth rate, which involves both diffusion and first-order interfacial kinetics, can be given by (Lieb and Osmers, 1973)

$$G = \frac{C_b - C_0}{\dfrac{1}{K_I} + \dfrac{\rho L}{D}} \tag{1}$$

The effect of surface curvature on the solubility of crystals in suspension is well known. The solubility of a newly formed nucleus is not the bulk solubility generally found in solubility tables but is a somewhat higher value expressed by the Gibbs-Thomson equation (Mullin, 1972). Therefore, in a given environment, the driving force for