Impact Tube Measurements in Dilute Polymer Solutions

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It has been reported (*1* to *3*) that considerable difficulties may be experienced in the measurement of velocity profiles in dilute polymer solutions with conventional impact tubes used, particularly if the calibration is based on Newtonian flows. Discharge computations based on integration of the velocity profiles so obtained do not necessarily agree with the flow discharge as determined by other methods. As measurement of the velocity profile in the boundary layer is desirable for further understanding of the basic mechanism of drag reduction with dilute polymer solutions, brief series of tests were initiated to determine the effect of these solutions on impact tube measurements.

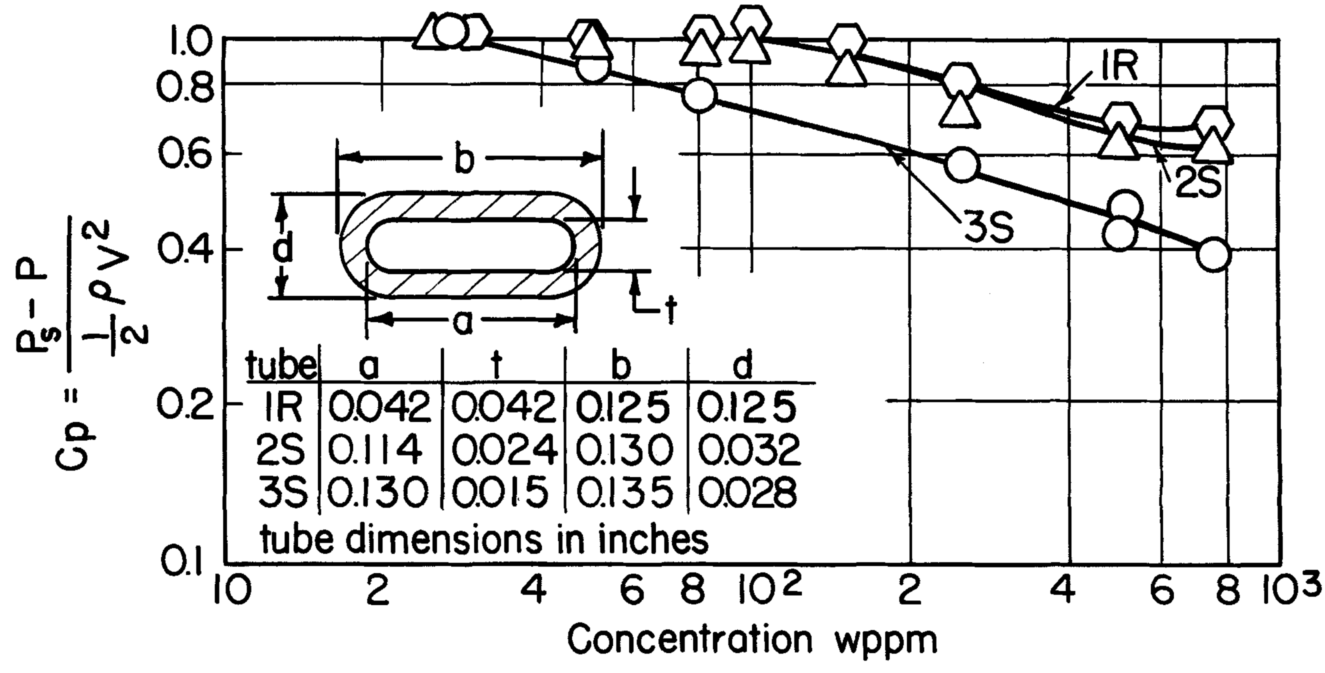
Impact tube corrections in Newtonian flow have been extensively discussed in the literature (*4*). It is known that corrections for a given tube geometry arise from viscous effects at low Reynolds numbers, from steep velocity gradients, and from turbulence. The particular correction to be discussed here for dilute polymer solutions is independent of the above-mentioned effects and is apparently associated with the viscoelastic properties of the fluid.

To permit accurate determination of the test velocity, the impact tubes were towed by the laboratory towing facility in a small tank specially fabricated to reduce the quantity of polymer additive required. The tank was 5 in. wide, 4 in. deep, and 180 ft. long, and was filled to a depth of 3½ in. for all tests. Three different impact tubes were selected: two square-ended flattened tubes and one with a hemispherical nose. Pertinent dimensions of the tubes are given in Figure 1. The dynamic pressure was measured with a Statham pressure transducer attached to the liquid filled tubes. Transducers with one and 4 lb./sq.in. ranges were used; the particular choice was dictated by the towing velocity. The towing velocity was varied from one to 16 ft./sec. From observations of the recorded pressure, the length of the test run was adequate to ensure the attainment of steady state conditions.

Polyethylene oxide (Polyox WSR-301, Union Carbide) was selected as the polymer additive. Dilute solutions of Polyox have been shown to exhibit remarkable drag reducing properties, and as a result these solutions have been subjected to rather extensive investigation (*5*, *6*). Concentrations of Polyox varying from 0 to 750 wt. p.p.m. were carefully mixed in tap water with a minimum of mechanical agitation. The temperature of the solutions was not controlled. Temperatures between 65° and 77°F. were noted, although repeat tests at different solution temperatures did not indicate any significant differences in the measured pressures.

It is well known that solutions of high molecular weight polymers, such as Polyox, are susceptible to mechanical degradation due to exposure to high shear rates (*5*, *6*). The viscosity of dilute polymer solutions may also change significantly during storage in a tank. To ensure that the test solution had not changed its properties, samples were taken after every series of tests and compared with freshly mixed solutions in a blowdown capillary tube apparatus. No change in solution properties was observed for the reported tests.

The results of the investigation are presented in Figure 1. The ordinate is the pressure coefficient, $C_p = (P_s - P)/\frac{1}{2}\rho V^2$, where P_s is stagnation pressure, P is static pressure, ρ is fluid density, and V is velocity. The differ-



tube	a	t	b	d
1R	0.042	0.042	0.125	0.125
2S	0.114	0.024	0.130	0.032
3S	0.130	0.015	0.135	0.028

tube dimensions in inches

Fig. 1. Influence of aqueous Polyox solutions on impact tube measurements.

ence between the stagnation and static pressure was measured directly with the pressure transducer. (The static pressure was the submergence of the tube, 1.5 in.) For the range of velocities used in the program, the pressure coefficient was independent of velocity. It is apparent from Figure 1 that as the concentration of the polymer is increased beyond a certain value, the sensitivity of the impact tube is drastically decreased. This effect is more pronounced for the smaller flattened tube, 3S, as reduction in the pressure coefficient is noted for concentrations greater than 25 wt. p.p.m. For the larger flattened tube, 2S, reduction is not noted until the concentration exceeds 100 wt. p.p.m. The response of the tube with a hemispherical head, 1R, was essentially the same as that of the larger flattened tube. It is felt that the effect noted here is not due to purely viscous effects, as the trend is in the opposite direction from that previously reported (*4*) for viscous Newtonian fluids. Also, the apparent viscosities of the aqueous polymer solutions were not greatly different from water.

The results indicate that extreme caution must be exercised in utilization of impact tubes in the measurement of velocity in polymer solutions. More extensive investigations should be carried out to clarify further the observed phenomenon.

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Dufour Effect in Liquid Systems

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The interaction between thermal and mass fluxes has long been recognized. Much effort has been devoted to the study of thermal diffusion (*6, 7, 8*). Its practical importance has been highlighted by the successful application of a thermal diffusion (Soret effect) process to the purification of uranium isotopes (*5*). Yet little or no attention has been paid to its counterpart, the Dufour effect, which represents the contribution to the energy transfer resulting from the mass fluxes. This is especially true for liquid systems. Statements have appeared repeatedly in the literature (*1, 10*) that the Dufour effect in liquid systems is usually assumed to be of minor importance. Unfortunately, these statements which were based only on a few experiments with binary systems, tended to discourage any real attempt to investigate the nature of such a phenomenon.

A recent study (*3*) of the general problem of nonisothermal multicomponent diffusion in the liquid phase has revealed that a significant Dufour effect may accompany diffusion in a liquid phase. A brief summary of this finding is given here.

FLUX REPRESENTATION

The general formulation of the nonisothermal diffusion problem is available elsewhere (*3*). Thus, only the resulting equations pertaining to the present discussion will be presented below.

For a multicomponent system, the unidirectional flux equations for the mass and heat transfer may be combined in a single form as

$$j_\alpha = -\sum_{i=1}^{n} D_{\alpha i} \frac{\partial \tau_i}{\partial x} \quad \alpha = 1,2, \ldots n-1, n \tag{1}$$

The indices 1 to $(n-1)$ designate the $(n-1)$ independent mass concentrations and fluxes while the index n refers to the thermal components (that is, $\rho C_p T$ and heat flux). If the transport process is restricted to a semi-infinite medium with fixed concentrations and temperature at its boundary, and constant physical properties and transport coefficients, then the diffusion equations can be uncoupled and solved using a linear transformation (*9*) as

$$\sum_{i=1}^{n} D_{\alpha i}\, Q_{i\beta} = \lambda_\beta\, Q_{\alpha\beta} \tag{2}$$

In Equation (2), the $Q_{\alpha\beta}$ are elements of a real matrix which diagonalizes the matrix of transport coefficients (*3*), and the λ_β are the positive real eigenvalues. The

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