Fig. 1. Radial migration inwards (curve 1) and outwards (curves 2 and 3) to the equilibrium position $r/R = 1/2$ approximately, exhibited by spheres, rods and disks at high Re_p ($> 10^{-5}$) when suspended in polyglycol oils flowing through a tube $R = 0.2$ cm. The curves are: (1) polystyrene disk of radius 0.034 cm having an initial orbit constant $C = 5.0$, the numbers in parentheses indicating the decrease in C with radial distance and time; (2) polystyrene sphere of radius 0.050 cm; (3) nylon rod of length 0.11 cm. The steady inward migration to the tube centre of a glycerol drop in a polyglycol oil mixture, viscosity ratio suspended phase/suspending phase = 10, is shown by curve 4
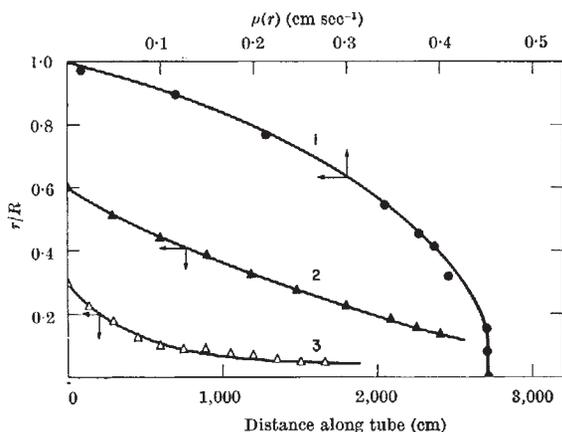

Fig. 2. Inward radial migration of 'Plexiglass' spheres in viscoelastic fluids flowing through a tube $R = 0.3$ cm at low Re_p ($< 10^{-4}$). Curve 1 shows the velocity profile, blunted near the tube centre, of a 6 per cent by weight solution of polyisobutylene in 'Decalin'. The inward migration to the central region of no shear of spheres of radii 0.016 and 0.021 cm suspended in the same solution is shown by curves 2 and 3 respectively

fixed at their initial values[4]. The drift in C and r at higher Re_p presumably are related effects due to inertia[6].

In striking contrast to rigid particles, liquid drops and elastomer filaments, which were deformed by the shear field in the tube, migrated inwards to $r = 0$ just as they did at low Re_p (refs. 3, 4). This behaviour was shown by liquid drops having a viscosity as high as 10 times that of the suspending medium (Fig. 1). When the ratio reached 50, and the drop deformation appeared negligible, the behaviour was as for rigid spheres, that is, no migration at low Re_p and migration to $r/R = 1/2$ at high Re_p. Thus the migration due to deformation[3,4] can dominate that due to inertia, and vice versa.

Inward migration of rigid particles occurred in the viscoelastic fluids at low Re_p ($< 10^{-6}$). Solutions of 3–6.3 weight per cent polyisobutylene ('Vistanex L-100', Enjay Chemical Co.) in decahydronaphthalene ('Decalin'), which have been well characterized rheologically[7], were used as the medium. As expected from the decrease in apparent viscosity with increasing rate of shear, the velocity profile $u(r)$ across the tube, instead of being parabolic as with the Newtonian liquids, was blunted in the central regions (Fig. 2). Rigid spheres, rods and disks placed near the wall rotated and migrated inwards to radial

positions at which the velocity profile was nearly flat (Fig. 2). The rate of migration increased with r and particle size. During migration, rods and disks drifted into rotational orbits corresponding to $C = 0$ and ∞ respectively; these orbits correspond to minimum energy dissipation in Couette flow and are in agreement with Saffman's theoretical prediction and observations for rigid spheroids in a non-Newtonian fluid of the type used[6]. Particles in the flat portion of the profile where the velocity gradient was zero, neither rotated nor moved radially. The particle migration observed in these experiments may arise from the combined action of normal stresses in the fluid and the variation in velocity gradient across the particle.

These experiments reveal three distinct mechanisms for radial migration during the flow of suspensions through tubes of which only one, that due to deformation at low Re_p, has been explained with any degree of completeness[1]. It is possible that there are additional mechanisms, especially at concentrations at which appreciable particle interaction can occur. These phenomena are of interest in connexion with the development of particle-free peripheral zones in the flow of various suspensions such as pulp fibre suspensions and blood through tubes.

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Secondary Electron Emission of Evaporated Titanium Films

IN our recent communication[1] we attributed the different secondary emission characteristics of oxidized titanium sheet and oxidized titanium films to the irregular surface on the sheet material influencing the incidence of the primary electron beam. However, we incorrectly stated that raising the incident angle of a primary electron beam should lower the value of the primary electron energy at which the secondary electron emission coefficient of a target reaches a maximum value. In fact the reverse is true, that is, raising the incident angle should increase the value of V_{max} (ref. 2). Our experimental results are not affected by this error, but the relation between the V_{max} for the oxidized titanium sheet and titanium films cannot be attributed to incidence.

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