Abstract

Measurements of the velocity characteristics of four concentrations of a weakly elastic shear-thinning polymer (sodium carboxymethyl cellulose), water and a viscous Newtonian fluid have been obtained by laser-Doppler velocimetry in a fully developed pipe flow encompassing a range of Reynolds numbers from 240 to 111,000, together with measurements of wall pressure by a differential pressure transducer. The results quantify the delay in transition from laminar to turbulent flow caused by shear-thinning, the suppression of turbulent fluctuations particularly in the radial and tangential components of Reynolds normal stress and the drag reduction at the higher Reynolds numbers. They also confirm that the maximum drag reduction asymptote and the ultimate velocity profile are appropriate to these shear-thinning solutions.

Similar measurements have been made in the flow around a disc baffle with 50 % blockage in a descending vertical pipe. At Reynolds numbers below 50,000 the mean flow results showed a decrease of the length of the recirculation bubble, as the Reynolds number is reduced for Newtonian fluids and each of the polymer solutions, whereas it increases with the increase in polymer concentration. With the Newtonian fluids, the turbulence was anisotropic with the axial normal stress twice as large as the radial and tangential normal stresses, and the maximum turbulent kinetic energy remained constant when the Reynolds number varied between 138,000 and 8,200 whereas with the increase in polymer concentration all normal Reynolds stresses were reduced, especially in the radial and tangential directions. For example, the maximum turbulent kinetic energy of a 0.2% by weight polymer solution at Reynolds numbers of 22,700 and 8,250 was 25 and 35 % lower than the corresponding values for a Newtonian fluid at the same Reynolds number. Non- Newtonian effects were seen to be important in regions of low strain rate of low Reynolds number flows so that, in the plane at the middle of the bubble (1.0D) inside the recirculation region and close to the shear layer, the ratio of average viscosity diffusion to turbulent diffusion between water and 0.4% CMC flows at maximum flow rate increased from under 0.5% to about 30% respectively, corresponding to a variation of 0.1 to 6% in the contribution of viscous diffusion to the pressure gradient, the largest term of the axial momentum balance.

Over a range of Reynolds numbers between 400 and 6,000 the flow was asymmetric and unsteady, an aerodynamic effect, and periodic oscillations of the instantaneous axial velocity were recorded within the recirculation region and defined a Strouhal number between 0.094 for Newtonian fluids and 0.07 with the 0.4 % by weight polymer solution. With the more concentrated polymer solutions the asymmetry and unsteadiness of the flow was preserved at Reynolds numbers higher than 6,000 in a manner reminiscent of the delay in transition observed in the pipe flow experiments.