Shear-thinning duct flow characteristics of relevance to stirred reactors

F. T. Pinho* and J. H. Whitelaw
Department of Mechanical Engineering, Imperial College of Science, Technology and Medicine, London SW7 2BX, England

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Improvements in the performance of stirred reactors operating with non-Newtonian fluids under turbulent flow conditions require detailed knowledge of their fluid-mechanic properties. The complexity of stirred vessel flows, the large variety of flow configurations, and possible non-Newtonian fluids indicate that such an undertaking should be preceded by an investigation aimed at selecting the fluids and to assess transitional Reynolds number and non-Newtonian effects in the flows with characteristics of relevance to the process of stirring tanks. Mean and turbulent velocity characteristics of the flow of aqueous solutions of CMC (carboxymethyl cellulose) in a 25.4 mm diam duct, with and without a 50% area blockage disk located on its axis, were measured with a laser velocimeter. The polymer solutions at concentrations of 0.1% to 0.4% by weight were weakly elastic and shear-thinning. Water and a viscous Newtonian fluid were also investigated for comparison. The pipe flow measurements encompassing a range of Reynolds numbers from 240 to 111 000 quantify the delay in transition from laminar to turbulent flow caused by shear-thinning, the suppression of turbulence fluctuations particularly in the radial and tangential directions, and the reduction in the drag coefficient. The baffle flow of Newtonian and non-Newtonian fluids was increasingly dependent on Reynolds numbers below 50 000 with the dampening of the normal Reynolds stresses also dependent on polymer concentration. At a Reynolds number 8000, the maximum values of turbulent kinetic energy with the 0.2% CMS and 0.4% CMC solutions were 35% and 45% lower than for water, respectively. Non-Newtonian effects are important in regions of low strain rates at low Reynolds numbers, and are represented by a decrease of turbulent diffusion and an increase of viscous diffusion, which would be enlarged by the effect of the elongational viscosity if higher than three times the viscometric viscosity. The performance of stirred vessel flows is likely to be impaired by the suppression of small-scale turbulence over the boundary layer of the blades and its possible early separation. A deterioration in the quality of micromixing is also likely to arise because of lower turbulence production in the shear layer of the jet emanating from the impeller. With strong shear-thinning fluids, the high viscosity in the large regions of low mean shear rate far from the impeller further contribute to turbulence suppression so that laminarizations of the flow may occur. However, the strong three-dimensionality of the mixer flow means that turbulence damping will occur for all Reynolds stresses rather than in preferential directions.

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