LDA measurements of non-Newtonian liquids in pipe flow

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Summary   In this paper we report measurements of mean and fluctuating axial velocities, measured using a laser Doppler anemometer, for a 0.125% solution of a polyacrylamide, Separan AP 273 E, in fully-developed pipe flow. Although the results cover the laminar, transitional and fully turbulent regime, particular attention is placed on the transition regime, where, as has been observed previously, the mean velocity profiles exhibit a stable, and repeatable, asymmetry. Radial distributions of axial velocity at three axial locations, for various azimuthal angles, highlight the three dimensional nature of this asymmetry.

Introduction   In the last decade considerable advances have been made in understanding the transition mechanism from laminar to turbulent flow for Newtonian liquids in pipes. For non-Newtonian liquids however, perhaps unsurprisingly given the inherent additional complexities involved, little is known. Aside from a handful of papers there is virtually no data about the transitional flow of such non-Newtonian liquids. Although limited, the existing literature for the transitional pipe-flow of non-Newtonian liquids reveals an interesting, and as yet unexplained, effect: above a certain Reynolds number the flow develops a stable asymmetry. For laminar and fully turbulent flows the profiles are symmetric. Independent observations of the same stable asymmetry have been observed in the UK, France and Australia. We have jointly published these, and additional, observations recently (Escudier et al (2005)) to highlight the effect. In the current paper we extend these results by recording the three-dimensional structure of such asymmetrical velocity profiles.

Results and Discussion The axial velocity profiles shown in **Figure 1** cover a range of Reynolds numbers which span the three flow regimes i.e. laminar, transitional and fully turbulent. The Reynolds number is based on a wall shear viscosity μ_w determined from a Carreau-Yasuda model fit at a shear stress estimated from pressure drop measurements. Also included in **Figure 1(a)** are reference curves corresponding to an average of the velocity data on either side of the centreline. Below the velocity profiles, in **Figure 1 (b)**, is the variation of the near-wall (r/R = 0.8) axial-velocity fluctuation level u′ (rms) which Escudier and Presti (1996) showed is a reliable indicator of the flow regime. At the lowest Re the flow is laminar and the profile symmetric. As Re is increased a progressive asymmetry develops. In agreement with previous observations (Escudier et al (2005)), a return to symmetric flow is observed at higher Reynolds numbers.
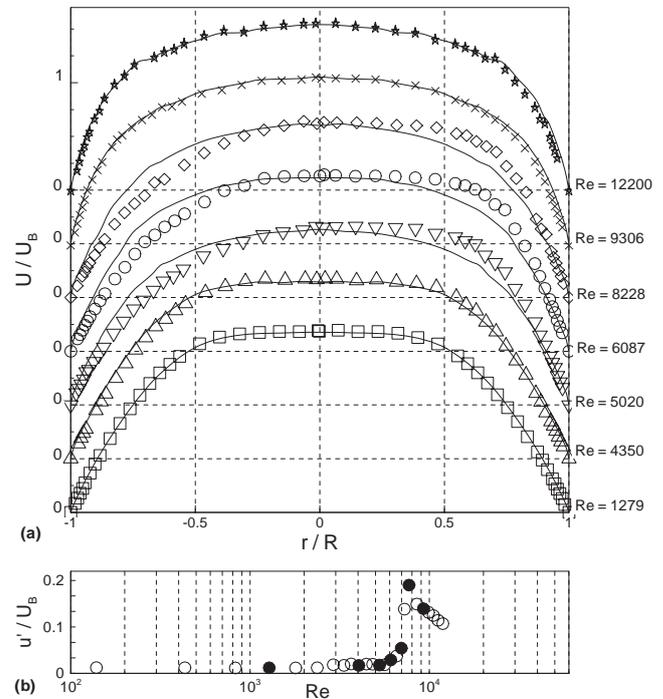

Fig. 1 (a) Mean velocity profiles for 0.125% PAA (including average data line) **(b)** Velocity fluctuation levels at r/R =0.8 to indicate transition.

Radial distributions of axial velocity were also obtained for various azimuthal angles for a profile exhibiting a high degree of asymmetry (Re=8230). In addition, profiles close to the pipe inlet confirm that the inlet profiles are essentially symmetric and that the asymmetry develops and grows with axial distance.

Conclusions   We have reported LDA axial velocity measurements for a shear-thinning, viscoelastic polymer solution (polyacrylamide) flowing through a pipe. Our results cover the laminar, transitional and fully turbulent regimes. In the transitional regime, as has been observed previously, the mean velocity profiles exhibit a stable, and repeatable, asymmetry. Radial distributions of mean axial velocity for various azimuthal angles highlight the three dimensional nature of this asymmetry. Profiles taken at various axial locations confirm that the inlet flow is essentially symmetric and show the progressive nature of the effect.

Reference
[1] M P Escudier, R J Poole, F Presti, C Dales, C Nouar, C Desaubry, L Graham and L Pullum (2005), J Non-Newt Fluid Mech. 127 p143.