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FULLY DEVELOPED TURBULENT FLOW OF NON-NEWTONIAN LIQUIDS THROUGH A SQUARE DUCT

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ABSTRACT

The results are reported of an experimental investigation of fully developed turbulent flow through an 80mm x 80mm duct of water and of two shear-thinning polymers, an aqueous solution of 0.1% carboxymethylcellulose + 0.1% xanthan gum (CMC/XG) and a 0.125% aqueous solution of polyacrylamide (PAA). The more elastic PAA leads to drag-reduction levels up to 77% compared with 65% for CMC/XG. It is well established (e.g. Nikuradse (1930), Melling and Whitelaw (1976) that contours of mean axial velocity are a good indicator of the strength of the turbulence-induced secondary flow. We find that for water the contours away from the walls and the channel centre bulge towards the corners as a consequence of the transport of fluid with high axial momentum into regions where the momentum would otherwise be low. For CMC/XG this tendency is much reduced and absent for PAA.

Over much of the duct cross section the contours of axial turbulence intensity $\tilde{u}_1/U_C$ for water and CMC/XG are similar to each other and to the contours for water reported by Melling and Whitelaw. In the vicinity of the duct centreline the levels for CMC/XG are slightly lower than for water and the peak $\tilde{u}_1$ values are about 0.15 U for both flows. For CMC/XG the peak values occur well away from the duct wall whereas for water the levels increase all the way to the wall. For PAA the peak $\tilde{u}_1/U_C$ values are reduced by about 50% and the tendency for the contours to push into the corners is suppressed.

Below the diagonal bisector (sector 2) the turbulence intensity $\tilde{u}_3$ corresponds to fluctuations parallel to the duct wall $(\tilde{w})$ and above the diagonal (sector 1) to fluctuations normal to the wall $(\tilde{v})$. For water the contours are again similar to those reported by Melling and Whitelaw. For all three fluids $\tilde{w} > \tilde{v}$ over most of the duct cross section. As for $\tilde{u}_1$, the peak values of $\tilde{v}$ and $\tilde{w}$ for CMC/XG and for PAA occur on the wall bisector some distance away from the duct wall whereas for water both peaks are closer to the wall. The overall turbulent kinetic energy levels are slightly reduced for CMC/XG and greatly so for PAA. The levels of anisotropy for CMC/XG and PAA are similar and much greater than for water.

For CMC/XG the $\overline{u_1 u_3}$ values are only about 40% of those for water while the levels for PAA are barely distinguishable from the background noise. For water the maximum value of $\overline{u_1 u_3}$ (in sector 2) is about 15% of that of $-\overline{u_1 u_3}$ (in sector 1) whereas for CMC/XG the ratio is closer to 0.5 and for PAA the two are of the same magnitude.