PURELY-ELASTIC INSTABILITIES IN SERPENTINE CHANNELS

R.J. Poole[1], M.A. Alves[2], J. Zilz[3], A. Lindner[3]

1 - University of Liverpool, School of Engineering, Liverpool, UK
2 - Porto University, Porto, Portugal
3 - PMMH/ESPCI, Paric, France

robpoole@liv.ac.uk

Purely-elastic instabilities, i.e. driven by elastic normal stresses in the absence of significant inertial effects, have been observed in a range of flows both viscometric and complex. It is now well known that such instabilities can arise as a consequence of the combination of elastic stresses and streamline curvature. Flow through a serpentine (or wavy) channel is one such geometry where an elastic instability has been observed experimentally [1]. Here we report the results of a combined numerical and experimental investigation to determine the variation of the critical Weissenberg number (Wi) at which the flow becomes unstable with the channel curvature.

The experiments utilize a microfluidic channel of width (side-length) either 50 μm or 100 μm and aspect ratios (width over height) between 0.5 and 3. The channel comprises a series of half loops of radius R which is systematically varied in the range $50\ \mu m < R < 1000\ \mu m$. The fluids - solutions of a high molecular weight polyethylene oxide ($M_w=10^6$ and $4x10^6$) in various glycerine/water solvents - enter the channel from two sides one of which is labelled with a fluorescent dye. The instability onset is defined via visualisations of fluctuations within the flow. In addition to the effects of channel curvature and aspect ratio, the effects of solvent viscosity, molecular weight and polymer concentration are investigated.

The numerical simulations make use of a finite-volume technique based on the log conformation formulation [2], together with the high resolution 'CUBISTA' scheme for the convective terms in the constitutive equations, to study the creeping flow ($Re = 0$) for a viscoelastic fluid obeying the upper-convected Maxwell model. Two-dimensional simulations matching the experimental conditions show that above a critical Weissenberg number the flow becomes unsteady. The scaling for this critical Wi is in good qualitative agreement with the experiments. More limited three-dimensional calculations have also been conducted and these simulations show that in this case, in agreement with linear stability predictions [3], prior to the unsteady instability a first steady instability occurs which results in a weak secondary flow.

References

[1] A. Groisman and V. Steinberg. Elastic Turbulence in curvilinear flows of polymer solutions, New J. Phys. 6, 29 (2004).
[2] R. Fattal and R. Kupferman. Constitutive laws for the matrix-logarithm of the conformation tensor, J. Non-Newt. Fluid Mech. 123 (2004) 281–285
[3] Y.L. Joo and E.S.G. Shaqfeh. A purely elastic instability in Dean and Taylor-Dean flow, Phys. Fluids, 4 (1992) 524-543.