On the origin of vortex ring formation in oscillatory pipe flow of wormlike micellar solutions

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Beyond a critical driving amplitude, the oscillatory pipe flow of wormlike micellar solutions is unstable against the formation of axisymmetric vortex rings. This instability is not driven by inertia, since the high viscosity of the solution ensures that the Reynolds number remains small. The basic parallel-shear flow, however, is markedly different from its Newtonian counterpart. If the wavelength of the shear waves launched by the periodic driving is comparable to the radius of the pipe, the flow is highly reversing. We show that this feature combines with the viscoelastic nature of the solution to render this flow unstable.

It is known that wormlike micellar solutions are shear-thinning at large strain rates. This property must be taken into account if a quantitative comparison to experiments is aimed. To this purpose we use a single-mode Giesekus equation. A simple analysis of the governing equations and numerical simulations of the base flow show that radial normal stresses diverge in this case. Using this divergence as a signature of the instability, we are able to reproduce quantitatively the instability threshold in the frequency-amplitude (or $De - Wi$) parameter space, and the amplitude dependence of the incubation periods required for the formation of vortex rings measured experimentally.