Stability of thixotropic fluids in pipe flow

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Abstract. Linear stability of a thixotropic fluid obeying the Moore model is investigated in pipe flow using a temporal stability analysis in which infinitesimally small perturbations, represented by normal modes, are superimposed on the base flow and their evolution in time is monitored in order to detect the onset of instability. An eigenvalue problem is obtained, which is solved numerically using the pseudo-spectral Chebyshev-based collocation method. The neutral instability curve is plotted as a function of the thixotropy number of the Moore model. Based on the results obtained in this work, it is concluded that the thixotropic behavior of the Moore fluid has a destabilizing effect on pipe flow.

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1. Introduction

Thixotropy appears to be a common effect among industrial fluids such as drilling muds [1-3]. Waxy crude oils are also known to exhibit thixotropic behavior at sufficiently low temperatures. The main cause of thixotropy in such complex fluid systems arises from an interaction between the fluid elements and the suspended particles or microstructures. In practice, these particles temporarily cross-link and form bonds, which are broken down by the action of shear. Simultaneously, these bonds are reformed through the Brownian motion, but, because structure reform takes place at a lower rate, in practice, one might witness a time-dependent thixotropic effect. For instance, the viscosity of such fluid systems may vary considerably with time in addition to its being a function of the shear rate [1-3]. Such time-dependent behavior is expected to affect the critical Reynolds number in confined flows [4,5]. In spite of its technological importance, instability of thixotropic fluids has rarely been addressed in the past. One can notably mention the work carried out by Pearson and Tardy [6], and Ebrahimi et al. [7], who have shown that thixotropy has a stabilizing effect on the Saffman-Taylor instability in a Hele-Shaw cell. On the other hand, Pourjafar et al. [8] have shown that in circular Coettte flow, the effect of thixotropy can be stabilizing or destabilizing depending on the gap size and the severity of the fluid’s thixotropy. To the best of our knowledge, the effect of thixotropy on the stability of pipe flow has not been addressed in the past.

The interest in the stability of pipe flow stems from the fact that this particular geometry is widely used for the transport of Newtonian and non-Newtonian fluids [9-15]. In previous studies dealing with non-Newtonian fluids, the effect of shear-thinning and yield stress has already been investigated on the critical Reynolds number in pipe flow. For example, we already know that shear-thinning has a stabilizing effect on pipe flow [16]. Also, based on current knowledge, it is well established that a non-zero yield stress increases the critical Reynolds number in pipe flow [17,18]. As to thixotropic fluids, it is also known that thixotropy can have a destabilizing effect on plane Poiseuille flow [19]. Surprisingly, however, the effect of thixotropy on the critical Reynolds number in circular