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A new fluid model for particles settling in a viscoplastic fluid

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ABSTRACT

The study of the settling behaviour of particles in viscoplastic fluids is closely related to the study of rheology. In this paper, a thorough examination of the flow behaviour of viscoplastic fluids, in the form of aqueous polyacrylamide solutions, has been presented. The results of this study suggest that the experimental fluids exhibit time-dependent flow characteristics, where the apparent viscosity of the solutions depends highly on their shear history. This time dependency has been attributed towards the processes of destruction and rejuvenation in the 'structural network' of the fluids (due to the presence of hydrogen bonding between polyacrylamide and water molecules), as they are subjected to changing rates of shear. A new fluid model was thus developed to capture this flow behaviour. This model, termed as 'semi-viscoplastic', features temporary yield stress characteristics that tend to dissipate once the structural network of the fluid is destroyed due to the application of shear. The time dependency of the fluid viscous parameters becomes apparent in the settling sphere experiment, where it has been demonstrated that a sphere that is following the flow path of another sphere tends to attain a fall velocity that is significantly higher than the preceding sphere. Based on this finding, a new generalised correlation has been developed, through which predictions of the fall velocity of spherical particles settling through viscoplastic fluids, of various shear history, can be made.

1. Introduction

The study of the settling behaviour of particles in viscoplastic fluids is one that concerns many processes in the chemical industry, particularly to mineral processing plants. In this industry, finely crushed rocks and minerals are normally suspended in a liquid medium for ease of handling and processing, thus forming 'thick' slurries that typically have a yield stress and/or viscoplastic flow characteristics.

An extensive number of studies have been conducted to determine the effects of yield stress on the settling motion of particles in visco-plastic media. Well known studies include Valentik and Whitmore (1965), duPlessis and Ansley (1967) and Ansley and Smith (1967), whereas many more have been reviewed by Chhabra (2007). Despite this apparent abundance of experimental data and analyses, this field of study is one that is still full of uncertainties. In his review in 2007, Chhabra provided a comprehensive record of the various values that have been suggested in the past regarding the definition of the settling criterion, i.e. the critical value of buoyant weight that a particle has to have for it to settle in a yield stress fluid. Through this analysis, Chhabra (2007) highlighted the fact that a wide range of values for settling criterion has indeed been suggested, indicating the high level of uncertainty that is involved with the study of the settling behaviour of particles in viscoplastic fluids.

The uncertainties mentioned above are largely attributed towards the inconsistencies involved with the definition and measurement of yield stress (Chhabra, 2007). Accurate measurement of the yield stress is notoriously difficult to obtain (Barnes and Walters, 1985; Nguyen and Boger, 1992). Furthermore, the flow characteristics of viscoplastic fluids are often further complicated by the presence of time-dependent rheological phenomena, such as thixotropy and elasticity (Chhabra, 2007; Barnes and Walters, 1985; Zheng and Phan-Thien, 1992).

The settling behaviour of particles in viscoplastic fluids has been found to be highly dependent on the state of the fluid, i.e. whether it is disturbed (dynamic settling) or undisturbed (static/terminal settling; Hariharaputhiran et al., 1998; Horsley et al., 2004; Gumulya et al., 2007). This discovery thus adds a degree of complexity to the analysis of the settling behaviour of particles in viscoplastic fluids. This dependence of the settling behaviour has been examined by Horsley et al. (2004), who observed that a particle that is released following the flow path of another tends to have a velocity that is higher than the earlier sphere. Gumulya et al. (2007) attributed this discrepancy in settling behaviour towards the changes in the viscous parameters of the fluid as a particle flows through and shears the medium. Different correlations have been proposed for the predictions of static and dynamic settling in viscoplastic fluids (Horsley et al. 2004; Gumulya et al., 2007; Wilson et al., 2003; Wilson and Horsley, 2004).

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The work presented in this paper is a continuation of those conducted by Horsley et al. (2004) and Gumulya et al. (2007). The settling behaviour of two spheres falling one behind the other, i.e. vertically aligned, will be re-examined, this time with particular attention towards the changes in the viscous parameters of the fluids as they are subjected to varying levels of shear forces. The results of this analysis will be used in conjunction with the correlation suggested by (Wilson et al., 2003; Wilson and Horsley, 2004), in which the fall velocity of particles is correlated with the viscous parameters of the fluid (here represented by a figure of 'equivalent viscosity'). Using this approach, a generalised correlation for the prediction of static and dynamic settling in viscoplastic fluids will be generated.

2. Experimental method

The flow characteristics of the slurries in this study have been represented by dilute aqueous solutions of polyacrylamide, commercially known as Magnafloc 5250L (supplied by BASF Australia Ltd, Kwinana, WA, formerly known as FLOXIT 5250L). These solutions have previously been identified to possess a significant yield stress as well as shear thinning characteristics (Horsley et al., 2004; Gumulya et al., 2007; Wilson et al., 2003; Wilson and Horsley, 2004). As these solutions are clear and transparent, their use in this experiment negates the problems caused by the opaqueness of commercial mineral slurries, allowing the motion of spherical particles falling through the viscoplastic fluid to be observed using an optical sensor

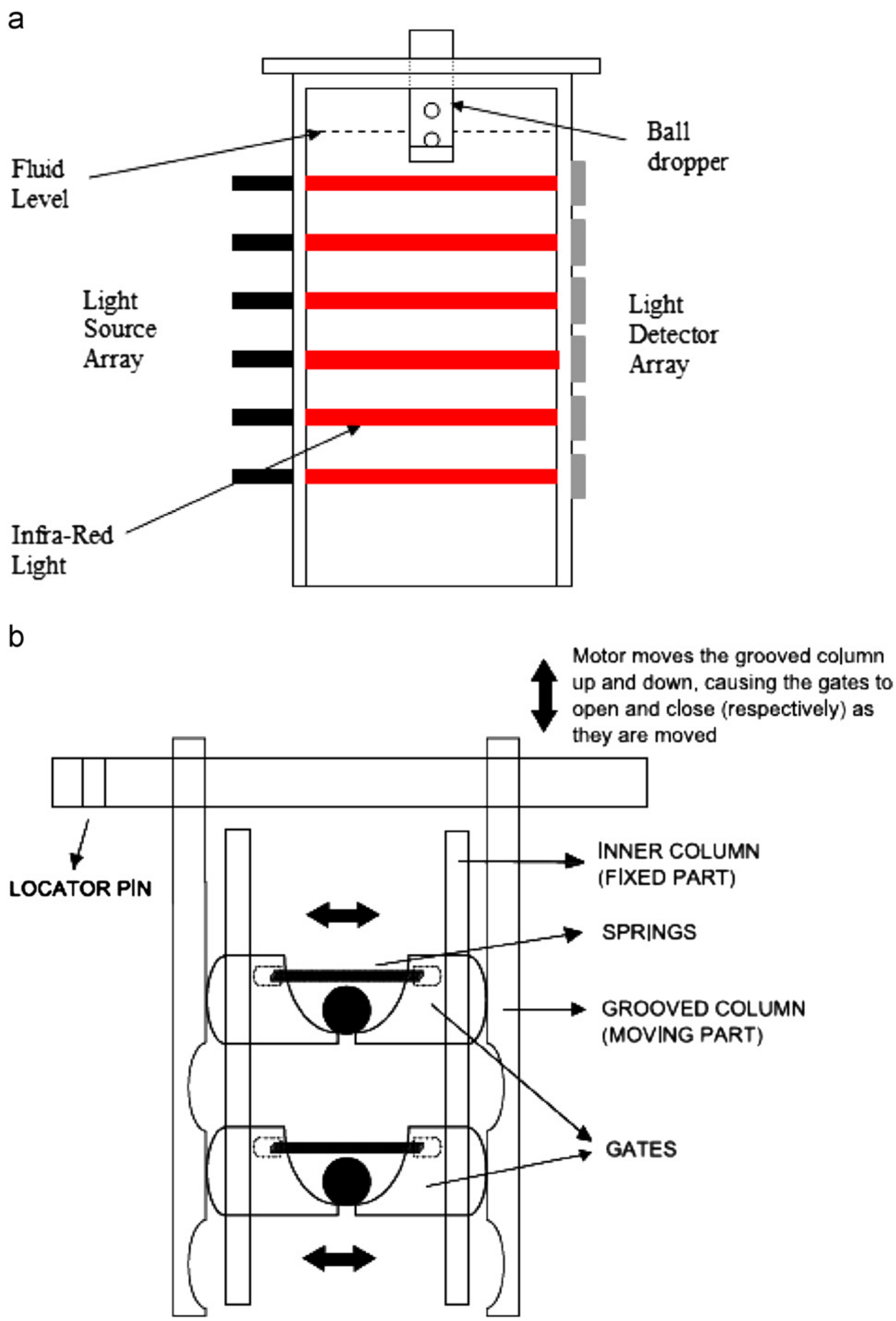

Fig. 1. (a) The schematic diagram of the optical sensors surrounding the column. (b) The schematic diagram of the ball dropping device that is fitted at the top of the column.