AN EXPERIMENTAL STUDY OF NON NEWTONIAN FLUIDS IN PIPE FLOW

Abdelhakim Benslimane [a)], Pierre François, Fabrice Lawniczak & Karim Bekkour
Institut de Mécanique des Fluides et des Solides, University of Strasbourg-CNRS, Strasbourg, 67000, France

Summary In this work, 5% by weight of bentonite suspension, a 0.1% solution of carboxymethil cellulose (CMC) and a blend of 5%/0.1% bentonite/CMC are investigated in terms of their rheology and hydrodynamic behaviour in pipe flows. In the laminar regime the flow parameters can be predicted by integration of the constitutive rheological model used. In the turbulent flow, the Dodge and Metzner model was applied to fit the experimental data.

INTRODUCTION

Bentonite suspensions are widely used as widespread thickening agents and as key component in various industrial fluid formulations. Among their uses in civil engineering are soil boring, slurry walls, or nuclear waste barrier, and other industrial applications include cosmetics (creams), chemical (paints), food products (wine), or petroleum (water-based drilling fluids). Precisely, in such applications, where the bentonite is the major component, the addition of organic additives to clay suspensions is of great industrial interest because of their capacity to modify their colloidal and rheological properties [1-3]. The flow of these fluids is complex and requires a significant amount of investigation to be better understood. However, the number of papers which are concerned with the pipe flow of bentonite clay or fluids having the same rheological properties is small. Park et al. [4] presented LDA measurements for laminar-turbulent flow of transparent slurry with yield stress obeying the Herschel-Bulkley law. Escudier and Presti [5] measured pressure drop, mean velocity profiles and RMS velocity fluctuations by LDA of laponite suspensions for laminar, transitional and turbulent flow regimes. They predicted accurately the laminar pipe flow with the Herschel-Bulkley model. In transitional flow, the measured profiles develop an unexplained asymmetry until the flow undergoes transition to turbulence. This asymmetry was reported by Escudier et al.[6] in a synthetic paper for many others shear thinning fluids. In the turbulent pipe flow, it was found that the mean velocity distribution was almost indistinguishable from that of Newtonian fluid [4, 5]. The turbulence pipe measurements of Pereira and Pinho [7] showed a small amount of drag reduction for the pure laponite suspensions. They reduced significantly the frictional drag by adding small amounts of polymer. It is obvious that additional experimental data are needed to understand the pipe flow of bentonite suspensions and the effect of the addition of polymer on their rheological behavior. The present work contributes to characterize in detail the pipe flow behavior of bentonite and a blend of bentonite/carboxymethylecellulose. Measurements of pressure drop and mean velocity profiles are presented.

MATERIELS AND METHODS

Experimental setup and instrumentation

The pipe flow is made of Plexiglas®, with an inner diameter of 20 mm and a length of 16 m. Sections are equipped with pressure transducers. Flow is provided by a volumetric pump fed directly from a 50 l capacity tank. The flow rate was measured with an electromagnetic flowmeter, and velocity profiles were obtained by ultrasound pulsed Doppler velocimetry (UPDV). The advantage of this technique is that it is not limited to optically transparent liquids. The measurement error on the calculated Doppler frequency was less than 3%.

The rheological measurements were performed by the use of a controlled stress rheometer, AR2000 from TA Instrument equipped with cone and plate geometry (acrylic cone, 60 mm diameter, 2° angle). All tests were carefully carried out under the same conditions to allow comparison of the results.

Materials and sample preparation

All the products used in this work were provided from VWR Prolabo (VWR, France). The bentonite used for the experiments was composed mainly of calcium montmorillonite, natural clay of the smectite group. Carboxymethyl cellulose (CMC) is a polymer derived from natural cellulose. In water-based drilling fluids, CMC is used to increase the stability and viscosity of the mud as it stabilizes the aqueous clay suspensions due to its high water retention. All the fluids were prepared using the same procedure.

RESULTS AND DISCUSSIONS

Viscometric measurements

The flow curves of 5% bentonite suspension, the 0.1% CMC solution, and the 5% bentonite/0.1% CMC blend were fitted with the Herschel-Bulkley model equation: $\tau = \tau_0 + k\dot{\gamma}^n$ where τ_0 is the yield stress, k is the consistency index and n is the flow index. The rheological properties of the 5% bentonite/0.1% CMC blend were found to be higher than those of both the bentonite suspension and the CMC solution. This result shows that one of the most important properties of CMC is to act as a thickening agent.

[a)] Corresponding author. Email: benslimane@etu.unistra.fr

Flow measurements

Figure a) illustrates typical velocity profiles of the three fluids in fully developed laminar flow. Moreover, one can observe that the experimental velocity profiles are in good agreement with the theoretical profiles which were plotted by the use of the Herchel-bulkley model. The velocity profiles for 5% bentonite and blend shows an overspeed at the top of the pipe. This could be explained as follows: at low flow rates, due to difference in densities between the two phases, sedimentation of particles occurs, resulting in a non-homogenous distribution of the particles in the pipe. The particle concentration is then greater at the bottom of the pipe, yielding higher velocities at the top of the pipe. Overspeed does not appear in the flow of the CMC solution.

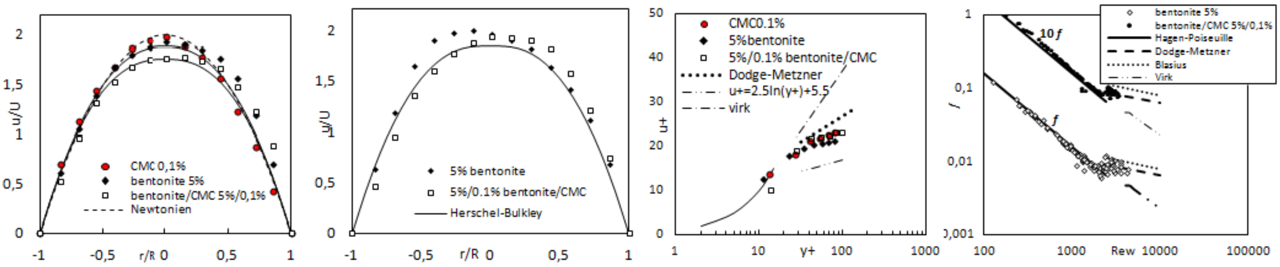
In the transitional flow the experimental velocity profiles present an asymmetry (figure b). Since it was observed over a decade ago [5], the existence of this phenomenon is now incontrovertible for viscoelastic, shear-thinning and yield stress fluids. Esmael and Nouar [8] suggested the existence of a robust coherent structure characterized by two weakly modulated counter-rotating longitudinal vortices mediating the transition from laminar to turbulent flow.

Figure c) shows mean velocity profile. The Newtonian laminar sublayer is shown by the full line and the Dodge-Metzner[9] equation and Virk's [10] maximum drag reduction asymptote are represented by dished lines.

The dimensionless friction factor for turbulent flow, according to the Dodge and Metzner's theory is written as:

$$\frac{1}{\sqrt{f}} = 0.8685\cdot n^{0.25}\ln\left(\frac{2n}{3n+1}\mathrm{Re}_{w}\sqrt{f}\right)+\frac{2.4082}{n^{0.75}}(1-n)-\frac{0.2}{n^{1.2}}$$

The friction factors derived from this equation are plotted in figure c) as a function of the wall Reynolds number for the bentonite suspension and the bentonite/CMC blend. It can be seen that the experimental data are pretty well correlated with the Poiseuille equation in the laminar regime. In the turbulent regime, for both fluids, it can be observed that the experimental data are in good agreement with the Dodge and Metzner correlation, whilst the Blasius equation overestimates the experimental measurements. This result confirms the main mechanism of drag reduction first described by Toms [11].



Figures: from left to right: a) Laminar velocity profiles. b) Transitional velocity profiles. c) Turbulent velocity profiles. d) Friction factor as a function of the Reynolds number Re_w.

CONCLUSION

A detailed experimental investigation of laminar, transitional and turbulent pipe flow of CMC (0.1 wt%) bentonite suspensions (5 wt%) and bentonite/CMC blends (5 wt% and 0.1 wt% of bentonite and CMC, respectively) was conducted using UPDV measurement techniques. In the laminar flow, the experimental data were found to be in satisfactorily agreement with the theoretical equations based upon the Herschel-Bulkley model. In the turbulent flow the Dodge and Metzner correlations were used to fit the experimental data. Furthermore, in the case of bentonite suspensions, probably due to their shear-thinning behavior, small drag reduction effects were found whilst the clay-polymer blends exhibited well more pronounced effects.

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