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Effect of drag-reducing polymers on horizontal oil–water flows

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Abstract

The effect of a drag-reducing polymer (DRP) in the water phase during horizontal oil–water flow was investigated in a 14 mm ID acrylic pipe. Oil (5.5 mPa s, 828 kg/m^3) and a co-polymer (Magnafloc 1011) of polyacrylamide and sodium acrylate were used. Two polymer concentrations were tested, 20 ppm and 50 ppm, made from a 1000 ppm master solution. The results showed a strong effect of DRP on flow patterns. The presence of DRP extended the region of *stratified* flow and delayed transition to *slug* flow. The addition of the polymer clearly damped interfacial waves. *Annular* flow changed in all cases investigated to *stratified* or *dual continuous* flow, while *slug* flow changed in most cases to *stratified* flow. In the cases where the *slug* and *bubble* flow patterns still appeared after the addition of the polymer, the oil slugs and bubbles were seen to flow closer together than in the flow without the polymer. The DRP caused a decrease in pressure gradient and a maximum drag reduction of about 50% was found when the polymer was introduced into annular flow. The height of the interface and the water hold up increased with DRP. There were no large differences on pressure gradient and hold up between the two DRP concentrations. Using a two-fluid model it was found that the addition of the polymer results in a decrease in both the interfacial and the water wall shear stresses.

Keywords: Polymer; Horizontal oil–water flow; Drag reduction; Hold up; Flow pattern transition

1. Introduction

The reduction of frictional pressure drop (*drag reduction*) caused by the addition of small amounts of polymers in single-phase flows (for reviews see Gyr and Bewersdorff, 1995; Manfield et al., 1999) has been the subject of extensive literature. The added polymers are also called *drag-reducing polymers* (DRP). Apart from single-phase systems, a number of studies exist on drag reduction in, mainly, two-phase gas–liquid but also three-phase gas–liquid–liquid flows. Recently, some of these studies revealed that apart from pressure drop, DRP can also affect the spatial distribution of the fluids in the pipe and the boundaries between different flow patterns.

The first experiments on drag reduction in gas–liquid flows were reported by Oliver and Young Hoon (1968) who used 1.3% polyethylene oxide (PEO) aqueous solution and air. They found that in slug flow the liquid exhibited considerably less circulation while in annular flow wave formation was damped resulting in a smoother liquid film. Greskovich and Shrier (1971) first used the term DRP in multiphase systems and found drag reduction

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that could reach 40% during slug air–water flow. Since then drag reduction has been documented by a number of investigators in a variety of systems with differing results (Otten and Fayed, 1976; Thwaites et al., 1976; Sylvester and Brill, 1976). During slug flow Rosehart et al. (1972), for example, found higher drag reduction than in single phase while Saether et al. (1989) found lower drag reduction. A comprehensive review of drag reduction with additives in multiphase flows up to 1999 was given by Manfield et al. (1999) where it was concluded that understanding the effect of drag-reducing agents on multiphase flows is insufficient. In publications that appeared after this review Al-Sarkhi and Hanratty (2001a,b) investigated the influence of a co-polymer of polyacrylamide and sodium acrylate on annular air–water flow in 9.53 cm ID and 2.54 cm ID pipes. The observed drag reduction was attributed to the reduction of interfacial waves which cause drop formation and help the liquid to spread around the pipe as an annulus. The maximum drag reduction was found when all the liquid was flowing at the bottom of the pipe in a stratified manner with relatively smooth interface. Drag reduction up to 63% was observed in the small pipe which was greater than the maximum drag reduction measured in the large pipe (48%).

In one of the first publications that specifically addressed the effect of DRP on flow pattern boundaries Soleimani et al. (2002) investigated the transition from stratified to roll waves and to slug flow in a 2.54 cm ID pipe. The experimental results showed that small wavelengths at the interface were damped which led to decreased interfacial friction. The critical liquid film thickness was increased for transition to roll waves due to the decrease in the interfacial friction factor and to slug flow due to suppression of turbulence in slugs. Similarly, in a large pipe with 9.53 cm ID the amplitude of interfacial waves in stratified flow was decreased and at low gas velocities the transition to slug flow was delayed to higher liquid velocity (Baik and Hanratty, 2003). Al-Sarkhi and Soleimani (2004) found in gas–liquid flow with DRP in a 2.54 cm ID horizontal pipe changes in the flow pattern boundaries and a sharp decrease in the interfacial shear stress. The maximum drag reduction appeared when the slug, pseudo slug and annular flow regimes changed to stratified flow after the addition of the polymer as was also seen by Al-Sarkhi and Hanratty (2001a,b). In a recent study Mowla and Naderi (2006) experimented with polyalpha–olefin in the oil phase during oil–air slug flow. Smooth and rough pipes of different diameters were used and drag reduction varied from 0% to about 40% for some experimental conditions. An optimum polymer concentration of 18 ppm was found for the different pipes investigated. However, higher drag reduction was encountered in the rough pipe, where turbulence is increased, than in the smooth one. In agreement with the work by Al-Sarkhi and Hanratty (2001a,b), drag reduction was found to be higher in the smaller than in the larger pipe.

There is currently no work available on the effect of DRPs on the flow patterns and pressure drop in liquid–liquid flows. As discussed above, adding DRPs in gas–liquid flows damps the waves in the gas–liquid interface and delays the transition from stratified to annular and slug flow patterns. This observation motivated the investigations carried out in this study, on the influence of drag-reducing polymers on the transition between stratified and non-stratified horizontal oil–water flows. If, in a manner similar to gas–liquid systems, interfacial waves are damped, then this would delay the initiation of drop formation (see Al-Wahaibi, 2006) and the transition to dispersed patterns. As oil–water mixtures are difficult to separate at the end of the pipeline, preserving the stratified pattern for a wider range of conditions would facilitate oil–water separation. In fact, stratification of the two liquids has been suggested as a means of separating water from oil in the pipeline (Haheim, 2001). Further, pressure drop reduction is also expected.

In this study, a DRP was added in the water phase at two different concentrations (50 ppm and 20 ppm) during oil–water flow in a horizontal pipe in order to investigate its effect on flow pattern boundaries and pressure drop. A high-speed video camera was used to monitor the flow before and after the injection of the polymer. From the high-speed images, the average height of the water interface before and after the addition of the polymer and the phase hold up were also found.

2. Experimental setup

The schematic of the experimental setup used in this study is shown in Fig. 1. Oil and water were the test fluids with average properties given in Table 1. Each phase is transferred with a pump from the respective storage tank to the test section via a variable area flowmeter. The liquids are joined in a Y-junction (Fig. 2) that reduces mixing of the two phases and ensures flow stratification at the inlet. The test section consists of a 3.5 m long acrylic pipe with 14 mm ID. The mixture returns via a PVC pipe to a separator tank, which allows the phases to separate and the dispersed drops to coalesce. Within each run the fluids are not recycled. At the end of a run the separated oil returns to its storage tank, while fresh water is used for each run.

A viewing box made from acrylic and filled with glycerol is placed around the test section to facilitate