DRAG REDUCTION IN DISTINCTLY DIFFERENT TWO-PHASE FLOW REGIMES*

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ABSTRACT

The drag reducing properties of Gaur-Gum and C.M.C. were tested in two-phase air/water flow in distinctly different flow regimes i.e bubbly and slug flows. The experimental work was performed in a 2.54 cm. I.D. horizontal pipe 12 mt. long. Positive effects in two-phase flow were found to depend on the Reynolds number of the liquid and gas and the polymer concentration. Results generally indicated that two-phase drag reduction was greater than in single-phase flow at the same superficial velocities. The percentage drag reduction in bubbly flow was shown to increase as the gas mass flow rate is increased. However, no further increase in drag reduction seemed to occur by increasing the gas flow rate after transition from bubbly to slug flow. In slug flow the drag reduction appeared to occur only in the liquid slug, not in the layer below the bubble. The flow regime seems unaffected by the polymer. The effect of Gaur Gum as drag reducing agent is much more pronounced than that of C.M.C.

INTRODUCTION

Concurrent gas liquid flow is frequently encountered in engineering processes. It occurs in boiler tubes, distillation collumns, in polymer processing, and in chemical reactor applications. This tupe of flow has many unique features, and these must be evaluated in each situation. However, one phenomenon which is nearly always undesirable is the high axial pressure gradient, with a resultant substantial energy consumption per unit volume of liquid throughput.

For many flow situations in conduits, the use of a drag reducing agent (normally a viscoelastic soluble polymer) increases flow rate for the same pressure drop in diverse systems, an effect now sometimes called the Toms phenomenon [1]. At the present time, no complete explanation exists for this behaviour. However, experimental evidence shows that drag reduction achieved by polymer solutions may be due to one of two effects, Patterson et al. [2]; the extension of laminar behaviour to very high Reynolds number, or the reduction of friction in fully developed turbulence. In turbulent flow, the momentum transfer rates are controlled by the turbulent processes that occur in the thin region near the tube wall. Earlier reported experiments indicated that the polymer-turbulence interaction must affect this region close to the pipe wall, Virk [3].

An interesting possibility exists that two-phase flow could be modified, by the addition of drag reducing agents, both by decreasing pressure drop and by modifying troublesome regimes. The pressure drop reduction could result both from reduced wall friction and from reduced holdup. However, if the momentum transfer across the gas-liquid interface is affected in a similar way as at the wall, the total gain might be small or negative.

Because of the industrial importance of gas-liquid flow and the associated problem of large axial pressure gradients, a program was undertaken to investigate the behaviour of a two-phase system containing a drag reducing polymer solution. The present study involves the bubbly and slug flow regimes. Special emphasis were put on slug flow for it is an important flow regime as far as transport processes are concerned. Rosehart [4] has demonstrated that for a two-phase chemical reactor, optimal operating conditions are often in the slug flow regime. Also Gorman [5] investigating wall pressure

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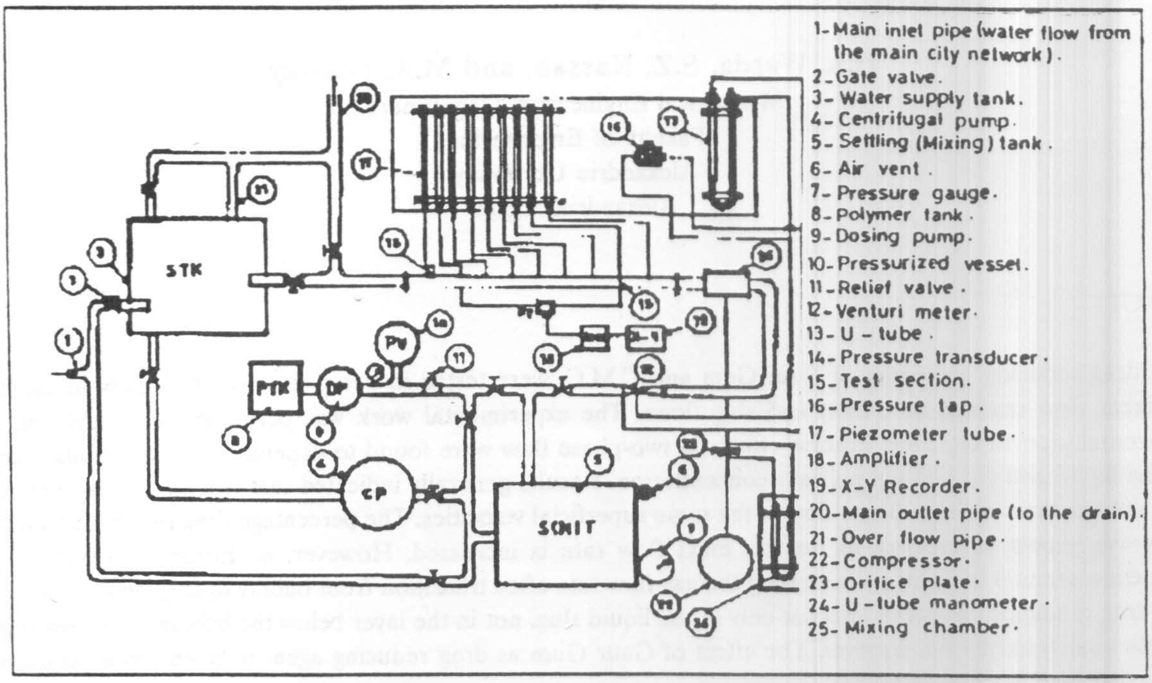

Figure 1. A Schematic representation of the experimental set-up.

fluctuations, and St. Pierre [6] investigating turbulent interchange mixing have observed maxima of phenomena under investigation in slug flow.

Therefore, several researchers have considered the effect of polymer on drag reduction. Sifferman and Greenkorn [7] have observed drag reduction in three distinctly different flow systems: dilute polymer solutions, two-phase solid/liquid suspentions, and three phase immiscible liquid/liquid flow with suspended solids. Drag reduction was shown to exist up to almost 80%. Rosehart et al. [8] studied two-phase slug flow for the case of liquid phase containing small amounts of polyacrylamide, a drag-reducing long chain polymer. Their results indicated that two-phase drag reduction was greater than in single-phase flow at the same superficial velocities. Sifferman [9] in an attempt to explain Rosehert's et al. results have reported that drag reduction seems to occur in the liquid slug, not in the layer below the bubble. The flow regimes in their work were unaffected by the polymers.

In the present study, Carboxy Methyle Cellulose (C.M.C), and Gaur-Gum have been utilized. Particular attention was given to the Gaur-Gum polymer because it is commercially available and is already used in the oil production industry in drilling operations, and the solution property remains the same as that of the solvant.

THE EXPERIMENTAL SET-UP

All experiments were performed in a loop with a horizontal pipe made of PVC, with an inner diameter of 25.4 mm. and 12 mt. long. The test section was made of a transparant pipe of 3 mt. length. The glass pipe not only provided a smooth surface but also allowed flow visualization. The pressure conditions were close to atmospheric, and the end of the pipe was vented to atmosphere. A diagram of the flow loop is given in Figure (1).

In any study involving dilute polymer solution, degradation due to aging and shear are highly important. For this reason, extreme care was taken in the preparation of the solution. Initially, it was hoped to recirculate the liquid phase, however, continuous shearing of the solution appeared to indicate some degradation. For this reason once-through operation was selected, and a positive reciprocating pump was used to introduce the polymer solution into the test loop, after the centrifugal pump, to avoid any shear degradation of the polymer material inside the pump. A constant pressure vessel was installed on the delivery of the reciprocating pump to insure continuity and steadiness of the injected polymer solution. With this procedure reproducibility of pressure measurements was satisfactory.

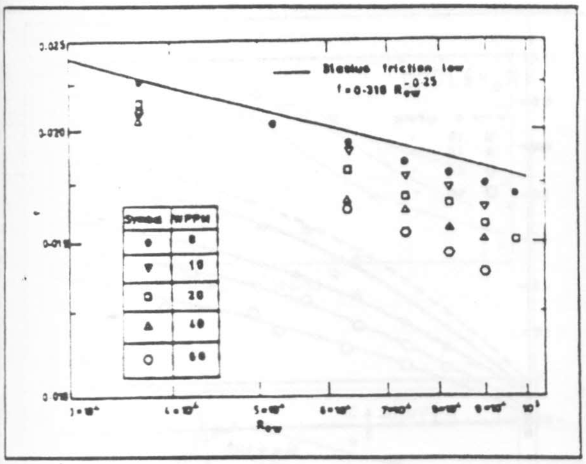

Figure 2. Friction factor for single-phase liquid flow with polymer added (Gaur-Gum).

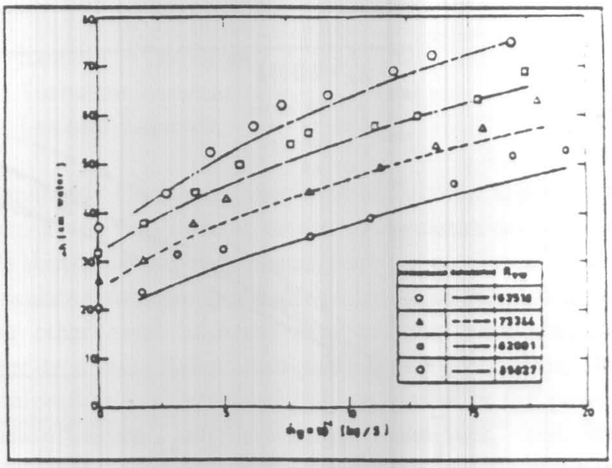

Figure 3. Comparison between experimental pressure drop with empirical correlations (Chaisholm).

Flow rates of the liquid and gas phases were measured by a venturi and orifice meters respectively; and the phases were subsequently introduced into a mixing chamber in the middle of the pipe. Since viscoelastic effects supposedly require a long entrance region, and long exit the flow loop was about 12 mt. long. Pressure drops were generally measured over a distance of 1 mt. by pressure transducers. The amplified, filtered signal was recorded on a x-y plotter. This system allowed for time averaging the pressure oscilations. The experiments were run to steady state before the data acquisitions were started. All experiments performed with the polymer solution were repeated with identical runs without the polymer.

EXPERIMENTAL RESULTS AND DISCUSSION

Single-phase Polymer Experiment

Prior to the two-phase experiments, the drag reduction characteristics of Gaur-Gum and CMC in single-phase flow of water performed to compare the characteristics of the polymer solution in water with that of the solvent. Runs of water with and without polymer were excuted at Reynolds number ranging from (36600-90000). Up to seven different concentrations were used ranging from 5 to 150 weight part per million (wppm). Parameters measured were: inlet volumetric flow rates, pressure distribution, absolute pressure and temperature. The Gaur-Gum results are presented in Figure (2), in terms of the standard Fanning friction factor "f" = $(2\delta p\, D/\rho v^2 L)$ versus 'Re' = $(\rho v d/\mu)$ where, 'δp' the pressure drop, 'D' the inner diameter, 'ρ' the liquid density, 'v' the liquid velocity, 'μ' liquid viscosity and 'L' is the length over which pressure drop is measured. In Figure (2) the Blasius friction factor for a smooth pipe defined by $f = 0.3164 \bullet (Re^{-0.25})$ has been plotted as a reference. At low concentrations there is an appreciable drag reduction effect which increases with polymer concentration. This observation is consistent with those made earlier [10].

Two-phase polymer experiments

In the two-phase flow work several flow regimes could be observed, depending on the flow conditions. The flow regimes that could be obtained in the present set-up were bubbly, slug, stratified smooth/wavy flow. However, results presented here are only for the bubbly and slug flow patterns, where the effectiveness of polymers as drag reducing agent is highest at the corresponding high Reynolds numbers. Two-phase pressure gradient data were obtained first to demonstrate the extent of the pressure drop increase due to the presence of the second phase.

In addition, the two-phase pressure gradient data obtained and flow pattern observed have been compared with empirical correlations. This has been carried out in two steps;

i. The flow pattern is defined first by calculating the coordinates of a flow regime chart. The flow regime was then established using Baker's [11] graph. Although the borders of the regimes are really broad transition zone, they were approximated by eight

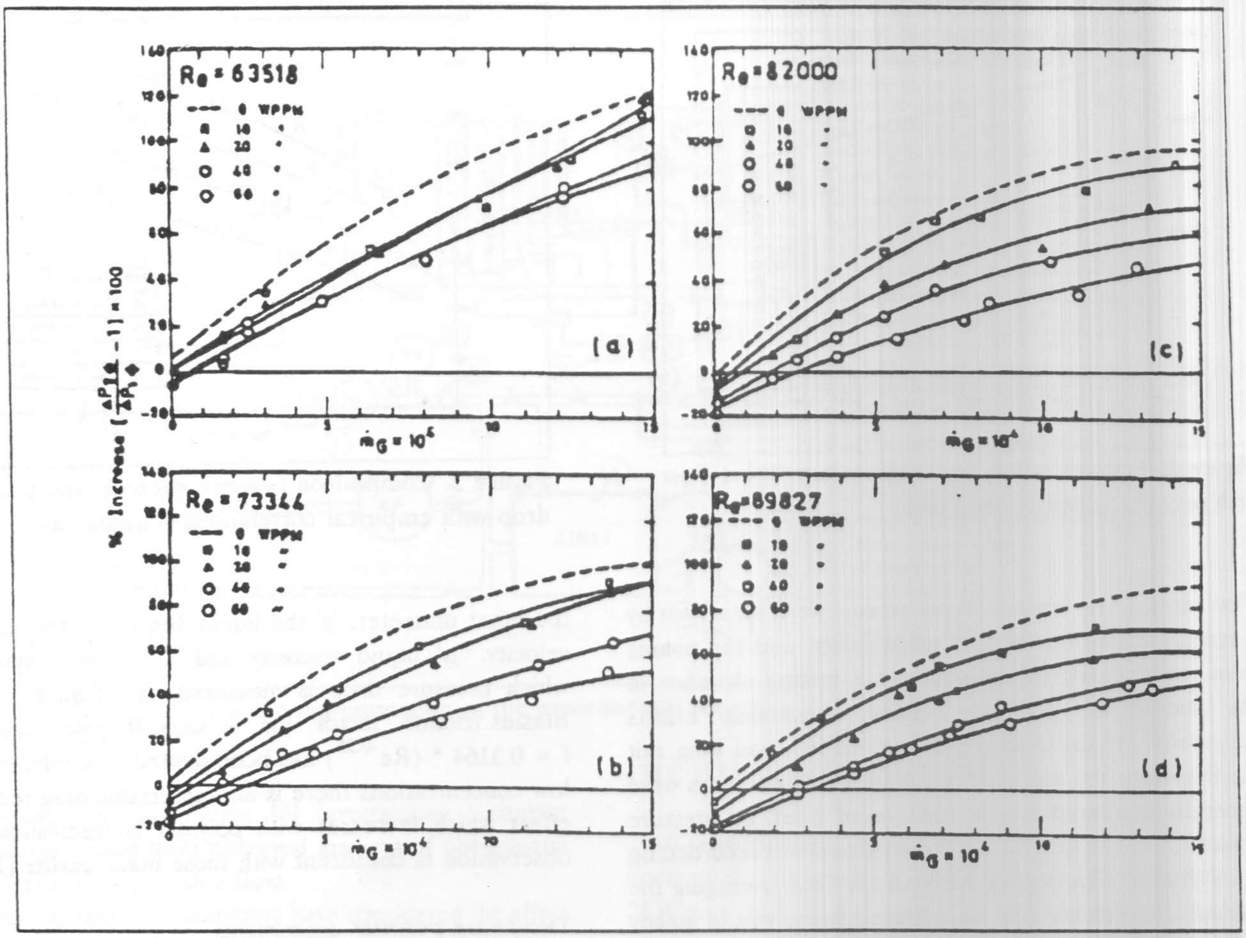

Figure 4. The effect of polymer addition (Gaur Gum) on the percentage increase in pressure drop in two-phase flow.

straight lines [12].

ii. The unit pressure loss could then be determined by calculating the gas-phase unit loss, corrected by an applicable correlation for two-phase flow. The correlation used for gas-liquid mixtures are based on the method of Lockhart and Martinelli [13]. The general equation is;

$$\delta p(\text{two-phase}) = \delta p\ (\text{gas})\ \phi^2$$

The pressure drop for the gas phase is calculated by assuming that only gas flows in the pipeline. The calculated gas-phase unit loss was then corrected using two correlations. The form of the two correlations are identical:

$$\phi = a\, X^b \quad , \quad \text{where}$$

$$X^2 = (dp/dl)_{1\phi\ \text{liquid}} / (dp/dl)_{1\phi\ \text{gas}}$$

The first correlation is the one developed by Baker [11] (table 1), and the second is the one by Chaisholm [14] (table 2).

Table 1. Two-phase flow correlations
[Baker]

For Bubbly Flow $\phi = 14.2\ X^{0.75}/(W_1/A)^{0.1}$

For Slug Flow $\phi = 1190\ X^{0.815}/(W_1/A)^{0.6}$

Table 2. Two-phase flow correlation
(Chaisholm)

$$\phi^2_L = 1 + C/X + 1/X^2$$

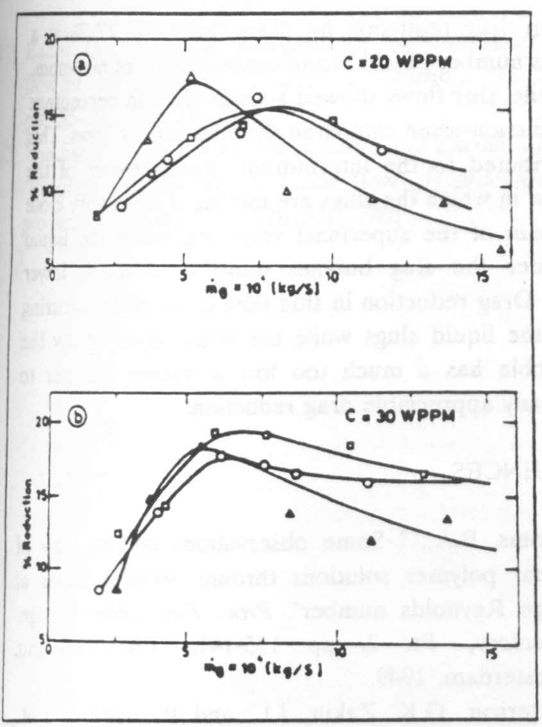

Figure 5a. Percentage drag reduction in two-phase flow for different Reynolds number at different polymer concentrations (Gaur Gum).

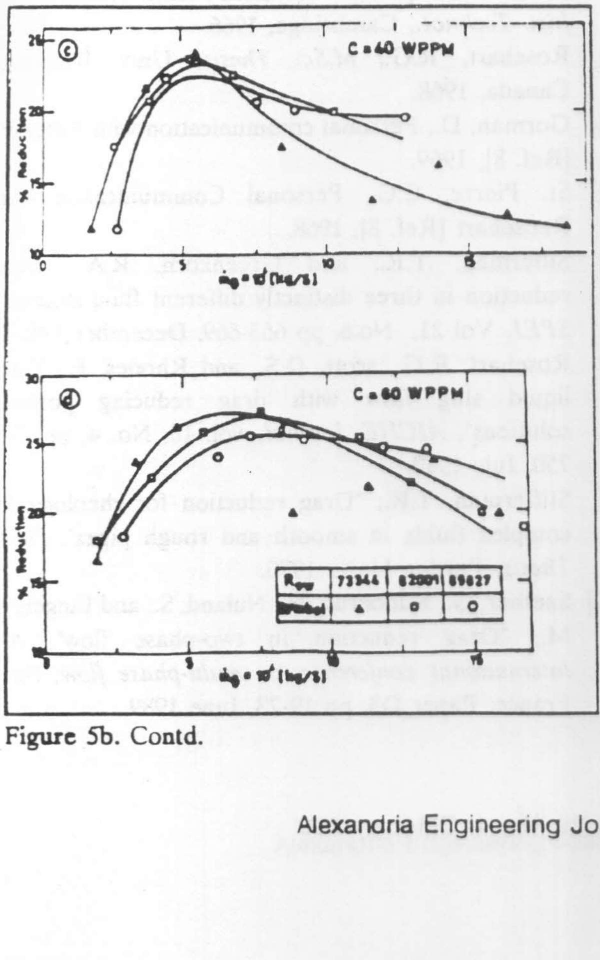

Figure 5b. Contd.

For Turbulent-Turbulent flow, C = 20
Laminar - Turbulent, C = 12
Turbulent-Laminar flow, C = 10
Laminar-Laminar, C = 5

Apparantly Chaisholm empirical correlation appeared to agreed very well with the measured 2pressure drop. Figure (3) shows the close agreement between measurement and calculated pressure drops using Chaisholm correlation. On the other hand observed flow patterns were correctly predicted using Baker's two-phase flow pattern graph. This comparison has increased the confidence in the present measurements and averaging techniques, and was necessary before presenting the two-phase drag reduction results.

The present two-phase experiments were performed with maximum superficial liquid velocities of 3 mt./sec. and superficial gas velocities of 3 mt./sec. Figure (4) shows the percentage increase in pressure gradient in two-phase flow, as compared with the corresponding pressure gradient in single-phase liquid flow, with the same superficial velocity. The percentage increase in pressure drop is plotted as a function of the gas mass flow rate for various concentrations of Gaur-Gum ranging from 0 wppm to 60 wppm. This relation is drawn for four different Reynolds number, based on the liquid phase superficial velocity, Figs (4.a-4.d). A comparison between the results with and without polymer shows that, whilst the frictional pressure drop increases as the gas is introduced into the flow, the addition of polymers has a dramatic effect on this phenomenon, and the extent of the increase in pressure drop (in two-phase flow) is significantly reduced. Comparing Figs. (4a-4d) demonstrates that this effect is further magnified as the Reynolds number is increased. The negative values shown in the figure demonstrate that at lower gas-mass flow rates the reduction of pressure drop due to polymer addition overweight the percentage increase due to the presence of the second gas phase.

Figure (5) represent a plot of the percentage reduction of two-phase pressure drop due to polymer addition versus the gas mass flow rate. The results show that the amount of drag reduction increases with increasing the gas flow rate.

However, it is clear that, initially the drag reduction increases rapidly then it tends to level off as the gas mass flow rate continues to be increased. It was interesting to note that the rapid increase in darg reduction was

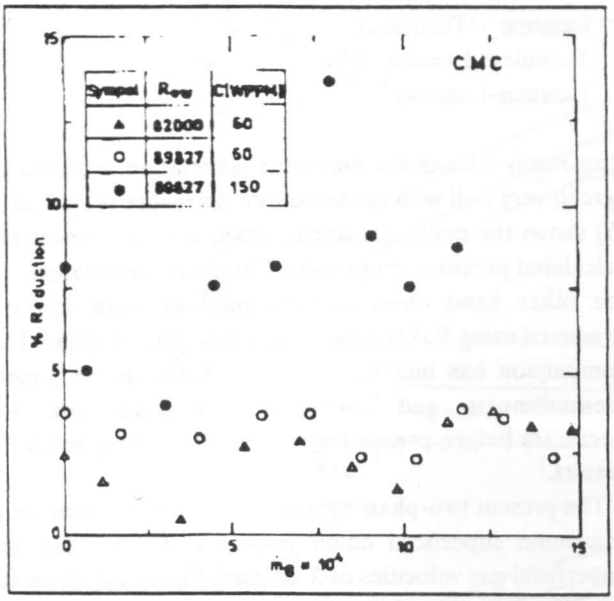

Figure 6. Percentage drag reduction in two-phase flow for different Reynolds number at different polymer concentrations (C.M.C.).

by Saether et al. [10], indicating that the lost energy component of the pressure gradient due to acceleration obtained in the bubbly flow regime. However, as the gas flow rate was further increased and a transition to slug flow occured, there was no further increase in drag reduction. This result supports the suggestion made earlier effects of 'scooping' in the slug flow regime is in fact greater than the frictional component of the axial pressure gradient. This indicates the importance of the liquid slug head because of its significantly higher velocity as the dominant factor in the axial pressure gradient. The same set of experiments were conducted using C.M.C. Figure (6) shows the percentage reduction in pressure drop at relatively high concentrations of C.M.C. (up to 150 wppm). The results indicate the same trends observed earlier with Gaur-Gum, (Figure 5), of reaching a maximum value of drag reduction as the gas mass flow rates are increased. However, the effectiveness of C.M.C. as drag reducing agent is very small compared to Gaur-Gum.

CONCLUSION

The polymer solution tested show a positive ability to reduce the frictional loss in horizontal two-phase bubbly and slug flows. However, the Gaur-Gum proved to be more effective as a drag reducing agent than C.M.C. The maximum drag reduction for Gaur-Gum was 27 % at a Reynolds number of 82000 and concentration of 60 wppm. Meanwhile, slug flows showed a lower value in percentage drag reduction when compared with the bubbly flows. This was attributed to the intermittent characteristics of the slug flow, in which the slugs are moving at a velocity close to the sum of the superficial velocities, while the liquid film under the slug bubbles move at a much lower velocity. Drag reduction in slug flow is therefore occuring only in the liquid slugs while the liquid layer below the slug bubble has a much too low Reynolds number to achieve any appreciable drag reduction.

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