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FLOW PATTERN SHIFTING AND DRAG REDUCTION IN OIL-WATER FLOW IN PIPE

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ABSTRACT

A major part of all chemical engineering process and operations is concerned with liquid-liquid two-phase flows where knowledge of the hydrodynamics is essential for its design and transportation through pipeline. The degree of drag reduction of oil-water flow in pipeline is presented in the present article. A model is developed to estimate and analyze the reduction capabilities of drag in the flow in the pipeline. The flow pattern shifting based on effect of drag reducing agent is also enunciated in the present work. From the present experimental results, as the drag reducing agent concentration increased percentage drag reduction is increased. The addition of 50-250 ppm of PEO causes about 18 t0 32% drag reduction at oil fraction of 0.30. The study may be useful for further understanding the flow behaviour of multiphase flow in pipeline in petroleum industry.

KEYWORDS: Hydrodynamics, Oil-Water Flow, Flow Pattern, Drag Reduction, DRA

INTRODUCTION

The flow patterns, drag and its reduction are most important factors in hydraulic transport of gas–liquid flow. The effect of gas flow on the hydraulic transport of fluid in a horizontal pipe may reduce or increase the pressure gradient in multi-phase flow in comparison with the conventional hydraulic transport of single fluid, depending on the physical properties and input fluxes of the phases, and the size of pipe. In petroleum industries during transportation and production, two-phase oil-water flows in pipelines are common occurrences. The oil and water transportation pipelines can have several effects such as interfacial structure between oil and water which complicates the hydrodynamic prediction of fluid flow. As explained by Brauner [1], the flow of two immiscible liquids is encountered widely in the chemical and petroleum industries. In liquid-liquid flows, as in gas-liquid systems, the two-phases can be distributed in the pipe in many configurations called flow patterns, differing from each other in the spatial distribution of the interface. Charles et al. [2] defined four flow patterns in their equal density oil-water flow in pipes water droplets in oil, concentric water with oil flowing in the core, oil slugs in water, and oil bubble in water.

They found that the resulting oil-water flow patterns were mostly independent of the oil viscosities. Other investigators worked on the hydrodynamics in pipeline with oil and water are Greskovich and Shrier [3]; Vedapuri et al. [4]; Angeli et al. [5]; Jana et al. [6]; Xu [7]; Grassi et al. [8]; Domenico et al. [9]; Foletti et al. [10]. The flow patterns of oil-water flow in inclined pipes are limited though some authors observed some typical flow patterns of oil-water flow. Still there is a gap to study more about the flow patterns in the inclined pipelines. The reduction of the pressure drop is of practical importance from an economic viewpoint since it may reduce the pumping energy of the fluid in long pipeline, hence reduce transportation cost, facilitate refinery loading and unloading operations, improve the fluid-mechanical efficiency using active agents, and increase the production rates.

Drag reduction is basically done in petroleum industries for transportation of liquid-liquid two-phase flow in pipelines from the reservoir to the processing facilities [11-15]. Soleimani et al. [16] suggested that the reduction of pressure can be done by elimination of small wavelength waves on roll waves rather than damping of the roll waves. Elimination of intermittent flow patterns are expected to have an effect on pressure reduction. Thus, pressure reduction can occur due solely to changing the flow pattern [17-21]. Drag reduction work is scarce when it comes to multiphase flow, compared to that achieved in single-phase flow. Most of the literature available for drag reduction is only for gas-liquid systems. The present work deals with the investigation of the degree of drag reduction of high viscous liquid-water flow in an inclined pipeline.

EXPERIMENTAL

The experiments are performed in a horizontal pipe. The setup has designed and fabricated to investigate the hydrodynamic aspects of oil-water flow through the pipe as shown in Figure 1. Test section is made up with 0.025 m internal diameter Perspex pipe of 1 m length. Water and oil were pumped into the test section using centrifugal and gear pump respectively from the storage tanks. After attaining steady state within a minimum of five minutes, an intensive observation of the flow phenomenon was noted and photographs were taken at the test section. After flowing through the test section oil and water mixture enters into the separator where the gravity separation of the phases takes place. Oil and water were separated and recycled to the respective storage tanks.

The same experimental procedure is repeated for different combinations of oil and water flow rates. The master polymeric surfactant Polyethylene oxide (PEO) with different concentration is used to perform the experiment for drag reduction. The surfactant solution is injected into the flow loop through a hole for the mixing purpose of fluids as per design. An injection device is used for the purpose. The flow rate is measured by a rotameter. This method is used for transferring the concentrated solution in order to avoid the degradation that would have occurred if a pump were used. A U-tube manometer and pressure transducer with data acquisition system are used to measure the pressure drop over a length of pipeline. Reproducibility of the experimental data was checked by performing the experiment at least four times. The physical properties of the system are shown in Table 1.

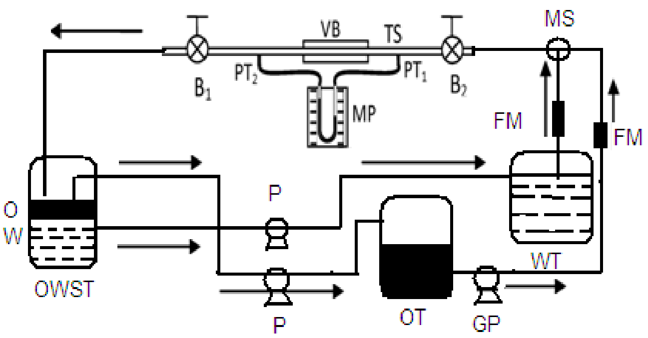

Figure 1: Schematic Diagram of Experimental Setup: Legend: B_1-B_2: Quick Closing Valves, OWST: Oil-Water Separation Tank; TS: Test Section GP: Gear Pump, MP: Manometer Panel, FM: Flow Meter, PT_1-PT_2: Pressure Ports, P: Pumps, OT: Oil Tank, WT: Water Tank, VB: View Box

Table 1: Physical Properties of Test Fluids

Physical Properties	Oil	Water	50 ppm SDS Solution	100 ppm SDS Solution	200 ppm SDS Solution
Density (Kg/m^3)	889	1000	1000.133	1000.212	999.47
Viscosity (Pa.s)	0.107	0.001	0.00183	0.00185	0.00191
Surface Tension (N/m)	0.0032	0.072	0.03900	0.0378	0.0339
Interfacial Tension (N/m)	0.024		0.0052	0.0043	0.0024

RESULTS AND DISCUSSIONS

From the present experiment, eight different types of flow patterns are observed in all flow rates. They are plug flow (PF), slug flow (SF), stratified smooth (SS), stratified wavy (SW), stratified mixed (SM), annular flow(AF), dispersion of oil in water (DOW) and dispersion of water in oil flow (DWO). Plug flow is observed at very low oil and water superficial velocities. In plug flow very small plugs are seen in the water continuous medium at the top of the pipe. The pattern gradually changes with increase in oil and water flow rates. All the flow regimes are shown in a flow regime map as shown in Figure 2. The slug flow is observed after the plug flow immediately by slightly increasing oil velocity. There is a water bridge between two consecutive slugs with increase in oil flow rate. As the oil velocity increases, water-bridge disappears in between them and forms continuous of oil phase at the top of pipe and water below and shows stratified smooth. In stratified flow it is initially characterized with smooth interface and waves and with no drops. As the oil and water superficial velocities increases after the stratified wavy flow developed, small drop are formed at the interface. Water is surrounded by the oil phase in core annular flow. Dispersion of oil in water flow occurred at highest superficial water velocities and lower superficial oil velocities. It is a continuous of both phases.

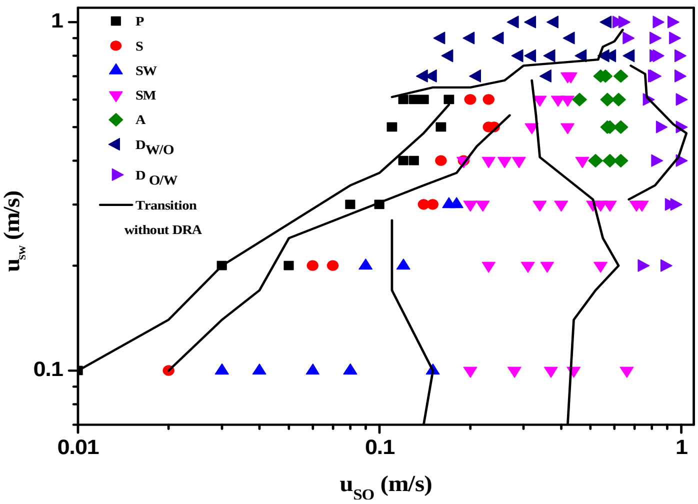

Figure 2: Flow Pattern Map of Oil-Water Flow with 50 ppm PEO

The boundary of the flow patterns are changed which are shown marking by solid boundary line. The degree of change of boundary of the flow patterns depend on the surfactant concentrations. As the surfactant concentrations increases the drag reduction also increases which results in changing the boundary of the flow patterns. The flow patterns are governed by the surface active forces between the phases and the wall shear stress during the flow of fluid. The interfacial shear stress depends on the fluid properties and the slip velocity. At higher concentration of the surfactant lower the surface tension and reduces the interfacial stress at a certain fluid velocity. In case of high viscous oil flow with water, the effective viscosity is reduced due to the change of shear stress with shear strain due to reduction of pressure drop. The drag-reducing agent has only a minor effect on transition from smooth stratified to slug flow at low water and oil velocities. But it is significant in case of higher surfactant concentration.

Visual observation showed that the mechanism of slug formation remains unchanged in the presence of surfactant. This may be due to a laminar liquid layer in stratified flow which is not changed by the addition of drag reducing surfactant. The pressure drop of the stratified flow pattern prior to transition is not changed by higher surfactant concentrations. At high oil velocity, an annular flow pattern will form. It is characterized as part of the water flowing along the wall as a water layer, which can be extended to form oil drops as surface roughness, and part as drops entrained in the oil phase in the core of the pipe. The annular flow pattern at lower oil velocity becomes stratified smooth and stratified wavy whereas at higher oil velocity this changes to stratified-mixed and, in which a fine size of oil drops forms at the lower part of the pipe.

At a very high superficial oil velocity an annular flow does not significantly change. At relatively low oil velocities the effectiveness of surfactant is greater than that at higher oil velocity. At low oil velocity the pattern changes from annular to stratified flow very quickly but at high oil velocity the change from annular to stratified flow occurs in a time period. First the frequency of the disturbance waves decreases and eventually disappears; then the flow changes pattern to stratified. The effect of oil velocity is greater than that of water velocity. The drag reduction decreases with increasing oil velocity. It is due to the high oil velocity in the annular flow. At high oil velocity the impingement of the oil on the surfactant solution may cause to some extent of degradation. This does not occur in the case of stratified flow. In pipe flow, shear stresses are highest at the wall. The main drag reduction equation can be expressed as

$$\%DR = \frac{f_{without\ DRA} - f_{with\ DRA}}{f_{without\ DRA}} \times 100 \tag{1}$$

In this equation (equation (1)), $f_{\text{without DRA}}$ is the friction factor of the liquid without DRA and $f_{\text{with DRA}}$ is the friction factor of the liquid containing the drag reducing agent in that liquid. The friction factor of the liquid is determined using equation given by

$$f = \frac{d_p \Delta P}{2L\rho U^2} \tag{2}$$

Based on the operating variables of the present study, a correlation has been developed to predict the fanning friction factor for the oil-water flow in smooth pipe which can be represented by

$$f_m = (21.011\text{-}2.032C_s)\left(\frac{\rho_o}{\rho_m}\right)\left(\frac{U_{so}}{U_m}\right)^2 \frac{\mathrm{Re}_o^{\,0.0012C_s\,-\,1.2172}}{\mathrm{Re}_w^{\,0.0057C_s+0.19227}} \tag{3}$$

The ranges of applicability of the correlation are from $0.254\times10^4 < \mathrm{Re}_w < 2.54\times10^4$ and $0.021\times10^2 < \mathrm{Re}_o < 2.76\times10^2$. Generally the drag reduction is more predominant at laminar condition. The drag reduction can also be predicted by the friction factor correlation as follows:

$$\%DR_{x=x} = \frac{f_{m,x=0} - f_{m,x=x}}{f_{m,x=0}} \times 100 \tag{4}$$

In the scope of present study, a correlation has also been developed to predict the drag reduction as a function of oil holdup. Overall it is seen that the drag is reduced with increase in oil holdup which can be represented as

$$\%DR = [0.0370 + 0.0153\ln(C_s)]\varepsilon_o + 4.75C_s^{0.35} \quad (5)$$

The addition of 250 ppm of PEO causes about 32% drag reduction and phase inversion point in dispersed flow regime occurred at oil fraction of 0.30.

CONCLUSIONS

From the present study the following conclusions can be made:

- The effect of drag reducing agent (DRA) on drag has immense effect on the flow regimes.
- At lower water velocities as the ppm level of drag reducing agent is increased, drag decreased at lower velocities of oil whereas at the higher water velocities as the increased ppm level increased the drag.
- As the DRA concentration increased percentage drag reduction is increased. The addition of 50-250 ppm of PEO causes about 18 t0 32% drag reduction at oil fraction of 0.30.
- The drag reduction is interpreted in terms of water holdup by developing a correlation which may be useful for further prediction of drag effect by drag reducing agent.
- The concept of developed correlations for mixture friction factor and the drag reduction may predict the degree of drag reduction in oil water flow for the specific drag reducing agent.
- The present study may be helpful for further study to understand the complex behaviour of multiphase flow through pipelines in oil industry.

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NOMENCLATURE

C_s	Amount of DRA, (ppm)
d_p	Pipe diameter, (m)
DR	Drag reduction, (%)
DRA	Drag reducing agent
f_m	Friction factor of mixture, (-)
L	Length of test section, (m)
Re	Reynolds number, (-)
Re_o	Reynolds number of oil, (-)
Re_w	Reynolds number of water, (-)

U_{so} Superficial oil velocity, (m/s)

U_{sw} Superficial water velocity, (m/s)

U_m Mixture velocity, (m/s)

ΔP Pressure drop, (Pa)

ρ_m Density of mixture, (kg/m^3)

ρ_o Density of oil, (kg/m^3)

ρ_w Density of water, (kg/m^3)

μ Viscosity, (Pa s)

μ_m Mixture viscosity, (Pa s)

μ_o Viscosity of oil, (Pa s)

μ_w Viscosity of water, (Pa s)

ε_o Oil.holdup, (-)

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