A.A. Alwasiti
Petroleum Technology Dep., University of Technology Baghdad, Iraq.

N.M. Farhan
Material Eng. Dep., University of Technology Baghdad, Iraq

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Effect of Surfactant Additives on Phase Inversion in Oil-Water Pipe Flow System

Abstract- *This research investigates the effect of surfactant additives on phase inversion point in the oil-water flow in horizontal pipe. Two types of surfactants were used in the experiments; anionic type (sodium lignosulfonate (SLS)) at 200 ppm and cationic type (hexadecyltrimethyl ammonium bromide (CTAB)) at 100 ppm. The experiments were carried at mixture velocities (0.8, 1, 1.9 and 2.3) m/s. The results showed that the phase inversion points are unaffected by surfactant addition or velocity at low mixture velocities while they shifted downward at high mixture velocities. The experiments show also that anionic surfactant addition caused a forward shifting in phase inversion point and downward shifting in the addition of cationic surfactant at high mixture velocities.*

Keywords- *Oil-water flow, Phase inversion, Pressure drop, Surfactant.*

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1. Introduction

A system consisting of two immiscible liquids (oil - water) flowing through a pipe is essential in many chemical and petrochemical processes.

Oil-water dispersions can be as oil drops in water continuous phase or water drops in oil continuous phase. When the amount of the disperse liquid is increased gradually the disperse phase becomes the continuous phase and the originally continuous phase becomes the disperse phase. This phenomenon called "phase inversion ". The phase inversion is defined as the change of dispersed phase to become continuous phase and continuous phase to become dispersed phase. The critical volume fraction at which inversion happen is the phase inversion point.

Knowledge of phase inversion is very important to the design of pipelines, downstream separation facilities, pumps as well as selection of operating condition in industries, since that when the phase inversion occurs the effective viscosity of the mixture become very large leading to maximize in pressure gradient.

The opposite processes of coalescence and break-up of the drop are among the most mechanisms used to explain the phase inversion [1] in which that inversion occurs when the rate of bubble break up exceeds the coalescence rate[2]. Ngan et al. [3] stated that, inversion occurs in the case at which both of oil in water and water in oil effective viscosities are the same.

Another mechanism was made by Pacek et al. [4] and Jahanzad et al. [5], who concluded that new continuous phase formed when a little parts of the continuous phase are trapped inside the scattered phase (dispersed phase), in which that the drops (forming the scattered phase) grow, coalesce with each other's Phase inversion and phase inversion point are affected by many factors such as fluid properties (density, viscosity, and interfacial tension) and also by the mixture velocity, wettability of the pipe material and the dimension of the pipe. etc .

Many researchers studied the phase inversion for many years. The first study was carried out in batch process and stirred vessels by Selker and Sleicher [6] who proposed that interfacial tension does not influence the type of dispersion; Yeh et. al. [7], found that the dispersion occurs at equal volumes of the two liquids, this caused by interfacial tension of the liquids; Clarke and Sawistowski [8] and Norato and Tsouris, [9] concluded that, the inversion more difficult to occur with decreasing the interfacial tension of liquids .

Salager et al. [10] studied the phase inversion in pipes; they found that, the addition of surfactant might change the inversion point of the mixture. Piela et al. [11] also found that the critical volume fraction has been effectuated by surfactant addition. Ngana et al. [12] studied the effect of adding a small amount of glycerol in the water phase on interfacial tension and phase inversion process during horizontal pipe, they found that the addition of glycerol delayed the overall inversion point to higher oil (lower water) fraction.

Most of the researchers who studied the effect of additives used one type of surfactant. Hence, more investigation is needed at this point. This work aims to study the effect of two surfactant types, anionic and cationic, on phase inversion

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2412-0758/University of Technology-Iraq, Baghdad, Iraq
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point for the oil-water system, as well as studying its effect with velocity.

2. Experimental Work

The experimental setup used in this investigation is shown in Figure 1. The test section consists of the horizontal acrylic pipeline with an internal diameter of 12.7 mm and 6 m in length. The two liquids are pumped (pump 1 & 2) from their respective storage tanks into the test section via a T-junction, which ensured minimum mixing. The mixture flows into a separator tank, after the test section, where oil and water separated by gravity. For each experiment, simultaneous measurements of pressure were carried out at six different positions from the pipe inlet over a distance of 1 m.

The two phases that used in the experiments were tap water, which is used as the aqueous phase, and oil (kerosene). The experiments were carried out at (0.8, 1, 1.9 and 2.3) m/s mixture velocity. The phase inversion was investigated starting from the water phase (aqueous phase) which was initially run as a single phase for few seconds to ensure that the pipe wall is wetted by the water. After that, the dispersed oil increased gradually by increasing the flow rate of oil and decreasing the aqueous phase flow rate to make sure that the mixture velocity remained constant. This continued until inversion was occurred and beyond up to single-phase oil flow. Flow rates of the water and oil are measured using two flow meters just before entering the test section. Each experiment run was repeated three times to confirm the results and the averaged results were reported.

In order to study the effect of additives on phase inversion, two types of additives were used sodium lingo sulfonate (SLS) at 200 ppm and hexadecltrimethylammonium bromide (CTAB) at 100ppm. The physical properties of these solutions are tabulated in Table 1.

3. Results and Discussion

I. Effect of velocity

The influence of velocity on phase inversion point was carried out for a wide range of mixture velocities (0.8, 1, 1.9 and 2.3 m/s) with Reynolds number ranged from 6903 to 22158. The results of these experiments are shown in the Fgure (2).

As can be seen from these figures that the influence of the mixture velocities on the phase inversion point is negligible for all systems at low mixture velocity (0.8and 1 m/sec), in which that the values of oil fraction at which phase inversion occurred remains 0.5. This means that there is no changing in phase inversion point for all systems at low mixture velocity.

At high values of Reynolds number the influence of the mixture velocity on the phase inversion point is significant. The oil fraction at which phase inversion occurred lowered to (0.45 and 0.43) in the case without any additives, (0.42 and 0.4) for CTAB surfactant addition and (0.57 and 0.54) for SLS addition at mixture velocities (1.9 and 2.3)m/s respectively. This could be attributed to the fact that the turbulent in pipe flow dominates the mixing between the two liquids leading to the high interaction between them.

Indeed, Figure 2 shows that the pressure drop increases with increasing mixture velocity. This attribute to the strong interaction between two liquids at high mixture velocity. Also, the pressure drop increases at inversion point for all systems. This attributes to the increase of oil - water mixture effective viscosity. The peak in pressure drop became more clear and bigger with increasing mixture velocity. Because the growth of the effective viscosity increased with increase in mixture velocity.

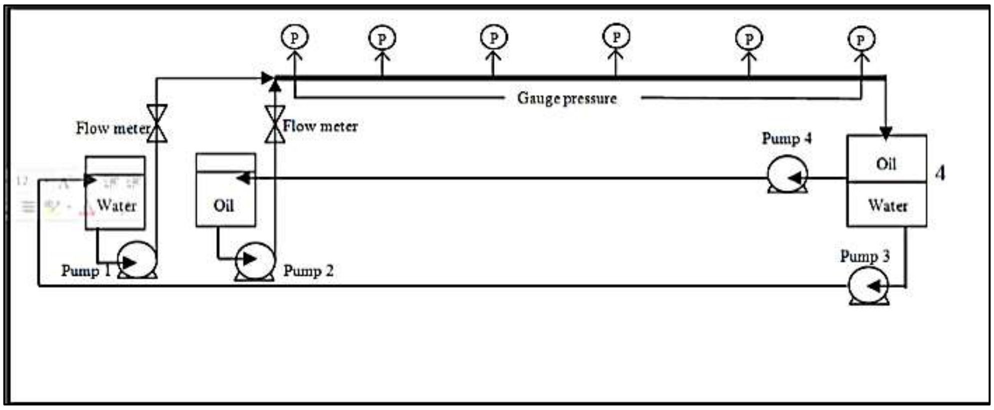

Figure 1: The schematic diagram

Table 1: Physical properties of solutions

		Oil	Pure water
Density (kg/m^3)		828	998.2
Viscosity (Cp)		5.5	1.002
Surface tension (mN/m)		27.5	72.75
Oil/water interfacial tension @ 20 ^{o}C (mN/m)		48	
Oil/200ppm of SLS interfacial tension (Mn/m)	45		
Oil/100ppm of CTAB interfacial tension (mN/m)	39		

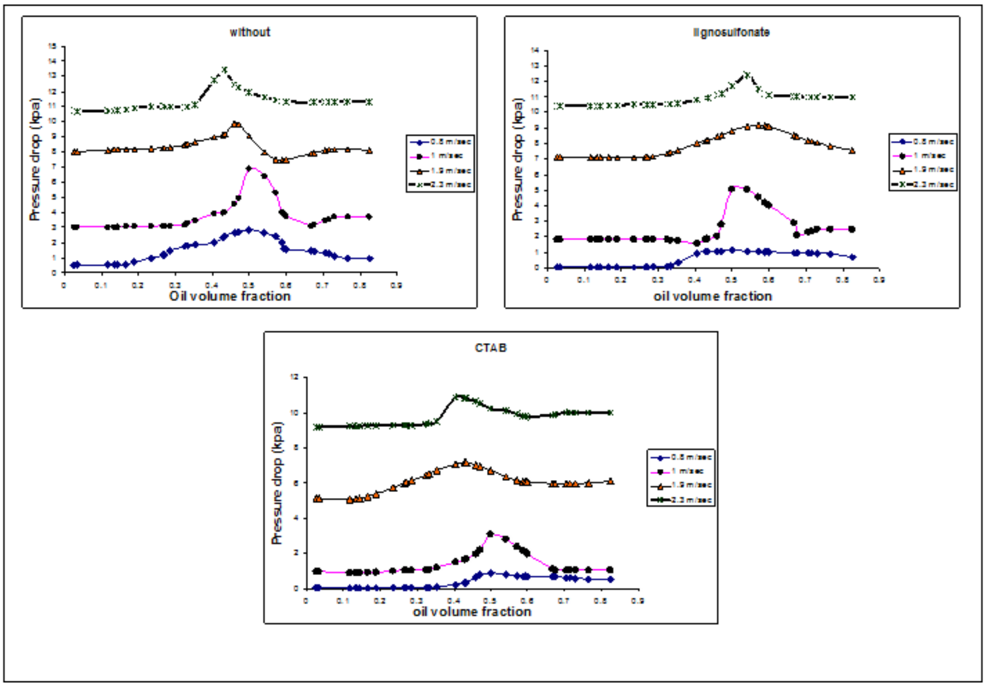

Figure 2: Pressure drop against oil fraction at different mixture flow rates for three systems

4. Effect of additives

The effect of additives on inversion point in oil-water two-phase flows along the horizontal pipe flow was studied by adding small concentrations of surfactant (CTAB and SLS) to the water phase respectively.

Figure 3 shows the pressure drop as a function of oil volume fraction for mixture velocity (0.8, 1, 1.9, 2.3 m/sec). These figures show the inversion point for all system with and without surfactant at each mixture velocity.

It is obviously shown from these figures that the phase inversion nearly constant at low mixture velocities (0.8 and 1) m/s while it shows an isotropic behavior at higher velocities (1.9 and 2.3) m/s. For SLS addition, the dispersion becomes less stable and phase inversion point is shifted forward from 0.5 oil fraction to 0.54 oil fractions comparing with that in case of without addition.

It is well known that surfactant acts an equal ratio between the polar and nonpolar portions. When placed in an oil-water system, the polar groups are attached to water, while nonpolar groups are oriented to the oil. Surfactant classified into three groups according to the type of polar group; cationic, ionic and nonionic surfactant. The mechanism of surfactant depends mainly on lowering the interfacial tension between oil and water phase. Indeed, some of them keeps the drops of oil in water by charging their surfaces that reduce the physical contact between drops.

SLS is one of the anionic surfactant types. Its solution in water is high molecular weight polyelectrolyte and sub collided.

They are not effective in lowering interfacial tension as shown in Table 1. Therefore, the main mechanism is that SLS adsorbed at oil-water interface establishing a semi-rigid film on oil drops which would prevent coalescence of of surfactant (CTAB and SLS) to the water phase respectively.

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So the main mechanism is that SLS adsorbed at oil-water interface establishing a semi-rigid film on oil drops which would prevent coalescence of drops. Indeed, they charged these drops to reduce the physical contact between drops reducing their potential of coalescence. Thus, higher dispersed phase volume fraction will thus be needed for inversion to occur.

The addition of CTAB shows different behavior in which the phase inversion shifted downward (0.4 oil fraction) comparing with no addition case. CTAB is one of the cationic surfactant types, its positive charge allowed it to adsorb on the interface where it act to lower the interfacial tension and to elicit Marangoni stresses. This effect slows down the drainage of the continuous phase film between two opposing droplets, which is an essential step leading to coalescence of oil droplet leading to decrease in dispersed phase fraction that required for inversion to occur.

5. Conclusion

In this work, it was observed that the presence of surfactant has a significant influence on phase inversion point at high mixture velocities, in a way of tending to favor one type of dispersion over the other. At low mixture velocity, the phase inversion point was unaffected by increasing mixture velocity or by surfactant addition.

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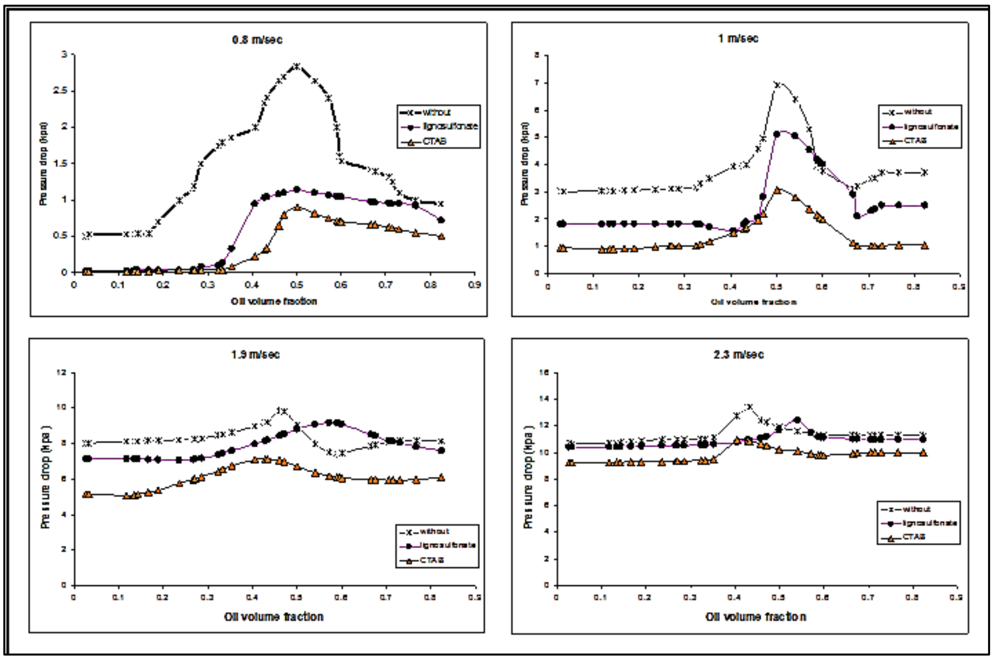

Figure 3: Pressure drop against oil fraction at different mixture velocities

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