OPTIMIZING VISCOUS FLOW IN PIPES THROUGH IMPROVED FLOW CONDITIONS AND CHEMICAL INJECTIONS

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ABSTRACT

Tests are carried out in three different pipe diameters (1,1½ and 3 inch), using four different surfactant types (SDBS, SLES, GEM, and NPH). The effects of oil flow rate, surfactant concentration, pipe diameter, and surfactant type have been experimentally investigated.

Percent drag reduction (%DR) for SDBS anionic surfactant reached up to 56.5%, thus it has been considered as an optimum one between the other types of surfactants used. Anionic surfactants gave higher percent drag reductions than non-ionic surfactants. Explanations for the drag reduction mechanism have been presented. And the presented data should be useful in possible field applications, in order to increase the flow capacity for the Iraqi crude oil transportation pipelines system.

INTRODUCTION

Drag Reduction, as defined by Savins[10], is the increase in pumpability of a fluid caused by the addition of small amounts of an additive to the fluid. The effectiveness of a drag reducer is normally expressed in terms of percent drag reduction. At a given flow rate, percent drag reduction is defined as:

$$\%DR = \frac{\Delta P - \Delta P_S}{\Delta P} \times 100 \qquad (1)$$

where ΔP is the base pressure drop of the untreated fluid, and ΔP_S is the pressure drop of the fluid containing drag reducer.

Percent drag reduction is a measure of drag reducing additive performance, but it does not reflect the primary end use of drag reducers. Normally, the increase pumpability is used to increase flow rate without exceeding the safe pressure limits within the flow system. The relationship between percent drag reduction and percent throughput increase can be estimated using the following equation[3]:

$$\%\text{Throughput increase} = \left[\left(\frac{1}{1 - \frac{\%DR}{100}}\right)^{0.55} - 1\right] \times 100 \qquad (2)$$

where %DR; is the percent drag reduction as defined in Eq. (1). Equation (2) assume that pressure drop for both the treated an untreated fluid is proportional to flow rate raised to 1.8 power.

Drag reduction may occur from one of two types; the extension of laminar behavior to abnormally high Reynolds numbers (turbulent suppression) or the reduction of friction in fully developed turbulence (wall layer modification). If the second behavior begins at low Reynolds number it will be difficult to distinguish it from the first one, unless the transition to a higher friction factor occurs finally (indicating the first type of behavior).

Drag reduction occurs only in turbulent flow, and it play an important role in different industrial applications such as; fire fighting, irrigation, sewage and floodwater disposal, hydrotransport of solids, water heating circuits, jet cutting, hydraulic machinery, marine applications, biomedical applications, and in petroleum transportation process like the large application of chemical additives to reduce the drag in Trans Alaska Pipeline system (TAPS).

Drag reduction is a phenomenon exhibited by many Newtonian and psedoplastic solutions, gells, and suspensions, and it can be considered as a departure from their "normal" viscous behavior. In general, polymers and soap solutions (particularly surfactants) are used as drag reducer. But because of their toxicity and highly cost raw materials, the use of polymers are limited gradually.

During the Second World War, the use of surfactants is begun with the first use of aluminum soaps [1,6]. Since then, a number of other soaps have been reported to produce drag reduction. Furthermore, there are only few studies involve more than one surfactant type.

The main object of this work is to select the best surfactant type and concentration that gives the highest percent drag reduction (i.e., optimum concentration), and to study the effects of pipe diameter, flow rate, and surfactant type and concentration on drag reductions, also to study the basic fundamentals that cause the drag reduction phenomenon. A further object of this work is to establish some understanding between anionic and non-ionic surface-active agents.

EXPERIMENTAL WORK

Four types of surfactants have been used in this work. Three types of them are anionic (SDBS, SLES, GEM), while the fourth one is non-ionic (NPH). The effects of surfactant type, pipe diameter, surfactant concentration, and flow rates have been investigated using a closed flow loop laboratory system.

The schematic diagram of the flow system is shown in Fig. (1), which includes the basic elements of the experimental apparatus: oil reservoir tank, pumps, Q.V.F. container, pipes, Mixer, and manometers. The main characteristics of these experimental apparatus are described in Reference [8].

Thirteen sets of experiments are carried out. Each set comprises various surfactant concentrations for a certain pipe diameter and about (6-10) data points (pressure drop vs. flow rate) are obtained for each one of these concentrations. Except the first set, (6-10) data points are obtained for each one of the three pipe diameters (1,1'/2, and 3 in. diameter) respectively and without any chemical additives. The summary of runs carried out is given in details in Reference [8].

RESULTS AND DISCUSSION

Figures (2 to 5) shows the percent drag reduction as a function of fluid velocity for 1½ inch diameter at different surfactant types, and concentrations. These figures show an increase in the drag reduction as the fluid velocity increased. Then at certain velocity, the drag reductions start to decrease slightly with increasing velocity. Determination of the drag reduction at limiting value of Reynolds number (which depends upon the size of the pipe) could be attributed to two reasons:

1. Degradation, that eventually occurred as a result of oxidation.
2. The pressure drop of the untreated crude oil increased very rapidly, while that of treated crude oil increased very slowly.

The previous results agreed very well with the results of Elson & Garside [2], Lescarboura et.al. [3], and Sarem [9].

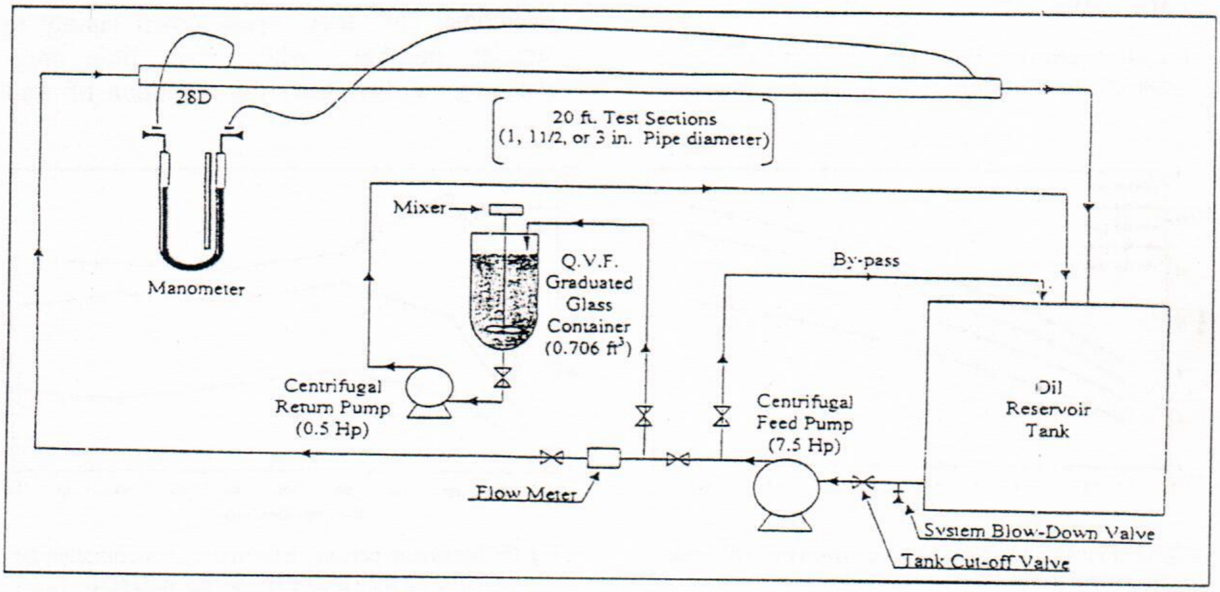


Fig. (1) A Schematic diagram of the flow system

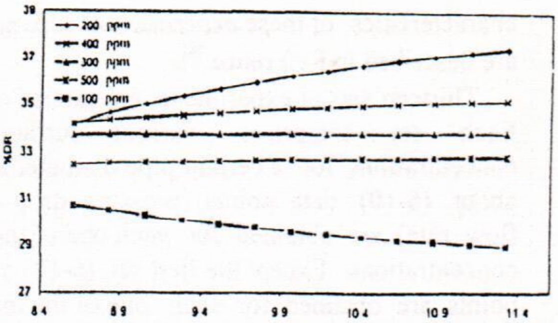


Fig. (2) Percent drag reduction vs. velocity for different concentrations of SDBS surfacant, 1½ inch diameter

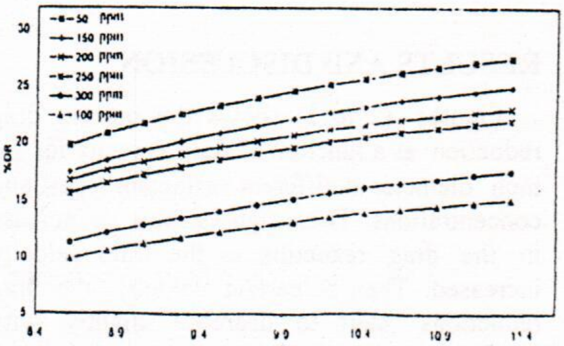


Fig. (3) Percent drag reduction vs. velocity for different concentrations of SLES surfacant, 1½ inch diameter

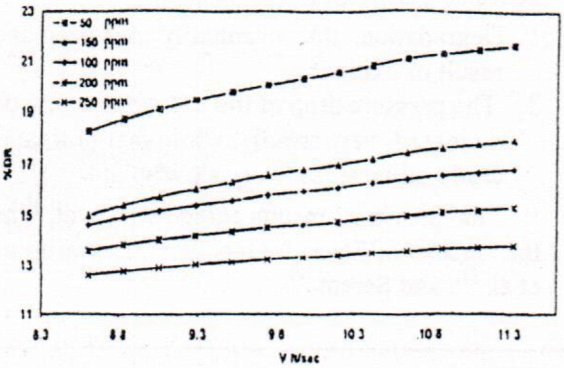


Fig. (4) Percent drag reduction vs. velocity for different concentrations of GEM surfacant, 1½ inch diameter

The effect of concentration is studied by adding small quantities of the surfactant to the crude oil. Figures (6 to 9) show the percent drag reduction and the percent flow-increase as a function of concentrations of SDBS and NPH surfactants for different pipe diameters.

Figures (6 and 7) show the percent drag reduction and the percent flow increase respectively as a function of SDBS surfactant concentration. In this test, five concentrations are used (100-500 ppm) using three pipe sizes (1,1½ and 3 inches). These figures show that %DR and %FI are increased as the concentration of the surfactant increased until a limited value. Optimum %DR and %FI values over the whole range of concentrations used is observed at 100 ppm for 3-inch diameter and at 200 ppm for (1½ and 1) inch diameters. And for NPH surfactant, Figures (8 and 9) show that the optimum %DR and %FI values are obtained at 50 ppm for 3-inch diameter and at 100 ppm for (1½ and 1) inch diameters. These results could be attributed to the following conclusions:

As the surfactant concentration increased, higher shear stress is needed to break down the micellar structures, and at lower velocities, the more concentrated solutions or (the more viscose fluids) give less drag reductions. Also, the time and shear degradation effects are very important for the law concentrations, while at high concentrations there are no aging effects, but there can be a temporary loss of drag reducing ability if the solutions are badly sheared. Because the (forces that hold soap agglomerates together) are apparently overcome and they break down rapidly to smaller particles which have little drag-reducing ability, then the reduction of wall

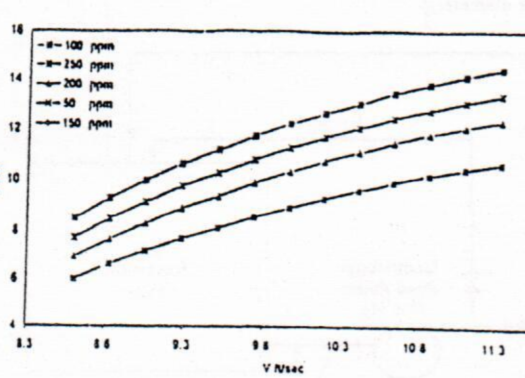


Fig. (5) Percent drag reduction vs. velocity for different concentrations of NPH surfactant, 1½ inch diameter

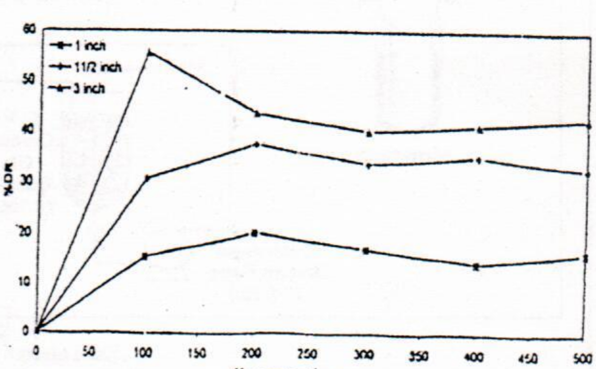


Fig. (6) Maximum percent reduction vs. concentration for different pipe diameters, SDBS surfactant

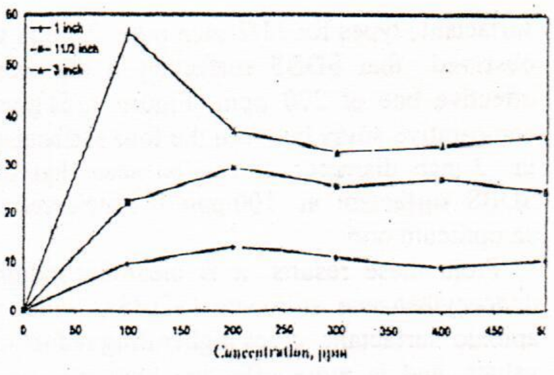


Fig. (7) Maximum percent flow increase vs. concentration for different pipe diameters, SDBS surfacant

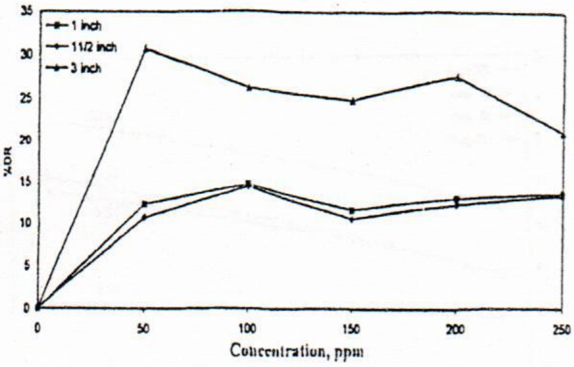


Fig. (8) Maximum percent drag reduction vs. concentration for different pipe diameters, NPH surfacant

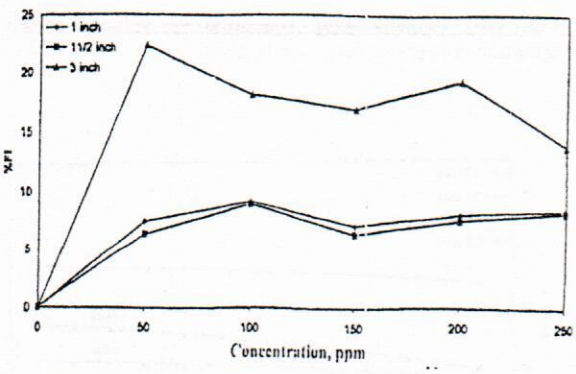


Fig. (9) Maximum percent flow increase vs. concentration for different pipe diameters, SDBS surfacant

shear stress below the critical values allows the agglomerates to reform and results in restoration of the drag-reducing character of the solution. Thus, mechanical degradation for these systems appears to be reversible.

The results agreed very well with the result of McMillan et. al. [5], Zakin et. al. [12], and Mansour-Aswad [4].

Figures (10 to 13) show the friction factor as determined by Jain's formula and %DR versus Reynolds number including the effects of surfactant type, pipe diameter, and concentration. These f-NRe relationships are plotted for each pipe diameter at the optimum concentration.

Figures (10 and 12) show f-NRe relationships for SDBS and NPH surfactants for different pipe diameters at the optimum concentrations, which is different from one size to another. As Reynolds number increases the corresponding friction factor decreases for certain pipe diameter.

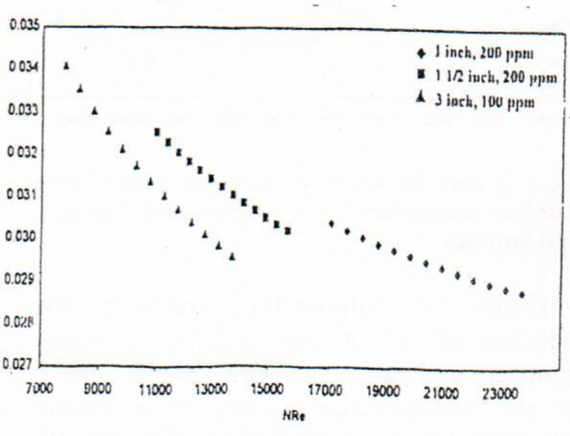
The %DR-NRe figures are plotted for each pipe diameter at the optimum concentration. Figures (11 and 13) show %DR-NRe relationships for SDBS and NPH surfactants for different pipe diameters at the optimum concentrations, which is also different from one size to another. At a certain pipe size, as Reynolds number increases the drag reduction increases too until reaching some limited values.

At a certain Reynolds number value, the smaller diameter gives higher friction factor values, which it means that they give higher values for pressure drops due to the friction. Consequently, they give higher drag reduction values as compared with the larger inside pipe diameter.

These finding agreed very well with the observations of Osterhout & Hall [7], White [11], Elson & Garside [2], and Mansour-Aswad [4].

This increase in drag reduction with increasing pipe diameter is attributed to the following reasons:

1. Difference in pipe wall roughness.
2. Differences in surfactant properties during the continuous re-circulation, due to shearing or temperature changes.



Fig(10) friction factor vs. Reynolds number at the optimum concentrations for different pipe diameters, SDBS surfactant.

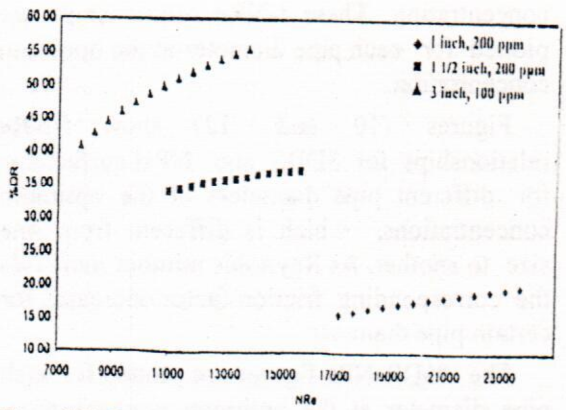


Fig (11) Drag reduction vs. Reynolds number at the optimum concentrations for different pipe diameters, SDBS surfacant.

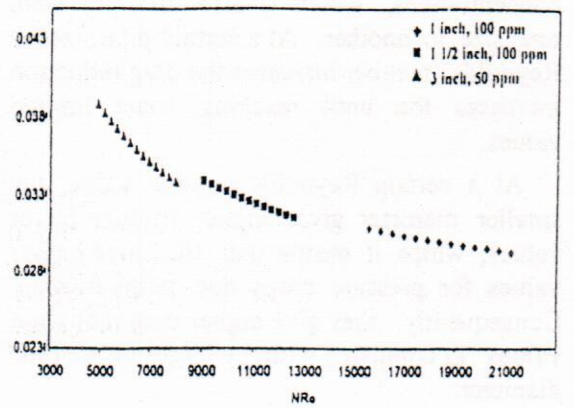


Fig. (12) Friction factor vs. Reynolds number at the optimum concentrations for different pipe diameters, NPH surfacant.

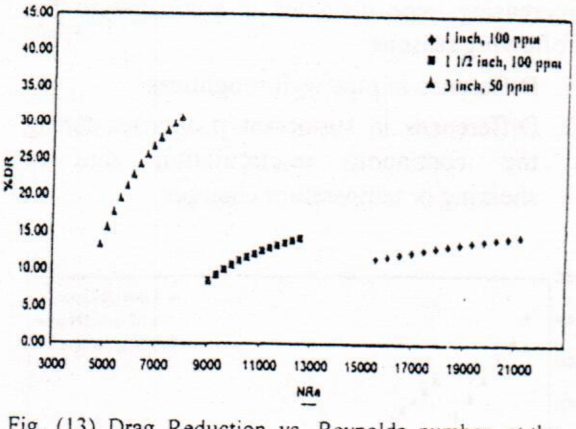


Fig. (13) Drag Reduction vs. Reynolds number at the optimum concentrations for different pipe diameters, NPH surfacant.

Figure (14), shows the increase in drag reduction as velocity increased for 1 inch pipe diameter and different surfactant types at various concentrations thus, at a certain velocity %DR for SDBS surfactant at 200 ppm concentration is higher than the others. Figure (15) shows comparative study between four surfactant types for 11/2-inch pipe. It could be observed that SDBS surfactant is the more effective one at 200 ppm. Figure (16) gives comparative study between the four surfactants in 3-inch diameter. It can be seen that the SDBS surfactant at 100 ppm is considered as an optimum one.

From these results, it is clear that sodium dodoecylbenzene sulfonate (SDBS), which is anionic surfactant gives higher drag reduction values and is more effective than the other surfactants at the optimum concentration. While NPH surfactant (Nonyl Phenol), which is non-ionic has lower drag reduction values.

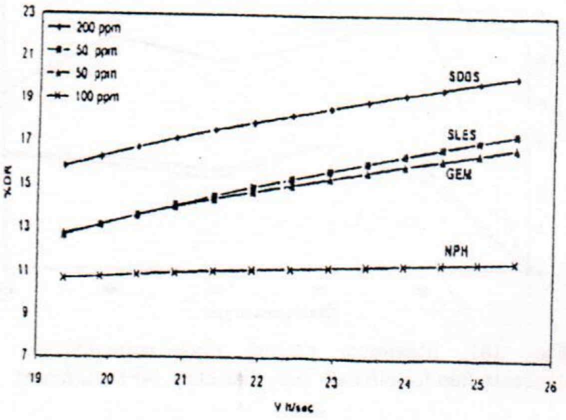


Fig. (14) Percent drag reduction vs. velocity at the optimum concentrations, 1-inch diameters.

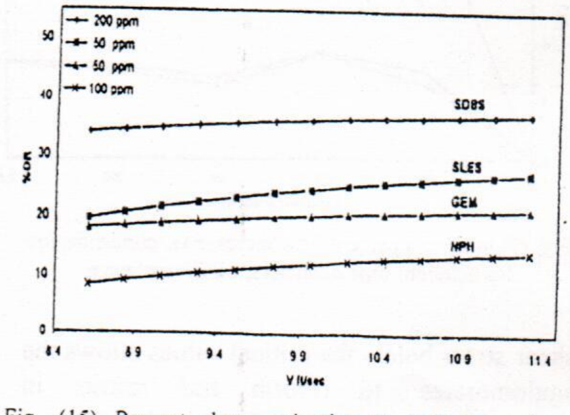


Fig. (15) Percent drag reduction vs. velocity at the optimum concentrations, 1½ -inch diameters.

Comparisons between more than the one-surfactant type especially between ionic and non-ionic surfactants are very rare in the literature. However, these results may be attributed to molecular weight variations between anionic and non-ionic surfactants or between the anionics themselves. Also it may be due to the shear stability of micelles structure or (the shape of the micelles) which gives the surfactant higher stabilities against shear forces as a result of rod-shaped micelles forming.

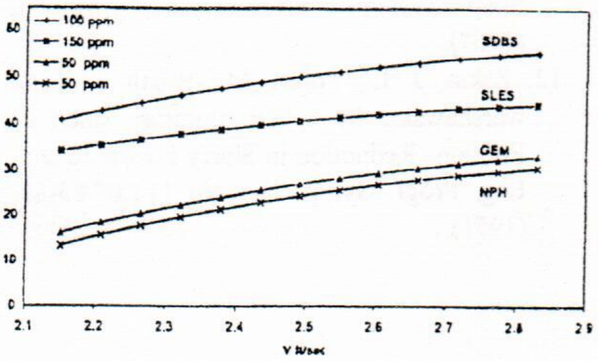


Fig. (16) Percent drag reduction vs. velocity at the optimum concentrations, 3-inch diameters.

CONCLUSIONS

1. Percent drag reduction (or percent flow increase) are increased as oil flow rates increased up to certain limits of velocity (i.e., the maximum velocity). Beyond these velocities, percent drag reduction (or percent flow increase) has been decreased gradually.
2. For each surfactant type, percent drag reduction is increased with increasing surfactant concentration up to a certain limit (i.e., an optimum concentration). Beyond this concentration, percent drag reduction is mostly decreased.
3. For all surfactants used and at a constant Reynolds number, lower friction factors are obtained for larger pipe diameters. Or higher percent drag reductions (or percent flow increases) are obtained for larger pipe diameters.
4. A value of 50 ppm and/or 100 ppm (i.e., 0.005% and/or 0.01%) surfactant concentration was enough to cause friction reduction for the selected Iraqi crude **oil.**
5. The drag reducing properties could be explained by the interaction of surfactant micelles with the crude oil, which allows the turbulence to be suppressed.
6. Anionic surfactants gave higher percent drag reductions (or percent flow increases) than non-ionic surfactants at their optimum concentrations. This could be attributed to the stability of anionic surfactants against shear stresses.
7. SDBS anionic surfactant and NPH non-ionic surfactant gave higher percent drag reductions (or percent flow increases) at lower concentrations in larger pipe diameters.
8. By using SDBS surfactant (which is made in Iraq) with Iraqi crude oil, the flow rate in pipelines could be increased up to 56.5% without making any change in the flow system design. Therefore, the cost of pumping crude oil could be reduced by an appreciable percentage.
9. For each surfactant type, percent flow increase is increased as surfactant concentration is increased up to a certain limit (i.e., an optimum concentration). Then, percent flow increase is mostly decreased.

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