ISSN 1996-3386

Asian Journal of Industrial Engineering

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Asian Journal of Industrial Engineering 2 (1): 17-27, 2010
ISSN 1996-3386 / DOI: 10.3923/ajie.2009.1.11

Drag Reduction Improvement in Two Phase Flow System Using Traces of SLES Surfactant*

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Abstract: In the present research, Sodium Lauryl Ether Sulphate (SLES) was investigated not only as a drag reducing agent for two phase system (solid-liquid). It is desired to divide the present study into two consequence steps which are, the addition of small amounts of solid particles that can be suspended in liquid used (kerosene), these suspensions may be used as drag reducing agents, then the other step is established by the addition of small quantities of certain surfactant to the suspension transported. The results showed that, percentage drag reduction (Dr%) increases by increasing the suspended particles concentration, suspended particle size, Surfactant concentration and solution velocity (Reynolds No.). Maximum Dr% of 34% was obtained using 1500 ppm of Sand powder suspended in Kerosene and pumped within maximum flow rate. This maximum percentage was increased to 44% by the addition of SLES with concentration up to 600 ppm with the same conditions above.

Key words: Drag reduction, surfactants, two phase flow, suspended solids, friction

INTRODUCTION

Power saving is the major headline for many investigations that deals with drag reduction. The word drag may be defined as the resistance force parallel to the direction of fluid flowing over a solid surface. Drag force may be expressed by two components: skin friction component which is equal to the stream wise component of all shearing stresses over the surface and pressure drag component which is equal to the stream wise component of all normal stresses.

In the last century, power sources and cost became one of the major problems facing the world. One of these problems was the losses of pumping power in pipelines carrying liquids, especially the pipelines that deal with crude oil and refinery products transportation.

In liquid transportation through pipelines, the addition of small amounts of chemical additions (generally polymers or surfactants) to the flowing liquid in turbulent mode, will lead to the reduction in pressure drop which is a clue to the power saving made in the system. The efficiency of these additives was proven in many investigations carried out by many authors. In the same time, a new technique with a new drag reducing agent was introduced. This new technique depends on the addition of small amounts of solid particles to flowing liquid in turbulent manner through pipelines. The addition of these particles showed excellent ability of improving the flow in pipelines and vanished one of the major assertions in the drag reduction technique by chemical addition which is solubility of the addition the transported liquid, where, it was assumed before that the drag reducer must be soluble or at least has the ability to penetrate or its molecules reorient in the transported liquid to be affected. This behavior suggested new and merely independent mechanism to explain the drag reduction phenomena (Fossa and Tagliafico, 1995).

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**Originally Published in Asian Journal of Industrial Engineering, 2009*

Numbers of investigations were carried out in the past few years to study the effect of suspended solids on the flow behavior of liquids. Vaseleski and Metzener (1974) proposed an analysis of the velocity profile and pressure drop relationship for turbulent flow fiber suspension though smooth tubes. Their investigation was carried experimentally over a range of flow rates, tube size, fiber concentration, fiber geometry and fiber type (nylon and asbestos). Surfactants in aqueous solution were also used to disperse both fiber types. Their results showed an increase in the drag reduction with increasing the fiber concentration and within experimental accuracy, there were no clear effects of tube diameter.

Simon *et al.* (1963) studied the effect of adding small amounts of high molecular weight polymer to sewer systems to prevent overflow which might be considered as one of the most promising applications of drag reduction. They suggested that, a rapid increase of the discharge can prevent a local overflow during heavy rainfall in-often old-sewer systems with insufficient cross-section.

Hideo *et al.* (2000) investigated the drag reduction and heat transfer characteristics of the water suspension flow mixed with fine fibers in a circular straight pipe. They measured the velocity and temperature profiles in a circular pipe were made in order to examine the flow drag and heat transfer characteristics of the turbulent and laminar flow. They clarified that the flow condition of the pulp fiber water suspension differed from that of the surfactant solution. Furthermore, the previous estimation method for the nondimensional velocity distribution equation could be applied to the pulp fiber water suspension. Finally, they concluded that the enhancement effect of heat transfer in the laminar flow and the heat transfer reduction effect in the turbulent flow were elucidated by the heat transfer measurements for the pulp fiber water suspension. It was found that the phenomenon of heat transfer enhancement in laminar flow was dependent on the secondary flow by the circulation of the fibers or the lump of the fibers.

The studies carried out by authors like Pereira and Pinho (2002), Helland *et al.* (2007), Inaba *et al.* (1995), Lyn (1991) and Sher and Hetsroni (2006), gave a great contribution to the understanding of the drag reduction mechanism with suspended solids.

Lim *et al.* (2005) derived a modified Reynolds mean motion equation of turbulent fiber suspension and the equation of probability distribution function for mean fiber orientation. Their derived equations and successive iteration method were verified by comparing the computational results with the experimental ones. Their obtained results showed that, the flow rate of the fiber suspension is large under the same pressure drop in comparison with the rate of Newtonian fluid in the absence of fiber suspension. The relative turbulent intensity and the Reynolds stress in the fiber suspension are smaller than those in the Newtonian flow, which illustrates that the fibers have an effect on suppressing the turbulence.

According to Wang *et al.* (1998), the resistance to flow is affected in two ways, i.e., by damping of the turbulence, which causes reduction in resistance and by increasing the viscous resistance. As a consequence, over rough boundaries, the resistance decreases due to damping of turbulence and over smooth boundary no drag reduction takes place as the two effects compensate each other.

Usui *et al.* (1995) investigated the heat transport system using the cationic surfactant (cetyltrimethyl ammonium chloride and oleyl-di-(2-hydroxyethyl)-methyl ammonium chloride) solution as a flow drag reduction additive. Furthermore, (Park *et al.*, 1996) examined the turbulent structure of the water solution with cetyltrimethyl ammonium chloride and they have elucidated the dispersion effect of the turbulence energy of the surfactant solution by means of the velocity distribution measurement in detail.

Nikora and Goring (2000) pointed out that turbulent open channel flows with mobile flat granular beds have complex boundary conditions due to effects of bed mobility and permeability. This may cause the structure of mobile bed flow to differ from that of fixed bed flows. They observed a decrease in the value of von Karman constant k for flow with weak mobile bed.

MATERIALS AND METHODS

Liquid Circulation System

Figure 1 shows a schematic diagram of a build up liquid circulation system used in the present investigation. Generally, this system consists of reservoir tank, pipes, valves, pump, flow meter and U-manometer. The reservoir tank used was supported with two exit pipes. The first exit pipe (0.0381 m I.D.) was connected to the entrance of the pump (3.0 hp, 6.5 m^3 h^{-1} maximum flow), while the other exit pipe (0.0127 m I.D.) was used as draining exit, the outlet pipe from the pump (0.0381 m I.D.) was separated into two sections, the first section returns back to the reservoir tank as by-pass (this pipe was supported with a ball valve to control the flow rate), while the 2nd section will form the testing section investigated. the testing section was divided into three sections, the first one starts with a ball valve and a 2.5 m long pipe (0.0381 m I.D.), this section was needed to accomplish a fully developed flow after entrance according to the relationship:

$$Le = 50\ D \tag{1}$$

Then, a 2 m long pipe is placed with two tips at the beginning and the end of it; these two tips were used for the pressure drop measurements. Finally, the 3rd part of this piping system, where the pipe returns back to the reservoir tank in a complete closed loop system. A flow meter (10 m^3 h^{-1} maximum reading) was connected to the system for the flow rate measurement as shown in Fig. 1. Finally, the pressure drop with both ends connected to two tips at the beginning and the end of the testing section.

Materials Investigated

Suspended Solids

Two types of solid materials were used as suspended solids (Alumina and Sand). These two types were selected due to the high difference in the physical properties as with the density ($\rho_{sand} \approx 2500$ kg m^{-3}, $\rho_{alumina} \approx 4000$ kg m^{-3}) and other properties to have a clear effect of the solid material type.

Drag Reducing Agent

The additive used in the present investigation was Anionic surfactant (Sodium Lauryl Ether Sulfate, SLES). SLES [CH_3 (CH_2)10 CH_2 (OCH_2CH_2)3 OSO_3- Na^+] is a sulfated ethers surfactant. It is a white gel material with a molecular weight of 372 g $gmol^{-1}$ and an active substance of 76%.

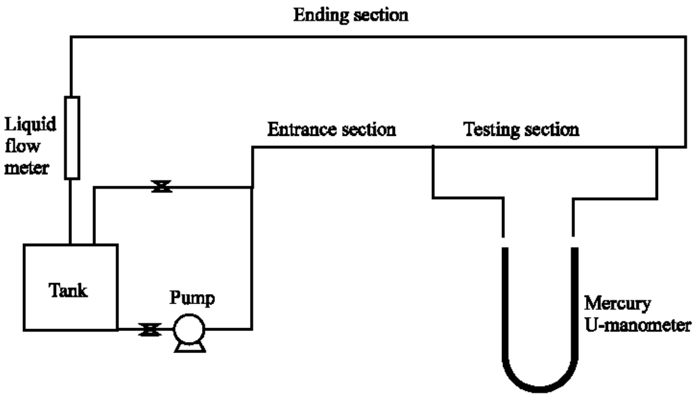

Fig. 1: Schematic of the flow system

Table 1: Physical properties of kerosene

Test	Kerosene	Test methods
Specific gravity at the rate of 15.6°C	0.7887	ASTM D-1298
API at the rate of 15.6°C	47.9	ASTM D-1298
Flash point (°C)	44	ASTM D-93
Viscosity at the rate of 20°C (C_{st})	1.6	ASTM D-445
Aniline point (°C)	60	ASTM D-86
Initial boiling point (°C)	151	ASTM D-86
End point (°C)	258	ASTM D-86

SLES is an anionic surfactant made from alcohol ether sulfates [$R(OCH_2CH_2)n\ OSO_3\ m+$], sulfated with chloroculfonic acid or SO_3 and then neutralized with sodium hydroxide to give the desired product (SLES)

Transported Liquid

The transported liquid used in the present investigation was commercial Kerosene. The physical properties of kerosene are shown in Table 1.

Experimental Procedure

All the experiments were carried in a constructed liquid circulation system, testing different variables, which are:

- Suspended solids type (Sand and Alumina)
- Suspended solids particle diameter (400 and 800 μm)
- Suspended solids addition concentration (600, 900, 1200 and 1500 ppm)
- SLES concentration (100, 200, 400 and 600 ppm)
- Solution flow rate (1, 1.5, 2.5, 3.5, 4.5, 5.5 and 6.5 $m^3\ h^{-1}$)

The experimental procedure starts by testing one of the selected suspended solids in certain concentration and particle diameter, mixing these solids with the transported liquid (kerosene).

The operation begins when, the pump starts delivering the solution through the testing section. The solution flow rate is fixed at certain value by controlling it from the by pass section. Pressure readings are taken to this flow rate. By changing the solution flow rate to another fixed point, pressure readings are taken again until finishing the desired values of flow rates. This procedure is repeated for transported kerosene before and after the addition of suspended particles and also after the surfactant addition with different concentrations to the suspended solution transported to test its effect on the drag reduction operation.

The average velocity V and Reynolds Number (Re) were calculated using the data observed from the experimental work (volumetric flow rate (Q)). Pressure readings through testing section before and after suspended solids and surfactant addition were needed to calculate the percentage Drag Reduction Dr% as follows (Virk, 1975).

$$\text{Dr}\ (\%) = \frac{\Delta P_b - \Delta P_a}{\Delta P_b} \times 100 \tag{2}$$

Fanning friction factor was calculated using the following equation:

$$f = \frac{\Delta P.D/4L}{\rho V^2/2} \tag{3}$$

RESULTS AND DISCUSSION

Effect of Fluid Velocity (Re) and Solid Particles Concentration

Figure 2 and 5 shows the effect of the transported fluid velocity on the percentage drag reduction (Dr%). The velocity (V) was represented by the dimensionless form of Reynolds Number (Re). Figure 2 and 3 shows the effect of (Re) on Dr% for kerosene transported with Alumina powder (400 and 800 μm) with different addition concentrations without any surfactant addition. Also, Fig. 4 and 5 shows the effect of (Re) on Dr% for kerosene transported with Sand powder (400 and 800 μm) with different addition concentrations without the addition of any surfactant.

From Fig. 4 and 5, it can be noticed that, the Dr% increases by increasing Re through the testing section. Increasing Re means increasing the degree of turbulence inside the pipe, which will provide the suitable media for the suspended solids to work properly. Also, Fig. 4 and 5 showed that Dr%

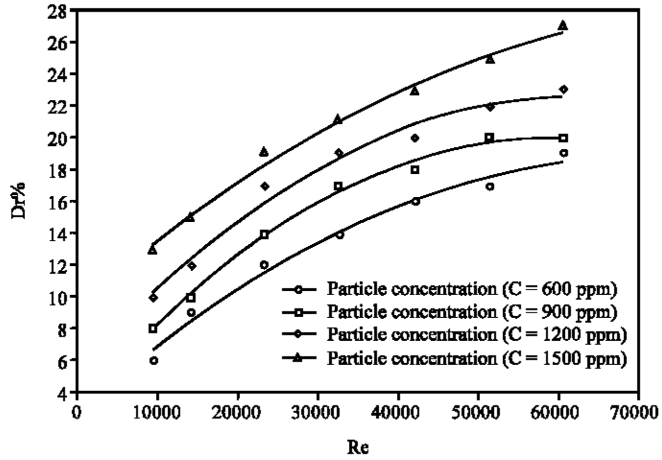

Fig. 2: Effect of Re on Dr% for transported kerosene with Alumina solid particles (400 μm) with different addition concentrations, as suspended solid and without any SLES addition

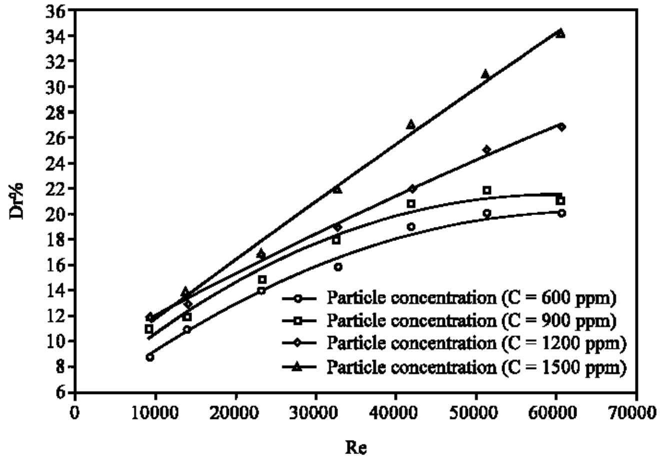

Fig. 3: Effect of Re on Dr% for transported kerosene with Alumina solid particles (800 μm) with different addition concentrations, as suspended solid and without any SLES addition

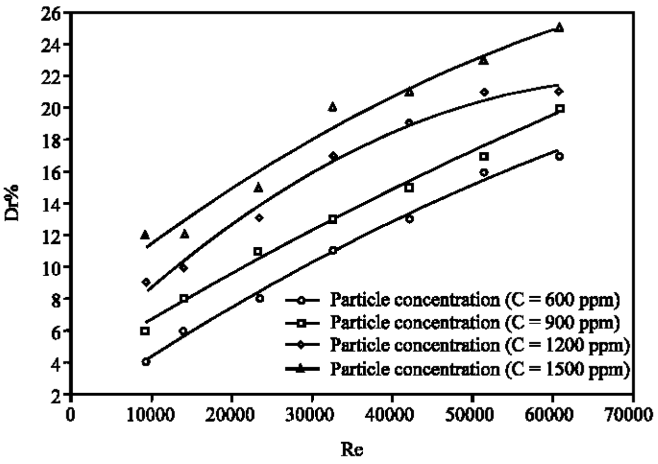

Fig. 4: Effect of Re on Dr% for transported kerosene with sand particles (400 µm) with different addition concentrations, as suspended solid and without any SLES addition

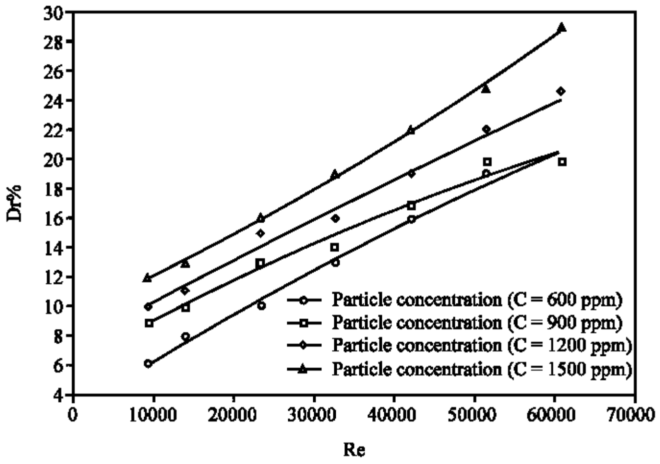

Fig. 5: Effect of Re on Dr% for transported kerosene with sand particles (800 µm) with different addition concentrations, as suspended solid and without any SLES addition

increases by increasing the solid particles concentration, which means increasing the number of solid particles involved in the Drag Reduction operation. In another words, within certain Re, increasing the solid particles concentration means increasing the turbulence spectrum that is under the particle effect. It is important to notice that, although Dr% increases with increasing the solid particles concentration, but its behaviour with Re at each concentration still the same.

Effect of Particle Size

Two sizes of solid particles were investigated during the present research (400 and 800 µm). Figure 6 and 7 shows a selected samples of solid particles size effect data. These results clearly shows that the Dr% of the solid particles with the size 800 µm is larger than that of the 400 µm (This comparison is made within the same operation conditions solid particle concentration, Reynolds number and particle type). This may be due to the large momentum needed to transport larger particles

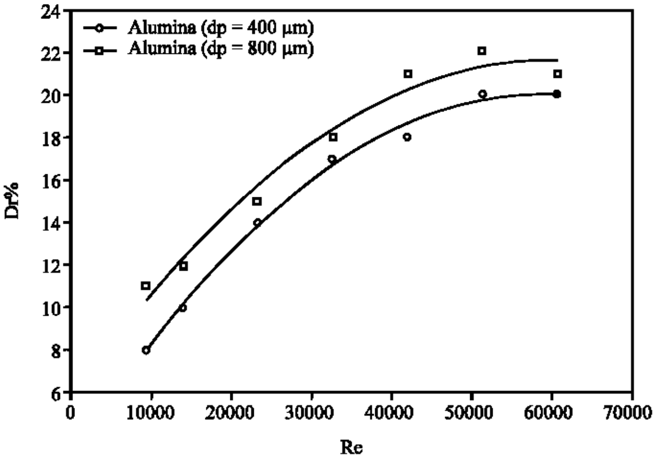

Fig. 6: Effect of changing the particle diameter (400 to 800 μm) on the Dr% for transported kerosene with alumina as suspended solid with different Re

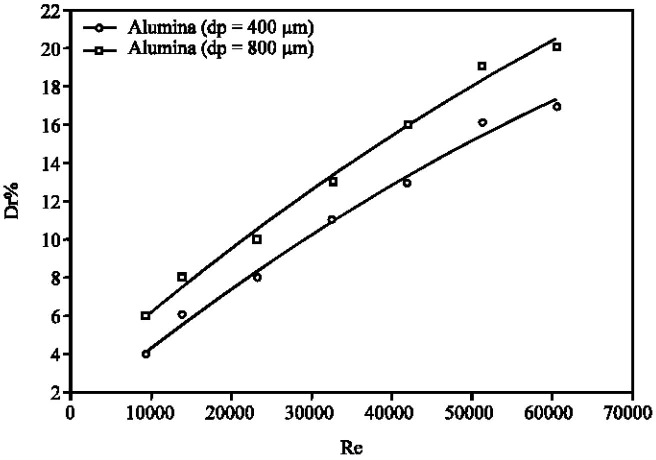

Fig. 7: Effect of changing the particle diameter (200 to 400 μm) on the Dr% for transported kerosene with sand as suspended solid with different Re

that make these particles not easily controlled by the turbulence but it play an opposite effect by decreasing the degree of turbulence and then the power dissipation made by the turbulence. It is harder to an eddy to make larger particles part of its shape during turbulent flow which will make those particles to behave as turbulence streaks breaking agent and that will lead to the fact that these particles will breakup the larger eddies to smaller ones which will result in increasing the Dr%.

Effect of Particle Type

Figure 8 and 9 shows a comparison in the Dr% values for selected samples data of the two types of suspended solids used (Sand and Alumina) within certain particle size and concentrations and at the same Re. It can be noticed that Dr% for Alumina powder is higher than that of sand powder. This may be due to the high difference between the two particles in physical properties, especially in density ($\rho_{sand} \approx 2500$ kg m^{-3}, $\rho_{alumina} \approx 4000$ kg m^{-3}) which will make the Alumina to have larger

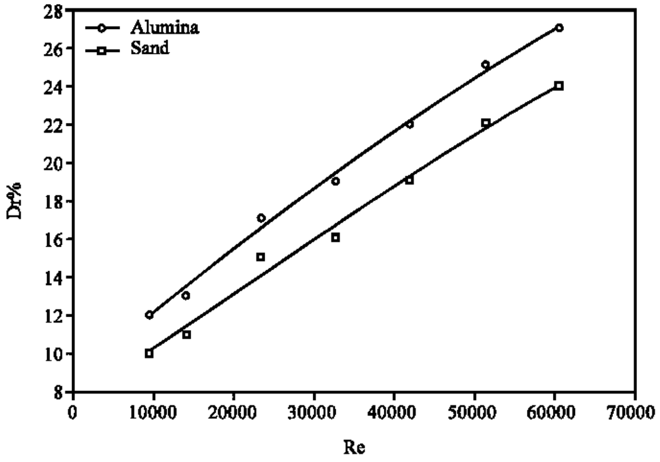

Fig. 8: Effect of particle type (Alumina and Sand) (800 μm) on the Dr% for transported kerosene with solid concentration of (1500 ppm)

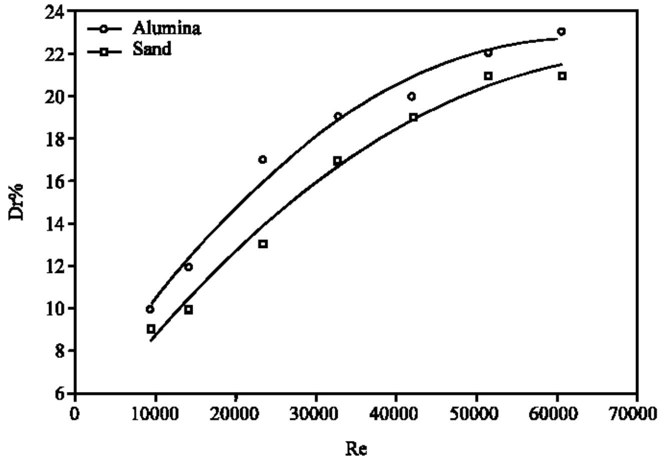

Fig. 9: Effect of particle type (Alumina and Sand) (400 μm) on the Dr% for transported kerosene with solid concentration of (1200 ppm)

effect on the turbulence inside the pipe, that whenever heavier particles are presented, the control of these particles by the turbulence will be harder which will not make these particles part of the turbulence structure, but, it will help to break the turbulent streaks and decrease the amount of power dissipated by turbulence.

Effect of Surfactant Addition

In the present investigation, the addition of SLES to the flow is to examine its effect on improving the flow (increasing Dr%). Figure 10 and 11 shows the effect of adding this SLES on the Dr% for a selected samples from the experimental data. It is clear that the addition of the surfactant improves the Dr% of the flowing suspensions. Also, Dr% was shown to increase by increasing the additive concentration reaching maximum values of 44% with concentrations up to 600 ppm of SLES in Kerosene-alumina suspension. This shows an increase about 22% when compared with 34%

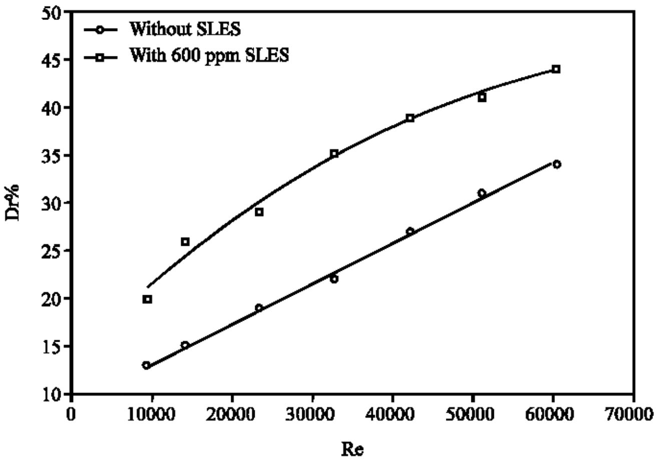

Fig. 10: Effect of adding 600 ppm of SLES on Dr% for kerosene-alumina suspension with solid concentration of 1500 ppm

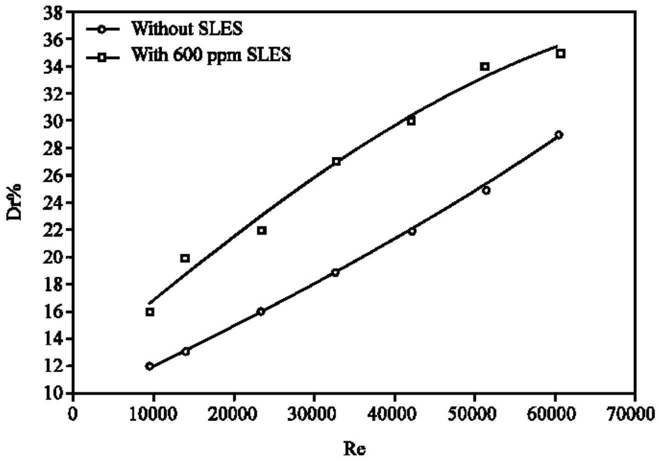

Fig. 11: Effect of adding 600 ppm of SLES on Dr% for kerosene-sand suspension with solid concentration of 1500 ppm

maximum Dr% of the same suspension within the same flowing conditions but without the surfactant addition. The same behavior was observed with the kerosene-sand suspension, that an increase in maximum Dr% of 34% was reported using 600 ppm of SLES with a 14% increase in Dr% compared with the same percentage but without the SLES addition (29%).

CONCLUSIONS

- Alumina and Sand solid particles were found to behave as good drag reducing agents.
- Dr% was found to increase by increasing Re, solid particles size and particles concentration.
- Dr% was found to increase by the addition of SLES surfactant. Also, it was found that Dr% Increases by increasing SLES concentration.

- The interaction between the suspended solution and the additives was successful in improving the flow and the solid addition drag reduction efficiency

GREEK SYMBOLS

ρ_g : Gas density (kg m^{-3})
λ_g : Gas no-slip hold up
μ_g : Gas viscosity (kg m^{-1} sec^{-1})
ρ_l : Liquid density (kg m^{-3})
λ_l : Liquid no-slip hold up
μ_l : Liquid viscosity (kg m^{-1} sec^{-1})
μ_{ns} : No-slip fluid viscosity (kg m^{-1} sec^{-1})
ν_{ns} : No-slip velocity (m sec^{-1})
Dr% : Percentage Drag Reduction
ΔP_a : Pressure drop after CDR101 addition
ΔP_b : Pressure drop before CDR101 addition
ν_{sg} : Superficial gas velocity (m sec^{-1})
ν_{sl} : Superficial liquid velocity (m sec^{-1})
τ_w : Wall shear stress (N m^{-2})
ρ_{ns} : No-slip fluid density (kg m^{-3})

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