



## SLES SURFACTANT AS DRAG REDUCING AGENT WITHIN GASOIL FLOWING THROUGH PIPELINES

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### ABSTRACT

Sodium Lauryl Ether Sulfate (SLES) with five different concentrations (from 50 to 100 ppm) were used as drag reducer. This surfactant was studied using gasoil with seven different fluid flow rates (from 1.9 to 4.5 m<sup>3</sup>/h) and a testing section length of 4 m. Percentage drag reduction ( $%Dr$ ) was found to increase by increasing the surfactant concentration and Reynolds number. Maximum drag reduction (45.5%) was achieved by using 300 ppm of SLES dissolved in gas oil for flow rate equals to 4.5 m<sup>3</sup>/h. Friction factor was calculated from the experimental data. For pure solvent; friction factor values lies near or at Blasius asymptote. While, by producing the surfactants into the flow, the friction factor values were positioned below Blasius asymptote towards Virk maximum drag reduction asymptote. Correlation equation was suggested for surfactant solutions. This correlation shows the friction factor as a function of Reynolds number ( $Re$ ) and surfactant concentration ( $C$ ). The results showed good agreement between the observed friction factor values and the predicted ones from the correlation equation.

### الخلاصة:

في البحث الحالي، تم اختبار نوع من "معاملات التوتر السطحي" SLES وبتراكيز مختلفة تتراوح من ٥٠ الى ١٠٠ جزء في المليون، كمعامل لتقليل الاعاقة في جريان زيت الغاز. حيث تم دراسة تأثير ذلك

المضاف عمليا في منظومة تدوير مغلقة ذات معدلات الجريان تتراوح ما بين ١.٩ الى ٤.٥ م<sup>٣</sup>/الساعة وبطول ٤م. اظهرت النتائج العملية ان نسبة تقليل الاعاقة ( $%Dr$ ) تتناسب طرديا مع كل من سرعة المحلول المدور الممثل بعدد رينولد ( $Re$ ) و تركيز المادة المضافة. وقد بلغت اعلى نسبة لتقليل الاعاقة ٤٥.٥ % بأستعمال ٣٠٠ جزء من المليون من مادة الـ SLES المذابة في زيت الغاز و بمعدل جريان ٤.٥ م<sup>٣</sup>/الساعة. بعد استخدام المضافات تم حساب معامل الاحتكاك ( $f$ ) من النتائج العملية و التي اظهرت ان قيم معاملات الاحتكاك للمشتق النقي تقع على او بالقرب من محاذي بلازييس. بعد استعمال المضافات الكيماوية، أظهرت النتائج ان معاملات الاحتكاك تقل باتجاه محاذي فيرك المقترح لاعلى درجات تقليل الاعاقة. معادلة ربط رياضية تم اقتراحها للمحالييل المدورة خلال المنظومة. هذه المعادلة بينت ان معامل الاحتكاك ( $f$ ) كدالة لكل من عدد رينولد ( $Re$ ) و تركيز المضافات الكيماوية ( $C$ ) و اظهرت النتائج تقاربا واضحا بين النتائج المستقاة من الجانب العملي من البحث و تلك التي ظهرت من المعادلة المقترحة.

## INTRODUCTION

Since the early forties, drag reduction has become an increasing interest in science and technical applications. Power saving is the major headline for many investigations that deals with drag reduction. Many techniques for reducing drag were suggested by many researchers for large number of applications. One of these techniques depends on suppressing turbulent eddies by using baffles with different heights in turbulent flow region, as in channel flow<sup>(1)</sup>. Other techniques used layers of greasy materials or bubble layers to reduce skin friction, as in some marine applications in ships<sup>(2)</sup>. One of the modern techniques in drag reduction is by the addition of minute quantities of chemical additives to liquids transported in turbulent flow through pipelines<sup>(3)</sup>. That in some cases, it is necessary to increase the transported liquid flow rate in built pipelines to avoid any extra costs and time spend on building new pipelines to have the same flow improvement needed. So, drag reducers were used to overcome this problem

Polymers and surfactants are the most popular chemical drag reducing agents in commercial applications. The commercial applications of polymeric drag reducers were established for crude oil transportation by many companies like CONOCCO and TAPS<sup>(4)</sup>. These applications showed the high ability of polymers in reducing drag and increasing oil flow rate without the need for any additional pumping stations or new pipelines. Also, these applications showed many disadvantages of using polymeric drag reducing agents, such as changing the transported liquid properties (especially viscosity) within certain limits of polymers concentrations and the polymer stability against high shear forces (shear degradation).



Surfactants were used as drag reducing agents in many commercial applications. The special configuration of the surfactants molecules plus their multiple personality, make it possible to overcome some of the polymers disadvantages. Surfactant molecules have the ability to form certain types of aggregates which are called “micelles”. These micelles do have the ability to reform their structure (regain their drag reducing ability) when the fluid enters lower shear regions.<sup>(1, 2)</sup> Also, surfactants are easier to handle during operation and commercially available. All these advantages made the surfactant to be preferred on many types of polymers in some commercial applications, especially with aqueous media<sup>(5)</sup>.

Even though a fully accepted theory behind the drag reduction does not exist<sup>(6)</sup>. The reason for the difficulty is the nature of the problem; it is a combination of physics, chemistry, rheology and hydrodynamic. The chaotic media that the drag reducer works in (turbulent flow), where masses of liquid moves randomly through the pipe in non-predictive manner and the absence of a modern technique to establish a clear mapping of turbulence inside the pipe made all the mechanisms suggested highly speculative and all have been subjected to criticism. However, the major categorize of drag reduction mechanisms suggested in the literatures were adsorption mechanism, structure mechanism and elasto-viscous mechanism<sup>(7-10)</sup>.

## EXPERIMENTAL WORK

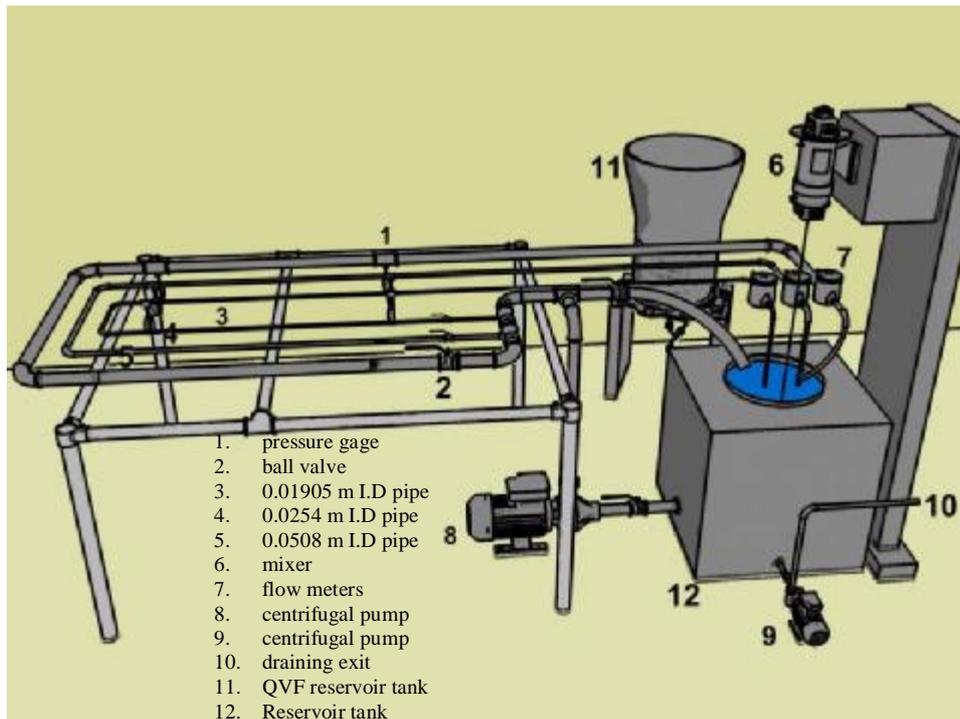
The flow system apparatus constructed in the present investigation can be seen from Fig. 1. The reservoir tank was supported with a 0.0508 m I.D. pipe connected to the main centrifugal pump which delivers the fluid to the testing sections. A carbon steel pipes of 0.01905 m I.D. were used in constructing the flow system.

The minimum entrance length required for a fully developed velocity profile in turbulent flow was calculated from the relationship suggested by Desissler<sup>(11)</sup>:

$$Le = 50 D \quad (1)$$

Therefore, the minimum entrance length for the present work according of the pipe diameter is 0.9525 m.

The testing section was 4 m long and it was away from the entrance according to pipe diameter. The reason to do that is to restrict the pressure drop measurements in fully developed region.



**Fig. 1 Schematic diagram of the closed loop circulation system**

One anionic surfactant was used in the present investigation as drag reducing agent for light gas oil which taken from Al-Dura Refinery. The SLES surfactant was taken from General Company of Vegetable Oil Industry.

The operation begins when the pump starts delivering the solution through the testing section. The solution flow rate is fixed at a certain value by controlling it from a bypass section and 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 seven desired values of flow rates.

Pressure drop readings through testing sections before and after drag reducer addition, were needed to calculate the percentage drag reduction  $\%Dr$  which calculated as follows <sup>(12)</sup>:

$$\%Dr = \frac{DP_b - DP_a}{DP_b} \quad (2)$$

Fanning friction factor was calculated using the following equation:



$$f = \frac{DP.D/4L}{r.V^2/2} \quad (3)$$

## RESULTS AND DISCUSSIONS

Figure 2 shows the effect of solution velocity ( $V$ ) on the percentage drag reduction ( $\%Dr$ ). The velocity component was represented by the dimensionless form of Reynolds number ( $Re$ ). Maximum  $\%Dr$  of 45.5% was established within additive concentration of 300 ppm. From this figure, it can be noticed that the percentage drag reduction increases by increasing  $Re$  (fluid velocity) through the testing section. Increasing the fluid velocity means increasing the degree of turbulence inside the pipe. This will provide a better media to the drag reducer (surfactant) to be more effective. In more details,  $\%Dr$  increases progressively with  $Re$  until reaching a certain range of  $Re$  where the  $\%Dr$  increase was slighter. This behavior may be explained due to relation between degree of turbulence controlled by the solution velocity and the additive effectiveness. Increasing the turbulence to certain limits (fluid velocity) mean improving the ability of the surfactant to reduce drag within these limits. This improvement was reflected by the progressive increase in  $\%Dr$  for the first range of  $Re$ . Further increase in  $Re$  showed that  $\%Dr$  reached its almost maximum values and the increase was slighter, which means that the turbulence reached a state where the drag reducer can no more be effective in the same degree as in the first range due to the very high shearing the drag reducer exposed to.

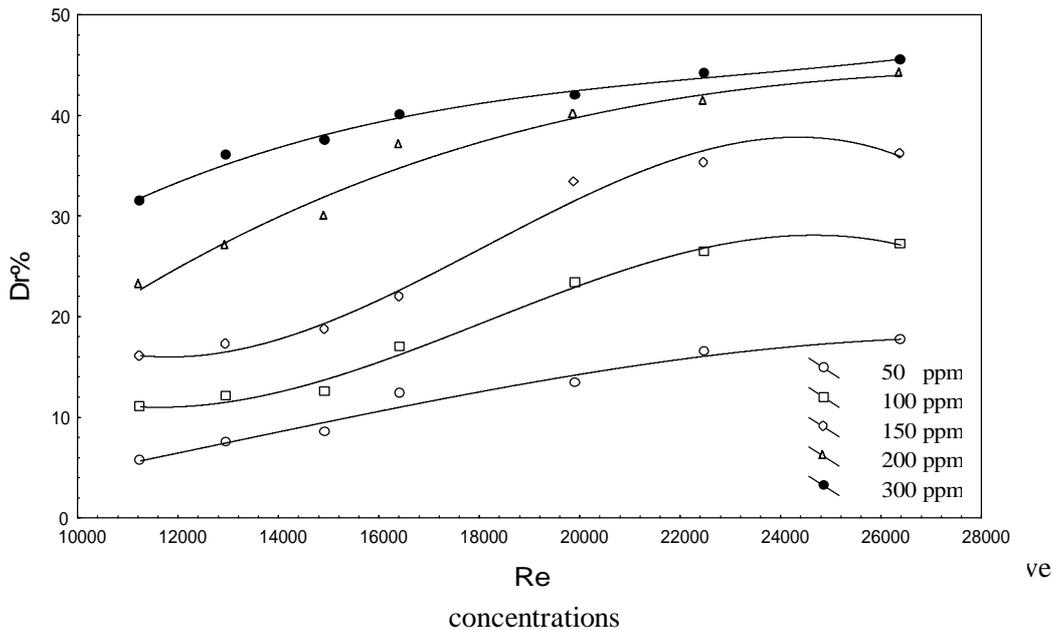
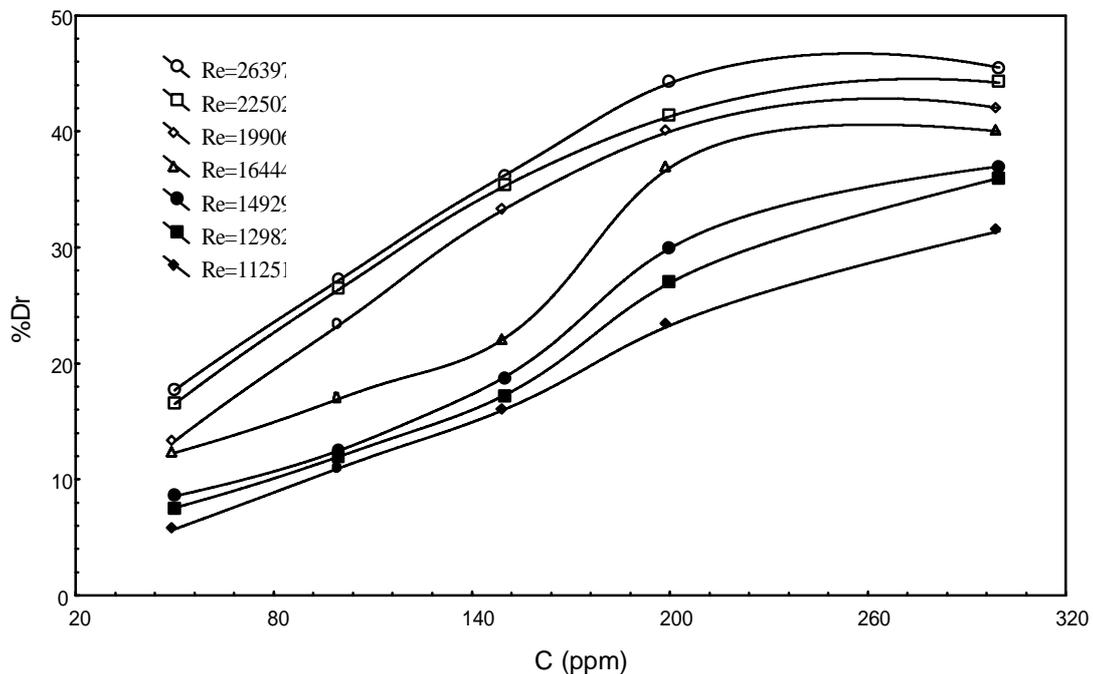


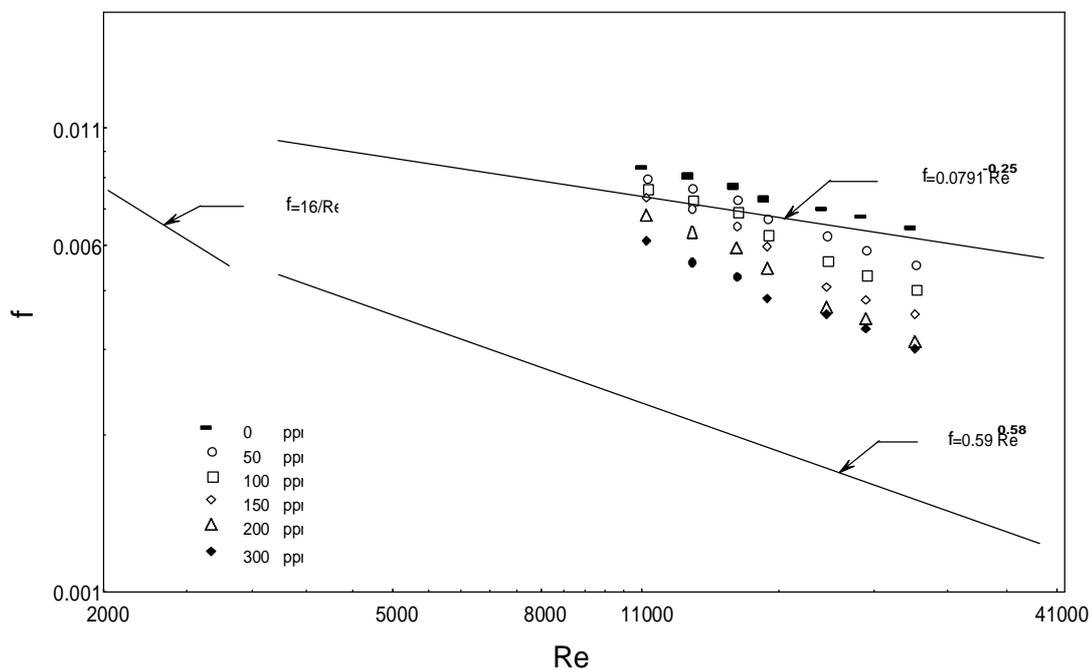
Figure 3 shows that %*Dr* increases by increasing the surfactant concentration. This means increasing the number of surfactant molecules involved in the drag reduction process. In other words, within certain *Re*, increasing the surfactant concentration means increasing the turbulence spectrum that is under the drag reducer effect. It is important to notice that, although %*Dr* increases by increasing the surfactant concentration, but its behavior with *Re* at each concentration still the same as reported before. Increasing the additive concentration during the drag reduction process is not unlimited. One of the important limitations of using drag reducer (especially within commercial application) is its effect on the apparent physical properties of the transported fluid. So, several tests were made on samples of gasoil solutions with different additive types and additive concentrations. These tests were made to ensure the validity of using SLES surfactant as drag reducer within hydrocarbon liquids without affecting the properties of the transported fluids. The results showed that, within the range of surfactant concentrations used (50 to 300 ppm), no noticeable change on the apparent physical properties of gasoil was reported.



**Fig. 3 Effect of additive concentration on percentage drag reduction within different Reynolds numbers**

Figure 4 shows the friction factor for various *Re* and surfactant concentration. It can be noticed that, when the surfactant concentration is zero (pure solvent), most

of the experimental data points are located at or close Blasius asymptote which give an indication that the starting points of the operation are close to that of the standard operation conditions suggested in the literatures. But when the surfactant is presented in the flow, the experimental data points are positioned in the direction of lowering friction towards Virk asymptote<sup>(13)</sup> that represent maximum limits of drag reduction, which will give the idea that, to reach such an asymptote, higher additive concentration and  $Re$  are needed. But, it must be considered that higher concentrations should not affect solvent properties.



**Fig. 4, Friction factor versus Reynolds number at different additive concentrations**

By applying the dimensional analysis using Buckingham  $p$  theorem<sup>(14)</sup>, the following non-dimensional relation was proposed:

$$F = a Re^b C^k \quad (4)$$

Least square method was used to determine the coefficients. This method was done by a computer program and the resulting equation is:

$$F = 1676.8 Re^{1.27} C^{0.11} \quad (5)$$

with variance equals to 0.951 and standard error of 7%.

## NOMENCLATURE

$a, b, k$	Constants in equation (4).
$C$	Concentration of surfactant (ppm).
$D$	Diameter of pipe (m).
$f$	Fanning friction factor (-).
$L$	Length of the pipe (m).
$Le$	Minimum entrance length for fully developed profile (m).
$Re$	Reynolds number (-).
$V$	Velocity of the fluid (m/h).
$r$	Density of the fluid ( $\text{kg/m}^3$ ).
$\%Dr$	Percentage drag reduction (-).
$DP$	Pressure drop in the pipe (kPa).
$DP_a$	pressure drop after drag reducer addition (kPa).
$DP_b$	pressure drop before drag reducer addition (kPa).

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