

## Experimental Study of Drag Reduction Phenomena within Pipe-Flow in a Closed Circuit System Using Surfactant Additives

**Dr. S. A. Alramadhni**

Chemical Engineering Department, University of Technology/Baghdad

Email: [Sahar\\_abd60@yahoo.com](mailto:Sahar_abd60@yahoo.com)

**Dr. N. J. Saleh**

Chemical Engineering Department / University of Technology/Baghdad

**Dr. G. A.R. Rassol**

Chemical Engineering Department, University of Baghdad/ Baghdad

### ABSTRACT

Pipe lines and tubes are used throughout the worlds for the economic transportation of crude oil, petroleum derivatives, gas and water. A drag reduction phenomenon within pipe flow in a closed circuit system was studying experimentally using Surfactant Additives.

Closed circuit system consist of two loops pipes (0.0254 m & 0.0508 m) ID respectively was constructed from carbon steel metal , total length of pipe was around 16 m and the test section was 4m. Similar closed circuit system consist of two loops of PVC pipes with the same diameters were also built. The idea of using PVC pipe was to be used inside carbon steel pipe to get smooth surface similar to using complaint coating like epoxy or polyethylene or poly vinyl chloride (PVC).

The effect of using two kinds of Anionic and Nonanionic surfactants (SDBS, POEA) Sodium Dodecyl Benzene Sulfonate and Polyoxyethylene Alcohol respectively were studied, Small amount of surfactant additives (50 ppm up to 300 ppm), were added to the solvent (kerosene) which was selected to be the fluid flow through the closed circuit system, choosing kerosene ( refinery product) to improve its flow (increasing flow rate).

A comparison between results obtained by carbon steel and PVC pipes were carried out. The best results obtained indicate that PVC pipe gave around (53% -66%) flow rate increase in kerosene compared with flowing in carbon steel pipe. On addition of additives for SDBS in kerosene improved flow rate about (61% to 69%).

**Key words:** Pipelines, Drag reduction, Flow rate, Surfactants.

تقليل قوة الاعاقة الناتجة عن جريان الموائع خلال نظام تدوير مغلق باستخدام  
مضافات مختلفة من معاملات الشد السطحي

### الخلاصة

يتم نقل النفط الخام والمنتجات النفطية بالإضافة إلى نقل الماء والغاز عبر استخدام خطوط الأنابيب حول العالم.

تم تشييد منظومة تدوير مغلقة مؤلفة من أنبوبين ذات أقطار مختلفة (0,0254 م و 0,0508 م) مصنوعة من معدن الكربون استيل (الفولاذ المقاوم للصدأ), الطول الكلي للأنابيب المستخدمة في

الدائرة الواحدة كان 16 م, طول المقطع المستخدم للاختبار كان 4 م, ومن ثم تم تشييد منظومة تدوير مغلقة اخرى من انابيب ال PVC وبنفس المواصفات, استخدام ال PVC للحصول سطح ناعم, والفكرة كانت استخدام انابيب ال PVC داخل انابيب الكاربون استيل لتحقيق تغطية وتغليف كامل للانابيب للحصول على سطح ناعم ودراسة تقليل قوة الاعاقة الناتجة عن الجريان وقياس نسبتها باستخدام هذا السطح مقارنة مع سطح انبوب الكاربون استيل الخشن, وبلاستعاضة عن استخدام انبوب داخل انبوب تم تشييد المنظومتين السابقة الذكر. هذا البحث يحقق في امكانية زيادة معدلات الجريان ونسبة تقليل الاعاقة في الجريان المضطرب لنوع من المشتقات النفطية (الكروسين) بمعدلات جريان مختلفة (2 الى 6 م<sup>3</sup> / ساعة), بالإضافة الى استخدام مضافات مختلفة من معاملات الشد السطحي الايونية و اللايونية ( SDBS , POEA ) صوديوم دودسيل بنزين سلفونيت, وبولي اوكسي اثيلين الكحول بالتعاقب, بتراكيز مختلفة من (50 صعودا الى 300 جزء من المليون), هذه النتائج قورنت مع تجارب اجريت باستخدام انابيب الكاربون استيل.

النتائج اثبتت ان انابيب البولي فانيل كلورايد المستخدمة اعطت حوالي (53 % الى 66%) زيادة في الجريان في الكروسين بالمقارنة مع الجريان في أنابيب الكاربون استيل, المضافات اظهرت تحسين نسبي لمعدلات الجريان بالمقارنة مع انابيب ال ( C.S ) حوالي ( 61% الى 69%), هذه المضافات ليس لها تأثير على الخواص الفيزيائية للمشتقات النفطية (الكروسين, زيت الغاز).

**الكلمات المرشدة:** خطوط الانابيب , تقليل الاعاقة , معدل الجريان , المضافات .

## INTRODUCTION

Since the early forties, drag reduction has become an increasing interest in science and technical applications due to power saving. Many techniques, (diluted polymer solutions, surfactants, micro bubbles and complaint coating,..Etc) as drag reducers have been used and discussed 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. Other techniques used layers of greasy materials or bubble layers to reduce skin friction, as in some marine applications in ships Toms [1], Gyr [3]. The modern techniques in drag reduction are by the edition of minute quantities of chemical additives to liquids transported in turbulent flow through pipelines in order to reduce the turbulent friction factor of a fluid. It can be used to reduce energy consumption of pumping, increase flow rate, and decrease the sizes of pumps, pipes, and fittings in flow systems.

The most successive commercial application of drag reduction using chemical additives was established in pipelines transporting crude oil or refinery products Burger [2] ConocoPhillips [4]. Also this technique was applied successfully in many fields as in sanitary engineering, hydro transport of solids, some medical application, fire fighting and irrigation Jakob ET al [5]. Polymers and surfactants are the most popular chemical drag reducing agents. By adding a certain amount of polymer solution to the crude oil in the pipeline, the desired discharge of two million barrels per day could be achieved without constructing additional pumping stations. However, with drag-reduction by a polymer solution, the network structure of the polymer solution which causes the drag reduction is broken easily due to mechanical shear stress of the pump, and the drag reduction is lost Cox and Dunlop[6]. Therefore, the polymer is not effective for an application with a closed circuit system. The special configuration of the surfactants molecules plus there multiple personality, make it possible to overcome some of the polymers disadvantages. Surfactants

molecules have the ability to form certain types of aggregates which are called "micelles" and have a self-repairing ability and can keep the drag-reducing effect through mechanical shear stress. Zakin,[7]. The existence of thread-like micelles seems to be necessary for drag reduction effectiveness. The microstructure of thread-like micelle directly observed in ethylene glycol/water can be well correlated with the DR effectiveness of surfactant solutions Zhang et al, [8]. The temperature and diameter effect on hydrodynamic characteristic of cationic surfactant drag reducing flows in pipes were studied, solution of oley bishydroxyethyl methyl ammonium chloride (Ethoquad O/12), 900 ppm, as a cationic surfactant and sodium salicylate (NaSal), 540 ppm, as a counter-ion was tested at 12, 25, 40, and 50 °C in pipes with diameter of 13, 25, and 40 mm Indortono et al, [9]. An aqueous solution of CTAC/NaSal (Cetyl Trimethyl Ammonium Chloride and Sodium Salicylate) in turbulent pipe flow system was used. Drag reduction experiments were carried out for different experimental conditions using pressure drop measurements Ferhat et al,[10].

Low concentrations of surfactant (>25 ppm) exhibit effective drag-reduction Li and al,[11]. Therefore, CetylTrimethyl Ammonium Chloride mixed with Sodium Salicylate (CTAC/NaSal) is being considered as particle drag reduction additives. CTAC/NaSal in solution are less affected by mechanical degradation Gyr and Bewersdof[3]. Numerous researches have been focused on mechanism of drag reduction. Indeed, some drag reducing solutions, like surfactant one, are not neither viscoelastic fluid nor present elongational viscosity Zakin,[12], Lu ET al,[13], Lin ET al,[14]. (Gyr and Bewersdof<sup>3</sup>) suggested that the shear induced structure (SIS) is responsible for drag reduction. Therefore, other hypotheses have been explored such as local shear-thickening Guillou and Makhoufi, [15] or wall slip Drappier et al, [16] Hadri et al,[17].

Because of this background, there has been intense research on drag-reduction with surfactant additives since the discovery of the Toms effect. In particular, many kinds of surfactants as drag reducing agent have been extensively investigated in many studies. However, there is not enough knowledge about this, and the actual mechanism of drag-reduction has yet to be fully explained. Therefore, it is worth investigating in more detailed which kinds of surfactants good drag reducing agent within refinery products even with applications having a closed-circuit system, such as air-conditioning systems or district heating/cooling (DHC) systems Tsukahara[23], Motzawa[24] .

### **EXPERIMENTAL SET-UP**

Two flow loop systems were constructed, first from PVC pipes, and the second from carbon steel pipes, to study the effect of using PVC pipes as drag reducer surface (smooth surface) instead of using carbon steel pipes which has rough surface.

Anionic surfactants and Nonionic surfactant with different range of concentrations (50-300 PPM) were used as drag reducing agents in addition to using PVC pipes.

Comparison was carried out for percent drag reduction when using:

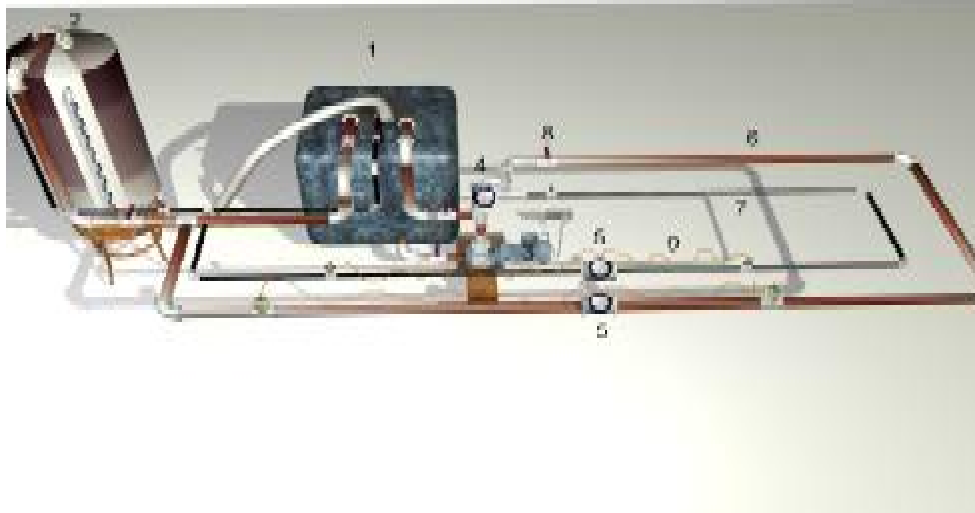
A- Carbon steel pipes.

B-PVC pipes alone

C-Additives with PVC pipes.

The flow loop system is illustrated in Figure (1) .This consisted of two recirculation pipes of inner diameter of (0.0254,0.0508 m ),connected with two tanks made of galvanized steel plate, first tank was a feed tank (0.8\*0.8\*1 m<sup>3</sup>) supported

with two exit pipes connected to centrifugal pumps. The first exit pipe with 0.0508 m I.D. was connected to the main centrifugal pump which delivers the fluid to the loop pipe. The other exit is of 0.0127 m I.D. was connected to the other centrifugal pump for the draining of the solution after each run. The second tank was cylindrical (0.455 m, diameter of the base and 1 m height) used for measuring the volume of the fluid with time for each reading of flow meter to calibrate it.



**Figure (1) Schematic diagram of the closed loop circulation system**  
**1- Feed tank, 2- Reservoir tank, 3- Pump, 4- Flow meter**  
**5- Gage pressure, 6- 0.0508 m PVC pipe, 7- 0.0254 m PVC pipe,**  
**8- Ball valves, 9- Tested tube section.**

The testing sections were 4 m long and they were away from the entrance according to pipe diameters and entrance length, the reason to do that is to restrict the pressure drop measurements in fully developed region. Finally all pipes returns back to the feed tank as shown in Figure (1).

One type of commercial refinery products was used; kerosene was taken from AL-Durra Refinery. The physical properties of kerosene were taken from Al-Durra refinery, to compare wither the properties of kerosene after using additives change or not, and this was done by making different tests on kerosene like (API and specific Gravity, Kinematic Viscosity, etc).

#### **EXPERIMENTAL PROCEDURE**

Pure kerosene was passed in PVC pipe at different flow rates ( $2 - 7.5 \text{ m}^3/\text{h}$ ) was controlled simultaneously by two valves, bypass valve and entrance valve of the loop which was selected to operate first. This procedure was repeated for the two loops of pipes (0.0254 & 0.0508 m) I.D. For each fixed flow rate and after few minutes reaching steady state, pressure drop readings were taken for every fixed flow rate. By changing the flow rate to another fixed point, pressure drop reading were also taken until the 12 desired values of flow rates were reported.

This procedure was repeated by using surfactant in kerosene solutions, for the two surfactants used (i.e. SDBS, POEA). Surfactant solution used in re-circulating system which was prepared by mixing and taken as part per million (PPM) in weight. To ensure that real quantity of surfactant was used, this quantity of surfactant was mixed with a sample of the solvent (kerosene) and then poured in the feed tank. The same procedure was repeated for every additive type (2) (SDBS, POEA), additive concentration (50,100,150,200,300 ppm), pipe diameter (0.0254 m, 0.0508 m).

In order to calculate the percent drag reduction by using PVC pipe, the same procedure used before was repeated for carbon steel pipe flow system.

**RESULT AND DISCUSSION**

**Pressure drop and drag reduction**

The fanning friction factor is defined as the ratio of the wall shear stress and of the kinetic energy of the flow (equation 1), where U represents the bulk velocity, ρ is the flow density and the wall shear stress τ<sub>w</sub> is linked to the pressure drop ΔP (which is measured) along the pipe of length L and of diameter D.

Drag reduction occurs if, at the same flow rate, the pressure drop is reduced or if, at the same pressure drop, the flow rate is increased. This implies two kinds of definition of the drag reduction rate. As Zakin et al, [7], the Drag reduction rate at constant flow rates was defined by equation (2), where Δp<sub>b</sub> and Δp<sub>a</sub> represent the pressure drop for the solvent alone and for drag reducing solution (respectively). Thus the pressure drop is plotted as a function of the Reynolds number based on the bulk velocity, the diameter of the pipe and the solvent’s viscosity.

$$f = \frac{2\tau_w}{\rho u^2} = \frac{\Delta p D}{2 \rho u^2 L} = \frac{\Delta p \pi^2 D^5}{32 \rho L Q^2} \quad \dots (1)$$

Percent drag reduction % DR was calculated as follow:

$$\%DR = \left(1 - \frac{\Delta p_a}{\Delta p_b}\right) \times 100 \quad \dots (2)$$

In this equation the subscript a, stand for using additives and subscript b, for pure solvent (before using additives).

Similarly % DR was calculated using friction factor as shown:

$$\%DR = \left(1 - \frac{f_a}{f_b}\right) \times 100\% \quad \dots (3)$$

f<sub>a</sub> & f<sub>b</sub> were evaluated for ΔP before & after using additives.

The relationship between percent drag reduction and percent flow increase can be estimated using the following equation:

$$\%fl = \left[ \left( \frac{100}{100 - \%DR} \right) - 1 \right]^{0.556} * 100 \quad \dots (4)$$

Flowing behavior of kerosene in 0.0254 m pipe diameter can be seen (as pressure differentials ( $\Delta P$ ) against flow rates) in Figure (2). As flow rate increases, so does pressure differential ( $\Delta P$ ).

**EFFECT OF DIFFERENT TYPE OF PIPES ON DRAG REDUCTION**

Pure kerosene flowing in carbon steel pipe gave higher values of pressure differentials ( $\Delta P$ ) than pure kerosene flowing in PVC pipes and (kerosene) solutions flowing in PVC pipe as shown in Figure (2).

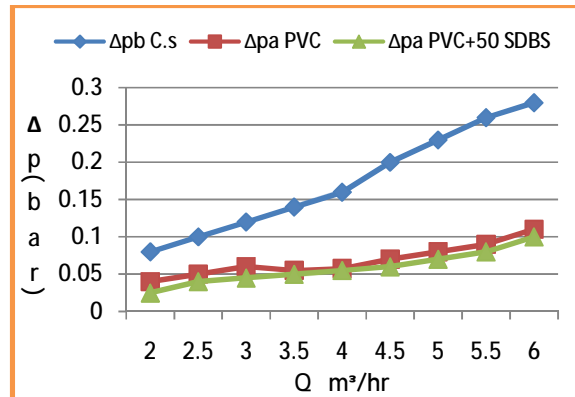


Figure (2) Pressure differentials against system flow Rates Kerosene flowing in 0.0254 m ID.

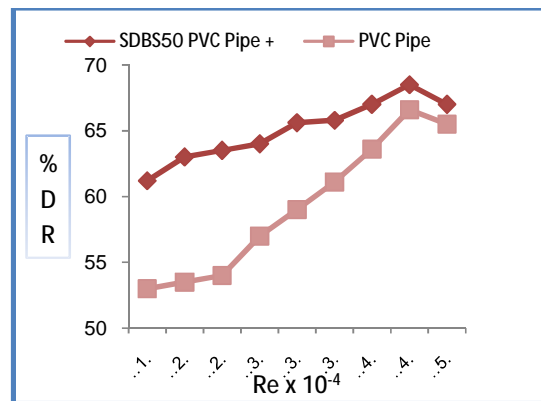


Figure (3) Effects of Reynolds number on percentage Drag Reduction for kerosene flowing in 0.0254 m ID.

Kerosene flow behavior can be shown in Figure (3) which represent (%DR) against Reynolds for pure kerosene flowing in 0.0254 m ID PVC pipe with a range of Re between (17400 & 52000), Q between (2 & 6 m³/h), giving a range of (%DR) between (53% & 66%) respectively. It means that polymer pipes have smooth surfaces compared with metallic pipes. Polymer pipes (PVC pipes) have hydrophobic surface compared with metallic which has liophobic surface. Therefore the polymers have negligible frictional resistance to fluid flow and have high resistance to corrosion of H: C fluids, so our results are in good agreement with KWH. Pipe, [18]. While for kerosene solution with 50 ppm concentration SDBS flowing in .0254 m ID

PVC pipe and for the same range of Re (17400 & 5200), (%DR) between (61% & 69%) respectively.

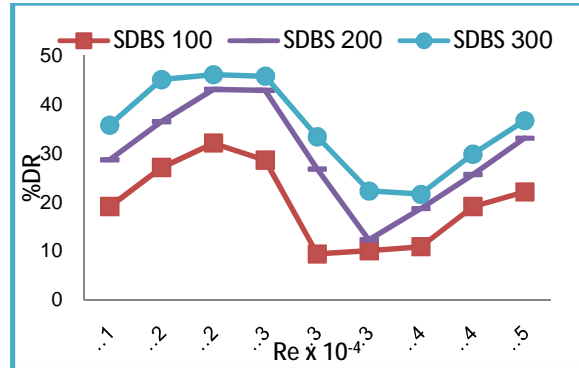


Figure (4) Effects of Reynolds number on percentage Drag Reduction for kerosene flowing in 0.0254 m ID. Using SDBS (100-300) conc.

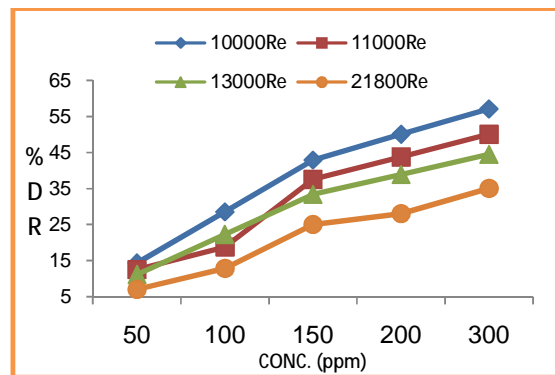


Figure (5) Effect of concentration of SDBS on percent Drag Reduction through 0.0508 m ID PVC pipe.

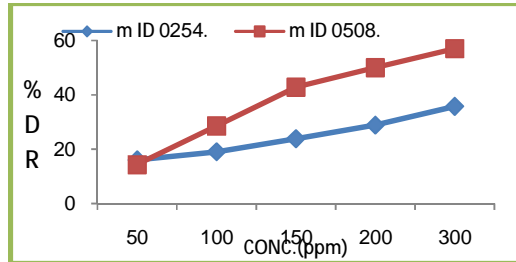
### PVC PIPE WITH SURFACTANT ADDITIVES

The behavior of kerosene solution with different concentration of SDBS (50-300 ppm) flowing in 0.0254 m ID PVC pipe can be shown in Figure (4). Higher values of (%DR) can be obtained at low flow rates, and lower values of (%DR) at high flow rates which were similar to the behavior for all anionic surfactant reported by Zakin[7]. It appears that the percentage of drag reduction increases to reach 36% at Re=16000 and approach 48% at Re=30000. When the Reynolds number is continually increased, it reaches a point where the drag reduction breaks down (break-down point). Such behavior was also described by (Bewersdorff and Ohlendorf, [20] for higher concentration surfactant solutions > (100 ppm). After this critical Reynolds number friction coefficient increases again till it reaches solvent behavior (kerosene).

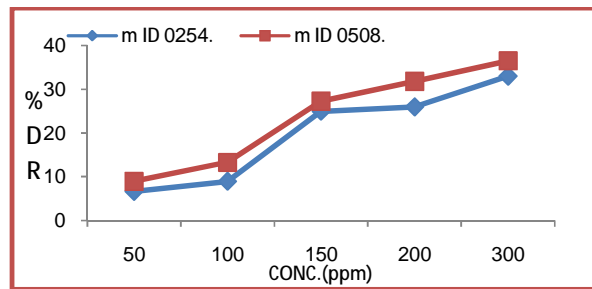
Figure (5) summarizes the effect of SDBS concentration on percentage drag reduction at different flow rates. A noticeable increase in pump ability of solvent was achieved, which is caused by addition of small amounts of SDBS to the fluid.

**EFFECT OF PVC PIPE DIAMETERS ON DRAG REDUCTION**

Effect of concentration of SDBS (50-300ppm) on drag reduction for kerosene solution flowing in two different diameters PVC pipes (i.e. 0.0254m ID & 0.0508 m ID) (Re=11000) can be observed in Figure (6). Higher values of drag reduction percent achieved in 0.0508m ID PVC pipe than in 0.0254m ID PVC pipe, the same result can be obtained at different value for (Re=17500) as shown in Figure (7).



**Figure (6) Effect of concentration of SDBS on percent Drag reduction for kerosene flowing in two different PVC pipe diameter (0.0254m & 0.0508m) Re= 11000.**

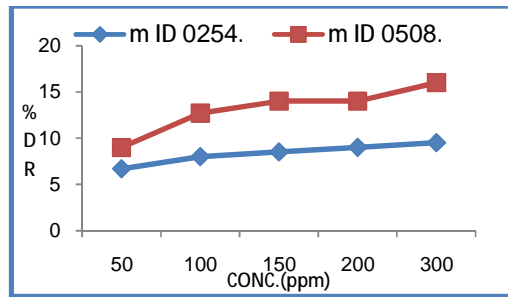


**Figure (7) Effect of concentration of SDBS on percent Drag reduction for kerosene flowing in two different PVC pipe diameter (0.0254m & 0.0508m) Re=17500.**

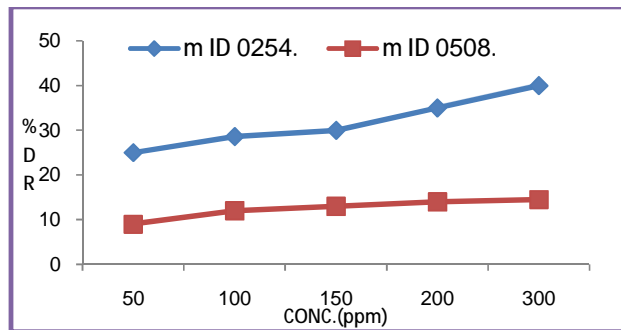
**EFFECT OF USING NONIONIC SURFACTANT ON PERCENT DRAG REDUCTION**

For Nonionic kerosene solution with different concentration (50-300 ppm) indicates a decrease in (%DR) with different flow rates for both diameters as we can see in Figures (8)&(9). It can be observed that for low flow rates small diameter give higher (%DR) (40%) at 300 ppm concentration of Nonionic surfactant (Polyoxyethylene alcohol POEA), while for higher flow rates large diameter give higher percent drag reduction than small diameter.





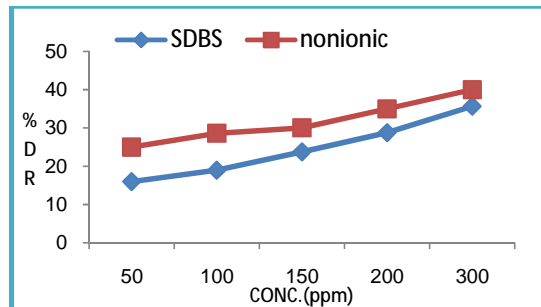
**Figure (8) Effect of concentration of Nonionic on percent Drag reduction for kerosene flowing in two Different PVC pipe diameter (0.0254m &0.0508m)Re= 17500.**



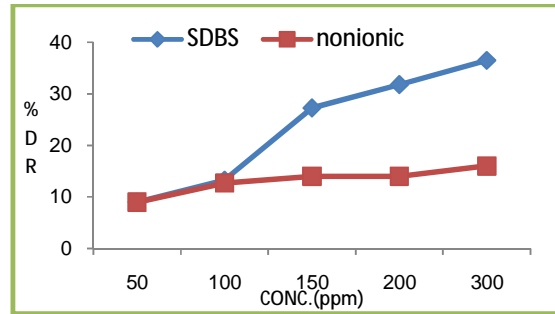
**Figure (9) Effect of concentration of Nonionic on percent Drag reduction for kerosene flowing in two Different PVC pipe diameter (0.0254m &0.0508m)Re=11000.**

The behavior of SDBS and Nonionic surfactants as a drag reducer and their different concentration effect on (%DR) for kerosene flowing in (0.0254m ID PVC pipe & Re=11000) once, and in (0.0508m ID PVC pipe & Re=17000) twice, shown in Figures (10) & (11), respectively.

It can be seen clearly Nonionic surfactants more effective in large diameter pipes than small pipes, where the (%DR= about 40%), while in small pipes (%DR= about 18%). The behavior of SDBS was nearly equal effective in the two diameter pipes for almost all flow rates of kerosene, where (%DR= about 39%) in the two Figures.



**Figure(10) Effect of concentration of (SDBS,POEA) on kerosene flowing in (0.0508m at Re=17500.**



**Figure(11) Effect of concentration of (SDBS,POEA) on (%DR) for ID PVC pipe (%DR) for kerosene flowing in (0.0254m ID PVC pipe) at Re=11000.**

The drag reduction properties of kerosene solution could be explained as the fanning friction factor verses solvent Reynolds number. The use of Reynolds number based on the solvent viscosity and pipe diameter provides a direct indication of the degree of drag reduction. An attempt was made to correlate the friction factor as a function of Reynolds number, for the considered surfactants concentrations and pipe diameters. The friction factor is usually correlated as a function of Reynolds number as shown in the following formula

$$f = a(Re)^b \quad \dots (5)$$

In accordance with the above formula and by using appropriate software program, the constants a, b had been found for kerosene, SDBS solution, and for kerosene, Nonionic solution as follow:

$$f = 0.95272 (Re)^{-0.4855} \quad \text{For Nonionic solution} \quad \dots (6)$$

$$f = 0.91233(Re)^{-0.53} \quad \text{For SDBS solution} \quad \dots (7)$$

The friction factor was evaluated for the used range of SDBS & Nonionic concentration (i.e. 0, 50-300 ppm) in kerosene flowing in 0.0254m ID PVC pipe diameter. The evaluated ( $f$ ) was then plotted with Re in the range of (17000- 52000) and it was found to fall between Von Karman[21] turbulent flow correlation and Virik[22] asymptote as shown in the Figures (12 & 13) respectively. The evaluated ( $f$ ) lies between (0.00480 & 0.01407) for kerosene with different amounts of SDBS or Nonionic surfactants.

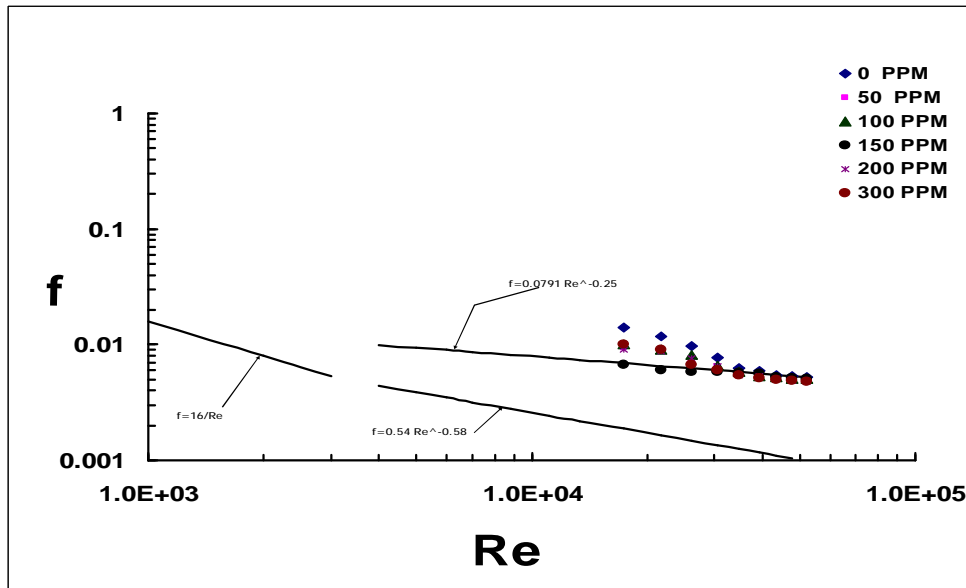


Figure (12) Effect of Reynolds number on friction factor for SDBS in kerosene flowing through 0.0254 m ID PVC pipe.

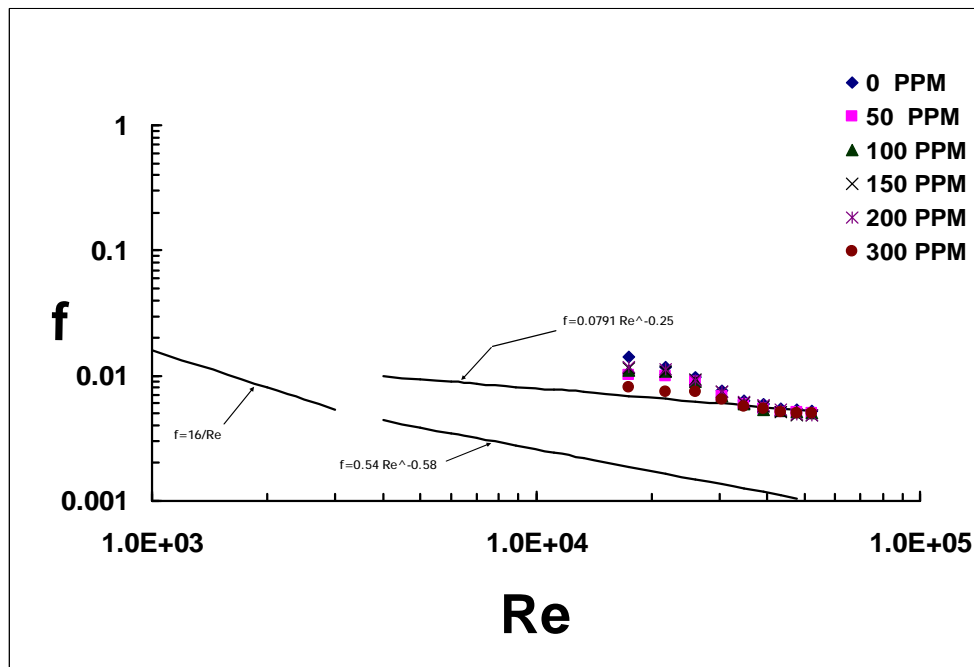


Figure (13) Effect of Reynolds number on friction factor for Nonionic surfactants in kerosene flowing through 0.0254m ID PVC pipe.

## CONCLUSIONS

Using PVC pipes (smooth surfaces compared with metallic pipes) giving a range of (%DR) between (53% & 66%), while for kerosene with 50 ppm SDBS flowing in PVC pipe, (%DR) between (61% & 69%) and this %DR evaluated with respect to carbon steel pipe.

One of the most important conclusions is that the drag reduction in surfactant solutions occurs always when the surfactant molecules form rod-like micelles. The drag reduction in turbulent flow expresses itself in friction reduction, change of velocity profile, and the structure of turbulence.

For PVC pipes with surfactant additives, higher values of (%DR) can be obtained at low flow rates, and lower values of (%DR) at high flow rates, maximum %DR approach (48%) at  $Re=30000$ .

As a comparison of the two PVC pipe diameter used, higher values of (%DR) achieved in 0.0508 m ID PVC pipe than in 0.0254 m ID PVC pipe.

Nonionic surfactant (POEA) gives higher values of (%DR) (40%) (300 ppm concentration) in large diameter than small diameter, SDBS also gives higher values of (%DR) (58%) (300 ppm concentration) in large diameter than small diameter.

The friction factor for Nonionic surfactant (POEA) solution  $f = 0.95272 (Re)^{-.4855}$ .

The friction factor for Anionic surfactant (SDBS) solution  $f = 0.91233 (Re)^{-.53}$ .

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