



Study the Characterization of Adding Polymer-Surfactant Agent on the Drag Reduction Phenomena in Pipeline Flow System

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(Received 30 June 2016; accepted 7 December 2016)

<https://doi.org/10.22153/kej.2017.12.004>

Abstract

In this study, the effect of carboxylic methyl cellulose (CMC), and sodium dodecyl benzene sulfonate (SDBS) as an aqueous solution on the drag reduction was investigated. Different concentrations of (CMC) and (SDBS) such as (50, 100, 150, 200, 250, 300, 350, 400, 450, and 500 ppm) were used to analyze the aqueous solution properties, including surface tension, conductivity, and shear viscosity. The optimum four concentrations (i.e., 50, 100, 200, and 300 ppm) of fluid properties were utilized to find their effect on the drag reduction. Two different PVC pipe diameters (i.e., 1" and 3/4") were used in this work. The results showed that blending CMC with SDBS gives a good drag reduction percent about (58%) more than using them individually, friction factor decreasing with increasing Reynolds number and gives good agreement with von Karmann equation and maximum drag reduction (MDR) asymptote. Reynolds number, pipe diameter, and polymer-surfactant concentrations were considered as influencing factors. In addition, critical micelle concentration, the onset of drag reduction, and the interactions between the mixed additives were discussed.

Keyword: CMC, SDBS, drag reduction, friction factor, blending of additives.

1. Introduction

Due to a wide extent of employment of surfactants and polymers, an extensive number of studies have been done on the depiction and attributes of surface-active-agent and polymer solutions. The balance in the interaction between the solvent and aqua phobic and aqua public segments of the polymer determines the solubility of a given polymer in solvent. The accumulation of surfactant molecules in aqueous solution depends on aqua phobic, aqua philic and ionic interactions. Due to a broad variety of molecular structures, polymer and surface-active-agent when blended unitedly in aqueous solution exhibit a species diversity and sometimes even very unusual pattern of attributes [1].

In the 1940s and 1950s, the study of interaction between proteins and synthetic ionic surfactants recognized the importance of electrical forces of attraction of charge groups. This led to the development of the concept of "binding" of

charge surfactants by the polymer macromolecule to explain the conformational changes in polymer macromolecules [1]. The complexes formed due to interaction of polymer and surfactants has a remarkable influence on the system properties leading to regenerated concern in the area in the current decades. However, many concepts traditionally used in polymer-surfactant studies need modification in order to be applicable to a wide variety of macromolecules such as hydrophobically modified polymers which are normally considered hydrophilic. In recent years, there has been a rising concern in reversely charged polymers and surface-active-agent due to their significance in both biological and technological utilizations [2, 3, 4]. They are also important in essential studies as coordinate to intermolecular influence and aquaphobic accumulation occurrence. In the case of reversible charged polymer and surfactants, both electrostatic and aquaphobic influences play a role. The characteristics of such combination

depend on many elements, such as surfactant chain length, backbone rigidity, polymer charge density and concentrations of polymer and surfactant [5].

The benefit of polymers and surfactants in mixing is found in a very wide extent of products, such as formulations of drugs and pesticides, detergents, paints, cosmetics, foods, polymer synthesis, and enhanced oil recovery. Here, one or more polymer is used in combination with surfactant to achieve different effects, such as viscosity enhancement, colloidal stability, emulsification, solubilization, catalysis, gel formation, cloud point elevation, and enzymatic reactions, surface conditioning, usability improvement, detergency, foaming and phase separation [6].

Besides the conventional uses of polymer and surfactant additives in altering solution properties, both polymers and surfactants are considered and are being used extensively as drag reducers to reduce the wall friction in turbulent pipe flow so as to increase the pump capacity or to reduce the pump power requirement. It has been found that little amount of certain contaminants in water can contribute to a great decrease in turbulent friction on the surface where the fluid flows or bodies moving through the fluid [1,6,7,8,9]. Over sixty years' extensive research in this field, additives like polymers, surfactants and air bubbles are discovered to be some of those "contaminants", which is also termed as Drag Reduction Agents (DRAs). By definition, DRAs are any material or additives that reduce frictional pressure during fluid in a conduit or pipeline. Researchers and engineers also found DRA has a variety of benefits, especially in industrial area. Firstly, it is possible to decrease pressure drop for the same flow rate of fluid in pipelines or increase flow using the same amount of energy. Then, as a prerequisite to maintain throughput, DRA can reduce transportation time and carbon emissions of pump stations, moreover, avoid the consumption cost and total investment. Certain DRA can perform a drag-reducing ability up to 80% or increase flow rates by more than 100%. DR has been applied to numerous applications currently in a large number of fields, for example, water heating and cooling systems, flood water disposal, oil pipelines, firefighting, oil well operations, field irrigation, marine systems, transport of suspension and slurries, as well as airplane tank [3]. Actually, as we know, drag reduction is not only limited in these aspects, it can also occur in some other fields created by

humans spontaneously or in nature, where need to be further discovered in the future.

The objective of this research is to investigate the possibility of interaction between polymers and surfactants; by means of measuring and analyzing several properties, such as surface tension, conductivity, shear viscosity and relative viscosity. To determine whether there exist a synergistic effect on drag reduction in transportation of polymer-surfactant solutions in the pipelines; Pilot-scale experiments were carried out to test the flow behaviors of polymer-surfactant solutions in pipelines. The collected data were compared with pure polymer solutions at the same conditions. The polymer selected was Carboxyl methyl cellulose (CMC). Anionic (Sodium dodecyl benzene sulfonate) were selected as surfactant. Two different diameter pipes, 1 inch and 3/4 inch, were utilized. The mass flow rate along with the pressure drop were measured and from these data, the drag reduction was calculated and compared to the drag reduction achieved by the pure polymer mixtures in the same setup. The mixtures were compared to find if they were more stable (slower degradation times), had a larger effective Reynolds range, and if they achieved higher levels of drag reduction than the pure polymer solutions.

2. Experimental Work and Method

Sodium dodecylbenzen sulfonate (SDBS) was selected as an anionic surfactant to add to an anionic polymer which is Carboxyl methyl cellulose (CMC) [10, 11, 12], to develop a new combination of surfactant additive which would applied to tap water circulation in pipeline system for measuring the drag reduction behavior and performance.

Different equal concentrations of CMC and SDBS were prepared by mixing them in tap water (i.e., 50, 100, 200 and 300 ppm) (wt.%).

The experimental system consists of four horizontal circulating PVC pipelines with 6 m long, pump, feed tank, and U-tube manometers, as shown in Figure 1. Testing sections were installed with a distance equal to 3 m. The first testing point was located at a distance enough to ensure the turbulent flow is fully developed before the testing section. Volumetric flow rate was controlled by using flow meters and bypass return to the tank by a valve. For each flow rate reading, the pressure drop was measured by using manometer connected to the points in the test section.

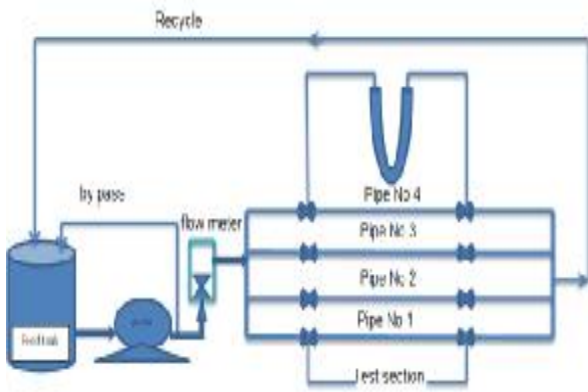


Fig. 1. Experimental rig.

The pipe dimensions and test point locations are shown in Table 1.

Table 1,
Pipe Dimensions and Test Point Locations.

Pipe No.	Internal Diameter Meter	Entrance length Meter	Test Section Length Meter
1	0.0254 (1")	1.35	3
2	0.01905 (3/4")	1.15	3
3	0.01905 (3/4")	2.15	3
4	0.0127 (1/2")	1.65	3

Entrance length more than 50 times diameter (50.D) to ensure fully developed region before the test section.

3. Experimental Steps

Only two pipe diameters (1" and 3/4") were used to carry out the experimental work.

The drag reduction(%) in pipes is defined as:

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

The subscript b, refers to pure solvent (water), and subscript a, after using additives. Different concentrations (50, 100, 200, and 300 ppm), for the three additives (polymer, surfactant, and a mixture of them) were used. %DR for each solution was calculated using equation (1). Each experiment was repeated about 3 times in order to obtain the accurate results.

The measured data were compared with the theoretical assumptions presented by von-Karman Equation and maximum drag reduction asymptote in turbulent regime [9].

Von Karman equation:

$$\frac{1}{\sqrt{f}} = 4.0 \text{Log} (Re\sqrt{f}) - 0.4 \text{ for } 5 \times 10^3 < Re < 5 \times 10^6 \quad \dots(2)$$

MDR asymptote:

$$\frac{1}{\sqrt{f}} = 19.0 \text{Log}(Re\sqrt{f}) - 32.4 \quad \dots(3)$$

where, f is the friction coefficient calculated by the equation below:

$$f = \frac{2\tau_w}{\rho V^2} \quad \dots(4)$$

and τ_w is the shear stress and calculated from:

$$\tau_w = \frac{D\Delta P}{4L} \quad \dots(5)$$

Re. No. in the pipe is calculated by:

$$Re = \frac{VD}{\eta} \quad \dots(6)$$

Where V , D , and η are the velocity of the fluid, the diameter of the pipe, and kinematic viscosity, respectively.

Finally, the Du Nuoy Ring method was used to investigate the surface tension of the additive solutions with different concentrations (50,100, 150, 200, 250, 300, 350, 400, 450, and 500 ppm) as shown in figure 2. The specific conductance was investigated for the same concentrations as specified for surface tension investigation by using viscometer device (BROOK FIELD) (DV-II+Pro VISCOMETER) as shown in figure 3.

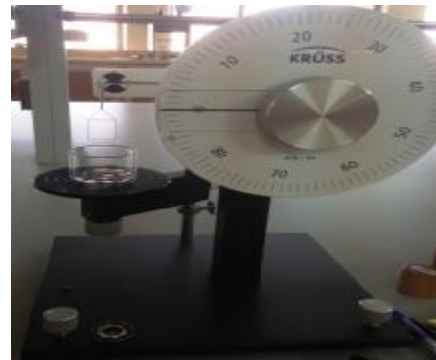


Fig. 2. Surface tension device.



Fig. 3. Viscometer device.

4. Results and Discussion

The effect of volumetric flow rate (Q) measured in liters per minutes, on the percentage drag reduction (%DR) for aqueous solutions flowing in (3/4 " and 1") ID pipe using CMC (50-300 ppm) is shown in Figure 4 (a & b).

In Figure 4a, the percentage of drag reduction increases more than 40% with increasing of the volumetric flow rate from 4 to 12 L/min. and decreases with further increases in volumetric flow rate for the pipe with a diameter of 3/4". Low volumetric flow rate means low shear rate, where the polymer starts to make a thread like structures which interact with the turbulent eddies and burst them, causing the drag reduction, which is continually increasing until a point on shear rate, mechanical degradation of polymer chains in high shear rate regions, is frequently observed, which lowers the molecular weight and causes a loss of drag reduction [13]. Several works that have been reported in the literature, studied the onset of drag reduction by dilution of polymer additives and the maximum drag reduction asymptote [11,14] in their researchs fixed the maximum drag reduction

for polymer additives. The earlier work on the subject were made by Toms [9], Lumely [15], and Landahi [16] who reported the effectiveness of drag reducing agent. Also, as the concentration of CMC increases from 50 to 300 ppm, the percentage of the drag reduction increases for about 13% of low volumetric flow rate (i.e., 4 L/min.) and 5% at high volumetric flow rate (i.e., 24 L/min.), as shown in Figure 4a. Whenever increased concentration leading to increase the composition of thread like micelles. However, in Figure 4b, it can be noticed that the percentage of the drag reduction is highly improved, where the drag reduction increased by about 20% at volumetric flow rates of 4 L/min. and 11% at 24 L/min. by using pipe diameter of 1" with increasing of the CMC concentration. Large pipe diameter means low velocities and low Reynolds number which may be in transition region which have more fluctuation. From this, it can be concluded that larger diameter gives better result on drag reduction percent than smaller diameter, the same behavior was noted with SDBS when used as a drag reducing agent in aqueous solution.

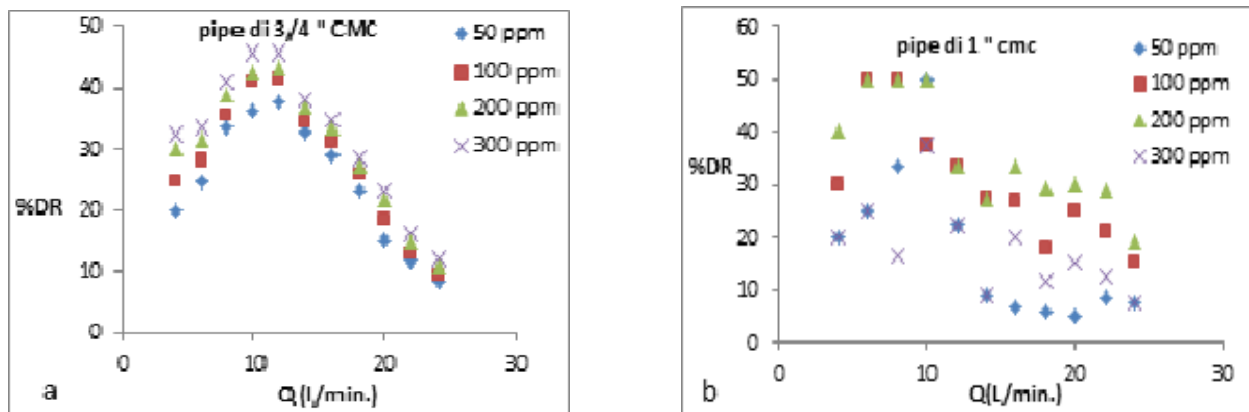


Fig. 4. (a, and b) Relation between %DR and Q (L/m) for CMC with different pipe diameters and concentrations.

Figure 5 (a, and b) shows the effect of volumetric flow rate on the percentage drag reduction for aqueous solution of different SDBS concentrations (i.e., 200, 300, and 400 ppm) by using 3/4" and 1" pipe diameters. Figure 5a depicts that the percentage drag reduction of the fluid in SDBS concentration was not clear, and the results oscillated with increasing SDBS concentration. While in Figure 5b, the behavior is clear by using 1" pipe diameter, it means that as the SDBS concentration increases, the percentage of the drag reduction is increasing and reaching maximum values (32, 45, and 52) % for (200,

300, and 400 ppm) concentration, respectively. The reduction occurs due to increasing the length of rod-like micelles and increasing an aggregation number of spherical micelles, similar results were shown by other workers [17-19] when the rod like micelles grow rapidly, as the concentration exceeds critical micelles concentration, forming a three-dimensional thread like micelles. These thread like micelles usually exhibit shear thinning behavior. After reaching these maximum values of drag reduction, it seems to be degraded as shown in Figure 3. This degradation occurs as a result of the break-up of the micelle

microstructure because of high shear stresses that exceed critical stress. The decreasing in drag reduction can be also explained if we know that for anionic surfactant the spherical micelles usually aggregate into cylindrical micelles, which

formed a network of interlaced rod-like elements, and the aggregation forces of the surfactant molecules are overcome by the shear stress, so the aggregates are broken down to small particles, which have little activity.

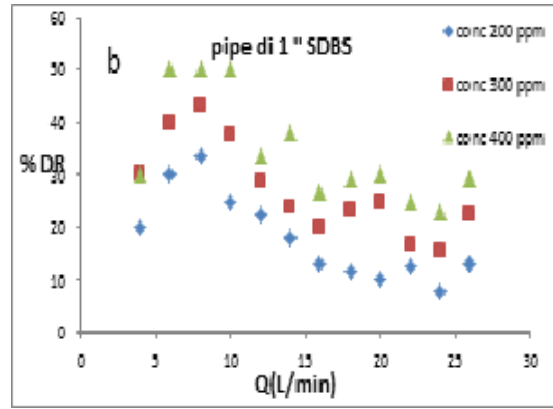
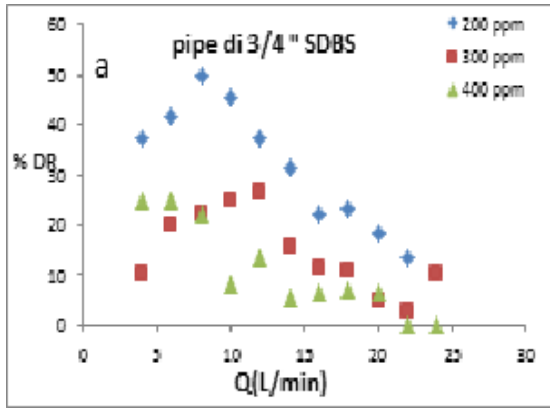


Fig. 5. (a, and b) Relation between %DR and Q (L/min) for SDBS with different pipe diameters and concentrations.

Other experiments were done using the two additives mixed with equal concentrations under different shear stresses. The results from these experiments are given in Figs. (6a-6b). The maximum drag reduction were (58, and 55) % for concentrations (300, and 200) ppm, respectively, as shown in Figure 4a for pipe diameter of 3/4". These percents are higher than that of polymer or surfactant individually. The interaction between surfactant and polymer chain represented by the polymer film, which is formed around surfactant micelles forming aggregate structure. This

structure has a drastic effect on the solution rheology. This takes an ordered orientation that minimizes resistance to flow, with increasing flow, they elongated and suppressed the turbulent eddies. Hence, the drag reduction increases with shear stress. Moreover, it can be seen that there is no significant effect of the 100 ppm concentration of the mixture on the drag reduction. Using a pipe diameter of 1", it can be noticed from Figure 4b that the best percentage of the drag reduction (58%) is obtained at 200 ppm of the mixture and volumetric flow rate of 7.5 L/min.

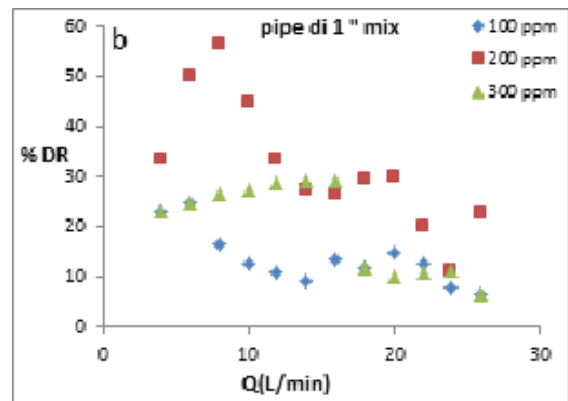
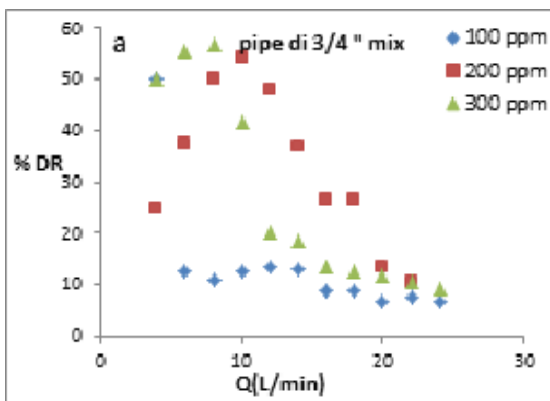


Fig. 6 (a, and b) Relation between %DR and Q (L/min) for MIX with different pipe diameters and concentrations.

The surface tension of every fluid is believed to be constant, and the data showed the same result as our expectation. From 50 ppm to 500 ppm, the surface tension of CMC keeps stable

around 68 dyne/cm as seen in Figure 7, which is because CMC is not surface-active polymer and will not have any effect on surface tension. Figure 8 describes the relationship between conductivity

and CMC concentration. Since the polymer used in the experiments is its sodium salt, sodium carboxyl methyl cellulose (anionic), the

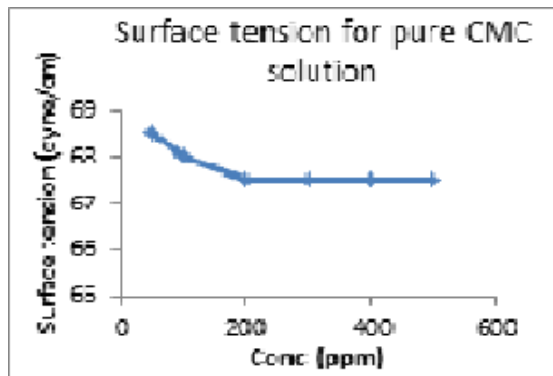


Fig.7. Surface Tension of Pure CMC Solutions.

The surface tension, and conductivity against concentration of mixing CMC and SDBS solution, are shown in Figures 9 & 10. It can be seen that the surface tension for mixture is lower than the pure CMC solution, where the latest is nearly constant about 68 dyne/cm, but the behavior of mixed solution is not constant and as the concentration of solution increases, the surface

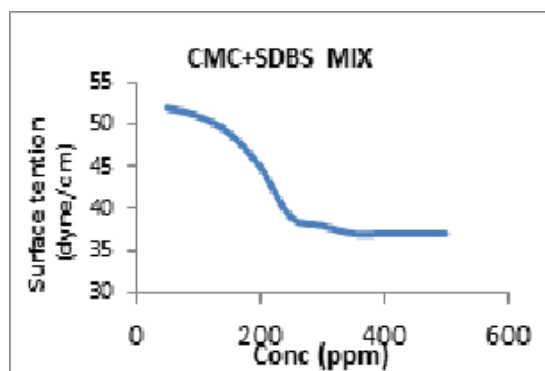


Fig. 9. Surface tension of mixed solution.

In Figure 10, there is a peak in the curve occurred between 200 and 300 ppm concentration of mixed solution. This peak shows a reduction in the conductivity of the mixed solution, as an increase in the mass per unit charge of the material in solution, and this explained as evidence of the formation at that point of micelles from the unassociated molecules of surfactant,

conductivity plot has a positive correlation with the concentration [20].

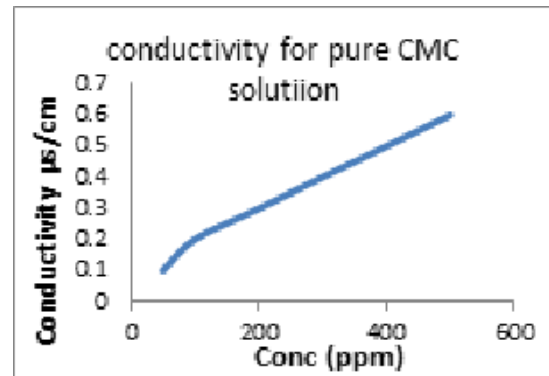


Fig. 8. Conductivity of Pure CMC Solution.

tension decreases until reaching a point between 200 and 300 ppm, in which the surface tension is constant whenever the concentration increases. This reflects a clear effect of adding a surfactant to the polymer. Critical micelle concentration can be specified between 200 and 300 ppm, where at that concentration macromolecular started to be aggregated.

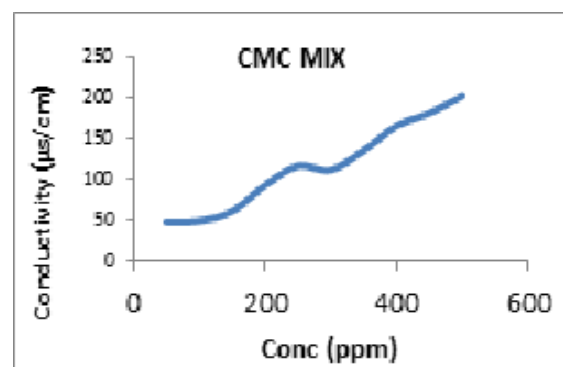


Fig. 10. Conductivity of mixed solution.

with part of the charge of the micelle neutralized by associating counter ions [18,3,4]

Figure 11 (a-f), show the comparison between the three additives, polymer, surfactant, and the mixture of them and their effects on the drag reduction percent vs. volumetric flow rate with different concentrations and different diameters.

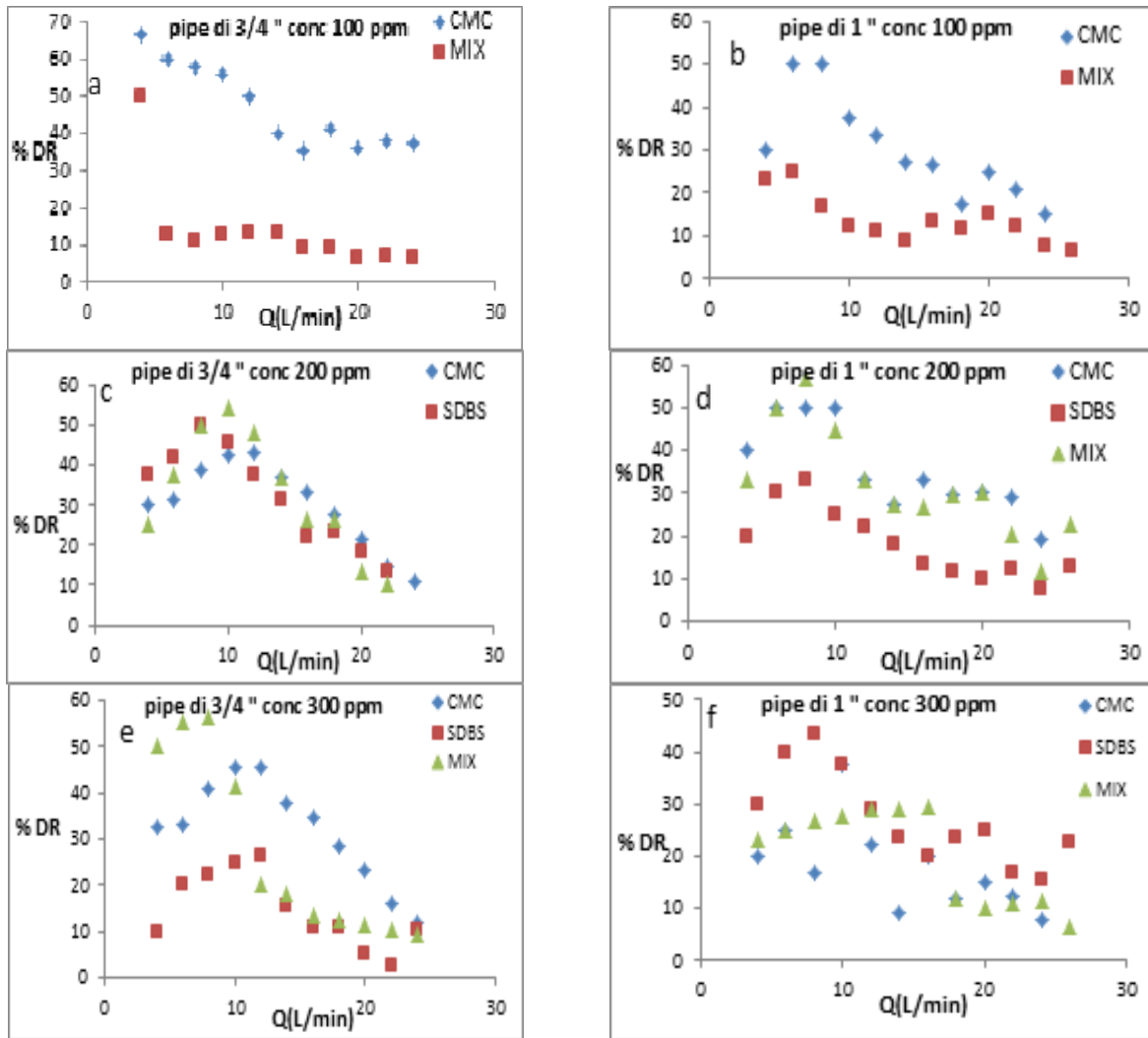


Fig. 11 (a-f). A comparison between polymer (CMC), surfactant (SDBS), and mixture of them at different pipe diameters and different concentrations.

Figure 11a shows no significant effect of the 100 ppm concentration of the mixture on the drag reduction, while CMC effect with the same concentration is clear and has a maximum percent drag reduction (62%), this is within pipe diameter 3/4". The same behavior and effects are observed within diameter of (1") for the same concentration (100 ppm); there is no significant effect for mixture and the maximum value of percent drag reduction when using CMC additives is only (52%), as shown in figure 9b.

Figures (11c & 11e) show a significant effect for the mixture of (200, and 300 ppm) concentration, and the maximum values of percent drag reduction reached (52, and 58) % respectively, within pipe diameter 3/4". Almost the same behavior for 200 ppm concentration of the mixture in pipe 1", and concentration 300 ppm is noticed since they have no significant effect, as shown in figures (11d, and 11f), respectively.

These results confirmed by the behavior of mixed solution in figures 9 and 10.

The effect of Reynolds number for the three additives (CMC, SDBS, and MIX) within the two pipe diameters and four different concentrations of the friction factor is shown in Figures 12a-12f, also these figures gives a comparison with Van Karman equation and MDR asymptote. This asymptote is dependent solely on the Reynolds number, [21 , 22].

It can be seen from these figures that the friction factor decreases with Re No. and with concentration, as concentration increases, friction factor decreases. According to some theories, the reduction of the friction coefficient in the turbulent flow of very dilute polymer solutions is due to elongation effects [23]. And more recently [5 , 24] others argue that this could be related to a strong strain-imposed resistance to elongation of the molecules and its effects upon the extensional

viscosity of the fluids. Thus, the magnitude of the viscosity would be larger than in the absence of such elongational deformations [25].

Viscosity is very significant in this research. Laminar flow and turbulent flow are two flow regimes in fluid dynamics, when increasing the Reynolds number, laminar flow will convert to turbulent flow. In turbulent flow, viscosity is easy to dampen Re which means it would be more

difficult for a fluid with a higher viscosity to form a turbulent flow. For this reason, viscosity and other rheological properties (shear rate, shear stress, and torque) were determined by using a Brookfield Viscometer Rotating Disk (RDA) at various concentrations (50, 100, 150, 200, 250, 300, 350, 400, 450, and 500) ppm individually and in the combined form under turbulent conditions at different rotational speeds.

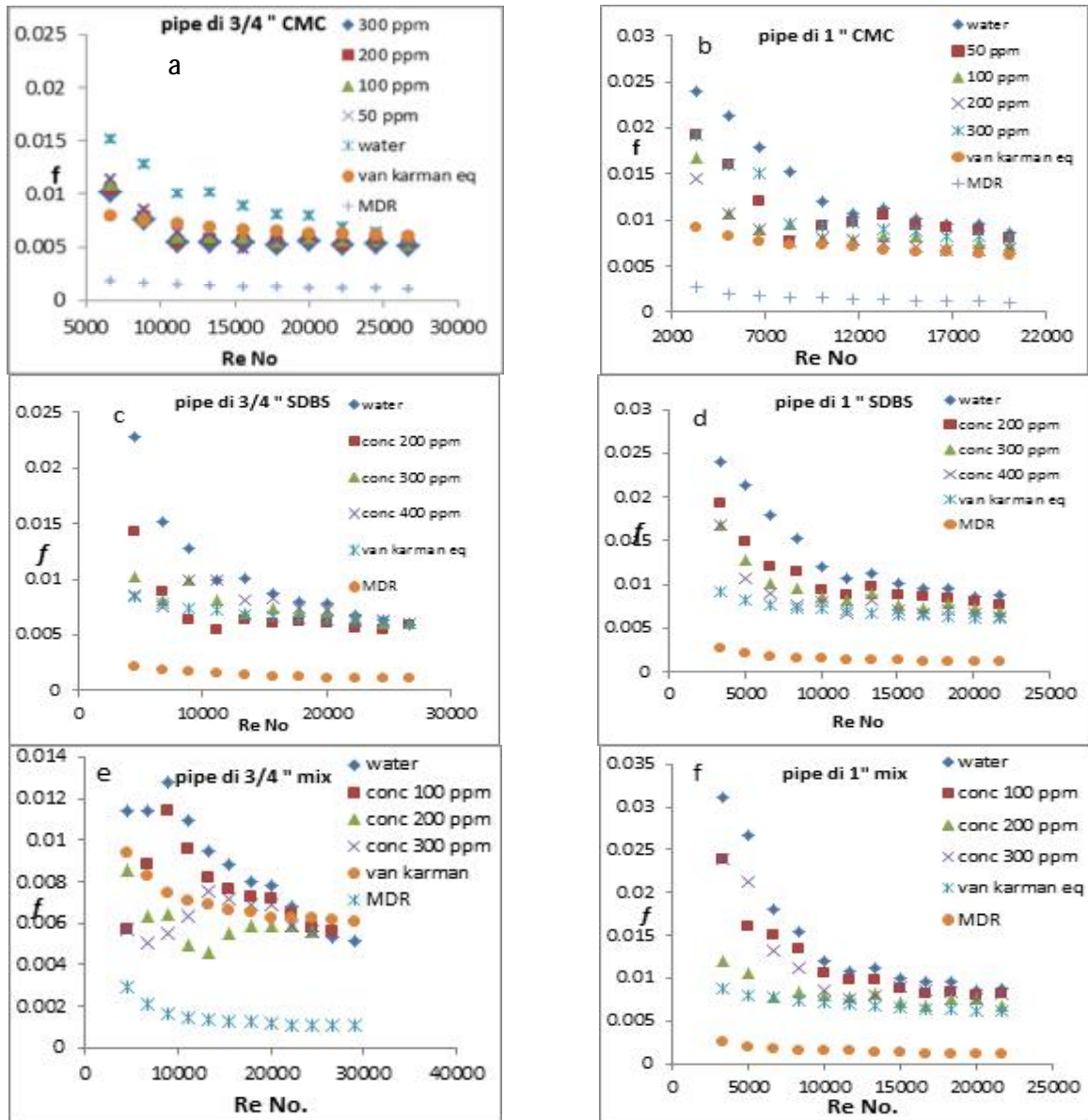


Fig. (12a-12f) . The relation between friction factor and Re No. for CMC polymer solution, SDBS surfactant solution, and their mixture at different pipe diameters and different concentrations.

Through the Figures 12a-12f, friction factor decreases with the increasing of the concentrations of all the three additives used, and with Re No. Comparing with von Karman equation and MDR asymptote, good results are obtained for friction factors for CMC, SDBS, and

their mixture solutions flowing through 3/4" pipe diameter and four different concentrations, these values of (f) located between von Karman equation and MDR asymptote, it means a good agreement with them.

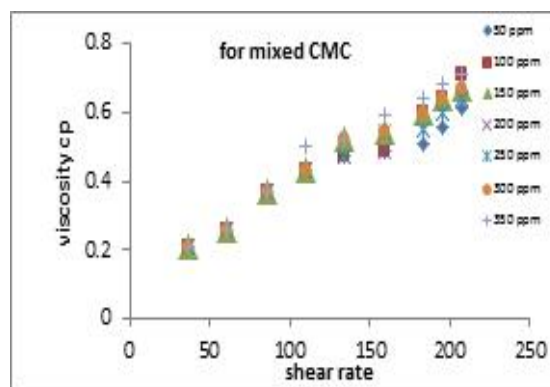
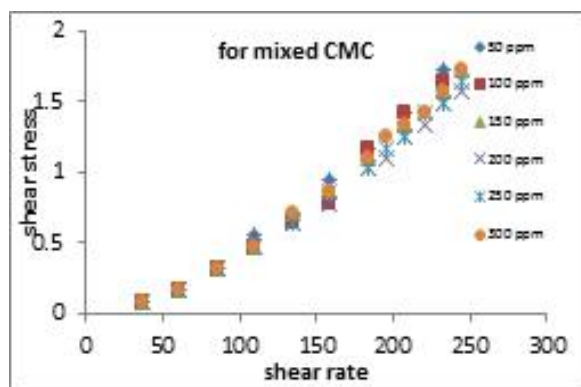


Fig. 13. Shear stress vs. shear rate for mixed solution, Fig. 14. Viscosity vs. shear rate for mixed solution.

The effect of shear rate on shear stress for mixture solution at different concentrations is shown in Figure 13. This figure indicates that the shear viscosity increases with the concentration of CMC solution. At the same rotational speed, higher CMC concentration solution exhibits a higher apparent viscosity. Also, with increasing the shear rate, the apparent viscosities showed an increasing trend, which means CMC mixture solutions are shear-thickening fluids (figure 14).

5. Conclusions

This research leads to the conclusion that a good drag reduction behavior of the three additives (CMC polymer, SDBS surfactant, and their mixture) was carried out in turbulent pipe flow (diameter 3/4"). It could also be concluded from this work that using a mix of polymer and surfactant resulted in a higher drag reduction (58-62) % than that using polymer or surfactant alone. The drag reduction increases with increasing additive concentration. The drag reduction of the mix additives showed more stable form among degradations due to the complexity of the aggregate structure that formed from the interaction between polymer and surfactant.

Low different concentrations were used and their effect were relatively uneven, but on the whole the percentage of drag reduction increases with the increasing of the concentration for the three kinds of additives used. But still this work needs to be completed by using higher concentration for polymer and surfactant, studying behavior of these higher concentrations on drag reduction percent, to make a comparison between low concentrations and higher concentrations and which of them is preferable.

6. References

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دراسة خصائص امكانية مزج بوليمر مع مواد تقليل الشد اسطحي وتأثيرها على ظاهرة تقليل الاحتكاك باستخدام نظام انابيب جريان

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الخلاصة

في هذا البحث تم دراسة تأثير استخدام كاربوكسيل ميثيل سليولوز، وصوديوم دودسيل بنزين سلفونيت بوصفها محاليل مائية على ظاهرة تقليل الأعاقة لجريان السوائل من خلال الانابيب. تراكيز مختلفة من هذه المواد مثل (50، 100، 150، 200، 250، 300، 350، 400، 450، 500 جزء من المليون) تم استخدامها لتحليل خواص هذه المحاليل المحضرة باستخدام هذه المضافات والتي تشمل "الشد السطحي، التوصيلية الكهربائية، واللزوجة" لكل من المضافات المستخدمة منفصلة و ممزوجة وبتراكيز مختلفة. افضل اربعة تراكيز مثل (50، 100، 200، 300 جزء من المليون) من خواص المحاليل المدروسة تم استخدامها لدراسة تأثيرها على ظاهرة تقليل الأعاقة لجريان السوائل، استخدمت انابيب (PVC) مختلفة الاقطار (1 انج، 3/4 انج) لدراسة تأثير هذه المضافات منفصلة و ممزوجة بوصفها مواد مقللة للاحتكاك عند جريان السوائل خلال هذه الانابيب. النتائج أوضحت امكانية المزج واعطت نسبة تقليل اعاقة حوالي 58 % اعلى مما لو استخدمت منفصلة ، تناقص معامل الاحتكاك مع تزايد عدد رينولدز و توافق جيد مع معادلة فون كارامن و MDR asymptote . عدد رينولدز، قطر الانابيب تركيز المضافات كلها تعد عوامل مؤثرة وقد تم مناقشة كل من التركيز الحرج لتكوين المذيلات وبداية ظاهرة تقليل الاعاقة والتداخلات بين المضافات الممزوجة.