Effect of Glycolic Acid Ethoxylate Lauryl Ether (GAL) Surfactant Solutions among Low and High Concentrations on Drag Reduction to Progress Flow in the Pipeline Networks Using RDA

Sajda S. Alsaedi[1*], Zainab Yousif[2], Sheymaa Alazzawi[3], Peter Filip[4]

[1]Mechanical Engineering Department, University of Technology, Baghdad, Iraq
[2]Chemical Engineering Department, University of Technology, Baghdad, Iraq
[3]Mechanical Engineering Department, University of Diyala,, Diyala, Iraq
[4]Department of Mechanical Engineering and Energy Processes, SIUc, USA
[*]Corresponding Author E-mail: **20051@uotechnology.edu.iq**&**sajda.sabri@siu.edu**

6th Iraq Oil and Gas Conference, 29-30/11/2021

Abstract

In the pipeline networks field, GAL surfactant can reduce drag forces relatively using a small quantity part per million (ppm). Accordingly, the drag reduction (DR) enhancement is highly recommended in many industrial applications specifically the crude oil transportation aspect. GAL solution was experimentally investigated at various concentrations. The experiments were performed at low concentrations range from 50 to 300 ppm, and high concentrations range from 1000 to 2000 ppm. The rotating disk apparatus (RDA) was used at various speeds range from 50 to 3000 rpm in all experiments. Torque values of the GAL solutions were compared with water alone. The results clearly show that the different concentrations of the Glycolic Acid Ethoxylate Lauryl Ether (GAL) are good drag reduction agents (DRAs), with clear and high torque reading differences. Further, GAL solutions have the same tendency at all concentrations. The torque finding was enhanced with increasing concentration.

Keywords: Crude oil Transportation, Drag Reduction Forces, Flow Enhancement in the Pipeline Networks, Turbulent Flow in the Closed Channels, surfactants.

1. Introduction

In interior fluid flow such as pipes, conduits, and channels, mechanical energy is dissipated and turned to friction losses in the path of flow due to fluids resistance. The friction caused by adjacent boundary layers is termed friction drag while friction caused by disconnected boundary layers of the wall is termed form drag. Form drag or

pressure drag can arise due to a difference in the pressure drops, additionally; the flow under turbulent conditions, drag forces will develop dramatically due to the formed eddies. Therefore, the highest drag force is translated into the greatest energy pumping requirement and increased energy costs then. To overcome the drag forces problems; a minor minute of additives that add to the fluid could be substantially decreasing the friction loss in the turbulent flow inside the pipeline. The drag Reduction (DR) phenomenon is known as "drag reduction", by drag reduction technique could be made a huge difference in the power saving that is used to transfer liquid in pipelines. In 1948, Toms [1] is the first pioneer noticed decreasing in the friction losses when he adds a small concentration of high molecular weight of the polymer in the turbulent flow. Forrest et.al [2] studied the pulpwood suspended in water solution were observed decreasing in pressure losses in the turbulent flow. Mysels [3] applied aluminum soap as drag reduction additives. Lumley [4] has been described the DR phenomenon as turbulent drag reduction which is decreasing skin friction in stormy flow less than the solution individual. Mysels [5] studied the surfactant effect on reducing drag performance. The surfactant agents were classified by Mysels into three categories namely: zwitterionic, nonionic, and ionic. The onset of researchers who study non-ionic surfactant is Zakin and Chang [6] applied triple types of non-ionic surfactants to study the effect of temperature, concentration, and shear stress on the drag reduction efficiency. The results indicated that the micelles geometric form can be changed due to the impact of the molecule structure of nonionic surfactants. In addition, the drag reduction efficiency is going to increase in these conditions. Zakin and Ge [7] stated that the activity of nonionic surfactants has a limited range only in the concentration and temperature. Zakin et al. [8] employed the cationic surfactant Cetyltrimethylammonium bromide (CTAB) to study its effect on drag-reducing. The CTAB- naphthol was mixed in various concentrations. the highest drag-reducing obtained is around 70%. Further, the shear-thinning features were examined at the same component to predict its drag reduction potential. They found the drag reduction of the mixture solution discontinuous at Re increase, which follows the same behavior of anionic surfactant solution. Suksamranchit and Sirivat [9] used a complex solution of polymer PEO and cationic surfactant. The linking between the polymer and

surfactant micelles could be changing the velocity of the solutions. The complex component has a great benefit such as decrease the optimization of polymer concentration and modification the drag reduction efficiency by decreasing the critical polymer molecular weight [10]. Mysels [5] one of the pioneers who employ an anionic aluminum soap with the gasoline in the pipe flow. Savins [11] applied the anionic surfactants to study drag reduction in aquatic solution in wide experimental attempts. The ammonium soaps and alkali metal about 0.2% in salt or ester of oleic acid solutions were used. The results revealed that the rod-like shape is formed when adding (KCl) to the solution due to the quicken union of the soap molecules. Further, the drag reduction is increased during the growth of the shear stress until a critical point, after this critical point the drag reduction is decreased with any more increasing in shear stress. This means the micelles bundles will be destroyed after the critical point of shear stress and this case reverses when the shear stress becomes below the critical point. In other words, the micelles will fix themselves. Eman et al. [12] investigated the impacts of biopolymer and surfactant additives on the features of DR, as well as the performance of (Chitosan, SLES) individually and their complex solution in different concentrations by RDA. The results showed the highest drag reduction performance of about 47.75% came with a mixed solution at 3000 RPM of RDA. Yunqing Gu et al. [13] studied the mechanism of additives and drag reduction properties. Further, they have discussed the factors that caused the decay and anti-decay in polymer and surfactant, respectively. The results revealed that the mixture solution has properties to resist a high shear and the drag reduction effected directly with increase Re. In previous studies were used one or more polymer or surfactants materials, where polymers are generally degraded after a certain time which driving the flow to lose their stability. Weili Liu et al. [14] have conducted a numerical and practical study to assess the drag reduction efficiency for electronic pipes. They have suggested a new surface form for pipes using narrow grooves to reduce the pressure gradient of liquid transportation. The comparative tests were achieved in a water tube. The results revealed that the eddy 'cushioning' and 'driving' impacts generated via eddies in narrow grooves were very important for drag drop. Paul et al. [15] a revision and investigation were achieved on the effect of additives on the drag using the flat

and curved pipes. Many parameters, such as additive mechanisms, flow methods, and friction effects were tested. The results indicate that the drag performance in flat pipelines is greater than in curved pipelines. The highest drag reduction percentage was obtained at about 3.21%. Also, indicated that drag performance depends extremely on the additive type, concentration, and bubble portion of nano-bubbles. While the SEM offers information about the surface of the material. These methods were displayed primely by Danino et al. and Bernheim et al. When they are shown branching in micelles and gradual network formation. The methods provide deep details of the complex flow structure. The Image of TEM is formed when the radiation energy passes and transmits through the sample, while SEM is provided image via revealing secondary electrons released from the surface of the sample caused by stimulation of the basic electron beam. Typically, SEM is employed to fabricate fine detail imaging to the surface of the samples such as natural or synthetic complex material, raw material, and microorganisms. Both techniques have been applied to find out the complex aggregations in detail [16].

Generally, the drag force was improved as the additive concentration increase. It believes that an increase was a result of the increased associated kinetic energy of additive molecules. this action was resulted to separate and diffuse turbulent eddies, that cause to reduce their control on

the flow, and then enhancing drag force [17] [18]. The primary significance of the investigation is to overcome the frictional pressure and power losses problem in pipelines applying a new drag reduction agent. The reduction of the friction force during flow can hugely decrease the cost of both pumping energy and pumping station units. The mechanism of Drag reduction depends on the addition of a material to the liquid transportation in a turbulent flow. This technique can develop energy consumption in pipeline systems. It will provide an enormous contribution and advantages to the industrial to decrease their annual cost and energy dissipation. The most common applications that used the DR technique are sewers, open channels, firefighting, and jet cutting or hydro transport. The goal of this work is to investigate the influence of a warty surfactant solution Glycolic Acid Ethoxylate Lauryl Ether (GAL) at low and high concentration on drag reduction performance employing

rotating disc apparatus (RDA) at different rotating velocities. The measurement set-up used in the torque measurement was developed in SIU/Engineering school laboratory. The morphological test has been done employing scanning electronic microscopy (SEM) technique.

1.1. Drag Reduction

In hydrodynamics science, drag is defined as a kind of frictional or fluid resistance force which is working reverse to the proportion motion of anybody regarding an ambient liquid. Drag is generally classified to four categories namely: form drag, skin friction, interference drag, lift-induced drag. The drag improver was remarked first in 1943 by Toms. It was observed when he added a minute amount of polymer to the pipeline in the turbulent flow that in (ppm) could give distinguish results through decreasing the friction force and flow resistance [19].

Recently, the drag reducers had significant value as a new process for decreasing power consumption in the fluid transportation field, especially power saving in pump stations. In other words, drag improver can considered as a substitutional trajectory to decrease the power losses in the pumps, which occur through a fluid transition by a pipeline system. This could occur by adding one or more drag improvers inside the fluid flow in the pipeline system, that leads to power saving, and reducing the cost that spends to update pieces equipment of pumping [20].
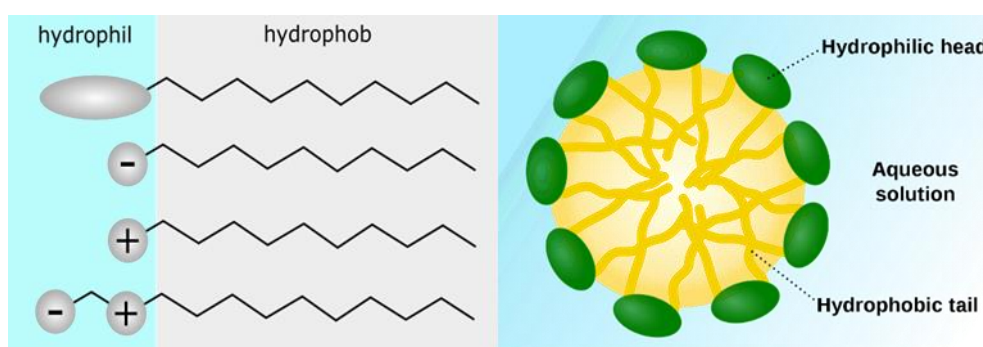
1.2 Surfactant

The surfactant is called surface-active agents, which is decreasing the surface tenseness in liquids and interfacial tenseness between twin immiscible liquids, particularly if used in minute amounts. The surfactant has a unique property which is the capability to form a remarkable structure called micelles, which can rejuvenate their basic shape after being deformation or exposed to high stresses due to self-repair. The formative groups of micelles shapes were named According to the solvent and the system situation, such as cylindrical, disk-like, ball shape, thread-like, and vesicle. Also, surfactants can change their form to another form. Mostly, surfactants have been used in moisturization products, detergent products, and emulsifying or separating

agents [21]. In general, the surfactants are categorized into two groups; the first group is called hydrophilic or head group. The second group is called hydrophobic or tail group, in case the solvent is water the structure of surfactants can be categorized chemically into two parts namely:

1- Polar (ionic) part, which is usually called a hydrophilic head group, that in an aqueous environment is attracted to water. Also, is widely used due to their ability to form hydrogen bonds.

2- Nonpolar part, which is usually called hydrophobic tail group, that in an aqueous environment is often interacting with water, that reason make the hydrophobic molecules combined with hydrocarbon atoms to avoid interaction with water. Also, is available and cheaper enough in different sources such as petroleum industry products and agriculture [22], [23], [24]. Figure (1) shows a schematic diagram of surfactant molecules [25]. The forces, which hold the surfactant molecules together in micelles, are much weaker than the primary chemical bonds of polymer molecules. But these forces persist even if the micelles encounter strong shear and break up. They reform or self-assemble when the strong shear disappears, while polymer molecules cannot reform after mechanical degradation. Thus, surfactants can be used in recirculation systems containing high shear pumps as they are self-repair.

Fig. (1): Shows schematic diagram of a micelle – the lipophilic tails of the surfactant ions remain inside the oil because they interact more strongly with oil than with water. The polar "heads" of the surfactant molecules coating the micelle interact more strongly with water, so they form a hydrophilic outer layer that forms a barrier between micelles.

2. <u>Experimental Set up</u>

The rotating disk apparatus was used to test the rheology characteristics and the resistance of the solutions to maximum levels of turbulence as shown schematically in Figure (2). To assess the mechanism of the solutions and their influence on the drag reduction, the torque and the viscosity of solutions are measured by the rotating disk apparatus. The RDA has included a stainless-steel container, its dimensions 88 mm height, and 180 mm diameter and closed by movable cap its dimension 60 mm thickness. The RDA is equipped with a 3 mm thickness and 148 mm in diameter. The highest capacity of the solution in the cylinder is about 1200 ml. The RDA is connected directly with the servo motor and an interface that captures the torque values at every rotational speed of the motor, thereby converting to readable form in the computer display system with SCADA software. The maximum rotational speed of RDA more than 3000 rpm. The torque and viscosity are observed, documented, and transferred to the data processing system.

The experiments were conducted using water alone to compare their torque values with the torque values of the selected additive solution. Further, the morphological trials were carried out to detect the fine details of aggregated structures of the complex additives by assisting Scanning Electronic Microscopy (SEM).

The sequences of RDA experiments are:

1. Samples were tested in different concentrations: (50, 300,1000, 2000 ppm) and in different rotating velocities in the range (50-3000 rpm).

2. Samples were mixed in the deionized water at room temperature.

3. Torque values were showed by a screen display, and it is plotted versus rotating velocity for each concentration.

4. Drag reduction percentage calculates using following equation: $\%Dr = \times 100$
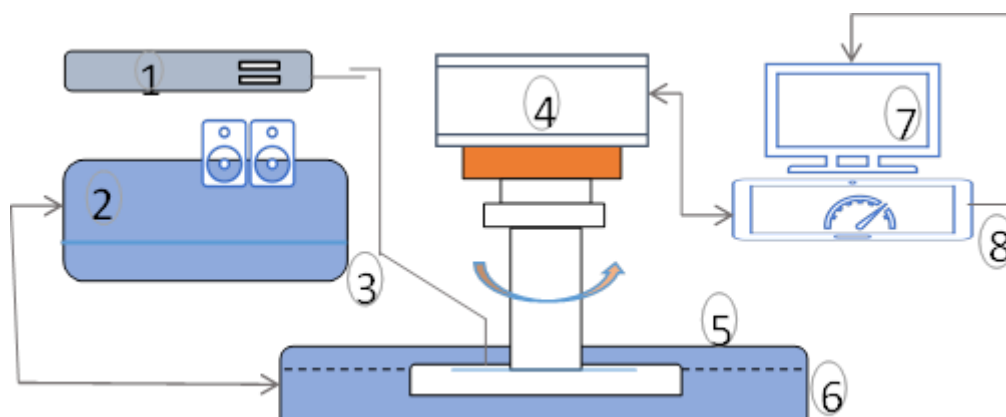
Fig. (2): Schematic of RDA:1. thermo-gauge 2. the system of water circulation 3. thermocouple 4. motor 5. dissolution tank 6. water jacket 7. personal computer 8. velocity observer.

2.1. Glycolic Acid Ethoxylate Lauryl Ether (GAL)

The surfactant of Glycolic acid ethoxylate lauryl ether (GAL) commercially is called Laureth-4 carboxylic acid. GAL is classified from the anionic surfactant group. Also, it does not cause any risk and is environmentally friendly. Figure (3) shows GAL, and its chemical structure. Material employed in this study was supplied by Sigma Aldrich, USA, and used as a liquid without any additional treatment.
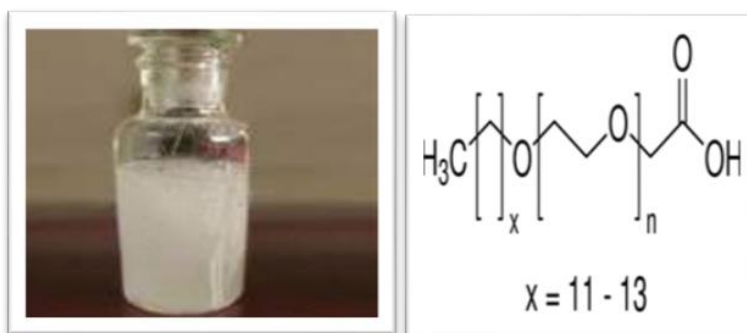
Fig. (3): Glycolic acid ethoxylate lauryl ether (GAL) liquid and its chemical structure

2.2. Preparing Solutions

The desired concentration was dissolved in a container with de-ionized water, then dispersed by a mechanical stirrer at a low speed for five hours, until the additive solutions become homogenous. The homogenous solution and water were poured into the main tank frequently and kept stirring for a certain period and the moment that

stirring was completed, the additive solutions were covered to avoid water drying up. The solution was relaxed for one day or more before doing the tests. All solutions were operated at low concentrations ranging between (50-300 ppm) and at high concentrations ranging between (1000-2000 ppm). Further, the rotational speeds of RDA were ranging from (50-3000 rpm) and the tests were conducted at room temperature. All these procedures were repeated in the individual solutions at each concentration.

2.3. Experimental Calculation

Drag reduction percentage calculates using the following equations:

$$\%Dr = \frac{Ta-Tb}{Ta} \times 100 \tag{1}$$

Where:

T_a is the torque values after adding GAL (water alone) (N.m)

T_b is the torque values before adding GAL (N.m).

$$NRe = \frac{\rho R^2 \omega}{\mu} \tag{2}$$

Where:

μ is a viscosity of a fluid

ρ is a density of a fluid

R is a radius of the disk

ω is an angular velocity

$N R_e >= 1 \times 10^5$ (turbulence because of using the rotational disk apparatus speed range 0-3500)

The major variables investigated are:

Speeds: RDA was used at different rotational speeds ranged (0-3000) and the torque value was calculated, which adopted with the dimensionless Reynolds number (Re).

Concentration: GAL an anionic surfactant type was used at low and Hight concentrations ranged (50-300) and (1000-2000) respectively.

3. Results and Discussion

3.1 Effect of GAL Enhancer on Viscosity

The effect of GAL additives on viscosity at different shear rates is illustrated in Figure (4). In Figure (4) it can notice that increasing shear rate caused an increase in viscosity values at all GAL concentrations. Indeed, Figure (4) shows that increasing the shear rate causes an increase in viscosity. This is caused since that the presence of the polar "heads" of the surfactant molecules coating the micelle interact more strongly with water, so they form a hydrophilic outer layer that forms a barrier between micelles to certain positions in the surfactant head causing an increase in viscosity. A similar tendency of increasing viscosity values with the shear rate when increased concentrations of surfactant can be noted in Figure (4), with larger values than that of using water alone.
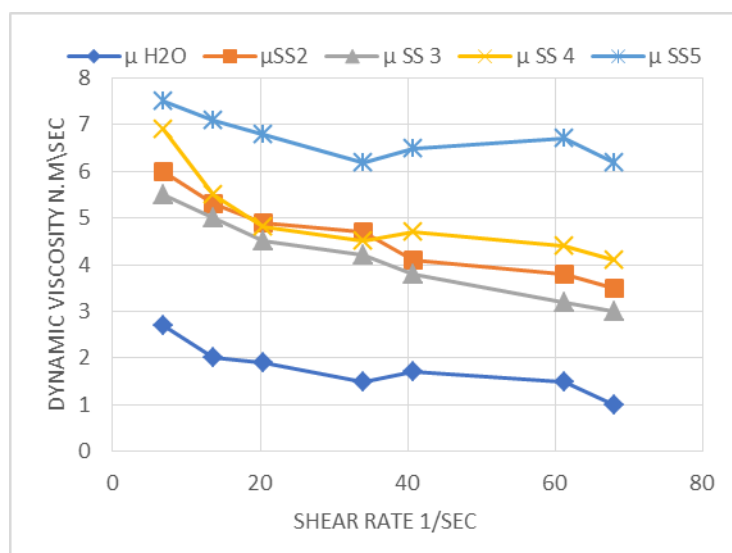

Fig. (4): The effect of shear rate on viscosity at different GAL surfactant solutions (concentrations)

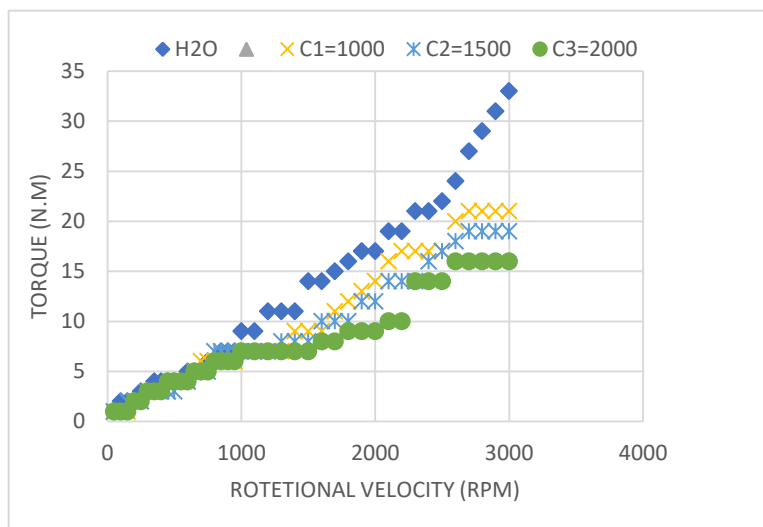### 3.2. Effect of Concentration and Rotational Speed on Drag reduction

Figures (5) and (6) show selected samples of the experimental results for testing the various additive concentrations of GAL in the RDA. The Figures report the torque effects against the rotational speed of the various additives of the Glycolic acid ethoxylate lauryl ether (GAL). Overall, the GAL tested at low and high concentrations were able to reduce drag as there is a noticeable increase in the torque reading against rotational speed. However, the best performance was observed with the highest

concentration until the lowest concentration, where the maximum torque reaches 35% at the highest speed of 3000 rpm and at the highest concentration 2000 ppm. This result might be due to self-repair of surfactant micelles after decay [26]. From this observation, it is opined that the concetration played an important role of the way this material reduces drag as highlighted via many authors earlier different DRAs in the pipeline networks [27, 28].

Further, there are few observable differences in the figures. It could be observed that the torque readings are more effective after 1200 rpm. This could be because of the increase in the degree of turbulence which in turn suppressed the eddies formation, in this type of behavior, there are favorable flow means for the additives to effectively interact together within the turbulent structures in the flow. Further, it could also be observed that all the concentrations showed drag reduction ability. From their degree of divergence from the water curve, the higher the concentration, the greater the divergence. This is a clear indication that this type of surfactant can reduce the drag (torque reading) further by increasing concentration. Our results have been agreed with previous.
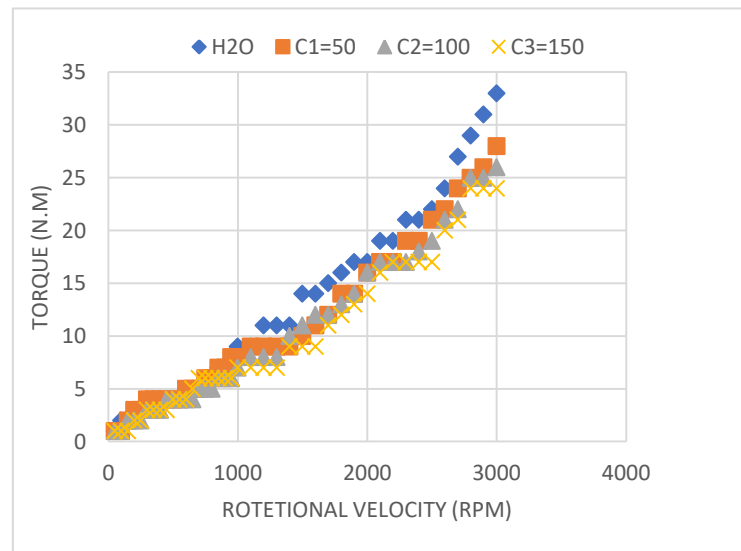

Fig. (5): Torque effect at various rotational speed and low concentrations of GAL solutions (50-150 ppm)

Fig. (6): Torque effect at various rotational speed and high concentrations of GAL solutions (1000-2000) ppm

The experimental work has been validated by comparing torque behavior after adding a GAL agent using RDA with previous experimental works at the same conditions. Where it found a good agreement with Edward's study [29] as shown in Figure (7).
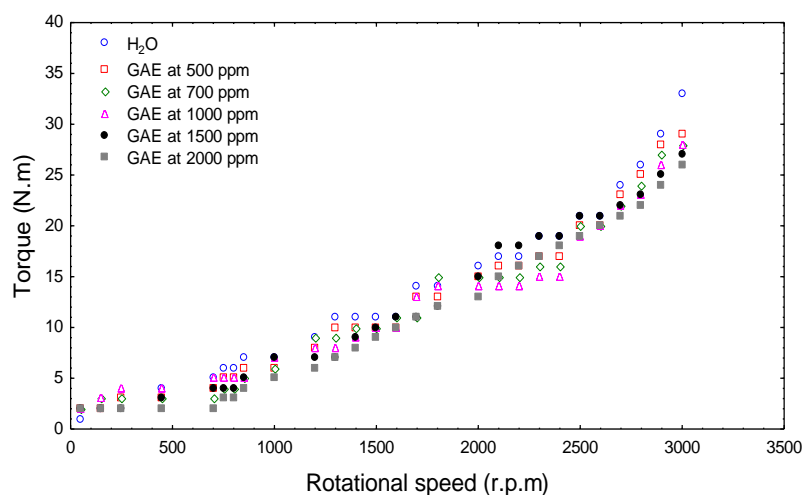
Fig. (7): Torque effect Glycolic acid ethoxylate lauryl ether GAE using RDA, [29].

3.3. The SEM microstructure

Figure 8 (a and b) shows the SEM images using the surfactant GAL with different polymers, which are PEO and HTA. Two solutions of the GAL-PEO and GAL-HTA are aggregations at the same concentration 1500 ppm. Figure 8 (a and b) demonstrates the SEM of GAL-PEO and GAL-HTA complexes and how an obvious of the two materials is formed. From the figure, it can be seen each complex shows a uniform surface through a semi-square shape in black color of polymer chains that surfaced with surfactant micelles in white color. The observation refers that the aggregation of the surfactant and polymers takes place when they are combined. It believes that the surface tension feature of surfactant with the polarity of surfactant and polymer generates strong aggregation of the surface.
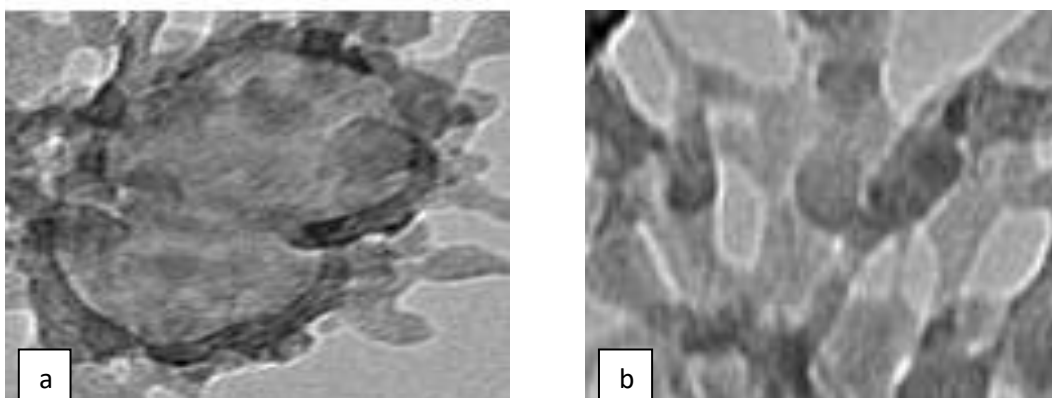
Fig. (8): (a and b) Shows the SEM images of complex additives at 1500 ppm concentration of GAL- PEO and GAL -HTA

4. Conclusions

In closing, the impact of Glycolic Acid Ethoxylate Lauryl Ether (GAL) surfactant at high and low concentrations and the rotational velocity on the drag forces was examined using a rotating disk apparatus, and it can be concluded:

1- The additives can overcome the trouble of shear forces. Whether DRAs confirm their stability as drag improvers or the stability comes as results of their complex solution (water plus GAL).

2- Drag reduction percent or flow increase percent are increased as the rotating velocity of solution increased.

3- The novel flow reducer (GAL) was examined successfully as drag reducing agent in a rotating disk apparatus.

4- The drag reduction performance increases by increasing the GAL concentrations. Increasing the additive concentration means increasing the formation of the surfactant micelles, that involved in the drag reduction operation, that leads to increase the area of turbulence, which is under the novel drag improver impact.

5- The SEM technique test showed surfactant micelle aggregate structures is highly strong.

5. Nomenclature

DR   Drag Reduction

DRAs   Drag Reduction Agents

Re   Reynolds number

RDA   Rotational disk apparatus

TEM   Transmission Electronic Microscopy

SEM   Scanning Electronic Microscopy

L   Length(mm)

d   Diameter ratio (mm)

%DR   Drag reduction percentage

ppm   Part per million

rpm   Revelation per minute

GAL   Glycolic acid ethoxylated lauryl ether

Ta   Torque values after adding GAL (water alone) (N.m)

Tb   Torque values before adding GAL (N.m).

References

[1]. B. A. Toms, "Some observations on the flow of linear polymer solutions through straight tubes at large Reynolds numbers," 1st International Congress on Rheology, vol. 2, pp. 135-141, 1948.

[2]. F. Forrest and G. A. H. Grierson, "Friction Losses in Cast Iron Pipe Carrying Paper Stock," Paper Trade Journal, vol. 22, no. 92, pp. 39-41, 1931.

[3]. K. J. Mysels, "Flow of Thickened Fluids," p. 2492173, 1949.

[4]. J. L. Lumley, "Annual Reviews," Fluid Mech, no. Palo Alto, Calif., pp. 1-367, 1965.

[5]. K. J. Mysels, "Napalm. Mixture of Aluminum Disoaps," Industrial & Engineering Chemistry, vol. 41(7), pp. 1435-1438, 1949.

[6]. J. L. Zakin and J. L. Chiang, "Non-ionic surfactants as drag reducing additives," Nature Physical Science, vol. 239(89), pp. 26-28, 1972.

[7]. J. L. Zakin and W. Ge, "Polymer and surfactant drag reduction in turbulent flows," John Wiley and Sons, Inc: New York , p. 776, 2010.

[8]. J. L. Zakin, M. Poreh, A. Brosh and M. Warshavsky, "Exploratory study of friction reduction in slurry flows," In Chemical Engineering Professional Symposium Series, vol. 67, pp. 85-89, 1971.

[9]. S. S. a. J. ,. Suksamranchit, "Polymer–surfactant complex formation and its effect on turbulent wall shear stress," Journal of Colloid and Interface science, vol. 294(1), pp. 212-221, 2006.

[10]. M. Hellsten, "Drag-reducing surfactants," Journal of Surfactants and Detergents, vol. 5(1), pp. 65-70, 2002.

[11]. J. Savins, "A stress-controlled drag-reduction phenomenon," Rheologica Acta, vol. 6(4), pp. 323-330, 1967.

[12]. W. Mahmood, W. Khadum and E. Eman, "Characterization and Performance Evaluation," Applied Rheology, vol. 29(1), pp. 12-20. , 2019.

[13]. Y. Gu, S. Yu, J. Mou, D. Wu and S. . Zheng, "Research Progress on the Collaborative Drag Reduction Effect of Polymers and Surfactants," Materials, vol. 13(2), p. 444, 2020.

[14]. W. Liu, H. Ni, P. Wang and Y. . Zhou, "An investigation on the drag reduction performance of bioinspired pipeline surfaces with transverse microgrooves," Beilstein Journal of Nanotechnology, vol. 11(1), pp. 24-40, 2020.

[15]. P. O. Ayegba, L. C. Edomwonyi-Otu, A. Abubakar and N. Yusuf, Drag Reduction by Additives in Curved Pipes for Single-Phase Liquid and Two-Phase Flows, A Review, 2020 .

[16]. M. S. I. Khan, S. W. Oh and Y. J. Kim, "Power of Scanning Electron Microscopy and Energy Dispersive X-Ray Analysis in Rapid Microbial Detection and Identification at the Single Cell Leve," Scientific reports, vol. 10(1), pp. 1-10, 2020.

[17]. A. Khadom and A. Abdul-Hadi, "Performance of polyacrylamide as drag reduction polymer of crude petroleum flow," Ain Shams Engineering Journal, vol. 5(3), pp. 861-865, 2014.

[18]. N. Esfandiari, R. Zareinezhad and Z. Habibi, "Esfandiari, N., Zareinezhad, R., & Habibi, Z. "The investigation and optimization of drag reduction in turbulent flow of Newtonian fluid passing through horizontal pipelines using functionalized magnetic nanophotocatalysts and lecithin". Chinese Jou," Chinese Journal of Chemical Engineering, vol. 28(1), pp. 63-75, 2020.

[19]. B. A. Toms, "Some observations on the flow of linear polymer solutions through straight tubes at large Reynolds numbers," 1st International Congress on Rheology, vol. 2, pp. 135-141, 1948.

[20]. C. A. Kim, D. S. Jo, H. J. Choi, C. B. Kim and M. S. Jhon, "A high-precision rotating disk apparatus for drag reduction characterization," Polymer Testing, vol. 20 (1), pp. 43-48, 2000.

[21]. A. T. Florence and D. Attwood, "Surfactant Systems: Their Chemistry, Pharmacy and Biology," Chappmann and Hall: London and New York., 1983.

[22]. J. L. Zakin, B. Lu and H. W. Bewersdorff, "Surfactant drag reduction," Reviews in Chemical Engineering , Vols. 14(4-5), pp. 253-320 , 1998.

[23]. Y. Zhang, Correlations among surfactant drag reduction, additive chemical structures, rheological properties and microstructures in water and water/co-solvent systems, Ohio State: the Ohio State University,Phd Thesis, 2005.

[24]. H. Zhang, D. Wang and H. Chen, "Experimental study on the effects of shear

induced structure in a drag-reducing surfactant solution flow," Archive of Applied Mechanics, vol. 79(8), pp. 773-778, 2009.

[25]. https://en.wikipedia.org/wiki/Surfactant.

[26]. J. Myska and V. Mik, "Degradation of surfactant solutions by age and by a flow and singularity," Chemical Engineering and Processing, vol. 43, pp. 1495-1501, 2004.

[27]. Y. Farsiani, Z. Saeed and B. R. Elbing, "Drag Reduction Performance of Mechanically Degraded Dilute Polyethylene Oxide Solutions," arXiv preprint arXiv, vol. 1907.07614, p. 1907.07614, 2019.

[28]. R. H. Sultan, A. B. Abduallah and O. M. S. M. Sultan, "IMPROVEMENT OF SHARARA CRUDE OIL FLOW USING POLYSTYRENE AND POLYDIMETHYLSILOXANE AS DRAG REDUCING AGENTS", Scientific Journal of Applied Sciences of Sabratha University, vol. 2(1), pp. 14-28, 2019.

[29]. Hayder, A., Y. Zainab, and b, Edward O. Zulkefli. "Novel polymer-surfactant complex for enhancing the flow in pipes." Journal of Purity, Utility Reaction and Environment 4.4, pp.161-170, 2015.