An Experimental Investigation on Drag Reduction by a Combination of Polymer, Laurel Soap, and Palm Fiber Through Circulated Newtonian Liquid

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ABSTRACT: *Flowability and reduced pressure are some of the economic values in the pipe network and pipeline transportation. In this study, we investigated the functionality of self-made drag coefficients composed of a combination of large molecular weight polymer, Laurel soap, and date palm fiber which were induced into a circulated piping system under turbulent water flow. The proposed combination formulas are proved to be a new cost-effective drag reduction approach, which could be adopted extensively in fluid transportation at an industrial scale. The efficiency of using a mixture of polymer, palm fiber, and soap on the drag reduction was thoroughly evaluated via investigating several case studies. Using pure polyelectrolyte showed that at the highest polymer concentration (50 ppm), the percentage of drag reduction reaches 50% in 10.3 mm pipe diameter and 70% drag reduction in 13.5 mm pipe diameter at a flow of low Reynolds number counted 17166.7. Upon applying a mixture of polyelectrolytes composed of (50 ppm) and fiber in the range (30-60 ppm), a drag reduction of 63% in 10.3 mm pipe diameter and 76% in 13.5 mm pipe diameter were achieved, respectively. Upon examining a mixture composed of polyelectrolyte (50 ppm) and soap in a range (50-150 ppm), the results showed that the highest drag reduction was achieved at a low concentration of soap and a bulk flow at a low Reynolds number. The aforementioned performance results were exemplified by attaining drag reductions of 70% in 10.3 mm pipe diameter and 96% in 13.5 mm pipe diameter, respectively. This is accomplished by optimizing the applied mixture formulas. Upon examining all cases, the estimated drag reductions were shown higher when applying the polymer mixture compared to that of pure polymer. However, a slight decrease in the attained drag reductions when using polymer soap was observed and attributed to the hindrance from the palm fiber, which ultimately reduces the chance for all soap particles to reach the stagnant wall layer.*

KEYWORDS: *Drag reduction; SNF polymer; Palm fiber; Laurel soap.*

INTRODUCTION

The concept of drag reduction in pipeline flow has been investigated intensively for decades. The main the objective of these research works is energy reduction for crude oil transportation in pipeline networks [1-4].

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This can be achieved by: (i) adding a small amount of water-soluble chemical material to stabilize the boundary layer; (ii) reducing the turbulent eddies; and (iii) reducing the friction losses. On the other hand, adding a small amount of drag reduction agents would limit the turbulence range and enhance energy efficiency.

Many studies have investigated the use of long-chain polymers (e.g., polyacrylamide, poly-isobutylene, super flat A110, etc.) [5-9]. *Mucharam et al.* [10] stated that the use of a polymer with a long chain and large molecular weight causes damping of eddies in the flow, resulting in turbulence limitation. Despite the large elongation viscosities of these polymers, which could stabilize flow boundary, it is reported that they may break down after some time of induction, and attributed to thermal or mechanical degradation associated with high shear stresses. At this condition, there would be a loss in the working efficiency of some polymers such as polyethylene oxide (PEO) [11]. It's also reported that in order to work in a safe flow regime, the recommended polymers for drag reduction shall have resistance to the mechanical degradation parameters [9,12].

Surfactants are another group of materials investigated and tested for drag reduction [13-15]. The surfactant forms a gel phase in turbulent flows, causing a wall slip (bilayer sheet of micelle), leading to a decrease in the wall friction and immediately providing a drag reduction mechanism. These chemicals form micelles network and hence impart viscoelasticity improving the flow of solution in the pipeline. The advantages of using surfactants are the ability to realign and self-repairing and form micelles after mechanical degradation [16].

Calin [17] showed that the use of surfactant material had a significant impact on the pressure drop in a piping system. The theoretical formula was developed to determine the Darcy coefficient for a range of Reynolds numbers (100 < Re < 10,000). Different emulsions samples of water oil were tested. The rheological properties of the samples were investigated for different flow regimes. However, some surfactants are toxic and non-biodegradable, especially when discharged into a sewage system. Thus, the choice of surfactants should consider their toxicity and biodegradability [18].

The mixtures of polymers and surfactants were also investigated for drag reduction, such as non-ionic polymer and ethoxylated alcohol [19]. The addition of surfactants to the mixture is certainly modifies the polymers' properties, and hence the polymer's viscosity could be significantly reduced [20,21]. Furthermore, other materials used for drag reduction are solid particles and nanofluid materials such as nano SiO_2, Cocus rucifer fiber, date pam fiber, etc.

Nanomaterials were also tested for improving drag reduction; however, only a few results were marked promising. Nanofluids provide filling for the internal pipe surface by the nanoparticles, reducing pipe roughness [10]. *Alwasiti* and *Ibrahim* [22] reported that silica nanoparticles have proved to be efficient and suitable to enhance the fluidity of Iraqi heavy crude oil at a constant temperature of 20ºC. The results showed that the presence of nano-silica particles in optimal dose (100 mg/L) has resulted in a lower pressure drop of (3.122 Pa) and viscosity of (24.5 cSt) that reduced by 24% compared with no existence of the nano-silica particles.

Ibrahim et al. [23] applied an effective electrical field by designing and implementing an invented capacitor. The optimum conditions were obtained using WinQSB and STATISTICA software. Locally prepared nano-silica has been employed with different concentrations (0–700 mg/L). The results showed the effectiveness of the electrical field on viscosity reduction. It also showed that the viscosity was reduced significantly with increasing treatment time, the distance between electrodes, and the voltage supplied.

Pouranfard et al. [24] have used SiO_2 nanoparticles as a material for drag reduction in water pipelines. The obtained results indicated that the drag reduction is significantly attained when using a rough pipe compared with a smooth pipe; however, only 24% drag reduction was achieved.

Akindoyo and *Abdulbari* [25] have investigated the effectiveness of combining silica nanomaterials and cationic surfactants on drag reduction using a rotating disc machine. Their results showed around 50% drag reduction was achieved.

The coccus Nucifera fiber was studied for reducing pressure drops in water pipelines by *Marmy et al.* [18]. The effect of several parameters was studied, such as pipe diameter, pipe roughness, fiber concentration, etc. The results showed that the use of coccus fiber would improve the percentage of drag by 56%. Rheological tests were also carried out using a programable rheometer for determining shear stress, surface tension, and viscosity of the samples under investigation.

Al Dawery and *Al‑Shereiqi* [26] found that the biomaterials were functional materials for drag reduction when applied to Omani crude oil. The obtained results showed that the limiting viscosity and yield stress were reduced by 50% and 30%, respectively.

Despite the numerous works on drag reduction by polymers, surfactant nanofluid, and fibers, the use of a combination of different materials in a mixture remains limited. To the best of the authors' knowledge, the effect of these customized mixtures on an improved drag reduction is still not fully covered in the literature.

The objective of this work was to utilize waste biomass palm fiber and nontoxic Laurel soap in combination with SNF polymer for improving drag reduction. In addition to that, the study investigated the efficiency and mechanism of drag reduction by combining polymer, soap, and palm fiber. The utilization of waste palm date fiber is known to be environmentally friendly and cost-effective. Laurel soap is considered biodegradable and nontoxic and has no harmful effect on sewage treatment. Hence, combining the three agents would attain positive implications on the flow regime in terms of improving drag reduction efficiency.

EXPERIMENTAL SECTION

Materials

SNF polyelectrolyte, laurel soap, and date palm fiber were used and investigated for drag reduction. SNF polymer (molecular weight $50x10^6$ g/mol) was supplied by SNF FLOERGER France. The chemical structure of the polymer is shown in Fig. 1. Laurel soap as a surfactant was purchased from a local market, and the soap is made with olive oil, laurel oil, water, and soda. The date palm fiber was collected from a local farm and washed, dried, then ground and sieved. The used particle size of the fiber was 150 µm. The date palm has significant features when used as an agent in the mixture, as it is non-reactive and does not absorb water or oil.

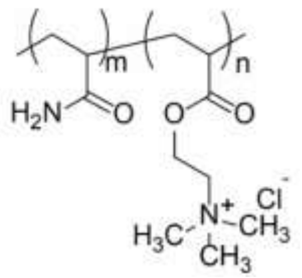

Fig. 1: Molecular structure of SNF polymer.

Experimental procedure

The experimental tests were performed using recirculating flow system that consists of polyvinyl chloride (PVC) pipe network, pump, valves, and rotary flowmeter. Two different pipe Internal Diameters (ID) were used; 10.3 and 13.5 mm. The schematic diagram is shown in Fig. 2. The pressure drop was taken between two different points of distance 1.5 m long using a portable pressure gauge. The testing media was water, which was pumped through the piping system at three different flow rates; 2, 4, and 6 GPM, ensuring that turbulent flow was fully developed.

During the experimental tests, different ranges of concentration of the chemicals and biomaterials were used; SNF polymer 10-50 ppm, palm fiber 30-60 ppm, and Laurel soap 50-150 ppm. Palm fiber was washed thoroughly with water, dried using a hot air oven at 60 °C, and then ground and sieved to obtain a powder with particle sizes; 150 µm. SNF solution was prepared by mixing 1 g of polyelectrolyte with one liter of deionized water and then stirring using a magnetic stirrer for at least 24 hours. Local liquid soap was used directly, and no preparation was required.

The percentage of the drag reduction DR% can be defined as the ratio of reduction in the pressure drop when using agents to the pressure drop attained without applying agents at a constant flow rate, as shown in Eq. (1).

$$DR\% = \frac{\Delta P_{without} - \Delta P_{with}}{\Delta P_{without}} \times 100\% \qquad (1)$$

Where $\Delta P_{without}$ is the pressure drop without using the agent of drag reduction. ΔP_{with} is the pressure drop using the agent of drag reduction.

The flow friction factor is based on the water flowing in the circulating piping systems is given by Eq. (2).

$$f = \frac{\Delta P}{\left(\rho u^2\right)\left(\frac{L}{D}\right)} \qquad (2)$$

Where f is the friction factor; D pipe diameter (m); L pipe length (m); u water velocity (m/s) and ρ water density (kg/m^3).

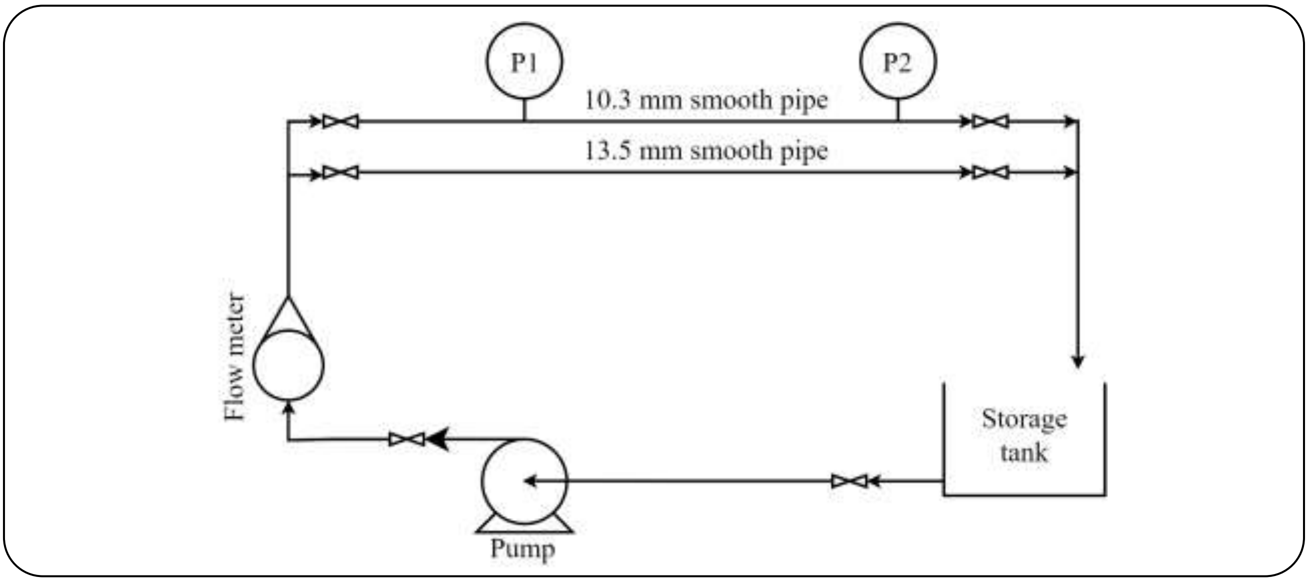

Fig. 2: Schematic diagram of the experiment for testing drag reduction.

For the fluid in turbulent flow, the amount of friction factor is approximated by *Blasius* Eq. (3) [27], as given in Equation (3):

$$f = \frac{0.079}{Re^{0.25}} \quad (3)$$

Where *Re* is the Reynolds number

RESULTS AND DISCUSSION

Several tests have been carried out for drag reduction in a recirculating water flow system using sole polyelectrolyte in one case and a mixture of polyelectrolyte, soap, and powder of palm fiber (150 μm average particle size) in the other case.

The friction factors for a smooth pipe were calculated using the Blasius equation. The results showed a very good match with that of the experimental data, as shown in Fig. 3. This matching picture proved that the measurement of drag reductions was reliable.

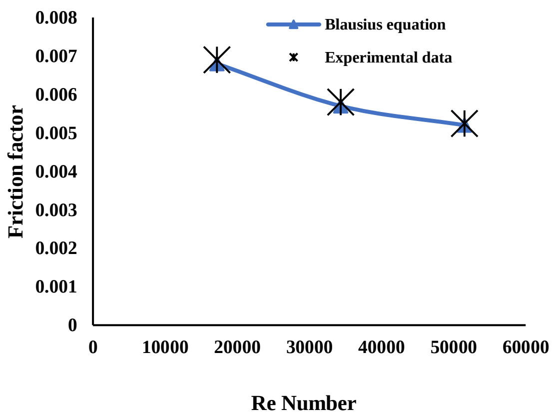

Fig. 3: Comparison between the friction factor measured experimentally and that calculated using Blausius equation.

The water density and viscosity were considered as ρ=1000 Kg/m^3 and μ=0.0009 Ns/m^2, respectively.

Friction test -using sole polyelectrolyte

Several tests were carried out to investigate the effect of applying sole polyelectrolyte and a mixture of polyelectrolyte, soap, and palm fiber, at different combinations, on the drag reduction. The tests were conducted by applying recirculating water flow system with two different pipe diameters (10.3 mm and 13.5mm) and three different flow rates (2 GPM, 4 GPM, and 6 GPM).

For pipe diameter 10.3 mm, the results of the estimated drag reduction using different concentrations of sole polyelectrolyte at different flow rates was plotted in Fig. 4. The results indicated that the percentage of drag reduction was shown higher for lower turbulence flow rate (i.e., low Reynolds number) than higher turbulence conditions. At the flow rate with Reynolds number 17166.7, the achieved drag reduction was at 34% using a value of 10 ppm of sole polyelectrolyte. In comparison, 19% was obtained at the same polymer concentration but under higher Reynolds numbers of 34333 and 51500.

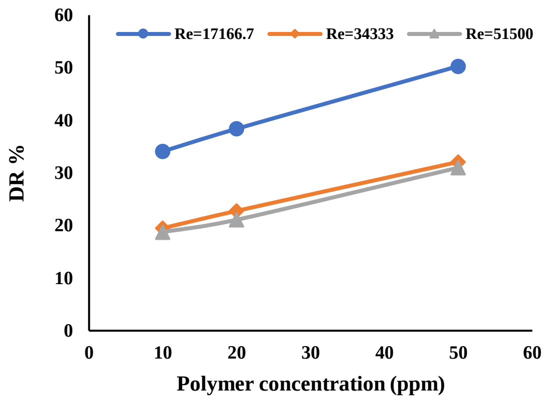

Fig. 4: Drag reduction (DR) measured when using sole polyelectrolyte at a different flow rate for pipe diameter = 10.3 mm.

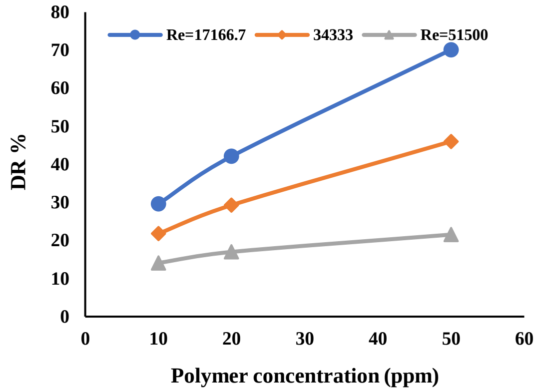

Fig. 5: Drag reduction (DR) measured when using sole polyelectrolyte at a different flow rate for pipe diameter = 13.5 mm.

The higher percentage of drag reduction at the lower water flow rate can be referred to as the strong connection of the fluid flow rate to the Reynolds number. This means that increasing the flow rate in the piping system can increase the turbulence degree, allowing the chemical agent to provide a larger impact on the drag reduction.

In addition, it was observed that the increase in the percentage of drag reduction was proportionally related to the polymer concentration. The percentage was also increased to 50% using 50 ppm polymer at flow rate when applying a flow regime at Re = 17166.7, while increased to 31% and 32% with other flow rates. This increase occurred due to applying higher polymer concentration, which means that more polymer chains become available and affecting damping eddies formation and then reducing the turbulence of flow.

Using a larger pipe diameter of 13.5 mm and the same operating conditions mentioned above, the results indicated higher drag reductions obtained compared to that of the smaller pipe diameter (10.3 mm), especially at higher polymer concentration. The results were plotted in Fig. 5. At flow with low Reynolds number 17166.7, the achieved drag reduction was estimated to be 70% using 50 ppm sole polymer. At the same time, the achieved reductions were estimated to be 41% and 22%, at higher Reynolds numbers of 34333 and 51500, respectively. Nonetheless, its observed that the measured drag reductions ranged between 14% to 30%, when applying sole polymer at lower concentrations for higher flow rates than the values mentioned above.

The percentage of the drag reduction was significantly increased with a larger pipe diameter (higher Reynolds number), which could be attributed to higher turbulence occurring and the effect of the dragging agent in reducing the pressure drop.

***Friction tests -using a mixture of polymer and palm fiber in pipe diameter 10.3 mm**,*

In order to improve drag reduction, mixtures of different polyelectrolyte concentrations and palm fiber at 30 and 60 ppm were used. The results at different flow rates were plotted in Figs. 6 and 7, respectively. The results in Fig. 6 indicated that the percentage of reduction was increased with the increase of the polymer concentrations. Also, a higher drag reduction was achieved at a lower Reynolds number. Using 30 ppm fiber indicated a reduction of 63% at 50 ppm of polymer and around 32% using a value of 10 ppm of polymer. At moderate Reynolds numbers, the achieved reductions were 30% and 23% using the same polymer concentrations. However, at lower flow rates, the achieved drag reductions ranged between 19% to 24%.

It's observed that the use of the combination of polymer and fiber has produced dual effects on drag reduction. The polymer damped the eddies, while the addition of fiber played another significant role by breaking the formed eddies and reducing their size, leading to an increase in the efficiency of drag reduction. The result of using palm date fiber agrees with the reported by *Marmy et al.* [18].

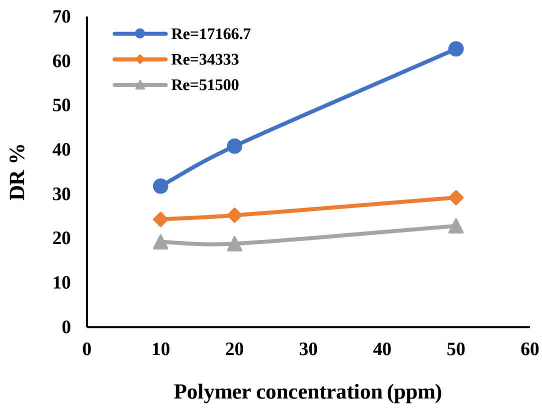

Fig. 6: Effect of adding polyelectrolyte at different concentrations and 30 ppm palm fiber on the drag reduction when applying various flow rates for a case of 10.3 mm pipe diameter.

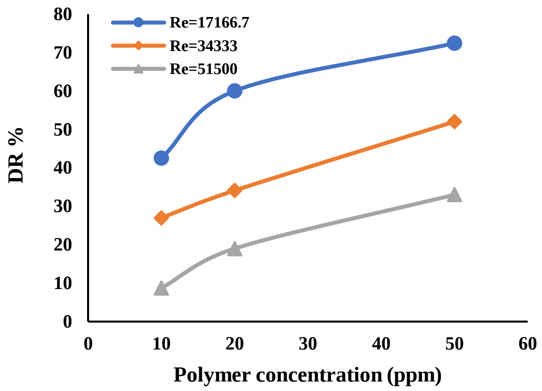

Fig. 8: Effect of adding polyelectrolyte at different concentrations and 30 ppm palm fiber on the drag reduction when applying various flow rates for a case of 13.5 mm pipe diameter.

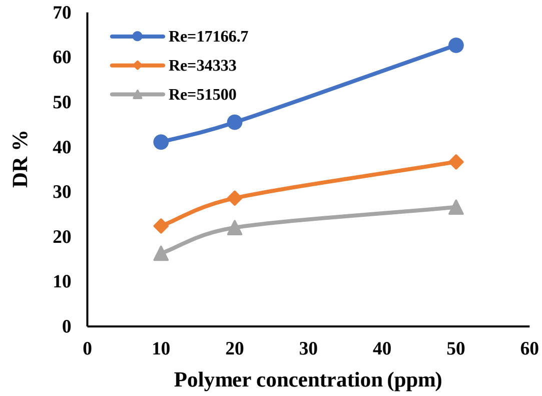

Fig. 7: Effect of adding polyelectrolyte at different concentrations and 60 ppm palm fiber on the drag reduction when applying various flow rates for a case of 10.3 mm pipe diameter.

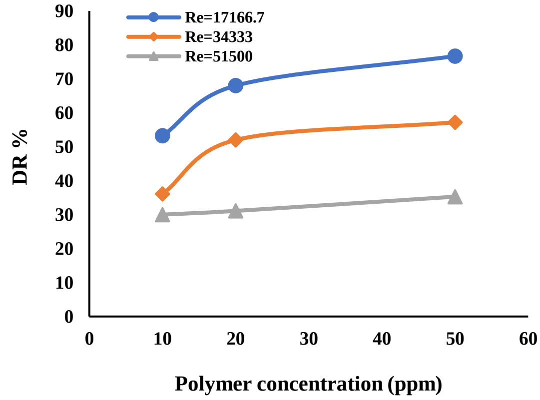

Fig. 9: Effect of adding polyelectrolyte at different concentrations and 60 ppm palm fiber on the drag reduction when applying various flow rates for a case of 13.5 mm pipe diameter.

For polyelectrolyte and 60 ppm fiber mixture, similar improvements were achieved especially at higher flow rates, as shown in Fig. 7. The results indicated a reduction of 62% at 50 ppm of polymer and around 42% using a value of 10 ppm of the polymer. At moderate and higher Reynolds numbers, they achieved reductions ranging 37% and 27%, and 16% to 23% respectively.

Friction tests -using a mixture of polymer and palm fiber in a pipe of 10.5 mm *diameter*

Using a larger pipe diameter of 13.5 mm and the same operating conditions as stated above, the results indicated higher drag reductions were obtained compared to that of the smaller pipe diameter. This is true at higher polymer concentrations and higher flow rates, as shown in Figs. 8 and 9. The results in Fig. 8, applying 30 ppm fiber, indicated that at a flow regime with low Reynolds number 17166.7, the achieved drag reduction was at 73% using 50 ppm polymer. Moreover, the achieved reductions were evaluated to be 52% and 33% at higher Reynolds numbers of 34333 and 51500, respectively. However, the drag reductions were estimated in the range 9% to 43% when applying lower polymer concentrations.

The polymer-fiber mixture (60 ppm fiber) showed a slight improvement, especially for higher flow rates, as shown in Fig. 9. The results indicated a reduction of 76% at 50 ppm of polymer and around 53% using a value of 10 ppm of polymer. At moderate and higher Reynolds numbers, the achieved reductions were ranging between 37% to 57% and 31% to 36% respectively.

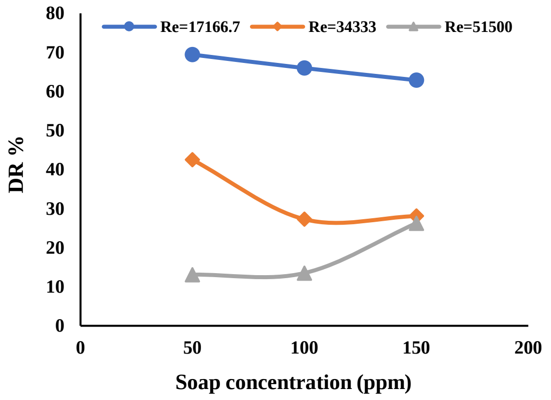

Fig. 10: Results of drag reduction using a mixture of 50 ppm polymer-soap of different flow rates using pipe diameter of 10.3 mm.

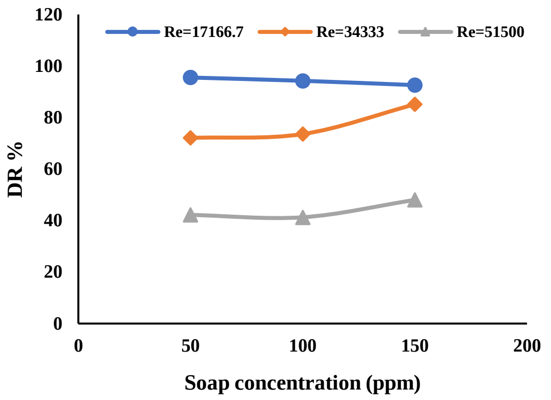

Fig. 11: Results of drag reduction using a mixture of 50 ppm polymer-soap of different flow rates using pipe diameter of 13.5 mm.

Friction tests -using a mixture of polymer and soap

Surfactant is considered one of the used chemicals for drag reduction, but it has less impact than polymer with high density. However, it has some advantages in terms of viscoelasticity and the ability to realign and self-repairing. In this work, an amount of Laurel soap was mixed with 50 ppm SNF polyelectrolyte to improve the percentage of drag reduction. The results using the two different pipe diameters were plotted in Figs. 10 and 11. It can be observed that significant improvements in drag reduction were obtained using both pipe diameters. This is true at a flow regime at low Reynolds number 17166.7. The improvements are substantial compared to the results achieved using sole polymer and a mixture of polymer and fiber for all ranges of flow rates, especially at low soap concentrations. For a 10.3 mm pipe diameter, the drag reduction was improved to 70%, while for a 13.5 mm pipe diameter, the drag reduction reached almost 96%. However, the increase in the soap concentration has resulted in a slight decrease in the percentage of the drag reduction.

The immense impact of the combination of polymer and soap on drag reduction can be explained as follows: The long-chain polymer interacts with and wraps the micelles of the soap, hence allowing the polymer chain to be stretched in its length due to the viscoelastic properties of the polymer. This action significantly affects damping eddies formation and sizes, increasing the percentage of drag reduction. The increase in soap concentration produced more chain loops of polymer-meciles, caused repulsion between wrapped meciles, and slightly reduced the rate of drag reduction. This result agrees with that reported by Prajapati [28].

Friction tests -using a mixture of polymer, palm fiber, and soap

The efficiency of using a mixture of polymer, palm fiber, and soap on drag reductions was studied. Two types of mixtures were used; the first type consists of 50 ppm polymer, 150 ppm soap, and 30 ppm palm fiber, while the second consists of 50 ppm polymer, 150 ppm soap, and 60 ppm palm fiber. The obtained results for two different pipe diameters were presented in Figs. 12 and 13. It can be seen that the percentage of drag reductions was improved compared to that of sole polymer and mixed polymer with only palm fiber, for all ranges of the examined flow rates, especially when using 30 ppm fiber for both pipe sizes and all water flow rates. At the same time, for higher water flow rates, similar drag reductions were achieved compared to that of mixed polymer and soap. Upon using a mixture with 60 ppm fiber, the percentage of drag reduction was slightly decreased compared to mixer polymer and soap. This means that the increased amount of palm fiber affected the interaction between the polymer soap and caused a slight decrease in the percentage of drag reduction compared to the results of mixed polymer and soap only.

Comparison between the results in pipe diameter 13.5 mm

The theory of friction factor refers to a high-pressure drop developed at a low flow rate. The obtained results indicated that the highest percentages of drag reduction

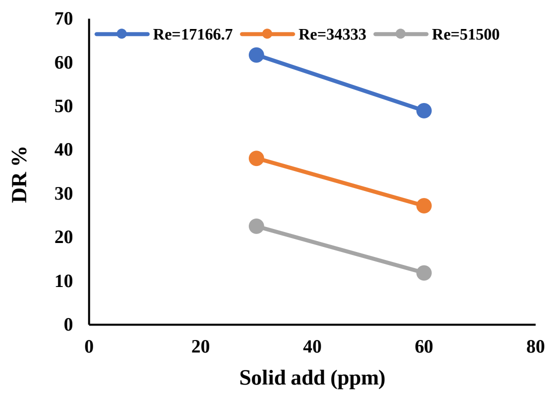

Fig. 12: Results of drag reduction using a mixture of 50 ppm polymer-150 ppm soap and palm fiber of different flow rates using a pipe diameter of 10.3 mm.

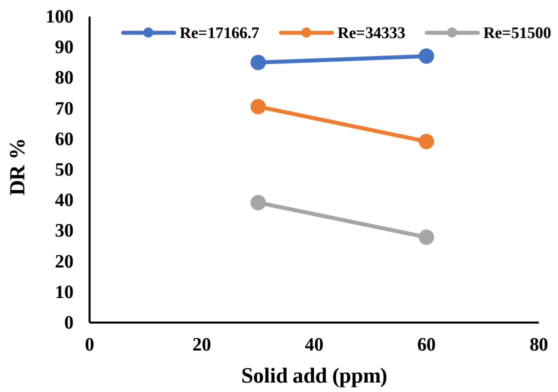

Fig. 13: Results of drag reduction using a mixture of 50 ppm polymer-150 ppm soap and palm fiber of different flow rates using pipe diameter of 13.5 mm.

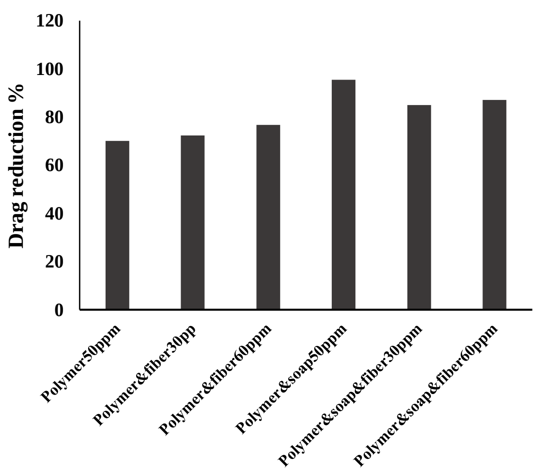

Fig. 14: Comparisons between the results of drag reductions at flow regime of Re = 17166.7 and pipe diameter 13.5 mm.

were achieved with flow rate and larger pipe diameter. In order to show the improvement in the percentage of drag reduction, comparisons were made between all tests at a flow rate with low Reynolds number 17166.7 in a pipe diameter of 13.5 mm, as shown in Fig. 14. The results indicated that the mixture of polymer (50 ppm) and soap \(50 ppm) had shown a significant impact on the drag reduction percentage compared with a mixture of polymer (50ppm), soap (50 ppm), and fiber (60 ppm). This could be attributed to the integrated effects on the boundary layer, which ultimately leads to developed flow regime formation.

CONCLUSIONS

In this work, several tests were carried out on the phenomenon of drag reduction. The following conclusions were obtained.

1- A larger percentage of drag reduction was obtained with a larger pipe diameter using sole polymer and all types of mixtures of polymer with Laurel soap and date palm fiber.

2- A larger drag reduction was obtained at a low flow rate where a more stagnant layer was developed.

3- A smaller amount of soap in the mixture gave a larger drag reduction especially at lower flow rates.

4- Almost 70% of the drag reduction was obtained with a larger polymer concentration.

5- A mixture of a small amount of date palm fiber with polymer improved the percentage of drag reduction (up to 76%).

6- Mixing a small amount of Laurel soap with polymer increased the percentage of drag reduction to 96%.

7- The mixture of all materials increased the drag reduction by almost 85%.

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