Triple Solutions of Nanoparticle plus Polymer-Surfactant compound for Enhancing the Drag Reduction Using a Rotational Disk Apparatus

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Abstract. In this paper, the ability of three types of drag reduction agents (DRAs) has been investigated to assess the impact of adding a small amount part per million (ppm) of polymer and surfactant, as well as nanoparticle substances, as drag improvers of internal flow via a pipeline network. The selected DRAs have been tested in the rotating disk apparatus (RDA) at various concentrations in the range of (50-1200) ppm and various rotating disk velocities in the range of (50-3000) rpm. Multiple trials have been done to figure out the best substance for enhancing drag force reduction. Impacts of the shear rate on viscosity (μ) at various concentrations of polymer and surfactant solutions have been analyzed with rheologic tests. The results detect that all selected substances have proved to be effective drag improvers in internal flow. Torque values were decreased with increased DRA concentrations, which caused a significant increase in drag reduction percentage (%DR). The drag reduction percentage of complex solutions at the highest concentration of 1200 ppm, results in around (44-47) % DR. In contrast, the results of the individual solutions at the same concentration results in around (32-38) % DR.

1. Introduction

The fundamental method for transportation of fluids from terminals to customers is the pipeline network. Some significant problems in the fluid transportation field are maintaining fluid transmission capability, decreasing energy losses, and cost reduction. One of the major reasons for energy losses is drag forces that are caused via turbulent flow. In interior fluid flow, such as in the pipeline networks, conduits, and channels, mechanical energy dissipates and turns into friction losses in the path of flow due to fluid resistance. Fluid resistance forces are well known as surface drag forces or form drag forces depending on the relative motion of any form moving through. In 1948, Tom revealed that adding a small amount of polymer molecules could reduce friction losses in turbulent flow.

Forrest et.al [2] studied pulpwod suspended in a water solution, observing a decrease in pressure losses in the turbulent flow, while Mysels [3] applied aluminum soap as a drag reduction additive. Also, Lumley [4] has described DR as turbulent stress reduction, which decreases skin friction in stormy flow.
less than regular turbulent. The turbulent drag reduction becomes very beneficial in the liquid transportation field, probably due to reducing the powerful energy that is required for pumping liquids in many applications. Since then, more additive materials have been used in terms of assessing drag reduction, e.g. polyethylene, surfactants, and nanoparticles, which are termed DRAs [5]. The applications of (DRAs) have spread worldwide since a successful application in Trans Alaska Pipelines (TAPs) in 1979 where polymer additive was used to reduce the drag reduction in the raw oil pipe network [6]. In of the firefighting aspect, polymer has been applied to increase the velocity of water in a fire and reduce extinguishing time [7].

Alaman et.al [8] have classified DR into three groups: passive drag reduction, active drag reduction, and interactive drag reduction. Also, many researchers have used several types of surfactant substances in their studies as drag reduction agents [9-12]. Surfactant substances possess a unique advantage, which is self-reform during produce micelles after degradation is occurring, nevertheless, it still less effective than polymers [13-15]. Further, several other substances have been used as drag improvers including fibers [16]. In general, drag reduction occurs mostly because of the interaction between drag agent molecules and the eddy structure. The structure of the eddies, which grows with the turbulent force of flow [17]. Four parameters including pipe diameter, test section length, concentration, and flow rate were tested to find out their effects on drag reduction. Closed loops of two different diameters (0.0127, 0.0381) m were built for this purpose. Grafted biopolymer (okra mucilage) has been examined in two-phase flow as transportation means in terms of DR. The results showed okra mucilage achieved the highest DR of about 60%. %DR increases by increased concentration and flow rate (water-soluble) while %DR decreases with increased flow rate (oil-soluble). Further, %DR by diameter 0.0381m was the best [18].

Fiona et al. [19] employed the natural plant additives using micro-channel in modeled on of the human body’s heart, to study the impact of mucilage (okra, aloe vera, hibiscus) on the blood flow streams in blood micro vessels to enhance the drag reduction in an atherosclerosis case. The results revealed that the highest drag reduction is 63.47% at 300 ppm of mucilage of hibiscus, while okra mucilage shows lower %DR. Lawrence et al. [20] examine the effects of two natural polymers, xanthan gum and guar gum, on drag reduction performance by using the horizontal pipeline system. The core fluid was tested one phase and in two phase flow at different concentrations (50-250) ppm and different flow rates of natural gums. The results exhibited an increase in %DR in both phases with an advance in the flow velocity, while showing a decrease in %DR by an increase in oil friction.

Eman et al. [21] 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 mixed solution at 3000 RPM of RDA. Generally, the previous studies emphasized using DRAs individually or a synthesis between two additives mixed with the solvent to improve %DR in the internal flow. Weili Liu et al. [22] 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. The highest drag reduction percentage obtained was 3.21%. A revision investigation has been achieved by Paul O. Ayegba et al [23]. The study was focused on the effect of additives in curved pipeline flow. The study has described many parameters, such as the additive mechanisms, flow methods, and friction effects. The results indicate that the drag performance in flat pipelines is greater than versus drag reduction performance in curved pipelines. Also, drag performance depends extremely on additives type, concentrations, and bubble portion of nano-bubbles.

Yunqing Gu et al. [24] 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, the impact of drag reduction at high Reynolds numbers, and lower critical micelle concentration. In previous studies have
been used one or two additives using polymeric materials, where polymers are generally degraded after a certain time driving the flow to instability. In contrast, using binary and/or triple solution of DRAs which possess different mechanisms, it can be promised to overcome any shortcoming that affects internal flow stability. This paper aims to characterize Polyisobutylene (PIB), Glycolic acid ethoxylated lauryl ether (GAL), and nanoparticle (Cu) as drag improvers in different combinations: individual, binary, and triple. Also, to investigate the impacts of many parameters, such as concentration, rotational velocity, and additive type on drag reduction using RDA.

2. Experimental Work

2.1. Materials

In this experimental work, three types of materials were presented as drag reduction agents. Polyisobutylene (PIB), Glycolic acid ethoxylated lauryl ether (GAL), and copper (Cu) were used in polymer, surfactant, and nanoparticle forms respectively. The solutions were in different aggregates: individual, binary and triple. Also, the solutions were applied in different concentrations (50, 150, 300, 600, 1200 ppm) and in different velocities of the rotating disk apparatus ranging from (50-3000) rpm. The materials were purchased from Sigma Aldrich, USA. Table 1 Shows the properties of DRAs.

| Materials (DRAs)          | Linear Formula                  | Molecular weight | Density (g/ml) at 25 °C |
|---------------------------|---------------------------------|------------------|-------------------------|
| Polyisobutylene (PIB)     | [CH2C(CH3)2] n                 | Mn ~600          | 0.92                    |
| Glycolic acid ethoxylated | CH3(CH2)11-13(OCH2CH2) n        | M∞ ~690          | 1                       |
| lauryl ether (GAL)        | OCH2CO2H                        |                  |                         |
| Copper (Cu)               | Empirical Formula Cu            | 60-80 (SAXS)     | 1083.4                  |

2.2. Preparing Solutions

2.2.1. Polymetric Solutions

All polymer (BIP), surfactant (GAL), and nanoparticle (Cu) were stocked in a receptacle at room temperature around 24 hours duration to resolve accurately. All additives solutions were tested at the same concentrations (50, 150, 300, 600, 1200 ppm). The solutions of BIP and GAL were mixed to resolve and homogenate the mixture completely. The entire mixture was resolved in distilled water and stocked in the tank for a one-day duration to get solution equilibrium.

2.2.2. Nanoparticle Solution

The nanoparticles of Cu at (50, 150, 300, 600, 1200 ppm) concentrations were mixed. Samples of nanoparticle were prepared using the ultrasonic method by the following actions: the samples at the known weight were sonicated in an ultrasonic bath for about 24 hours; then they were placed in water and dispersant material was added until the mixture reached a specific (PH) grade. The mixture was treated with a homogenizer under the high shear force for a specific duration. Solutions were found stable for months without sediment via the ultrasonic method [25].
2.3. Rheologic Tests
All rheologic tests: the viscosity, shear force, and shear strain were performed through a Brookfield Rheometer, as shown in figure 1. Brookfield Rheometer was designed for this purpose. The main parts of the device are a container, spindle, and a display screen. The container is 120 mm high with 82.5 mm inner diameter and 200 ml capacity. The range of spindle speed is 50-200 rpm. Selected samples of RDAs were mixed with de-ionized water in the container 24 hours period. Solutions were prepared at different concentrations (50, 150, 300, 600, 1200 ppm) at room temperature.

2.4. Rotational Disk Apparatus Tests
All trials to calculate the drag reduction were carried out in the rotational disk apparatus RDA. Figure (2) presents the principal parts of the RDA, which includes a stainless-steel container with 88 mm height and a 180 mm diameter closed by the movable cap of 60 mm thickness. The capacity of the cylinder is about 1200 ml and the maximum rotational velocity of RDA is more than 3000 rpm. The RDA is used to measure the torque values to assess the drag reduction performance. The torque values were observed, documented, and transferred to the portable display screen.

Figure 1. Fabricated Brookfield Dial Viscometer  
Figure 2. Graphic of Rotating Disk Apparatus (RDA)

2.5. Experimental Procedures in the RDA
All selected DRAs samples were mixed with de-ionized water at room temperature to evaluate the drag reduction. These DRAs were prepared at different components: individual, binary, and triple. Also, the samples were tested in different concentrations (50, 150, 300, 600, 1200 ppm) in a cylinder has a capacity of 1200 ml. All samples and water were tested in the RDA in different rotational velocities in the range of 50-3000 rpm. DR performance was assessed by measuring torque for water before adding DRA and after adding DRA. The torque values were plotted versus the rotational velocity to investigate and compare the results for the water individually and in the DRA solution.

2.6. Experimental Factors
Table 2 Shows the experimental factors and variables in the current study.

| Factors       | Variables       |
|---------------|-----------------|
| Velocity of RDA | (50-3000) rpm |
| Concentration  | (50-1200) ppm  |
| RDAs type     | PIB, GAL, Cu    |
3. Mathematical Formula
The below equation has been adopted to calculate drag reduction percentage.

\[ \%Dr = \frac{Tw - Ts}{Tw} \times 100 \]

Where: \( Tw \) is torque of water, \( Ts \) is torque of solution

4. Results and Discussion

4.1. Effect DRAs on Viscosity
To predict the change in apparent characteristics of the solutions, the rheologic tests were carried out for both BIP and GAL individually. The impact of BIP and GAL additives on viscosity, at a various shear rate, is demonstrated in figures 3 and 4. The same trend of decreasing in viscosity values with the shear rate in both additives. The results of the tests showed that the apparent features did not change after adding the drag reduction additives, but the viscosity of the solution was changed, as shown in the figures 3 and 4. From these figures, it can be observed that viscosity decreased with increase shear rate. This change in the solution viscosity predicts the abilities of drag improvers to increase the pressure reduction, increase the flow velocity in the pipeline, and reduce power consumption. Moreover, increasing BIP and GAL made an obvious decrease with the entirety of shear rate values, due to increased particle accumulation with increased concentrations.

![Figure 3](image-url)

**Figure 3.** Effect of shear rate on the viscosity of (BIP) at various concentrations compared with water
4.2. Individual Solution

The results of picked samples trials were displayed by figures (5-7). The figures revealed the torque impacts versus rotational velocity of the different individual additives: Polyisobutylene (PIB), Glycolic acid ethoxylated lauryl ether (GAL), and Copper (Cu) respectively using RDA. All the additives tested and of each concentration were capable to decrease drag, as there are shown a significant increase in the torque value reading versus rotational velocity. The tests have proven that all additives used capable to reduce drag, where they are shown a remarkable increase in the torque value versus rotation velocity. These figures show that the effects of the torque were started from 900 ppm and kept to increase until the highest rotation velocity 3000 rpm. Moreover, the torque readings were decreased by increased additive concentrations when compared with water alone and the highest decrease in the torque occurs at the highest concentration of 1200 ppm. Also, the stability in torque readings at the greatest rotation velocity has appeared by these figures, maybe due to increasing turbulence intensity that increased additive molecule collisions, which affects the DRAs performance positively [26]. Generally, the figures clearly showed that the concentration of DRAs in individual solutions have a major effect on these trials. Hence, the best concentration is 1200 ppm in most solutions and the highest drag reduction performance occurs around (32-38)%%. The results of these experiments are in agreement with Zainab and Kim trails results [27, 28].

![Figure 4. Effect of shear rate on the viscosity of (GAL) at various concentrations compared with water](image-url)
Figure 5. Impact of the rotating velocity on the torque values at vary concentrations for (BIP) individually

Figure 6. Impact of the rotating velocity on the torque values at vary concentrations for (GAL) individually
4.3. Binary Solution

The purpose of improvement and formation of polymer, surfactant, nanoparticle to binary is to update and promote DRAs capability and to increase their resistance to shear stress. Figures (8-10) show the torque values for different binaries formed from merging polymer-surfactant, surfactant-nanoparticle, and nanoparticle-polymer. In all figures (8-10), the impact of rotational velocity for all tested binaries on torque values was illustrated. All these figures draw the effect of DRAs concentration on the torque with rotational velocity increased, although the influences of the torque which normally exerts high shear stress on the additive molecules. Thus, a rise in additive concentrations were capable to resist molecular deterioration in these DRAs. It can be detected from this observation that the concentration has a significant role in drag enhancing. Further, the additive mechanism works upon an increase in the ratio of drag reduction molecules that supported by an increase in their concentration. Thereby, any additional in the DRA concentration corresponds instantly increase in solution viscosity, which reduces turbulent force intensity. As shown in these figures there is no big variance in the torque values at the initial values of most of these solutions in a rotational velocity less than 900, where additives do not show up much effect on the torque. But when they keep going increasing the additives concentrations with their rotational velocity show up a significant impact on the torque. From figures, the results revealed that the binary solutions at all concentrations were efficient to decrease the torque compared with water alone. Also, the binary solutions of BIP+Cu and GAL+Cu were presented a great drag reduction percentage of around (40-44) % at the highest concentration of 1200 ppm, while, BIP+GAL solution was showed less percentage of the drag reduction of around 40%. It can notice that the binary solutions with exist the nanoparticle Cu given the best percentage, maybe the reason for these results return to the sonication method that modified the surface of DRA then performed to enhance the drag reduction [29].

![Figure 7](image.png)

**Figure 7.** Impact of the rotating velocity on the torque values at vary concentrations for (Cu) individually.
Figure 8. Impact of the rotational velocity on torque with vary concentrations for (GAL+ Cu) binary

Figure 9. Impact of the rotational velocity on torque with vary concentrations for (BIP+ Cu) binary
4.4. Triple Solution

Figure 11 displays the impact of torque on the rotational velocity in the triple mixture of three DRA: Polyisobutylene (PIB), Glycolic acid ethoxylated lauryl ether (GAL), and Copper (Cu) combined in various concentrations. It can be noticed that the concentration of the additive rises, in contrast, the diverging in the water curve could be noticed: this an indicator that the concentration can change drag reduction. Moreover, the increase of turbulent flow due to the increase in rotational velocity affects solution conduct. The drag reduction was mostly negligible at low rotational velocities from 50 to 500 rpm but after this range, the drag reduction was increased rapidly with increased concentrations. A synergetic between PIB, GAL, and Cu of the triple solution was remarked in the drag reducing; whereby these additives were capable to enhance the drag reduction maybe due to the sonication method of nanoparticle (Cu) and disperse their molecules in the solution, and the extension of polymer coils due to turbulent forces, and self-repaired of surfactant micelles. All these reasons assisted to prevent the solution from degradation [30-31]. Therefore, these additives made a strong network of the triple solution unlike individually and binary solutions, which produced the greatest drag reduction percentage is around 47%.

Figure 10. Impact of the rotational velocity on torque with vary concentrations for (PIB+ GAL) binary
Figure 11. Impact of the rotational velocity on torque with vary concentrations for (BIP+GAL+ Cu) triple

5. Conclusions
Many goals have accomplished in the present work in terms of enhancing drag reduction performance employing polymer, surfactant, and nanoparticle as drag reduction agents DRAs by assisting rotational disk apparatus RDA. The influence of these additives individually, binary, and triple were tested to assess the DR performance by measuring the torque. All complex solutions were showed their capability to increase drag reduction. All the tests carried out on the selected additives revealed that the additive concentration, rotational velocity, and the additive type and its mechanism were worked a major role to enhance drag drop.

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