Improvement of Drag Reduction for Water Flow in Pipe Based Nanofluid

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Abstract—In the present work, the effect of Nano fluids as drag reducing agents for water flowing in pipelines was studied. Tap water was chosen to be the tested liquid and the Nano fluid was a dilute solution of water and titanium dioxide (TiO₂) Nano particles which was used at five different concentrations (50, 100, 150, 200, and 250) ppm. The test section of the experimental setup consisted of a stainless steel pipe of 29.6 mm I.D (DN25) and 1.2 m long. Water was pumped with eight different flow rates (1.0 - 8.0 m³/hr) through the pipe at room temperature (35±1) °C. The effect of the nano particle concentration and the flow rate (or Reynolds number) on percentage drag reduction (%Dr) and flow rate increases (%FI) was examined. Generally, a gradual increase of %Dr &%FI was observed with increasing the NP concentration and bulk velocity. The highest TiO₂ concentration of 250 ppm and Re.No. of 106230 offered the maximum drag reduction which was 29.7%. Friction factors were also calculated from experimental data. Their values for pure water transported lies near or at Blasuis asymptote. While by introducing the additives, their values were positioned below Blasuis asymptotes towards Virk maximum drag reduction asymptotes.

Keywords—Drag Reduction, Nanofluid, Energy Losses, Nano particles.

1. Introduction

Generally, it is needed to pump liquids over long distances in the processing industries, thus there will be a considerable drop in pressure in both the pipeline and in entity units. To recompense the frictional energy losses, more energy must be added. Therefore, reducing the friction loss leads to lower power consumption or a higher flow rate within the normal pumping conditions [3]. One of the methods that are used to increase the efficiency of piping systems is called "drag reduction technique". This phenomenon was first discovered by the British Chemist Toms in 1949, therefore it can be termed as "Tom’s effect" [1].

Drag reduction may occur using different technologies with different type of materials. By adding small quantities of chemical additives (usually Polymers or Surfactants) to the turbulent liquid flow, noticeable reduction in pressure drop will be obtained. Another technique depends on adding small amount of solid particles (such as nano particles) to liquid flowing in turbulent mode during pipelines [12]. Modern experiments generally showed that these nanofluids can be used in petroleum transportation due to its advanced properties such as drag reduction, modification of wettability, binder for sand reinforcement and decreasing interfacial tension (Xiangling and Michael, 2010). Moreover, these fluids can be helpful in some other problems such as instability of well, lost circulation and pipe sticking troubles [12].

In the petroleum industry, the uses of NPs are in its early stages because of higher danger and elevated cost of adapting new technologies. According to the results in the laboratory tests and papers, large-scale recovery of oil and gas can be improved by nanotechnology and utilizing of nanotechnology is so expectable in the petroleum industry in the near next years [11].

The reason behind that various nanofluids have perfect lubricating properties is that these materials exhibit high friction reducing properties as the Nanoparticles in the fluid make a protecting layer with low hardness and elastic modulus on the surface.

Wasan and Nikolov in [4] utilized reflected light digital video microscopy to study the mechanism of spreading dynamics for liquids with nano polystyrene particles. They...
could show two dimensional crystal-like construction of the polystyrene spheres in water, this structure improves the dispersion properties for the micellar liquid in the three-phase area as shown in Fig. 1 [4].

As meeting the oil drop, the polystyrene nanoparticles concentrate and reorganize near the drop making region like a wedge between the oil drop and the surface. The nanoparticles then distribute into the wedge film causing an increase in concentration and subsequently an increase in pressure around the film region. Owing to the increase in pressure, the oil-solution interface moves forward allowing the polystyrene nanoparticles to spread along the surface. This mechanism causes the oil drop to separate completely away of the surface. Additional work must be done to determine such behavior of nanofluids [4].

![Figure 1:](image)

Abdulbari et al. 2010 was reported that these materials are good drag reducers and their drag reduction ability increases with an increase in the particle concentration. In present work, TiO$_2$ nanoparticles which are confirmed to have good dispersivity, stability in organic solvents are used as drag reducing agents [5].

2. Experimental procedure

2.1 Materials and preparation

In this study, nanofluids with five different addition concentrations (50, 100, 150, 200, and 250) ppm were prepared by mixing tap water (base fluid) with the defined amounts of TiO$_2$ nanoparticles which were suspended in water. These concentrations were chosen based on the economical consideration to ensure inexpensive and effective drag reduction.

In this method, known as the two-step method the nano particles are purchased as dry powder and then dispersed in the liquid medium. The nano particle content is expressed in terms of ppm which represents the weight of solid in milligram respect to a liter of distilled water. The calculated amount of nanoparticle was added to a one liter of water under laboratory temperature and mixed using high speed mechanical mixer at 2000 rpm for at least 1 hour to ensure uniform distribution through the solution. This process was applied to break down the agglomeration between the particles, which leads to achieving a uniform dispersion and a stable suspenstion. The drag reduction performance of the solutions was then tested using the closed loop recirculation system. These nanoparticles were chosen because they are produced in large scale in industry and they are chemically more stable, easily available and not harmful for human being.

The characteristics of TiO$_2$ nanoparticles and water are presented in Tables 1 and 2 respectively [10].

| Characteristic | Value |
|---------------|-------|
| Purity        | 99.9% |
| Color         | White |
| Size Outer diameter | 100 (nm) |
| Specific surface area | 85m$^2$/g |
| Bulk Density  | 0.65 g/cm$^3$ |
| True Density  | 3.9 g/cm$^3$ |

Table 1: Characteristics of TiO$_2$ nanoparticles

| Characteristic | Value |
|---------------|-------|
| Chemical formula | H$_2$O |
| Molar mass     | 18.02 (g/mol) |
| Density        | 989 (kg/m$^3$) |
| pH             | 7.5 |
| Conductivity   | 356 (µs/cm) |
| T.D.S          | 174 (ppm) |
| Turbidity      | 0.26 NTU |
| Kinematic viscosity | 0.9*10$^{-6}$ (m$^2$/s) |

Table 2: Characteristics of water:

2.2 Closed Loop Liquid Recirculation System

A closed loop circulation system was designed to investigate the effectiveness of the TiO$_2$ Nano particles in tap water under turbulent pipe flow conditions. One test section of 1.2 m was used to investigate the performance of additives. (A photo of the final experimental set up is shown in Fig. 2.)

![Figure 2:](image)
Experiments of effectiveness of DRA were carried out in circulating manner during (10- 15) minutes. Prior to the test, the concentrated Nano fluid solution was mixed with tap water in the reservoir to get homogeneous fluid. Typically (15- 30) minutes mixing time was used depending on the Nano fluid concentrations (50-250) ppm.

Calibration of the test section for the pipe was performed with untreated water prior to testing the drag-reduction additives. A differential mercury manometer was used to calibrate the electronic differential pressure transmitters (PdI2). The tank was filled with tap water and operated at various flow rates then the readings of mercury manometer and of the differential pressure transmitter (PdI2) were recorded as shown in Fig.3.

The effectiveness of a drag reducer is expressed in terms of percent drag reduction. At a given flow rate, the percent drag-reduction is calculated from the following equation:

\[
\% DR = \left( \frac{\Delta p_{\text{untreated}} - \Delta p_{\text{treated}}}{\Delta p_{\text{untreated}}} \right) \times 100
\]

(1)

\((\Delta p)_{\text{untreated}}\) pressure drop in the pipe without a DRA.

\((\Delta p)_{\text{treated}}\) pressure drop in the pipe when the DRA is added.

The increase in the throughput, \(\% FI\) which is more practical term than drag reduction percentage for a given pipeline, can be estimated using the following equation:

\[
\% FI = \left( \frac{1}{1 - \frac{\% DR}{100}} \right) \times 100
\]

(2)

Eq. (2) assumes that the pressure drop for both treated and untreated fluids is proportional to flow rate rise.

3. Results and discussion:

3.1 Effects of Different Parameters on Drag Reduction:

3.1.1 Effect of Concentration

Drag reduction efficiency of TiO_2 Nano particles had been studied in turbulent flow of tap water as a function of concentration. This concentration ranged from 50 up to 250 ppm.

Figure 4 shows that percentage drag-reduction increases gradually as TiO_2 concentrations increase. Such results are expected since any increase in the additives concentration means increasing the number of additives molecules involved in the drag reduction process and that will cover wider range of the turbulent eddies in the turbulence suppression process.

The maximum percentage drag-reduction about 29.6 % for Nano titanium oxide at 250 ppm and Reynolds number equal to 106230 as illustrated in Fig.4.
3.1.2 Effect of Reynolds number

It is well known that the drag reduction phenomenon as it is recognized, works in turbulent flow [2, 6]. Therefore, the degree of turbulence has a predominant effect on its effectiveness, as shown in Fig. 6. Fig. 6 shows the variation of drag reduction with Reynolds number for water flowing in a pipe at different nano concentrations. It is shown that the percentage drag reduction increases as the Reynolds number increase (flow rate increase). Such behavior agrees with Berman and his workers [7, 8] who reported that the degree of turbulence is highly controlled by the liquid flow rates, especially in turbulent flow where the turbulence structures are formed (eddies). This will lead to control the additive contact interaction with turbulent structures formed inside the pipe and this will enable more Nano molecules to interfere within the turbulent median and suppress the eddies formed inside the pipe and thereby the flow is improved.

The combined effect of concentration and Reynolds number on percent drag reduction have been illustrated in three dimension plots. For more elaboration, Fig. 7 is plotted for this purpose, which represent the extension of overlapping the two effects on percent drag reduction.

3.2 Effects of Friction Factor as function of Reynolds Number

The drag-reduction properties of solutions could be explained as the fanning friction factor versus solvent Reynolds number. The use of Reynolds number based on the solvent viscosity and pipe diameter provides a direct indication of the degree of drag reduction. The Friction factor was calculated from the experimental data based on pressure drop measurements, as in equation 3.

\[ f = \frac{\Delta p g}{2 \left( \frac{1}{u^2} \right)} \left( \frac{D}{L} \right) \]  

The effect of Nano additives at various concentrations on friction factor values as function of Reynolds number are plotted in Figs. 8 & 9. It is shown that for untreated solvent friction factor values lies near Blasius asymptote (Fig.8), while by adding minute amounts of Nano particles into the flow, the friction factor values were positioned below Blasius asymptote towards the maximum drag reduction region which is represented by “Virk asymptote”[9] as in Fig.9.

Figure 5: (%FI) as a function of Reynolds number for TiO₂ through st.st pipe

Figure 6: Effect of flow rate on percentage drag reduction for Nano TiO₂

Figure 7: Effect of concentration and Reynolds number on percent drag reduction for Nano TiO₂

Figure 8: Effect of f as function of Re No. for pure water
4. Conclusion

Velocities increase. Lower friction factors were obtained as the flow number increases, and that the results show that the considered nanoparticle solutions are effective in turbulent drag reduction and that the calculated results give a good agreement with the experimental values. According to SE, the correlation results for friction factor as a function of Reynolds number as shown in the following formula:

\[ f = a \left( \frac{Re}{D} \right)^b \]  

(4)

An attempt was made to correlate the fanning friction factor values as a function of Reynolds number, for the considered Nano concentrations.

The friction factor is usually correlated as a function of Reynolds number as shown in the following formula

\[ f = a \left( \frac{Re}{D} \right)^b \]  

(4)

According to the above formula and by using appropriate software program, the constants a, b had been found. Therefore, the correlation results for friction factor calculation by Eq. (4) are illustrated in Table 3 for different concentrations of TiO2.

**Table 3:** Values of a & b of correlation equations for friction factor as result of Reynolds number in st. st pipe of DN25

| Material   | Conc. (ppm) | a     | b     | Correlation eq.          |
|------------|-------------|-------|-------|--------------------------|
| Pure water | 0           | 3.23  | -0.575| \( f = 3.231Re^{-0.575} \) |
| TiO2       | 50          | 4.45  | -0.622| \( f = 4.452Re^{-0.622} \) |
| TiO2       | 150         | 4.93  | -0.634| \( f = 4.938Re^{-0.634} \) |
| TiO2       | 250         | 4.15  | -0.627| \( f = 4.151Re^{-0.627} \) |

The calculated results give a good agreement with the friction factor obtained experimentally and calculated by Eq. (4).

4. Conclusions:

The drag reduction efficiency of titanium dioxide (TiO2) Nano particles was examined in tap water flow loop. The results show that the considered nanoparticle solutions are effective in turbulent drag reduction and that their efficiencies increase as their concentrations and flow velocities increase. Lower friction factors were obtained for high additive concentrations and high Reynolds number.

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**Nomenclature**

| Symbol | Description |
|--------|-------------|
| f      | Fanning friction factor |
| D      | Diameter (m) |
| L      | Length (m) |
| h      | Height (m) |
| g      | Acceleration of gravity(m/s²) |
| u      | Flow velocity(m/s) |
| a,b    | Constants in correlation equation of friction factor as a function of Reynolds number |
تحسين تقليل الاعاقة لجريان المياه في الأنبوب بإضافة المواد النانوية

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الخلاصة - في هذا البحث دراسة تأثير المواد النانوية كعوامل مقلة لخصائص الطاقتة الناتجة أثناء نقل المياه في خطوط الأنبوب. حيث تم اختيار مياه الحنفية ليكون السائل الذي يجري اختباره، والمياه الذي استخدمت من مخلوط من مياه نانوسيدات ثاني أكسيد التيتانيوم (TiO2) في مراحل تركز مختلفة (0, 25, 50, 100, 150, 200, و250) جزء في المليون. تم تجربة مياه نانوسيدات ثانوي أكسيد التيتانيوم على الأنبوب DN25، حيث تم ضخ المياه خلاله بعمر معدلات جرين مختلفة من 1.0 إلى 8.0 (م3/ساعة) ودرجة حرارة الغرفة (36±2) درجة مئوية. تم دراسة تأثير تركيز الإضافة، ومعدل الجرين، على نسبة التقليل من الأعاق (PR) ونسبة الزائدة في التدفق (FI) كنسبة من مريحة ، كما تم حساب أفضل الظروف التشغيلية اللازمة لتقليل الإعاقة في الأنبوب (PR). حيث اظهرت تركيزات المختلفة من الإعاقة (PR) ونسبة التدفق (FI) عند استخدام السرعة العالية، كما تم حساب قيم الإعاقات في الأنبوب (PR) وبمعدل 29.7%، كما تم حساب قيم عوامل الإحترام للانبوب باستخدام المواد النانوية حيث لوحظ وجود انخفاض في قيم عوامل الإحترام وذلك بسبب التقليل في خسائر الإحترام مع الجرد الداخلي للأنبوب.

الكلمات الرئيسية - تقليل الإعاقة، المواد النانوية، خسائر الطاقة، جزيئات ثانوي أوكسيد التيتانيوم النانوية.