Applying Carbon Nanotubes for Enhancing Fluid Flow

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Abstract: One of the economical important challenges in pipeline transportation is reducing the drag; e.g reducing the pressure drop along the pipe as much as possible. Although many efforts have been made, a universal mechanism and environmentally friendly approach to reduce the drag is still setbacks. The present work introduces an environmentally friendly method to reduce drag using microbubble, polyethylene oxide (PEO) with concentrations (100, 400,1100,1900 and 2500 ppm) and nanoparticles (carbon nano tube CNT) with concentrations (100, 400,1100,1900 and 2500 ppm). The pipeline loop was used to individually study the materials, their complexes as well as the combination of either of these with micro bubbles. The experiments were conducted in a pipeline loop to mimic the practice in the petroleum industries. The result showed that the drag reduction increases as flow and additive concentration increases and the maximum reduction was 40% for PEO and 58% for CNT. The results also show that the use of blend additives has greater effect than the individual materials and combining the polymer, CNT suspended, and the microbubbles gave 80% drag reduction.

1. Introduction
Drag reduction in pipeline transportation of liquids is a subject of continuous research as a result of its importance whenever liquids are to be transported from one place to the other. The first technique of drag reduction was discovered in the year 1948 by [1]. Since that, several researches have investigated the concept of drag reduction and categorized it into three major categories: Active, passive and interactive [2]. Many authors have investigated drag reduction with the introduction of flexible polymers [3], polymers [4], surfactants [5], solid particles [6] and [7], complexes of two or more additives [8] and microbubbles [9]. Among all these drag reducing agents (DRAs), many factors such as the chemical structure, concentration, flowrates, morphology, molecular weights, intrinsic viscosity of the DRAs have all been investigated at various flow parameters e.g pipe diameters and fluid velocity [10] [11] and [12]. Further investigations have shown that the combination of two or more DRAs are capable of forming complexes where it is believed that such combination will give better performance compared to each of these singly tested [8]. In view of this, complexes such as polymer and surfactants, polymer and fibers [13], polymer and nano particles as nanofluids have been initially investigated with convincing results [14].
In a recent study Akindoyo [8], rigid polymers were investigated with Carbon nanotubes (CNT) as a complex which reduce the drag reduction of fluids in a rotating disk apparatus. The suspended fiber particles with unequaled anti-wear attributes, friction reduction or load capacity have shown good performance in various applications. Such performance is likely to be as a result of their stability and dispersivity in organic solvents. Although these materials have been studied either alone or with the introduction of microbubbles to investigate the role of microbubbles in the flow system. However, to the best of the knowledge of the authors due to the literature available to the authors, there is no known study used to investigate the complex mixtures of rigid polymers and Nano particles with the introduction of microbubbles. In this present study, polymer (PEO) has been used to form complexes with nano material and microbubble introduced to investigate their drag reduction capability.

2. Theoretical Parts

The fully developed turbulent flow along a pipe wall can be consist of three layers, characterized by the distance from the wall. The first layer is the laminar sublayer, which is very thin layer next to the wall with viscous effects. This layer velocity profile is almost linear with streamlined flow. The next layer is the buffer layer. The flow in this layer is still showed viscous effects but the turbulent effects are becoming significant. The last layer is the turbulent (or outer) layer in which the turbulent effects dominate over the viscous effects [15]. In spite of the very small thickness of the viscous sublayer (less than 1% of the pipe diameter), but it plays a vital role on flow behavior due to the large velocity gradients it includes. The wall inhibits any eddy action, so this layer flow is basically laminar with laminar shear stress that is proportional to viscosity of the fluid. Then the viscous sublayer velocity gradient stays almost constant at du/dy = w/y, and the shear stress of the wall is expressed as [15],

\[ \tau_w = \mu \frac{du}{dy} = \mu \frac{u}{y} = \rho \frac{\partial u}{\partial y} \]  

(1)

Where y represents the laminar sublayer thickness or the distance from the wall (for a circular pipe, y = R - r).

Velocity is one dimension of the square root of (tw/ρ), its can be as a fictitious velocity and called the friction velocity which can be expressed as:

\[ u^* = \sqrt{\tau_w/\rho} \]

Substituting above term into equation, so the viscous sublayer velocity profile can be written in dimensionless form as follows [15]:

\[ \frac{u}{u^*} = \frac{yu^*}{\theta} \]  

(2)

In regard to the near-wall turbulence modeling, it is convenient to work with non dimensionalized distance and non dimensionalized velocity (Nondimensionalized variables), which can be expressed as [15]:

\[ U^+ = \frac{u}{u^*} \quad \text{and} \quad y^+ = \frac{yu^*}{v} \]  

(3)

There are many empirical velocity profiles using for turbulent flow system. power-law velocity profile is the best and the simplest one and it can be expressed as [15]:

\[ \frac{u}{u_{\text{max}}} = \left(1 - \frac{r}{R}\right)^{1/n} \]  

(4)

Where n is constant and it depends on Reynolds number, which increases by increasing Reynolds number. The magnitude of n = 7 normally approximates numerous flow systems in practice.
3. Materials and Experimental Procedures

3.1. Materials and Solution Preparation

The materials used in the present work are Polyethylene Oxide PEGs (anionic polymer) and carbon nano tube multi-walled CNTs. They were supplied by Chengdu Organic Chemicals Co. Ltd. China and used as it is as drag reducers. Table 1 and

| Colour       | white solid |
|--------------|-------------|
| Chemical formula | $C_2nH_{4n+2}O_{n+1}$ |
| Melting point  | 67 °C        |
| Molecular weight | 100,000,    |
| Solubility     | water        |
| Form           | Waxy         |

Table 1 showed the properties of the used raw materials.

| Colour       | white solid |
|--------------|-------------|
| Diameter     | 20–40 nm    |
| Lengths      | 10–30 μm    |
| Physical State | powder    |
| Molecular weight, $M_v$ | 2.0X106 g/mol |

Table 2 showed the properties of the used raw materials.

A required amount of PEO was dissolved in distilled water using a magnetic stirrer to make mixture with different concentrations. The mixture was homogenized for two hours before the experiment start to get perfect dispersion. Furthermore, to make the combines the similar concentrations was used in an interactive method, so different complexes were created for each concentration.

In this present research, the carbon nano tubes were prepared by dissolving the surfactant in the base liquid. The baseline solution was prepared using 55 weight percentage glycerin and 45 weight percentage of water to 60 weight percentage glycerin and 40 weight percentage of water in attaining viscosity of $7.10^{10}$ mPa.s. This was followed by preparing a conservative polymer drag reduced liquid solution by mechanically mixing the PEO with the baseline solution, other than it is of attention that these additives are prone to agglomeration, therefore, they were dispersed before additional studies. The nano material has been well dispersed by (a) sonication in ultrasonic bath for a period of time, (b) Dispersed in distilled water containing other dispersant at known adjusted pH (pH 7), (c) High shear homogenizer (THER-3A/ THER-3M, Double-layer homogenizer, China Co., Ltd., Shaanxi, available at University Malaysia Pahang, Malaysia) treatment for some time, all of these have been reported. Nano carbon tubes produced in this manner are stable for months without any form of sedimentations. But in this study work, a surfactant, sodium dodecyl sulfate (SDS) was used as the dispersant where it was initially dissolved in the
base liquid, at 0.5 weight percentage with magnetic and sonicated with 9 W of 30 kHz ultrasonic processor for a period of 11h. Nano were then produced within the range of 0.5-1.0 weight percentage nano concentrations [17]. The Transmission Electron Microscopy (TEM) is used to evaluate samples of the CNT as well as PEO individually and Nano–polymer complexes. This test was carried out using a FEI Tecnai™ TEM, available at School of Pharmacy, University Technology Mara, Malaysia.

3.2. Flow System Description

Schematic representation of the pipe loop used in the present work is presented as Figure 1, which consists of a reservoir tank with dimension of (0.6 m× 0.40 m × 0.5 m volume), centrifugal pump (flow rate = 5m³/hr; Power = 25 hp) used to circulate the solution through the pipeline, while another pump (flow rate = 1m³/hr; Power = 0.5 hp), serving the purposes of water temperature control, solution delivery and water circulation. With these, continuous system is guaranteed. Other components are flow meters, pipes, pressure drop gauge/sensors, and which are all built to enhance optimum flexibility of the loop during operations. The system shut down when the temperature increases in order to prevent materials degradation. With this arrangement, the variables such as pressure drops, flow rates were measured and analysed during the solutions circulating.

3.3. The Microbubble Rig

The experimental setup comprises of a jet using a BT50 Micro-Nano Bubble Nozzle. The major requirements for generating microbubbles is best explained in figure 2. The pump power required to generate the microbubble per single unit of the BT50 Micro-Nano Bubble Nozzle is between 60w-210w/1000 liters (264 Gallons). The Bubbles generated travel through a distance within the pipe to the bubble generator chamber and acted upon by turbulence and shear stresses for a period of time. They are further broken down into lesser bubbles. Air flow into the chamber by air nozzles of the BT and blended with the water flow inside the chamber. In circuit, the flow with bubbles are circulated together with the
solution within the pipe loop. It is further taken to the water and air separation tank where the water devoid of microbubbles is recirculated by the pump until the completion of the experiment.

**3.4. Methodology**

After preparation the samples, the data were taken, from the flow loop system, at different flow rates (5, 4.6, 4, 3.5 and 2.5 $m^3$/hr) for material concentrations of (100, 400, 1100, 1900 and 2500 ppm), for both of PEO and CNT, at pipe lengths: 1.0 m, 2.0 m, 3.0 m and 4.0 m. The experiments were repeated using complex additives of (PEO and CNT) and (PEO, CNT and microbubbles). After the dissolution, materials were poured in the tank and left undisturbed for little time and then circulated round the tank for a minute before taking data.

4. Results and Discussions

4.1. Experimental Results

Figure 3 and 4 depict the effects of the drag reduction percent against fluid velocity observed for different concentrations of PEO and CNT tested in the pipelines. It could be seen from these figures that the increase in the drag reduction obtained, of these materials, increases with the fluid velocity. Such observation could be related to the degree of turbulence increase and same suppressed of the eddies formed in the pipe. At the point of eddies formation, the fluid velocity will modify the contact between additive and their interactions with each other or with the turbulent structures produced within the pipe.
The figures also show that the drag reduction increases with concentration. It is well known that adding additives can cause an increase in its viscosity. This causes a reduction in the turbulent strength for these materials, which decreases the frictional drag in the flow system. It could be also seen from the figures that the best drag reduction efficacy occurred at the higher concentration of the prepared sample. This is due to the high availability of additive molecules to decrease the drag. Similar observation was also reported by many other authors [18 - 21].

The combined effect of PEO and NCT on drag reduction is shown in figure 6. As it is expected that the high concentration of additive results in higher values of drag reduction till 45%, which is more than...
using these additives individually. Moreover, it could be noted that the complex mixture showed drag reduction ability and its drag reduction increased with Reynolds number increasing. However, a synergy was existed between these materials which leads to increase the drag reduction based on the additive concentration. Such increase may be due to the total modification of the formed complex apparent physical properties, which produce a shear thickening behavior. This behavior is expected with turbulent flow system, which indicate that the formed complexes have non-linear behavior with non-Newtonian flow mode that enable drag reduction achievement.

![Figure 5](image)

**Figure 5.** The drag Force percent against fluid velocity observed for different concentrations of complex PEO + CNT.

Figure 6 describes the drag reduction percentage with Reynolds number for the selected additives and their complexes. This figure shows the comparison between the different additives as a confirmation of the role of the complex formed by the PEO, CNT and the microbubbles. Basically, drag reduction percent increases as the Reynolds number increase, this is attributed to the combined process whereby the turbulence degree was increased with the Re. That was leaded to a good media where these additives could interfere and interact with the formed turbulent structures.

All additives showed a good drag reduction efficiency. The use of CNT gives lower values of drag reduction for all values of Reynolds number, while maximum reduction is 80% gained by using complex of PEO, CNT and microbubbles. This is followed by the complex of PEO and CNT and complex of PEO and microbubbles. The contrast of this behavior between these complexes may attributed to the disparity in physical attraction which effect on the shear thickening of the flow. The microbubbles influence the viscoelastic property of the solution, which invariably leads to the addition of their various viscoelastic properties to the main flow. Such actions prevent the formed eddies in the present system to complete their shape and such is expected to lead to the drag reduction concept.
4.2. TEM Results
In this research, the TEM test was used to clarify the combines form of the complex an individual martials, whether the major elements are oppositely or similarly charged. Figure 7 shows the TEM test of PEO solution and how the polymer aggregates are interacted with eddies in turbulent flow at high concentration (2500ppm), where all polymer molecule shaped as network. The figure proved clearly that the polymer core molecule network is becoming hardly obvious. The polymer of the solution networking is completely different shape and homogeneous.

Figure 8 shows the CNT solution at high concentration (2500ppm). The figure clearly illustrates that CNT solution is already shaped with homogeneous aggregates that usually distribute the molecules in a cloud of nano particle

Figure 9 illustrates the combined shape of nano- polymer solution at 2500ppm concentration. The photo proved that the interaction between nano and polymer molecules (dark hemispherical figure) does not happen as usual and the interaction is at the minimum possible surface area, Hence, the polymer molecules are not capable to form any type of networking over the particle.

Figure 6. Drag reduction percentage vs. Re for different PEO concentrations, copper powder (at 1100 PPM) and microbubble complexes.
Figure 8. TEM shape of the Nano individual at 2500 ppm concentrations.

Figure 9. TEM shape of the polymer -nano complex at 2500 ppm concentrations.

4.3. Turbulent Velocity Profile Results
The typical velocity profile for turbulent boundary layer for the additives that used in this work is shown in figures (10-12). These figures show the universal non-dimensional mean velocity profile with the non-dimensional radial distance from the wall.
**Figure 10.** Mean Axial Velocity Profiles of Water and different Concentration of NCNT Solutions in Terms of Wall Units at Reynolds number of 81396.8

**Figure 11.** Mean Axial Velocity Profiles of Water and different Concentration of PEO Solutions in Terms of Wall Units at Reynolds number of 81396.8
In Figures 10 to 11, the profiles slope increases by increasing additives concentration. lower wall shear stresses were produced with high concentrations thus lower friction velocities were used to scale the velocities in the figure. According to Den Toonder and Nieuwstadt [22], the buffer layer is thickened due to the effect of drag reducing additives which causes an upward shift of logarithmic profile.

5. Conclusions
1- Using of each additives complexe is able to reduce drag better than the individual additives in drag reduction.
2- The additives concentration have a vital role in the drag reduction efficiency.
3- The synergy between the individual additives is control the performance of any complex.

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