Drag Reduction and Flow Enhancement in Iraqi Crude Oil Pipelines using PMMA polymer and CNTs

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Abstract. Crude oil flowing in pipelines suffers from a problem fluid flow pressure drop and high energy consumption for fluid pumping. The flow can be enhanced using either viscosity reduction or drag reduction techniques. Drag reduction (DR) can be considered as the most effective and applicable method. Such method contributes in reducing the frictional energy losses during the flow by addition of little amounts of drag reducing agents (DRAs). The present work focuses on comparing between the effect of PMMA only and PMMA with CNT on drag reduction. In order to achieve this object, an experimental rig has been designed and implemented. It should be mentioned that the ring consists of: a crude oil Perspex pipe, oil pump, pressure sensors. Two additive materials including PMMA and CNT with different concentrations have been used to reduce the drag inside the oil pipe. polymethyl metha acrylate polymer (PMMA) with different concentrations 1000, 2000, 3000, 4000 mg/ L. It has been shown 3000ppm is the best where the percentage of drag reduction reached to 65%. While, A mixture of CNT and PMMA with (1000, 2000, 3000, 4000, 5000) mg/L are used and the results showed that 50% of DR is achieved at 2000 mg/L.

1. Introduction
The first paragraph Pipeline can be considered as the safest tools to transport crude oil for long distance. Thereby such tools are usually utilized for crude oil exporting. When fluids are transported through the pipeline, fluid pressure will be decreed, due to the friction between the wall of oil pipe and fluids. Here, fluids must be transported under sufficient pressure to achieve the desired productivity, and then more pressure must be directed. However, pipeline design limitations lead to reduce the amount of pressure that can be used. It should be stated that the problems associated with pressure reduction are compounded when the fluids are transported over long distances. Such decreases results in increasing the volume of the equipment and costs[1,2].

The additives are polymers or nano materials. Polymer works as a DRAs by dampening present eddies in order to greatly reduce turbulence, as several scientists concluded [3-5]. It was also discovered that the efficiency of polymer was influenced by several variables such as: concentration impact, tube and geometry size, molecular polymer weight, chain flexibility and flow rate [3]. Addition
of little amount of long-chain polymers to a liquid flow will cause massive decreases within the frictional resistance at the wall [6]. Moreover, it reduces the hydrodynamic drag level when pumping oil or oil products, which provides the possibility of easy pipe operation, i.e. increasing the volume flow rate when piping through the overloaded pipeline section; accelerating to compensate for some unavoidable time losses; minimizing the loading and unloading of oil barges; increasing the pipeline flow capacity in offshore oil development [4, 5]. Ptasinski, P. K., et al, (2001) [7] studied hydrolyzed polyacrylamide (PAMH) in water, The main part of the setup consists of a smooth straight pipe of Plexiglas with a length of 34 m and an inner diameter of 40.37 mm. It was shown that the highest DR of 70% obtained with 435ppm. Liberatore, Matthew W, et al, (2004) [8] used polyacrylamide (PAM) in water with different concentration 200, 500 and 1000 ppm and 3m test section of rectangular pipe, 58% of DR occurred at 1000ppm concentration.

Kim, Nam-Jin, et al, (2010) [9] applied polyethylene oxides (PEO) on water, inner diameter and length line were (17.1mm and 2000mm), respectively. The maximum drag reduction rate was 50% at 20ppm concentration. Nicholas B. Wyatt, et al, (2011) [10] used polyelectrolyte xanthan in water with three separate pipes of varying diameters and materials (1/4 iN. stainless steel, 1/2 iN. copper, and 1 iN. copper), the result showed that maximum DR 35% obtained at 200ppm. Zadrazil, I, et al, (2012) [11] used PEO with diverse concentration 5, 10, 25, 50, 75, 125 and 250ppm, a stainless steel horizontal pipe test section of length 8m and inner diameter of 25.3m, 68% of DR achieved at 250ppm. Anees A. Khadom, et al, (2014) [12] Investigated the impact of polyacrylamide (PAM) as a drag-reducing polymer on Iraqi crude oil flows in pipe lines. Five concentration of PAM (10,20,30,40,50) ppm and pipes made of carbon steel with length of 3 m and diverse inner diameters (0.0508, 0.0254 and 0.0191 m) were used. The maximum reduction in drag was 40.64% with 50 ppm of PAM polymer flowing in 0.0508 m I.D straight pipes. ŞERIFE, Z, et al, (2014) [13] Utilized low molecular weight sodium carboxy methyl cellulose (CMC) in water with four concentrations (200 to 500 ppm) The flow system consists of a test section that is 6 m long with 46 mm inner diameter of PVC pipe. Themaximum drag reduction obtained was 22% using 500 ppm CMC solution. Tian, Meng, et al, (2015) [14] applied Hydroxypropyl xanthan gum (HXG) whichprepared from xanthan gum (XG) in water, the test section was a smooth tube made of stainless steel (2.0 m length and 20.5 mm inner diameter). The maximum drag reduction for 1 g/L for XG and HXG were 68.1% and 72.8% respectively. L. Marylin Pumisacho, et al, (2016) [15] used hydrolyzed polyacrylamide (PAMH) in water with test pipe section of 34-mm inner diameter and 6-m length made of Plexiglas, at 20ppm the DR decreased by 35%. Siti S, et al, (2016)[16]. Studied the synthesizing of biopolymer, Carboxymethylcellulose (CMC) on water, and studied its effectiveness in drag reduction at different concentration and flow rate. At1000 ppm DR was 27.27%. Hassananean, M. H., et al,(2016) [1]. Studied the impact of polyalpha olefin on crude oil stream lines situated in the western Egyptian desert (field Fagour) owned by Khalda Petroleum Company with a pipeline length of 16 km from Fagour to Bouchis with a nominal 6 inch pipeline diameter and 12 km from Bouchis to Kalabsha with a nominal 8 inch pipeline diameter. Following the field application of 60 ppm of the DR%, the pressure drop was decreased by 36%. Danfu Caoa, et al, (2018) [17]. discussed the influence of Poly-α-olefin as DR on crude oil , a field experiment of the tubular dispersing device was carried out in a short-range product oil pipeline in China, the maximum DR was 56%.

Nano scale materials are defined as a set of materials in which at least one dimensions is less than approximately 100 nanometers. Nano materials can be nano scale in one dimension (eg. surface films), two dimensions (eg strands or fibrs ), or three dimensions (eg. particles). Engineered nanomaterials are resources designed at the level of the molecular (nanometer) to take advantage of their small size and new properties that are generally not found in their conventional counterparts [18]. Nano materials additive can be used as drag reducers and can set the contact surface to make the fluid flow smoother and more effective [19]. CNT with flexible polymer such as PMMA or xanthan gum (XG) can be used as a DRA[20]. So after sonication it can be used as a good drag reduction agent especially when it would bedissolved in an organic liquid. Pouranfard A R., et al, (2014) [6]applied nanosilica on water, the test section of the experimental set-up consisted of a smooth unique pipe (5 layers composite pipe of poly ethyleneand aluminum). Four pipes with length of 9 m and the diameters 1.27, 1.905, 2.54, 3.175 cm,
respectively parallel horizontal galvanized rough pipes were tested. At 1 % wt and 1.27 ID, the maximum DR was 24 %.\cite{Abdulbari} studied the effect of three nano powder additives (bismuth oxide, iron oxide, silica and titanium oxide) on DR. Straight micro channels of 50, 100, and 200μm with a length of 58.5 mm were employed in this study. The optimum DR% were calculated on the basis of the experimental results. The optimum percentages were as follows: bismuth oxides: ~65% DR, 200 ppm and 100μm microchannel size; iron oxides: 57% DR, 300 ppm, and 50μm microchannel size; titanium oxides: 57% DR, 200 ppm, and 50μm microchannel size; and silica: 55% DR, 200 ppm, and 50μm microchannel size.

\cite{Akindoyo} studied the effect of mixture Carbon Nanotubes (CNT) and Xanthan Gum (XG) on water using rotating disk apparatus. The CNT diameter was 20–40nm and the length was 10-30μm, the rotating disk was of 148mm diameter and 3mm thickness. The maximum drag reduction of approximately 50% was observed at 0.6 concentrations.

\cite{Yanuar} employed Al2O3 nanoparticles on water in a ratio of 100 ppm, 200 ppm and 300 ppm as well as 30 minutes, 60 minutes and 120 minutes mixing time. A circular pipe was used as a spiral pipe comparison and both were horizontally mounted. The ratio of the spiral pipe was (P / Di=10.8) and the inner circular pipe diameter was 3 mm. Nanoparticles mixing time and composition ratio in basic fluid affect the drag reduction results. Nanofluid flows through the test pipe showed high drag reduction at a mixture concentration of 300 ppm and 120 minutes of mixing time in the spiral pipe as 38%.

2. Experimental set-up

Drag reduction was measured in a closed flow loop. The experiment is performed in a re-circulatory flow facility which is shown in Figure 1. This system consists of Control unit, oil pump, Pressure gauge, Pressure Sensor, PVC pipe with a diameter of 0.5 inch and length of 2m, oil tank.

![Figure 1. The experimental system.](image-url)
3. Experimental work:
Firstly poly methylmethacrylate (PMMA) with density of 0.032g/cm³ and five concentration (1000,2000,3000,4000,5000) ppmis mixed with crude oil by magnetic stirrer for 20 minutes and adding to the oil tank to measure each of pressure drop, DR%, viscosity, density, friction factor, Reynolds number and power consumption.
Secondly carbon nano tube (CNT) with 90% purity, (5-10nm) inner diameter, (10-30nm) out diameter and 0.06g/cm³ bulk density, is mixed with PMMA in the rate of (25% of CNT with 75% of PMMA) and mixed by ultrasonic for 1 hour then mixed using magnetic stirrer for 30 minutes and adding to oil tank to measure each of pressure drop, viscosity, density, friction factor, Reynolds number and power consumption.
Table (1) shows the device specifications:

| Table 1. Device specifications |
|-------------------------------|
| device                        | Type                  | Specifications                                      |
| Oil pump                      | WCB75                 | 220/380V,750W,50L/min,Max Head 30m,0.3Mpa (43 psi) |
| Pressure Sensor               | PA-21Y/81554.33       | Rang 0-10 bar,Out/GND 4-20mA                       |
| Accurate electronic balance   | FRAGILE               | 230V50HZ,0.001g-500g                               |
| Magnetic stirrer              | 78-1HOT PLATE &STIRRER| 250V, 6A                                           |
| Viscometer                    | Cannon-Fenske-routine | Size 200, Constant (cst/s)=0.1, Kinematic Vis (cst) |
| Pycnometer                    | Duran                 | Volume 25.81cm³                                    |
| Ultrasonic                    | KQ3200E               | 220v, 50 HZ, 150 watt                              |

4. Experimental Calculations:

Percentage of drag reduction
Pressure drop reading through the pressure sensor before and after additive. Percentage of drag reduction can be calculated by:[22]

\[ DR = \frac{4p_b - 4p_a}{4p_b} \] (1)

Where \( p_a \) is a pressure drop before additive and \( p_b \)is pressure drop after additive.

Power consumption, Reynolds number and friction factor
Flow rate \( Q \) (m³/s), Re Reynolds number density \( \rho \), viscosity \( \mu \),u velocity, D diameter of pipe, f friction factor , L length of pipe [23,24]
\[ P_E = Q \Delta p \]  \hspace{1cm} (2)

\[ Re = \frac{\rho u D}{\mu} \]  \hspace{1cm} (3)

\[ f = \frac{\Delta P \cdot D}{2 \cdot \rho \cdot u^2} \]  \hspace{1cm} (4)

5. Results and discussion

5.1 Effect of PMMA

Figures 2 to 7 show the effect of PMMA with five concentration (1000, 2000, 3000, 4000, 5000) ppm on friction factor, pressure drop, drag reduction, viscosity, Reynolds number and power consumption.

5.1.1 Effect of PMMA on friction factor:

Figure 2 shows the effect of PMMA on friction factor in which the polymer acts as lubricating oil, where the slippage between the crude oil molecules increases with each other and between the oil molecules with the pipe wall. Thereby, reducing friction it was noticed that when adding 3000ppm of PMMA the friction factor decreases from 0.0052 where there was no addition to be 0.0016. After 3000ppm the friction gradually increased until it reached 0.0036 at 5000ppm where increasing the polymer led to increase the viscosity of fluid, which increased the friction factor.

\[ \text{Figure 2. Effect of PMMA on friction factor} \]

5.1.2 Effect of PMMA on pressure drop:

Figure 3 represents the effect of PMMA on pressure drop, where the pressure drop decreases from 46000Pa to 16000Pa at 3000ppm. The pressure drop is proportional to the friction factor, where the low friction factor leads to a drop in the pressure drop. This is because lowering the friction between the crude oil molecules with each other and the pipe wall saves the energy of the liquid particles and keeps...
the stream energy in the form of pressure. After 3000ppm, the pressure drop gradually increased to 3600 at concentration of 5000ppm.

![Figure 3. Impact of PMMA on pressure drop](image)

5.1.3 Impact of PMMA on DR:

Figure 4 shows that adding 3000ppm of PMMA leads to increase the drag reduction rate by 65%. It should be noted that pressure drop reduction results in drag reduction. After 3000ppm the DR% decreased to 22% at concentration of 5000ppm.

![Figure 4. Impact of PMMA on DR](image)
5.1.4 Effect of PMMA on viscosity:

Figure 5 shows the effect of PMMA on viscosity, where the viscosity of crude oil decreases from 21.5cst at no addition to 15.37cst at 3000ppm. This is due to the lubrication characteristics of the polymer which leads to increase sliding liquid particles with each other leading to reduce the viscosity. After 3000ppm the viscosity increased to 18.16cst.

![Figure 5. Effect of PMMA on viscosity](image)

5.1.5 Effect of PMMA on Reynolds number:

Figure 6 shows that the Reynolds number values increase from 3264.12 without addition to 5218.22 at 3000ppm concentration of polymer addition. Thereby, an enhancement in flow rate of crude oil inside the pipe when using the polymer can be achieved. After 3000ppm the Reynolds number gradually decreased to 4140.5 at 5000ppm.

![Figure 6. Effect of PMMA on Reynolds number](image)
5.1.6 Effect of PMMA on power consumption:

Figure 7 shows that power consumption decreased from 32 watt at no addition to 11watt at 3000ppm. As the value of power consumption is proportional to pressure drop it decreased by 65.21% when using 3000ppm of PMMA. After 3000ppm the power consumption gradually increased to 25watt at 5000ppm.

![Figure 7. Effect of PMMA on pumping power consumption](image)

5.2 Effect of PMMA with CNT

Figures 8 to 13 show the effect of PMMA with Carbon nano tube using six concentrations as (1000, 2000, 3000, 4000, 5000, 6000) ppm on each of friction factor, pressure drop, drag reduction, viscosity, Reynolds number and power consumption.

5.2.1 Effect of PMMA with CNT on friction factor:

Figure 8 illustrates the effect of PMMA with CNT on friction factor. Clearly, the friction factor decreases from 0.0052 without addition to 0.0022 at 2000ppm. This is because of the nano particles encapsulate the inner surface of the pipe wall and acts as a buffer between the inner surface of the tube and the crude oil molecules, which makes the flow in the center of the tube, and consequently reduces the friction factor values. After 2000ppm the friction factor gradually increases to 0.00305 at 5000 and 6000 ppm. This behavior may be due to aggregations of nano particles within the pipe, which gives the reverse outcomes.
5.2.2 Effect of PMMA with CNT on pressure drop:
Figure 9 illustrates that pressure drop decreased from 46000Pa without addition to be 23000Pa at 2000ppm concentration of PMMA with CNT. The pressure drop is decreasing because the friction reduction inside the pipe, therefore the molecules of the fluid saving in their flow energy. After 2000ppm the friction factor gradually increased to 37000 at 5000 and 6000 ppm.
5.2.3 **Effect of PMMA with CNT on drag reduction:**
Figure 10 shows the variation of the drag reduction with different concentrations of PMMA with CNT. It can be observed that 50% of DR is obtained when adding 2000ppm of PMMA with CNT to the crude oil. This DR% is considered as a good result in comparison with PMMA and fiber (28.26%). After 2000ppm the DR% gradually decreased and reached to 19.5% at 5000 and 6000ppm.

![Figure 10. Effect of PMMA with CNT on drag reduction](image)

5.2.4 **Effect of PMMA with CNT on viscosity:**
Figure 11 shows that the viscosity is decreasing from 21.5cst at zero addition to 14cst at 2000ppm of PMMA with CNT. This is because that CNT are formed in longitudinal chains that allow fluid layers to slide over each other and thus reduce the viscosity of the fluid. After 2000ppm the viscosity gradually increased to 17cst.

![Figure 11. Effect of PMMA with CNT on viscosity](image)
5.2.5 Effect of PMMA with CNT on Reynolds number:
Figure 12 shows that the Reynolds number increases from 3246.12 at zero addition to be 5585.64 at 2000 ppm. The values of Reynolds number reaches the turbulent region indicates a clear flow enhancement inside the crude oil pipe. After 2000ppm Reynolds number gradually decreased to 4305.07.

![Figure 12. Effect of PMMA with CNT on Reynolds number](image)

5.2.6 Effect of PMMA with CNT on power consumption:
Figure 13 shows that the power consumption decrease from 32 watt at zero addition to 17.94 watt at 2000ppm. The percentage of power consumption decreasing was 42% which indicates a good saving in power when additives material such as polymer and nano are used. After 2000ppm the power consumption gradually increased to 27 watt.

![Figure 13. Effect of PMMA with CNT on power consumption](image)
6. Conclusions
The addition of 3000ppm of PMMA to the crude oil leads to reduce the friction factor and the pressure drop to 0.0016 and 16000Pa, respectively. On the other hand, the DR% increases by 65% results in decreasing the power consumption to 8 watt. Also, the addition of 2000ppm of PMMA with CNT decreases the friction factor to be 0.0022, the pressure drop will be decreased to 23000Pa, while the DR% rate increases by 50% so the power consumption decrease to be 17.94watt.

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