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Viscosity reduction for flowability enhancement in Iraqi crude oil pipelines using novel capacitor and locally prepared nanosilica

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ABSTRACT

The aim of the present work is to reduce the viscosity of Iraqi heavy crude oil to enhance its flowability in pipelines. This has been done by applying an effective electrical field through design and implementation of an invented capacitor. In order to attain this objective; an experimental rig has been built. It consisted of: a crude oil pipe, a novel parallel plate capacitor, an oil pump, a solenoid valve, a viscometer, and a control unit (relay, voltage regulator, rectifier, timer, and digital voltmeter). The experimental work was performed according to central composite rotatable design for three operating variables: treatment time (0–60 s), applied voltage (140–220 v), and space between capacitor electrodes of (2–10 cm). The optimum conditions were obtained using STATISTICA and WinQSB softwares. At optimum conditions, locally prepared nanosilica has been employed with different concentrations (0–700 mg/L) to show its effect on crude oil viscosity in the presence of an electrical field impact. The results showed that the viscosity was reduced significantly with increasing treatment time, voltage, and distance between electrodes. The Minimum viscosity obtained was at 32 s treatment time, 188 V, and 6.11 cm distance between capacitor electrodes. This represented the optimum conditions with a minimum viscosity of 20.479 cSt. Afterwards, the viscosity increased due to particles aggregation. At optimum conditions the fluid flow characteristics obtained were: 2630.93, 0.4089 gm/cm^2, 0.2657 gm/cm^2, and 57.059 W S, for Reynolds number, shear stress, pressure drop, and power consumption, respectively. The experimental results proved that the invented capacitor offered a good reduction in viscosity and a good saving in power of 37% at optimum conditions achieved at 10 ± 2 °C. The nanosilica optimum concentration was 100 mg/L that gave a minimum viscosity of 12.8 cSt with a reduction percentage and power saving of 60.6%. The viscosity reduction has lasted for 11 h.

1. Introduction

In Iraq, the oil industry represents the lifeblood of its economy. Petroleum is the main source of country's income, therefore crude oil is considered as the major export. There are many oil strategic lines arranged in a pipelines network to transport oil to neighboring countries for export. These pipelines suffer from serious issues related with crude oil viscosity and flow difficulties especially in cold weather. Crude oil viscosity is an important physical property that controls and influences the flow of crude oil through pipelines. Viscosity introduces resistance to motion by causing shear or friction force between fluid particles and boundary walls. High viscosity problem of heavy crude oil becomes a critical issue for inshore and offshore crude oil when the temperature is very low. This high viscosity makes the pressure required to pump crude oil via a pipeline very high to overcome the growing shear and frictional forces. The current used methods are heating or dilution of crude oil with gasoline or diesel. Heating is a form of substantial physical technology, closely applied to transport the waxy crude oil with high viscosity. Shadi et al. (2010), and Jaimes et al. (2013) used heating and dilution with light oil concentrations. Fabian (2013), and João Felipe et al. (2016) also used heating. This method is much more energy consumer, very slow and much less efficient [Tao and Gu (2015)]. Other techniques such as addition of polymers, fibers or surfactants as drag reduction agents, addition of suspended solid particles, and gas injection in turbulent flows have been studied by many researchers: Anselmo and Soares (2012) used two different polymers: Polyacrylamide (PAM) and Polyethylene oxide (PEO). Marmy et al. (2012) used coconut fiber as a drag reducing agent in aqueous media flow in pipelines. Ahmed and Shah (2013) used Aromox APA-T surfactant-based fluids, and Hazlina et al. (2014) used chemical additives and emulsification as a drag reducing agent, while Edward and

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Abdulbari (2015) used surfactant and xanthan gum as a drag reducing agent. Magnetic field was also considered as a potential drag reduction technique along side with suspended metal solid particles i.e. iron; it has an effect on some kinds of paraffin base crude oil, but has little effect on other kinds of asphalting base crude oil as experienced by Tao and Gu (2015). Abdulbari and Kor (2011) used magnetic field as a drag reducer and flow enhancer in suspended solutions. The application of a suitable pulsed magnetic field or pulsed electric field can significantly reduce the viscosity of crude oil for several hours. Specifically, for paraffin-base crude oil, in which a magnetic field pulse can be used to reduce its viscosity. While, for asphalt-base crude oil or mixed-base crude oil; the same can be done with an electric field pulse. This viscosity reduction method does not change the temperature of the crude oil; instead, it temporary aggregates paraffin particles or asphaltene particles inside the crude oil into large ones. The particle aggregation changes the rheological property of the crude oil and leads to the viscosity reduction. While this viscosity reduction is not permanent, it lasts for several hours and is repeatable. This is suitable for many important applications, such as oil transport via deepwater pipelines rather than over ground pipelines [Tao and Xu (2006)] . Electric field is the best technique for viscosity reduction because of its effect on asphalting and paraffinic base crude oil. It consumes very little energy conversely it awards great energy saving in crude oil pumping energy due to considerable viscosity reduction, as well as it is believed to be environmental friendly technique as proved by several researches [Tao and Xu (2006), Hong et al. (2011), Tao and Tang (2014), and Tao and Gu (2015)]. Nanomaterials have been used as a drag reducing agent to improve flow ability of liquids. A nanohybrid pour-point depressant (PPD) was used by Wang et al. (2011) in such industries like. Cost effective and efficient SiO_2 nanoparticles were used to modify rigid polar additives and to produce nanofluids. Nanosilica has high porosity and large surface area; it can be widely used in materials such as fillers, pharmaceuticals, and catalysts. Industrial production of silica material uses sodium silicate as a silicon source. However, sodium silicate produced by melting quartz sand and sodium carbonate at 1300 °C requires a large amount of energy. It has been produced also from waste materials like rice husk by Tzong-Horng and Chun-Chen (2011). Nanosilica was produced in excellent characteristics using top-down method with sulfuric acid assisted ball milling from local silica sand by Najat et al. (2015). Edward and Abdulbari (2015) utilized nanosilica in rotating disc apparatus to reduce drag. A good drag reduction results have been found using nanosilica. In this work, an effective electric field has been applied through design and implementation of a novel capacitor to apply the electric field within the pipe. Also, locally prepared nanosilica has been used for the first time in conjunction with electric field impact to reduce the viscosity. An optimization technique has been utilized employing STATSTICA and WinQSB software as well to attain optimum operating conditions to enhance the flowability in pipelines.

2. The optimization technique

Before studying any process, it is necessary to determine the parameters which have a considerable effect on the system behavior, or the factors that influence the system objective function. So one must carry out several experiments to cover the effect of each parameter as well as the interactions between these parameters if they are not independent. The systematic method which satisfies the above function with minimum number of experiments is called **"Experimental Design"**. The application of the experimental design to plan the experiments required to examine the system, will extract the information from pre-existing data by using a statistical method to interpret the results in a regular form with the minimum number of observations. The experimental design technique consists of two parts: the first one is planning the experiments according to a specified plan, taking into account the description of the variable values in the plan by a coded form. The second one includes achieving the regression analysis for the specified set of runs in the plan, taking into account the coded form of the variables and the results of the objective function regarding each experiment in the set. There are many techniques for the application of experimental planning. The proper technique for planning a system of three variables is "**Central composite rotatable design** (CCRD)". The total number of treatment combinations in the above design is equal to (2^k+2k+1), where k is the number of variables, plus additional further treatments to take the lack of fit and experimental error into account, the central composite rotatable design will reduce the number of the experiments required for the system of three variables to (20) experiments, compared with (125) required for the application of factorial design [Mahsa et al. (2012), Ali D. Salman (2015), and Marcin et al. (2015)].

3. Fluid flow governing equations

The fluid flow characteristics have been calculated using the following fluid flow governing equations [Franke M. White (2009), William S. Jaunah (2010), and Sarbjit Singh (2012)]:

Reynolds number has been calculated from eq. (1) as:

$$Re = u\, d\, \rho / \mu \tag{1}$$

Shear stress is extracted when there is a shear rate, and shear rate for laminar flow is:

$$\gamma = 8\, u/d \tag{2}$$

With velocity equal to 1.253 cm/s, and shear stress is:

$$\tau_W = -\mu\, \gamma \tag{3}$$

An important factor for reducing the power consumption is to reduce the pressure drop between the boundary layer of crude oil and the area around the pipe and the inside. It is directly proportional to the shear stress. The pressure drop was calculated by the following equation:

$$\Delta P = 4\, \tau_W\, \frac{l}{d} \tag{4}$$

Power consumption for pumping is:

$$P = 18.18\, \Delta P / \eta \tag{5}$$

where the efficiency of pump was 0.85.

Dynamic viscosity can be obtained from kinematic viscosity measurements according to equation:

$$\mu = \nu\, \rho \tag{6}$$

4. Materials and methods

4.1. Materials

The materials used in the experimental work were: Iraqi crude oil named as Basrah heavy supplied from Al-Doura refinery, its specifications are given in Table 1. The other material was Nanosilica prepared locally in previous work [Najat et al. (2015)]. The specifications of prepared nanosilica are shown in Table 2.

Table 1
Physical properties of crude oil supplied from Al-Doura refinery laboratories.

Properties of heavy crude oil	
Sp.gr at 15.6 °C	0.8697
API at 15.6 °C	31.2
Density at 15 °C	0.8692
Kin. Viscosity at 10 °C (cSt)	30.5
Asphaltenes content (wt %)	2.83
Vanadium (PPM)	59.4
Nickel (PPM)	18.14