International Journal of Chemical Engineering and Analytical Science
Vol. 1, No. 1, 2016, pp. 24-30
http://www.aiscience.org/journal/ijceas

The Parametric Evaluation of Basic Parameters in Dynamic Flow of Petroleum

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Abstract

In this paper, the tests are designed for investigation of the effects of the synthesized oxide molybdenum nano particle prepared by ultrasonic on the crude oil flowing properties. Rheological and thermal properties of crude oil with nano particle are surveyed, experimentally. Nano particles which are prepared with method of ultrasonic are applied in crude. Experiments are held in heated tube section for both simple oil and nano oil which contains nano molybdenum oxide. Addition of nano molybdenum oxide from 1 wt% to 4wt% increases the value of overall heat transfer coefficient about 1.5 times. Also the increase of nano particle from 1 wt% to 11 wt% increases the value of conductive heat transfer coefficient about 2.47 times.

Keywords

Rheology, Crude Oil, Heat Properties, Ultra-sonic, Nano Particles

Received: May 19, 2016 / Accepted: June 1, 2016 / Published online: June 20, 2016

1. Introduction

1.1. Crude Oil

Crude oil, liquid petroleum that is found accumulated in various porous rock formations in Earth's crust and is extracted for burning as fuel or for processing into chemical products[1]. Although it is often called "black gold," crude oil has ranging viscosity and can vary in color to various shades of black and yellow depending on its hydrocarbon composition [2]. Undoubtedly, crude oil is one of the powerful sources of energy provision in the world. Access to oil was and still is a major factor in several military conflicts of the twentieth century, including World War II, during which oil facilities were a major strategic asset and were extensively bombed. The German invasion of the Soviet Union included the goal to capture the Baku oilfields, as it would provide much needed oil-supplies for the German military which was suffering from blockades. Oil exploration in North America during the early 20th century later led to the US becoming the leading producer by mid-century. As petroleum production in the US peaked during the 1960s, however, the United States was surpassed by Saudi Arabia and the Soviet Union [3]. Today, about 90 percent of vehicular fuel needs are met by oil [4]. Petroleum also makes up 40 percent of total energy consumption in the United States, but is responsible for only 1 percent of electricity generation. Petroleum's worth as a portable, dense energy source powering the vast majority of vehicles and as the base of many industrial chemicals makes it one of the world's most important commodities [5]. Viability of the oil commodity is controlled by several key parameters, number of vehicles in the world competing for fuel, quantity of oil exported to the world market (Export Land Model), Net Energy Gain (economically useful energy provided minus energy consumed), political stability of oil exporting nations and ability to defend oil supply lines [6 and 7]. The top three oil producing countries are Russia, Saudi Arabia and the United States. About 80 percent of the world's readily accessible reserves are located in the Middle East, with 62.5 percent coming from the Arab 5: Saudi Arabia, UAE, Iraq, Qatar and Kuwait. A large portion of the world's total oil

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exists as unconventional sources, such as bitumen in Canada and extra heavy oil in Venezuela. While significant volumes of oil are extracted from oil sands, particularly in Canada, logistical and technical hurdles remain, as oil extraction requires large amounts of heat and water, making its net energy content quite low relative to conventional crude oil. Thus, Canada's oil sands are not expected to provide more than a few million barrels per day in the foreseeable future [8 and 9]. In its strictest sense, petroleum includes only crude oil, but in common usage it includes all liquid, gaseous, and solid hydrocarbons [10]. Under surface pressure and temperature conditions, lighter hydrocarbons methane, ethane, propane and butane occur as gases, while pentane and heavier ones are in the form of liquids or solids [11]. However, in an underground oil reservoir the proportions of gas, liquid, and solid depend on subsurface conditions and on the phase diagram of the petroleum mixture [12]. An oil well produces predominantly crude oil, with some natural gas dissolved in it. Because the pressure is lower at the surface than underground, some of the gas will come out of solution and be recovered (or burned) as associated gas or solution gas. A gas well produces predominantly natural gas [13]. However, because the underground temperature and pressure are higher than at the surface, the gas may contain heavier hydrocarbons such as pentane, hexane, and heptane in the gaseous state. At surface conditions these will condense out of the gas to form natural gas condensate, often shortened to condensate [14]. Condensate resembles petrol in appearance and is similar in composition to some volatile light crude oils. The proportion of light hydrocarbons in the petroleum mixture varies greatly among different oil fields, ranging from as much as 97 percent by weight in the lighter oils to as little as 50 percent in the heavier oils and bitumens [15]. The hydrocarbons in crude oil are mostly alkanes, cycloalkanes and various aromatic hydrocarbons while the other organic compounds contain nitrogen, oxygen and sulfur, and trace amounts of metals such as iron, nickel, copper and vanadium [16]. The exact molecular composition varies widely from formation to formation but the proportion of chemical elements varies over fairly narrow limits as follows [17].

1.2. Nanotechnology

In recent years, development in the miniaturization technologies results in fabrication of micro-scale electronic devices which is used in various industries such as aerospace and automotive. For maximum performance of these micro devices which is known as MEMS (Micro Electromechanical Systems), the temperatures should be in a certain range. Micro channel as Compact and efficient cooling devices have been developed for the thermal control of MEMS [18]. Utilizing nano fluid as working fluid could improve the cooling and heating performance. Because of more stable nature of nano fluid compared with its pioneer generation (including micro and millimeter particles) and exceptional thermal conductivity of nanoparticles, it could considerably enhance the convective heat transfer coefficient in micro channel. During the last decade, many studies on convective heat transfer with nano fluids have been considered [19]. Some researchers revealed that the heat transfer coefficients of the nano fluids increase with increasing the volume fraction of nanoparticles and the Reynolds number. Scientifics studied the laminar mixed convection of an Al_2O_3/water nano fluid in a horizontal tube numerically using a two-phase mixture model [20]. They showed that the nanoparticle concentration did not have significant effects on the hydrodynamics parameters, but its effects on the thermal parameters were important for the fully developed region. The other Scientifics considered the laminar forced convection of an Al_2O_3/water nano fluid flowing in an annulus [21]. Their results indicate that the friction coefficient depends on the nanoparticle concentration when the order of magnitude of heating energy is much higher than the momentum energy. Thermal transport of nano fluid flow in micro channels has also attracted a few investigators due to its promising applications [22]. In a study in previous literature the cooling performance of the micro channel was significantly improved by the significant reduction in the temperature difference between the heated wall and the nano fluids [23]. The other researchers experimentally assessed forced convective cooling and heating performance of a copper micro channel heat sink with Al_2O_3/water nano fluid as a coolant [24]. Their results show that the nano fluid cooled heat sink outperforms the water-cooled one, having significantly higher average heat transfer coefficient and thereby markedly lower thermal resistance and wall temperature at high pumping power, in particular. Meanwhile, in an experiment using SiO_2–water nano fluids in an aluminum heat sink consisted of an array of 4 mm diameter circular channels with a length of 40 mm [25]. The experimental results showed that dispersing Al_2O_3 and SiO_2 nanoparticles in water significantly increased the overall heat transfer coefficient while thermal resistance of heat sink was decreased up to 10%. Also they numerically investigated corresponding configuration [26]. The results revealed that channel diameter, as well as heat sink height and number of channels in a heat sink have significant effects on the maximum temperature of heat sink [27]. Regarding numerical aspects, Scientifics demonstrated when the commonly used assumption of constant heat flux boundary condition is applicable in heat and fluid flow analysis in microfluidic systems [28]. Also a general Nusselt number correlation for fully developed laminar flow was developed as a function of two dimensionless parameters, namely, Biot number and relative conductivity, to take the conduction effects of the solid substrate on heat transfer into account.

1.3. Rheological Models

Fluids are classified by their rheological behaviour American Petroleum Institute. All fluids are classified as either Newtonian or Non-Newtonian, the clearest distinction between different types of fluids [29].

1.4. Fluid Mechanics

Fluid mechanics is the study of the forces involved in both still and flowing fluids [30]. Reynolds introduced a dimensionless number in order to compare fluid flow independent of which medium surrounded them and other variables. The Reynolds number is the ratio of inertial forces to viscous forces in fluid flow [31].

1.5. Flow Regimes

Flow in circular pipes can behave in different ways. Most common fluids are transported in circular pipes [32]. This is because pipes can withstand a large difference in pressure between the inside and outside of the pipe, without being significantly distorted [33]. The theory behind fluid flow is commonly well understood, yet only fully developed laminar flow is theoretically obtained [34]. Therefore flow with other characteristics, like turbulent flow, must rely on experimental and empirical relations [35]. The borderlines between laminar, transitional and turbulent flow regimes are set by the Reynolds number of the flow. For laminar flow, the viscous forces dominate, while for turbulent flow the inertial forces play the bigger role American Petroleum Institute. All fluid flow inside a pipe has the velocity profile of zero at the pipe wall due to no-slip condition to a maximum at the center of the pipe.

1.5.1. Laminar Flow

Laminar flows are relatively easy to describe both mathematically, physically, and graphically. Laminar flow is characterized by smooth streamlines and a highly ordered motion. In general they have low Reynolds number values, and can therefore be described as slow flowing. For circular pipes the flow regime is generally laminar if the Reynolds number is under 2300. The pressure required to move fluid under laminar conditions increases when velocity or viscosity is increased. The velocity profile of a laminar flow is quite easy to depict. In pipes, the cross section along the pipe, the velocity profile will be parabolic.

1.5.2. Turbulent Flow

Turbulent flows are characterized by velocity fluctuations for a single element particle and a highly disordered motion. The reason behind these fluctuations is rapid mixing between the fluid particles from adjacent layers. This leads to a momentum transfer between fluid particles, and thereby increasing the friction force on the pipe wall. Since the friction is higher for turbulent flow than laminar, a higher pressure drop is needed for turbulent flows, which in reality often means artificial power (pumping). Fluids flowing in circular pipes will act turbulent if the Reynolds number is higher than approximately 4000. Fundamental theories are valid. It is quite complicated to model the flow under such conditions, due to the irregular and unstable nature of turbulence.

1.5.3. Transitional Flow

The transition from laminar to turbulent flow does not happen suddenly. It occurs over some regions where the flow fluctuates between laminar and turbulent. It is therefore described as a separate regime. The transition is controlled by the relative importance of viscous forces and inertial forces on the flow that is the Reynolds number.

1.5.4. Friction Factor

The Darcy friction is an important parameter that predicts the frictional energy loss of drilling fluid in a pipe based on the velocity of the fluid and the resistance due to friction. It is used almost exclusively to calculate head loss due to friction in flow.

$$h_f = \frac{fLV^2}{2Dg} \tag{1}$$

2. Materials and Method

2.1. API of Crude Oil

The API of crude oil is classified according to the Table 1.

Table 1. Composition of drilling fluid.

component	API
Crude oil	30

2.2. Preparing Nano-sized MoO2

Molybdenum dioxide (MoO2) is a transition metal oxide that has long been known to be active for hydrocarbon decomposition and has more recently shown to display high reforming activity for various long-chain Hydrocarbons. Researches showed that MoO2 is highly active for reforming isooctane via partial oxidation. This process is exothermic ($\Delta H° = -659.9$ kJ/mol) and in the presence of MoO2 proceeds to full conversion at 700°C and 1 atm. The catalytic activity shown by MoO2 can be explained in terms of the Mars-van Krevelen mechanism, which involves the consumption of nucleo philic oxygen ions provided by the oxygen sub-lattice with the purpose of sustaining the redox cycles taking place on the catalyst surface. Despite its interesting catalytic properties, a very limited number of studies have been conducted examining the potential of MoO2 as a catalyst for reforming processes. Such studies were carried out using commercial MoO2, with particle sizes in the range of a few micrometres and Brunauer, Emmett, and Teller (BET) surface areas <10 m2/g. By utilizing nanoparticles we have shown that it is possible to significantly increase the total reactive surface area and thus achieve reforming processes with much higher efficiency levels than those of commercial MoO2. Nanoparticle MoO2 was synthesized by reduction of molybdenum trioxide (MoO3) powder in a 1:3 volume ratio of ethylene glycol to distilled water16. The mixture was combined in a 45 ml Teflon-lined general-purpose vessel, which was subsequently sealed and heated to 180°C for 12h. After cooling, the dark colored MoO2 was filtered and air dried at 100°C. Figure 2 shows scanning electron microscope (SEM) and transmission electron microscope (TEM) images of nanoparticle MoO2. These images indicate that the agglomerates consist of nanoparticle MoO2 with sizes ranging from 54-83 nm. The BET surface area of the nanoparticle MoO2 was determined to be 48 square meter per gram, which is about an order of magnitude greater than that of the commercially available material. Figure 2-a) shows the SEM photos of molybdenum oxide nano particles. In addition, the Figures 1 and 2 illustrate the SEM and TEM of synthesized nano particles. In addition the Table 2 shows the XRD of molybdenum oxide nano particles.

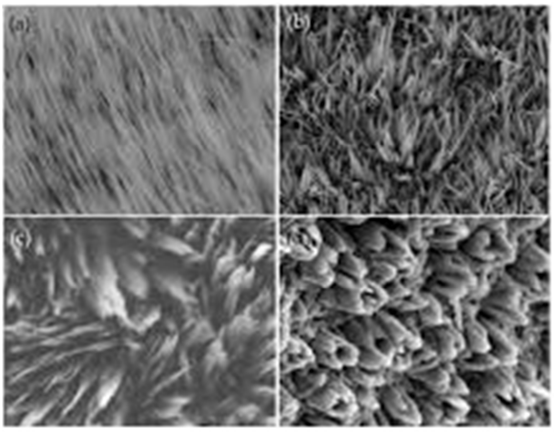

Figure 1. SEM picture.

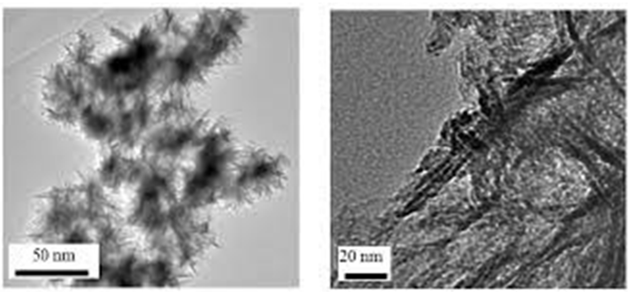

Figure 2. TEM picture.

Table 2. The amount of XRD of aluminum oxide nano particles.

XRD	2teta
211	21
220	30
311	35
400	43
422	54
511	57
440	63
620	72
533	75
444	80

The physical property of synthesized aluminum oxide nano particles is mentioned in the Table 3.

Table 3. Physical properties of molybdenum nano particles.

Molybdenum oxide nano properties	
Assay	99.8% Trace metal basis
Form	Nano powder
Resistivity	5.0 μΩ-cm, 20°C
Average Particle Size	<100 nm (TEM)

2.3. Experimental Set up

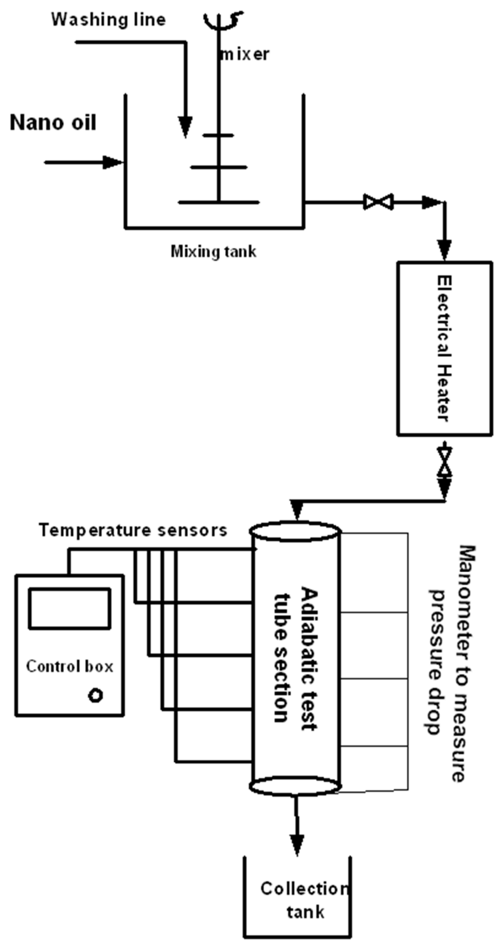

Figure 3. A schematic of set up.

The experimental set up includes mixing tank, adiabatic tube test section and electrical heater is used to survey the behaviour of nano crude oil. At the beginning, the crude oil is mixed by molybdenum oxide nano particles in a ultrasonic (With 400Watt, for 3hour), then the nano crude oil is mixed in mixing tank, passing through an electrical heater to reach the desired temperature in range of, 30 C to 90 C and 25 C to 85 C. Vertical adiabatic test tube with 0.3 m and 0.025 m in length and diameter, respectively is used. Digital sensors transmit the obtaining parameters to the control box.

Finally, nano crude oil is collected in a tank. All parameters are obtained with one type of crude oil then all the set-up is drained and washed with water stream injection from water inlet port located in mixing tank. The Figure 3 shows the experimental setup. This setup is used for mixing of nano particles to evaluate the physical properties of crude oil.

2.4. Rheology Measurements

There are different methods and equipment for measuring the rheological properties of a fluid. For crude oil the most common way is by using a Fann 35 Viscometer. A viscometer is a rotational type of rheometer and can only perform measurements under one flow condition (one shear rate at one specific temperature).

2.4.1. Fann 35 Viscometer

A Fann 35 viscometer has six different settings, speeds/shear rates, in order to measure the viscosity of the fluid. Since there are only six shear rates, a model is applied to the measurements, making extrapolations possible. This gives an idea on how the fluid behavior will be under changing circumstances.

$$\mu_{pl} = \frac{\tau_{600} - \tau_{300}}{\dot{\gamma}_{600} - \dot{\gamma}_{300}} \quad (2)$$

The subscripts indicate rotation speed in RPM. The yield point is found by rearranging Equation 3.

$$\tau_y = \tau_{600} - \mu_{pl}\,\dot{\gamma}_{600} \quad (3)$$

2.4.2. Empirical Correlations to Compute Heat Transfer Performance

Laboratory measurements have usually determined the relationship for heat transfer between a flowing fluid and a solid surface. These measurements, either for natural or forced convection, are normally correlated in terms of dimensionless parameters such as the Nusselt (Nu) or the Stanton (St) numbers.

3. Results and Discussion

Experiments are held to investigate the properties and the behaviour of nano oil comparing with simple oil. Thermo-physical properties like density, viscosity, thermal conductivity, thermal diffusivity with changes in temperature and amount of nano particle are surveyed. Some of important dimensionless numbers such as Reynolds, Prandtle, Peclet and Stanton numbers are also presented. Results are evaluated as follow.

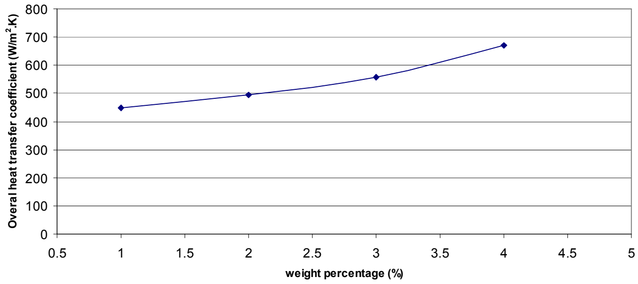

Figure 4. The amount of overall heat transfer versus nano particle weight percent.

The amounts of overall heat transfer coefficient versus weight percent of nano particles is shown in Figure 4. Changes in the amount of nano particles in ranges of (1, 2, 3 and 4 wt%) change the amounts of overall heat transfer coefficient of oil in ranges of 448 to 669 ($w/m^2.K$). According to the Figure 4, the higher amounts of nano particle obtain the higher amounts of overall heat transfer coefficient. The higher amounts of conductive heat transfer coefficient of nano particle than that value for oil, also the positive effect of nano particle on increasing the value of convective heat transfer coefficient may be responsible of the obtained increase in value of nano oil overall heat transfer coefficient.

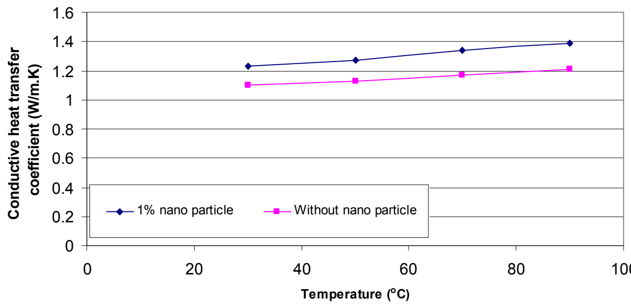

Figure 5. Values of conductive heat transfer coefficient versus temperature.

Values of conductive heat transfer coefficient of nano oil with 1% nano molybdenum are compared with those values for simple oil in the Figure 5. The results for nano oil are higher than those are obtained for simple oil at the same value of temperature. Obviously, one kind of average thermal conductivity value of oil and particles obtain the thermal conductivity value of nano oil. Nano molybdenum solid particles have higher values of thermal conductivities than liquid oil at the same temperature, so the higher values of thermal conductivity (13.4%) of nano oil are obtained than simple oil at the same temperature. Also, the effect of temperature is shown for both simple and nano oil in the Figure 5. The temperature changes in values of 30, 50, 70 and 90 C show the ranges of 1.23 (W/m.C) to 1.39 (W/m.C) for nano oil (1 wt%) and 1.1 (W/m.C) to 1.21 (W/m.C) for simple oil. The higher values of temperature results the higher values of conductive heat transfer coefficients for both simple oil and nano oil. This may be related to the higher kinetic energy of nano molybdenum particles on the higher values of temperatures which increases the nano oil conductive heat transfer coefficient.

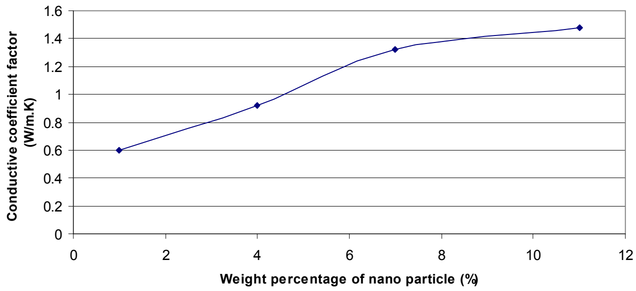

Figure 6. Conductive coefficient factor versus amount of nano particle.

Effect of amounts of nano particle in weight percent on the amounts of conductive coefficient is shown in the Figure 6. The increase in the amounts of nano particle in weight percent from 1% to 11% increases the values of conductive coefficient factor from 0.6 (W/m.K) to 1.45 (W/m.K). However the rate of increase in the amounts of conductive coefficient decreases when the weight percent of nano particle increases from 7% to 11%.

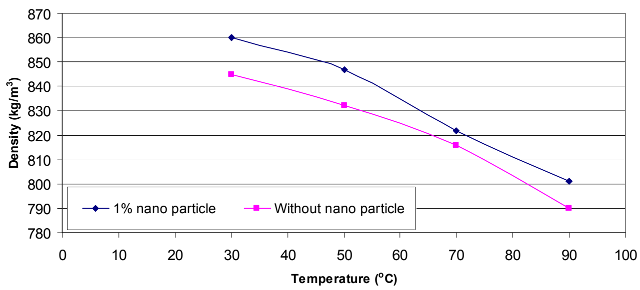

Figure 7. Density versus temperature.

Figure 7 shows the decrease trend of density of both simple and nano oil (1wt%) with temperature enhancement. Temperature changes in range of (30, 50, 70 and 90 C) changes values of density for simple oil from 845 kg/m3 to 790 kg/m3 and for nano oil from 860 kg/m3 to 800 kg/m3. Higher values of density are obtained for nano oil than simple oil at the same temperature. This is obviously relates to the higher value of nano oil mass than simple oil mass at per unit volume of each oil. The decrease trend of density with temperature is also described by the increase in the amount of kinetic energy, the increase in volume of both simple and nano oil which decreases the value of density for two types of oil.

The fluid flow specifications are so important to predict the behaviour of fluid in the transferring line. Fluid velocity is representative of behaviour of fluid.

4. Conclusions

Application of nano molybdenum oxide in oil is studied in this manuscript. The effect of addition of different weight percentage of nano particle into the oil which flows vertically under different temperatures (ranges from 30-80 C, 25- 85 C, 30- 90 C) in a tube section is investigated, experimentally. Test tube with 0.025 m in diameter and 0.3 m in length is used in the study. Some important thermo-physical properties are measured. Besides, some applicable dimensionless groups in hydrodynamic calculations and heat transfer are presented. Addition of nano molybdenum oxide from 1wt% to 4wt% increases the value of overall heat transfer coefficient about 1.5 times. Also the increase of nano particle from 1 wt% to 11 wt% increases the value of conductive heat transfer coefficient about 2.47 times.

References

[1] Storm D. A., McKeon R. J., McKinzie H. L., Redus C. L., Drag Reduction in Heavy Oil, J. Energy Resour. Technol. 1999; 121(3): 145-148.

[2] Rached Ben-Mansour, Pervez Ahmed, Habib M. A., Simulation of Oxy-fuel combustion of heavy oil fuelin a model furnace, J. Energy Resour. Technol. 2015, 137: 032206.

[3] Shadi WH, Mamdouh TG, Nabil E. Heavy crude oil viscosity reduction and rheology for pipeline transportation. Fuel 2010; 89: 1095–100.

[4] Martnez-Palou R, Mosqueira ML, Zapata-Rendón B, Mar-Juárez E, Bernal-Huicochea C, Clavel-López J. C., Transportation of heavy and extra-heavy crude oil by pipeline: a review. J. Pet. Sci. Eng. 2011; 75: 274–82.

[5] Elphingstone G. M., Greenhill K. L., Hsu J. J. C., Modeling of Multiphase Wax Deposition, J. Energy Resour. Technol. 1999; 121(2), 81-85.

[6] Weissman J.G. Review of processes for downhole catalytic upgrading of heavy crude oil. Fuel Proc. Technol. 1997; 50: 199–213.

[7] Rana MS, Sámano V, Ancheyta J, Diaz JAI. A review of recent advances on process technologies for upgrading of heavy oils and residua. Fuel 2007; 86: 1216–31.

[8] Naseri A, Nikazar M, Mousavi DSA. A correlation approach for prediction of crude oil viscosities. J. Pet. Sci. Eng. 2005; 47: 163–74.

[9] Hossain MS, Sarica C, Zhang HQ. Assessment and development of heavy-oil viscosity correlations. In: SPE International Thermal Operations and Heavy Oil Symposium, Kalgary, 1–3 November 2005. p. 1–9.

[10] Alomair O, Elsharkawy A, Alkandari H. Viscosity predictions of Kuwaiti heavy crudes at elevated temperatures. In: SPE Heavy Oil Conference and Exhibition, Kuwait, 12–14 December 2011. p. 1–18.

[11] Yigit Ahmet S., Christoforou Andreas P., Stick-Slip and Bit-Bounce Interaction in oil-well Drillstrings, J. Energy Resour. Technol. 2006; 128(4): 268-274.

[12] Barrufet MA, Setiadarma A. Reliable heavy oil-solvent viscosity mixing rules for viscosities up to 450 K, oil-solvent viscosity ratios up to 4 _ 105, and any solvent proportion. Fluid Phase Equilib. 2003; 213: 65–79.

[13] Luis F. Ayala, Doruk Alp, Evaluation of “Marching Algorithms” in the Analysis of Multiphase Flow in Natural Gas Pipelines, J. Energy Resour. Technol. 2008; 130(4), 043003.

[14] Yilin Wang John, Well Completion for Effective Deliquification of Natural Gas wells, J. Energy Resour. Technol. 2011; 134(1):013102.

[15] Chuan Lu, Huiqing Liu, Qiang Zheng, Qingbang Meng, Experimental Study of Reasonable Drawdown Pressure of Horizontal Wells in Oil Reservoir With Bottom Water, J. Energy Resour. Technol. 2014; 136(3):034502.

[16] Junlai Wu; Yuetian Liu; Haining Yang, New Method of Productivity Equation for Multibranch Horizontal Well in Three-Dimensional Anisotropic Oil Reservoirs, J. Energy Resour. Technol.. 2012; 134(3):032801-032801-5.

[17] Anuj Gupta, Performance Optimization of Abrasive Fluid Jet for Completion and Stimulation of Oil and Gas Wells, J. Energy Resour. Technol. 2012; 134(2):021001.

[18] N. Bhuwakietkumjohn, S. Rittidech, Internal flow patterns on heat transfer characteristics of a closed-loop oscillating heat-pipe with check valves using ethanol and a silver nano-ethanol mixture, Exp. Therm. Fluid Sci. 34 (2010) 1000-1007.

[19] T. Cho, I. Baek, J. Lee, S.Park, Preparation of nano-fluids containing suspended silver particles for enhancing fluid thermal conductivity offluids, J. Industrial Eng. Chem. 11 (2005) 400–406.

[20] Pavel Ferkl, Richard Pokorný, Marek Bobák, Juraj Kosek, Heat transfer in one-dimensional micro- and nano-cellular foams, Chem. Eng. Sci. 97 (2013) 50-58.

[21] S.P. Jang, S.U.S. Choi, Role of Brownian motion in the enhanced thermal conductivity of nanofluids, Appl. Phys. Letter. 84 (2004) 4316–4318.

[22] A.E. Kabeel, El. Maaty T. Abou, Y. El. Samadony, The effect of using nano-particles on corrugated plate heat exchanger performance, Appl. Therm. Eng. 52 (2013) 221-229.

[23] S. Nadeem, Rashid Mehmood, Noreen Sher Akbar, Non-orthogonal stagnation point flow of a nano non-Newtonian fluid towards a stretching surface with heat transfer International, J. Heat Mass Trans. 57 (2013) 679-689.

[24] Hamid Reza Taghiyari, Effects of Nano-Silver and Nano-Zycosil on Mechanical Strength of Heat, Vapor, and Dry-Ice-Treated Biscuit and Dovetail Medium-Density Fiberboard Miter Joints, Mat. Des. 51 (2013) 695–700.

[25] X. Wang, J. Xian, L. Hai, L. Xin, W. Fang, F. Zhou, L. Fang, Stability of TiO2 and Al2O3 nanofluids, Chin. Phys. Letter. 28 (2011) 086601.

[26] W. C. Wei, S. H. Tsai, S. Y. Yang, S.W. Kang, Effect of nano-fluid on heat pipe thermal performance, in: Proceedings of the 3rd IASME/ WSEAS International Conference on Heat Transfer, Therm. Eng. Environ. 2 (2005a) 115–117.

[27] W. C. Wei, S.H. Tsai, S.Y. Yang, S.W. Kang, Effect of nano-fluid concentration on heat pipe thermal performance, IASME Trans. 2 (2005b) 1432–1439.

[28] Ahn, C. K., Kim, Y. M., Woo, S. H., Park, J. M., 2008. Soil washing using various nonionic surfactants and their recovery by selective adsorption with activated carbon. J. Hazard. Mater. 154, 153–160.

[29] Barnea, E., Mizrahi, J., 1973. A generalized approach to the fluid dynamics of particulate systems: Part 1. General correlation for fluidization and sedimentation in solid multiparticle systems. Chem. Eng. J. 5, 171–189.

[30] Boyer, C., Duquenne, A.-M., Wild, G., 2002. Measuring techniques in gas–liquid and gas–liquid–solid reactors. Chem. Eng. Sci. 57, 3185–3215.

[31] Dong, X., Pham, T., Yu, A., Zulli, P., 2009. Flooding diagram for multi-phase flow in a moving bed. ISIJ Int. 49, 189–194.

[32] Elgin, J. C., Foust, H. C., 1950. Countercurrent flow of particles through moving fluid. Ind. Eng. Chem. 42, 1127–1141.

[33] Garside, J., Al-Dibouni, M. R., 1977. Velocity-voidage relationships for fluidization and sedimentation in solid–liquid systems. Ind. Eng. Chem. Proc. Des. Dev. 16, 206–214.

[34] Gong, Z., Alef, K., Wilke, B.-M., Li, P., 2005. Dissolution and removal of PAHs from a contaminated soil using sunflower oil. Chemosphere 58, 291–298.

[35] Gong, Z., Alef, K., Wilke, B.M., Li, P., 2007. Activated carbon adsorption of PAHs from vegetable oil used in soil remediation. J. Hazard. Mater. 143, 372–378.