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The effect of nanoparticles on the heat transfer properties of drilling fluids

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ABSTRACT

Efficiency of drilling fluids in performing certain functions is mainly due to a particular heat transfer and rheological properties. This paper has been focused on improvement of the drilling fluid performance to increase the heat transfer property of the drilling fluids using nano-materials. The performance of water-based drilling fluids in the presence of multiwall carbon nanotube, nano zinc oxide, silica nanoparticle and hybrid of CNT-silica nano-particle have been studied at different velocities, temperatures and nano-particle concentrations.

Multiwall carbon nanotube, nano zinc oxide and silica nano-particle have been synthesized using a chemical vapor deposition (CVD), spray pyrolysis and sol-gel methods, respectively. A hybrid of CNT-silica nano-particle has been synthesized using functionalized MWNTs and silica nano-particle under certain conditions. Shape and particle size characterizations are made using SEM and TEM. Different mass fractions of nano-particles were stabilized in distillated water using gum arabic and homogenized in drilling mud.

It has been found that the velocity and temperature have an important effect on the thermal property of mud. The thermal performance factor for all the cases is greater than base mud (5–22% for 0.01–2 wt% nano-material) and convection results showed that the maximum thermal performance was found for the hybrid of CNT-silica nano-particle in higher Reynolds number. The heat transfer enhancement in 4200 Reynolds number, is 31%, 24% and 74% in 200, 400 and 588 W (heat fluxes), respectively. Furthermore, the rheological properties such as apparent viscosity (AV), plastic viscosity (PV) and yield point (YP) are improved by adding nano-particles to the drilling mud.

1. Introduction

The three main categories of drilling fluids include water-based drilling fluids, non-aqueous drilling fluids (oil-based drilling fluids) and gaseous drilling fluids. Liquid drilling fluids that often are called drilling muds are used to cool, lubricate the drilling bit, support the bit and drilling assembly, transmit hydraulic energy to tools and bit,remove cuttings from the well, suspend and release cuttings, maintain wellbore and shale stability, minimizing formation damage, corrosion control in acceptable level and facilitate cementing. Theses fluids should be thermally stable, easy to pump environmental friendly and stabilize the pressure in the well (Domari Ganji et al., 2015; Kirubadurai et al., 2014; Esmaeilizadeh and Mohebbi Najm Abad Mollaabbasi, 2014).

On the last decades, nanotechnology has improved the drilling fluids by affecting on rheological and heat transfer properties. Successful applications of nano-sized particles in drilling mud are due to the size, shape and chemical interactions of nanoparticle and mud, which makes the desired properties and drilling performance of drilling fluid. The main difference between drilling fluids containing nanoparticles and the conventional base fluids is due to the very small sizes of the particles dispersed in them. Quantum effects of nanoparticles in drilling fluid make many physical changes without alteration in their bulk chemistry. Hence, research has been focused on using nanotechnology to improve the heat transfer and rheological properties of drilling muds by suspending nanometer-sized particles in them (Ionscu Vasii and Fatseyeu, 2011; Sedaghatzadeh et al., 2012; Xie et al., 2011; Amani et al., 2012; Hoelscher et al., 2012; Zhu et al., 2007).

Nasser et al. (2013) modified drilling mud by adding nano-particles. They concluded that nanoparticles lead to better maintenance of the rheological properties at higher pressures and

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Nomenclature

C_p	Specific heat of fluid [J/kg K]
d	tube inside diameter [m]
h	Heat transfer coefficient [W/m^{2}K]
$\bar{h}$	Mean convection heat transfer coefficient [W/m^{2}K]
k	Fluid thermal conductivity [W/mK]
L	Tube length [m]
$\dot{m}$	Mass flow rate [kg/s]
P	Perimeter of tube [m]
q''	Heat flux [W/m^2]
Q	Heating rate by electric heater [W]
Re	Reynolds number
T	Temperature [°C]
T_w	Wall temperature [°C]
T_b	Bulk temperature [°C]
T_i	inlet temperature of the flow [°C]
V	Velocity [m/s]
X	test section length [m]

Greek symbols

μ	Fluid dynamic viscosity [kg/m s]
ν	Fluid kinematic viscosity [m^2/s]
ρ	Fluid density [kg/m^2]

temperatures. Their work indicated that nanotechnology can be used for enhancing the performances of drilling fluids.

Abdo and Haneef (2012, 2013) modified drilling fluids by clay nanoparticles for drilling of deep hydrocarbon wells. Synthesized spherical silica/multiwall carbon nanotubes hybrid for investigation of thermal conductivity of related nano-fluids. They reported the effect of nano-materials concentration and their percentage in a hybrid, on the increasing of effective thermal conductivity of the nano-fluids. They compared various hybrids and confirmed that a hybrid with higher percentage of MWCNTs will show higher effective thermal conductivity.

Zakaria (2013) reported their theoretical and experimental studies on filtration properties and claimed that drilling fluid including nanoparticles show improved rheological properties, good fluid loss control and lubricity profile. They extended their work based on the specific characteristics of nano-materials in comparison with bulk materials, and showed that smaller particles can be more effectively dispersed than the larger particles and due to their larger surface area can easily bond to other particles.

Some researchers have been studied regarding the application of metal nano-fluid as ultimate coolant, taking advantage of the high thermal conductivity due to addition of more conductive nano-particles (Ma and Liu, 2007).

Various researchers were studied the improvement of lifting capacity, thermal, electrical and rheological properties of mud using different type of nano-particles (William et al., 2014; Samsuri and Hamzah 2011; Saadoon Al-Yasiri and Tareq Al-Sallami, 2015; Long et al., 2012).

This work showed that improving the thermal conductivity and convection coefficient are the key idea to improve the heat transfer characteristics of conventional drilling fluids. Four nanoparticles were selected for suspending in the base fluid. These nanoparticles lead to innovative heat transfer fluids which are expected to exhibit high thermal conductivities and enhancement on the heat transfer compared to common drilling muds. The effects of these nanoparticles on rheological properties were also investigated.

2. Experimental

2.1. Synthesis and characterization of nano-particles

The nano-particles used in this work were multiwall carbon nanotube, nano zinc oxide, silica nano-particle and hybrid of CNT-silica nano-particle. The main reason for choosing these nanoparticles in the present work is related to their excellent chemical and physical properties, for example high thermal conductivity of CNTs compared to different nonmetallic and metallic solids (almost 3000 W/m K). The multi walled carbon nanotube has been prepared using a chemical vapor deposition (CVD) method over Co-Mo/MgO catalyst by methane decomposition at 600–900 °C in the research institute of petroleum industry (R.I.P.I.-MWNT) (Rashidi et al., 2007). Prepared MWNT has been characterized using Scanning electron micrograph (Fig. 1-a).

Silica nano-particle has been synthesized using aqueous solution of $Na_2SiO_3 \cdot 9H_2O$ at room temperature. N-cetyl-N, N, N-tri methyl ammonium bromide (CTAB) as a surfactant and dimethyl formamide (Merck) has been dissolved in distilled water while stirring for around 15 min. The product has been filtered, calcinated at 570 °C for 8 h and characterized using SEM (Fig. 1-b).

For preparation of ZnO nano-particle, the aqueous solution of zinc acetate has been used at a pressure of 7 bar by spray pyrolysis method. SEM image of prepared ZnO nano-particle shows that the average sizes is under 20 nm (Fig. 1-c) (Ghaffarian et al., 2011).

For synthesis hybrid nanostructures, MWNTs have been functionalized with carboxylated groups and added to solution of sodium silicate in distilled water and stirring continued for 3 h at 25 °C and the pH adjusted at 12. The solid product has been filtered and calcinated at 570 °C for 8 h under flow of nitrogen for removing the impurities and characterized using SEM (Fig. 1-d).

2.2. Experimental apparatus

KD_2 apparatus (Labcell Ltd, UK) has been applied to measure thermal conductivity of various nano-fluids with the accuracy of 5%, which works based on the transient hot wire method. The KD_2 meter has a probe with 60 mm in length and 0.9 mm in diameter, and integrates in its interior a heating element and a thermo-resistor that is connected to a microprocessor for controlling and conducting the measurements.

The rotational viscometer (FANN-35, Fann Instrument Co., USA) and rolling oven apparatus (OFITE-173-00, OFI Testing Equipment Inc., USA) have been applied to measure the rheological properties of drilling fluid samples.

In addition, an experimental apparatus has been designed to measure the convective heat transfer coefficient of working fluids (Emami Meibodi et al., 2010; Ashtiani et al., 2012).

The schematic diagram of experimental apparatus is shown in Fig. 2. The flow loop consists of test section, reservoir, centrifugal pump, heat exchanger, flow controlling system and thermocouples. The fluid leaving the test section enters to the flow measuring apparatus, and then pumps through a shell and tube heat exchanger (cooler) in which laboratory water and ethylene glycol (EG) is used as a coolant, and again enters to the test section.

This apparatus has been used to measure heat transfer characteristic of working fluids over the length of the test section. A copper tube of 8.72 mm inner diameter, 9.42 mm outer diameter