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The Effect of Metal-based Nanopowder on Viscosity Reduction of Heavy Oil

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Abstract

Nano technology has been widely used in various fields. In oil production, nano particles have been shown to be able to act as catalysts in breaking carbon bonds in heavy oils. Previous researches showed that nano particle can significantly increase the heating process of heavy oils. In this research, a study was conducted to examine the effect of various metal-based nanopowders on the effectiveness of viscosity reduction using microwave heating. The experimental set-up was carried out based on previous experiment using sandpack model. The nanopowder used were Ferro Oxide (Fe_2O_3), Aluminum Oxide (Al_2O_3), and Copper Oxide (CuO). Those nanopowder compounds are metal-based with different magnetic susceptibility. Ferro oxide and copper oxide has positive magnetic susceptibility (paramagnetic), so it's heating rate would be faster than aluminium oxide that has negatif magnetic susceptibility (diamagnetic). Ferro Oxide reaches a temperature of 90 ^{o}C in 240 seconds which was the fastest time that can be achieved compared to the use of other nanopowders. The results of subsequent experiments with copper oxide and aluminum oxide respectively were 460 seconds and 780 seconds. Aluminum oxide reaches the longest time of this heating process due to its natural properties as an insulator in heat and electricity.

Introduction

The electromagnetic wave induction has been utilized for heavy oil reservoir heating. The main purpose of well stimulation is to increase oil productivity. In electromagnetic heating, the oil productivity gain is affected by the extent of wave penetration. Based on the frequency, electromagnetic heating is divided into four methods namely resistive heating, inductive heating, radio frequency heating and microwave heating[1].

Microwave is a part of the electromagnetic wave spectrum that moves at the speed of light with the wavelength between 1 mm to 1 m[1]. Microwave heating occurs when the energy in the form of electromagnetic waves hits the reservoir fluids, the dipoles on dielectric material molecules try to align themselves with the electric field in electromagnetic waves with a rotational motion. The movements of these molecules then produce heat and cause a rise of temperature in the reservoir. The further absorption of energy (the heat penetration) occurs in the reservoir, the higher the productivity.

The microwave penetration is influenced by two main factors, which are the frequency used and the wave absorbing material. The research to determine the right frequency was done by using COMSOL Multiphysics simulation and obtained a frequency of 915 MHz [1,2]. However, the frequency of microwave commonly used in research is 2.45 GHz, which is the permitted commercial use of frequency (microwave oven). This becomes a limitation in laboratory experiments on electromagnetic heating.

The second factor that must be considered in optimizing penetration is the electromagnetic wave absorbent material. Heterogeneity in heavy oil reservoirs makes it a dielectric non-magnetic material with low electrical conductivity[3] so that increasing electrical conductivity of reservoir fluid is one way to enhanced the penetration of electromagnetic heating.

In order to increase the electrical conductivity, a preliminary study was carried out by adding several types of nanopowder to the experimental sample. Nanoparticles are particle with size ranging from 1 to 100 nanometers with an interface layer around them that usually consists of ions, inorganic and organic molecules. Nano particles have been shown to act as catalysts in breaking carbon bonds in heavy oils. In the research that has been done before, various nanopowders used are nickel and copper[4], silicon oxide, aluminium oxide, titanium oxide[5], cobalt[6], iron oxide[7,8]. All studies showed that nano materials can significantly increase heating in heavy oil stimulation.

Experimental Method

The effect of nanopowder was observed from two experiments. The first experiment is by viscosity measurement and the second is measuring the effect of microwave heating on the sandpack. The viscosity measurement was conducted by Viscometer Fann model 35 on four samples. One is pure crude oil and the others was mixtures of the crude oil and metal-based nanopowder which are Ferro Oxide (Fe_2O_3), Aluminum Oxide (Al_2O_3), and Copper Oxide (CuO) with concentration of 14 ppm[9]. The selection of nanopowder used in this study was focused on it's magnetic susceptibility (χ), which is a measure of how much a material will become magnetized in an applied magnetic field[10].

The second experiment was conducted by simulating a reservoir in the form of a sandpack with microwave heating technique. There are four sandpack prepared. Sandpack was made by mixing silica sand sized of 45-50 mesh with a mixture of nano fluids. Nano fluids were made by mixing brine with nano powders. The composition of nano fluids were crude oil with a density of 22 ^{o}API, brine with a density of 1,024 gr/ml and salinity 15,793 mg/l, oil-based emulsifier and nanopowder. The fourth sandpack was made without nanopowder. This was become a reference for the next experiment.

The heating process was set with power at 900 watts and data collection was carried out every 20 seconds until the temperature at the first test point reached 90 ^{o}C. There were two measurement points, the first test point was two cm from the bottom of the experimental glass and the second test point was 8 cm from the bottom of the glass. The design of the heating process in this research used the same configuration as the previous heating research[7,8] as can be seen in figure 1.

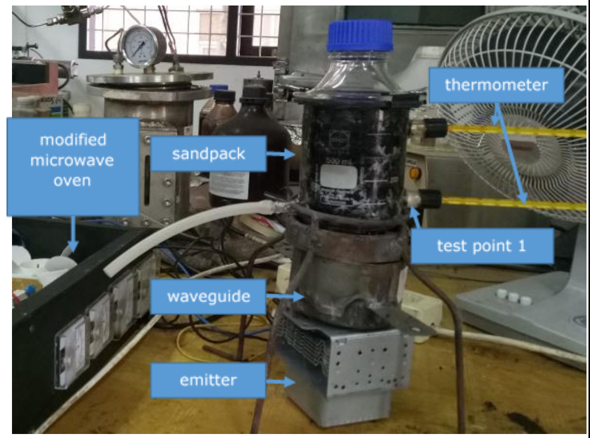

Figure 1: Experimental set up

Result and Discussion

To see the direct effect of nanopowder to the viscosity reduction, a viscosity measurement using Viscometer Fann model 35 was carried out with low speed RPM. The results can be seen in figure 2. The second experiment used sandpack to simulate the reservoir by microwave heating so that the influence of the nanopowder could be observed for the actual thermal stimulation process. The results of the experiment are shown in figure 3 and 4.

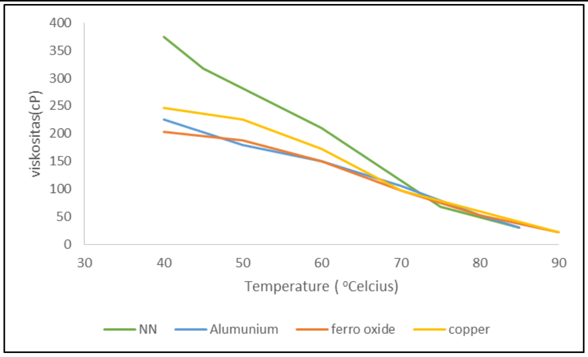

Figure 2 : The changes of viscosity due to nanopowder addition

From the picture above it appears that there was a viscosity reduction compared to the viscosity of pure crude oil. The percentage of viscosity reduction respectively was 46% using ferrous oxide, 40% using aluminum oxide and 34.4% using copper oxide.

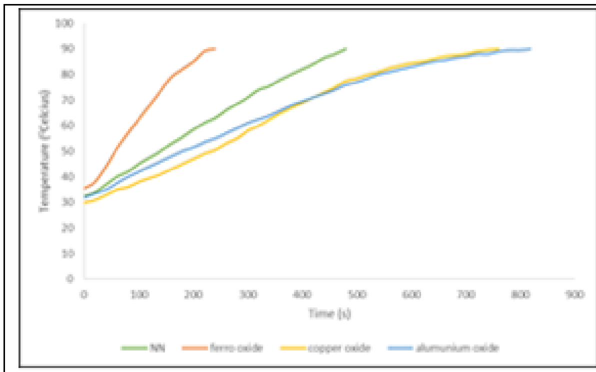

Figure 3 : Comparison of heating rate of various types of nanopowder at test point 1

The microwave heating experimental results showed that the first test point reached a temperature of 90 ^{o}C after 900 seconds in the sandpack mixture without nanopowder. Ferro Oxide reached a temperature of 90 ^{o}C in 240 seconds and was the fastest time that can be achieved compared to the use of other nanopowder. The results of subsequent experiments with copper oxide and aluminum oxide respectively were 460 seconds and 780 seconds.

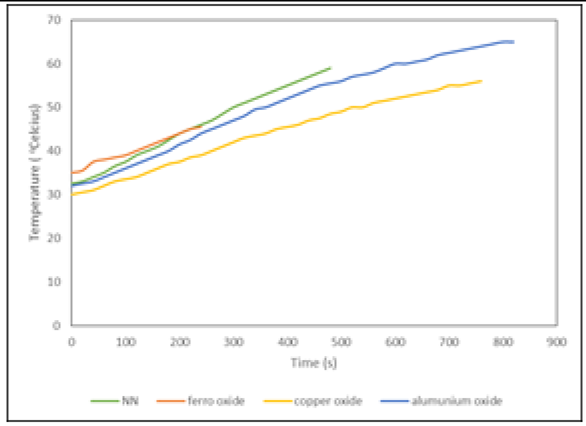

Figure 4 : Comparison of heating rate of various types of nanopowder at test point 2

Data on the second test point was carried out as described in the picture above, at the second test point, ferro oxide only reached a temperature of 45.5 ^{o}C as the first test point reached 90 ^{o}C (figure 3). Meanwhile higher temperature was observed when other nanopowder was used.

Ferro oxide shows the best heating rate compared to pure crude oil and other types of nanopowder. But observations showed the heating radius using ferro oxide was low, evidenced by the low temperature of the second point which is 8 cm from the heating source (microwave antenna). While at the same point copper oxide and aluminum oxide showed higher temperatures.

Ferro oxide with magnetic susceptibility of $+3{,}586.0.10^{-6}$ cm^3/mol[10], naturally has high magnetic properties so it is easier to deliver wave when induced by magnetic fields. Ferro oxide and copper oxide (χ $+238.9.10^{-6}$ cm^3/mol[10]) has positive magnetic susceptibility which means that these compounds are paramagnetic, a form of magnetism whereby some materials are weakly attracted by an externally applied magnetic field, and form internal, induced magnetic fields in the direction of the applied magnetic field. This characteristics made ferro oxide and copper oxide reach temperature at 90 ^{o}C faster than aluminium oxide.

Aluminum oxide has negatif magnetic susceptibility (χ $-37.0.10^{-6}$ cm^3/mol[10]) which means that the compound is diamagnetic, materials are repelled by magnetic fields and form induced magnetic fields in the direction opposite to that of the applied magnetic field. This material reached the longest time of this heating process due to its natural properties as an insulator in heat and electricity.

Conclusions

The effect of nanopwoder to reduce oil viscosity during heating process has been successfully conducted without and with using sandpack. In the case of sandpack, heating was carried out with microwave heating techniques. The use of sandpack in the research also showed that the presence of rocks was a barrier in the delivery of microwave heat.

The result showed that nanopowder can reduce the viscosity of heavy oils directly. The heating penetration radius was short with the use of ferro oxide, however this nanopowder was the fastest in delivering heat with microwave heating techniques so a combination of nanopowder and other materials was needed to increase the conductivity of the fluid and reservoir rocks.

The heating radius obtained from the microwave heating technique has not been deeply investigated. Further studies are needed to see the relationship between the heating rate and the heat penetration radius of this method, also the use of other materials that can be combined with nanopowder so that this stimulation method can achieve maximum results.

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