PROCEEDINGS
JOINT CONVENTION BANDUNG (JCB) 2021
November 23rd – 25th 2021

Investigation of Performance of Electromagnetic Heating with Nano-Ferro Fluid and NaCl Solution for Recovery Heavy Oil Deposits

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Abstract

In providing a solution for lifting up the viscous oil which is immensely concerned in a mature field, thermal recovery is commonly applied to recover the oil with API gravities approximately 20 by using the steam injection and in situ combustions. It had been the way out to lower enough the viscosity so that the oil would flow toward more effortless than the viscous one for the recent times. Applying electromagnetic microwave to heat up the reservoir can overcome the depth limitation which is often found in conventional thermal recovery methods. This method uses the nano-ferro fluid as a stimulant that conveniently radiates heat in a reservoir. It is important to analyze the brine formation in affecting the optimization of the thermal period while the nano-ferro fluid being directly introduced to formation fluid. Therefore, NaCl solution becomes variable which was used to represent brine formation in investigating the heating time of saturated artificial cores. Meanwhile, the optimal concentration of nano-ferro had been recognized. The microwave was also varied in the sequence of power, 378 Watt, 468 Watt, 657 Watt, 792 Watt, and 900 Watt. For example, applying 50,000 ppm, 100,000 ppm, and 350,000 ppm in performing an investigation that would give a significant performance while thermal process. When 657 Watt was set to heat up the compartment contained an artificial core, the temperature could reach up to 90 °C in 110 seconds, 82 seconds, and 54 seconds consecutively from low to high NaCl solution. In that way, the sensitivity of this variable was proved that NaCl solution greatly affects the temperature increment in times. Furthermore, this research can be a considerable study in finding out the behavior of formation fluid which contributes to optimizing nano-ferro fluid thermal recovery.

Keywords: Electromagnetic Microwave, Heavy Oil, NaCl Solution, Nano-Ferro Fluid, Thermal Enhanced Oil Recovery.

Introduction

Petroleum liquids are classified as either light, medium or heavy oil based on their API gravity, a type of inverse specific gravity commonly used in the oil and gas industry, referenced to water properties at standard conditions of 60 °F and atmospheric pressure. Heavy oil is defined as liquid petroleum of less than 20 °API gravity or more than 200 cp viscosity at reservoir conditions. Heavy oil and bitumen resources account for approximately 70% of the remaining oil discovered to date in the world (Nizamidin, 2016). Further, in contrast to conventional crude oils, heavy crude oils are darker in color and may even be black. In addition to high viscosity and high specific gravity, heavy oils typically have low hydrogen-to-carbon ratios, high contents of asphalting, high carbon residues, sulfur, nitrogen, and heavy-metal content, as well as higher acid numbers (Alabdulmohsen, 2015; Carrizales, 2010; Green & Willhite, 1998; Nizamidin, 2016; Sahni et al., 2000; Silset, 2008). While heavy oil is abundant, it also presents significant economic and technological challenges. High viscosity is a major concern for the recovery from heavy-oil reservoirs. However, as the world energy demands grow, major conventional oil discoveries are rare (and difficult to find) and the costs of discovering and producing conventional oil go up, the economics of heavy oil will steadily improve.

If the heavy oil/bitumen reservoirs are shallow, surface mining is used. Otherwise, introducing heat to the formation has proven to be an effective way of lowering the oil viscosity by raising the temperature in the host formation. Thermal recovery involves well-known processes such as steam injection (cyclic steam stimulation or huff and puff, steam drive, and steam-assisted gravity drainage), in situ combustions, and a more recent technique that consists of heating the reservoir with electrical energy. Thermal recovery methods have the common objective of accelerating the hydrocarbon recovery process (Carrizales, 2010). Steam injection is the most effective method for improving heavy oil production. However, there are certain situations where it may not work very well (Sahni et al., 2000).

Generally, for steam stimulation and steam drive techniques, where heat loss occurs along the wellbore, the maximum depth of the well is 3,000 ft. While for in-situ combustion the maximum depth of the well is 11,500 ft due to the difficulty of maintaining air injection pressure to stay above the reservoir pressure due to the decrease of pressure along the wellbore. Another obstacle to forward in-situ combustion technique is the availability of sufficient crude oil in the reservoir to maintain the combustion front (Green & Willhite, 1998).

Electromagnetic Heating (EM) can be considered as an alternative recovery technique from heavy oil reservoirs that are not attractive to steam because of steam flooding many limitations. EM heating does not require a heat transporting fluid such as steam or a hot fluid injection process. EM heating can apply to situations where generating and injecting steam may be environmentally unacceptable, a single well can be used to introduce energy to the formation through a power source as well as to recover produced fluids. Production may occur during or immediately after EM heating if the formation pressure is large enough. With EM, the higher heat efficiency is achieved for thin pay-zones, where the use of steam is not economically feasible because of excessive heat loss through the overburden.

Electromagnetic (EM) heating is a process where high-frequency electrical energy is transformed into heat energy by dielectric losses when an electromagnetic wave is radiated from antennas into oil-bearing formations.

By EM heating, energy is propagated by electromagnetic waves from antennas that are impeded and absorbed by the polar molecules (water) and other reservoir materials, providing resistance to the flow. As a result, the intensity of the propagating wave is reduced and the energy is converted to heat, and then transferred by conduction to the oil and reservoir rock increasing the formation temperature. Figure 1 shows a schematic view of the EM heating process for co-current flow. The antenna is placed at the center of an injector well in front of the reservoir confined by the adjacent layers. EM energy flows into the formation and is transformed into heat with the subsequent increase of fluid flowing toward the producing well located at the opposite end of the system. Two wells are used for this EM heating process (Carrizales, 2010).

Electrical heating of a formation can occurs in three ways, depending on the frequency of the electrical current namely; low-frequency Electric Resistive Heating (ERH), high-frequency microwave heating and inductive heating.

The radiation with frequencies within a range of 300 MHz to 300 GHz and corresponding wavelengths from 1 to 0.001 m are referred to as microwaves (MW). The analysis of high-frequency heating is described by Maxwell’s equations with material properties represented by permittivity (ε), magnetic permeability (μ), and electrical conductivity (σ).

At high frequencies, dielectric heating dominates and heat is generated through the absorption of electromagnetic energy by the polar molecules (connate water) in the formation.

The amount of energy absorbed will depend on the electrical properties of the formation, which are a function of its composition and water saturation as well as on the operating frequency. The magnitude of the change in temperature of the formation will depend on the energy absorbed.

For linear and homogeneous conducting medium, plane radiation propagating in the +x direction will be absorbed according to the following relationship (Santoso et al., 2016):

$$\frac{d\phi\ (x)}{dx} = -\alpha\ \phi\ (x) \tag{1}$$

Where,

$\phi\ (x)$ = power density, Watt/cm^3
x = position coordinate, cm
α = power absorption coefficient, 1/cm

The power absorption coefficient (α) depends on the properties of the absorbing medium in the following manner:

$$\alpha = 0.02 \tag{2}$$

And

$$\alpha_0^2 = \frac{\omega^2 \underline{\mu}\ \varepsilon}{2}\left\{\left(1 + \left[\frac{\sigma}{\omega\ \varepsilon}\right]^2\right)^{\frac{3}{2}} - 1\right\} \tag{3}$$

Where,

α_0 = electric field absorption coefficient, 1/cm
σ = conductivity, mho/meter
$\underline{\mu}$ = permeability, H/meter
ε = permittivity, F/meter
ω = angular frequency, ($2\pi \times$ frequency)

As the porous media absorbs electromagnetic energy, the increase in temperature can be calculated from the following simple equation:

$$\frac{dT}{dt} = \frac{\sigma E^2}{\rho c_p} \tag{4}$$

Where,

c_p = specific heat at constant pressure
E = electric field intensity, Volt/meter
ρ = mass density, Kg/m^3

Varied materials have varying specific heat capacities. Or rather, different amounts of energy are needed to heat different materials. When salt is dissolved in water, it changes several properties, one of which is the specific heat capacity. The experiment showed that as the concentration of salt increased, the specific capacity of the solution decreased (Qu, 2016).

Recent studies have been conducted for heavy oil recovery that coupled Microwave Heating with Nano Ferro Fluid (Indriani et al., 2017). In their study, the primary objective was to investigate the effects of nano ferrous concentrations on the temperature changes of the sand pack due to microwave heating. To reflect the real reservoir microwave heating in laboratory experiments, they used sand pack consists of sand, heavy oil (22 °API), brine or nano ferrous (Fe_2O_3) fluid and emulsifier (oil-based, 3%).

Therefore, the study intends to investigate the effects of the added salinity concentration of the brine on the temperature changes (rise) of the formation (and pack) and hence the viscosity of heavy oil. Combining solvent injection and EM heating might further reduce the energy intensity of the process. The merits of using a solvent in EM heating include diluting heavy oil and thereby increasing its mobility, serving as a heat carrier by reinforcing heat convection in porous media and facilitating gravity drainage by forming a vapor chamber (Hu et al., 2016).

Data and Method

This study will employ the same sand pack compositions used in (Indriani et al., 2017) experimental work.

Artificial cores are made by mixing the sand and resin with approximately 5% of the total mass. The artificial core will then be weighed in its dry weight. Furthermore, porosity measurements would be taken. The artificial core will then be saturated with heavy oil.

The nanoparticles that will be used is nano-ferrous (hematite, α-Fe_2O_3). The nano-ferro fluids of 14 ppm concentration are made up by mixing nano-ferro powder with brine (density of 1.024 gr/ml) using both handshaking and sonicator for not less than 20 minutes.

The heating process will be conducted by using a microwave heating technique. It includes the assembly of microwave circuits, magnetron, waveguide, sand pack, and thermometer for experimental measurement. There are 4 thermometers that are separated 2 cm each other vertically and are inserted into the middle of the sand pack to measure the change of temperature. Then the heating of the sand pack will be conducted by varying the power input and salinity concentration of the brine.

In both cases, the changes in temperature of sand pack and heavy oil viscosity (measured by viscometer) will be recorded at every 20 seconds from 25 °C until any point of measurement reaches the heating temperature of 90 °C to avoid water evaporation and oil flows through the slits between thermometer and the glass container, both happen at temperature of 100 °C.

Result and Discussion

The results of the experiment with the salinity concentration of the brine varied show that it could lead to the optimum heating temperature as well. The experiment conditions are made up of 50,000 ppm salinity concentration. Furthermore, by using 900 watt power of electromagnetic heating, the temperature of the sand pack performing increases up to 90 °C in 40 seconds. On the other way, the temperature increment had already occurred using 14 ppm of nano-ferro fluid in an identic condition which is influenced by 900 watt power of electromagnetic heating. Furthermore, it needs 100 seconds to reach 90 °C with 14 ppm of nano-ferro fluid in the same conditions even it was at point 1 which is the nearest one to the heat source. It is shown that the 10 ppm of nano-ferro fluid provides the temperature target more than 100 seconds as well. It could notice that high salinity brine has considerable influence as a heating stimulant to the sand pack according to the thermal heating time to reach 90 °C.

At the lowest point, the heating process could not reach to 90 °C due to the lowest power was used that leads to reduce the performance of heating distribution in which 50,000 ppm of brine applied.

Besides using 50,000 ppm salinity of the brine, the experiment also used 100,000 ppm and 350,000 ppm salinity of the brine. The results indicate that the high salinity of the brine can significantly affect the performance of the increasing temperature of the sand pack. In other words, performing heat in using a huge salinity can reduce the time needed for the heating process. Moreover, the heating process under higher salinity has a great influence to obtain the high temperature as well.

As indicated, a gradually decreasing power used also provides an effect on the performance of the heating process. The lower the power used, the longer the temperature increment takes due to the frequency radiated regarding the applied power. The thermal produced by the low power needs more time to heat up in certain conditions in which using either nano-ferro fluid or high salinity brine as a stimulant. As indicated below, the usage of higher salinity brine apparently has less time needed to heat up which is compared to the high concentration of nano-ferro fluid as a stimulant.

Furthermore, the study could bring to indicating the condition of the minimum cost as using for heating stimulant according to the time taken in which heating process. Obviously, the figure 5 shows that the usage of NaCl solution has less heating time which can minimize the heating cost up to 60% compared to exposing nano-ferro fluid. In most cases, to provide the high concentration salinity fluid could be said reasonably affordable in which conducting to brine formation.

Conclusions

In accordance with the data obtained during the experiment, it obviously indicates that NaCl solution has a significant influence to enhance the radiating thermal process for reducing the viscosity of heavy oil of the sand pack. Accordingly, it is pointed out that the thermal process using a high concentration of nano-ferro fluid as a stimulant requires more time to heat up the sand pack containing heavy oil to the temperature set up which is compared to the usage of high NaCl solution.

In other words, applying the NaCl solution as a heating stimulant can reduce the heating cost regarding less time taken in power consumption to heat up the sand pack. Approximately it would be minimized up to 60% compared to the introduction of nano-ferro fluid. By way of this case, the salinity can be a considerable parameter to compensate for the high concentration of nano-ferro fluid as a thermal stimulant fluid which can optimize the time needed in lowering a huge viscosity of heavy oil.

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Acknowledgements

The authors wish to thank all kind support and contributions provided by Polytechnic of Energy and Mineral "Akamigas" Cepu

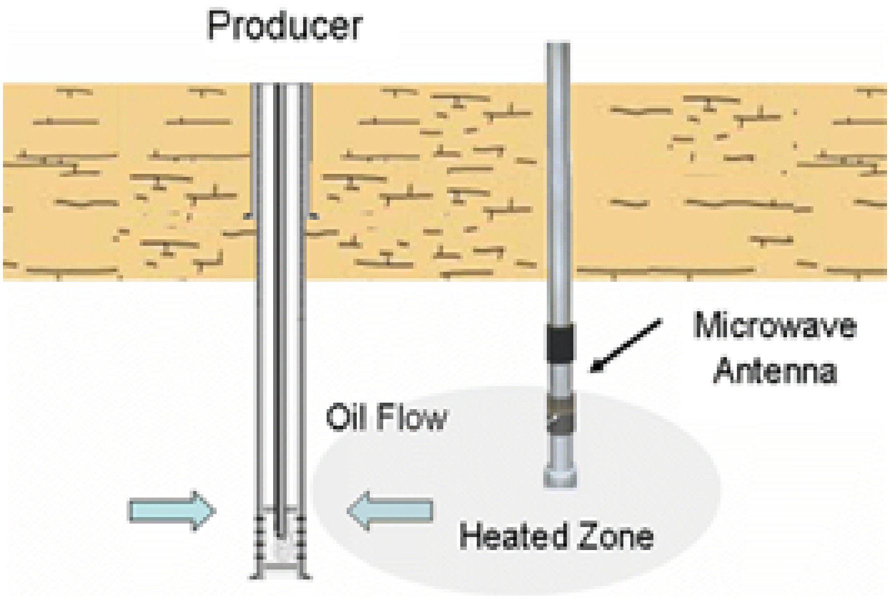

Figure 1: Schematic view of EM heating process for co-current flow (Carrizales, 2010)

The main source of heat generation in this study is microwave heating, it comprises of the microwave circuit, waveguide, and magnetron. The other tools used during the heating process of heavy oil in a laboratory are such as thermometers, containers, beakers, sonicators (agitator), viscometer, stopwatch, and cooling fans.

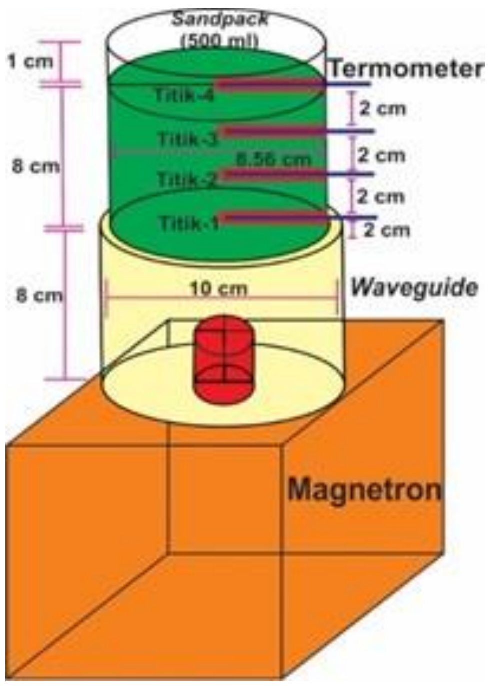

Figure 2: Microwave heating configuration (Indriani et al., 2017)

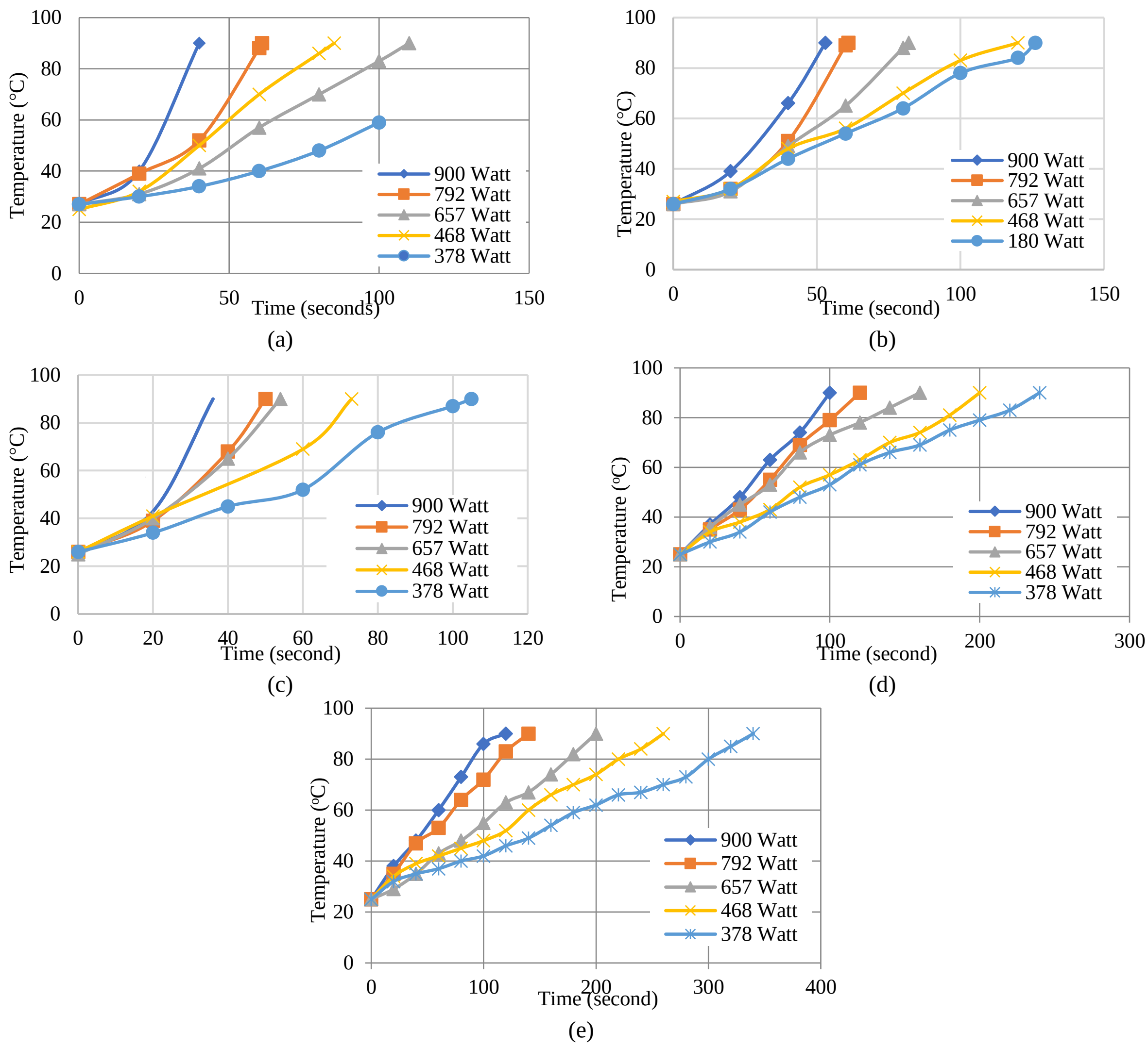

Figure 3: T (°C) vs time (second) using power varied with (a) 50,000 ppm; (b) 100,000 ppm; (c) 350,000 ppm salinity concentration of the brine, (d) 14 ppm; (e) 10 ppm of nano ferro fluid

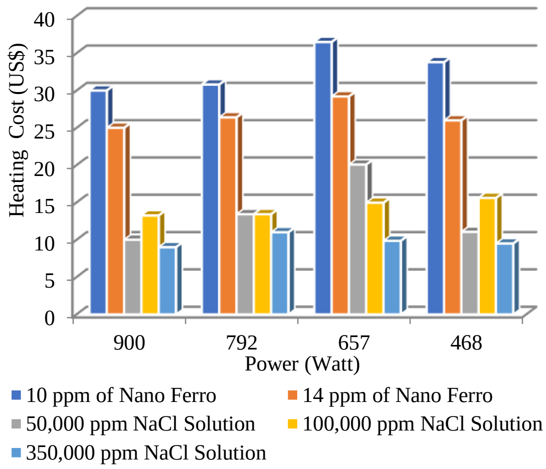

Figure 4: Comparison of heating cost within nano ferro fluid and solution of NaCl