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Original Research Article

An Experimental Investigation of Fe_2O_3 Additives Effect on Viscosity and Steam Flooding Oil Recovery for a Sudanese Heavy Oil Field

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Abstract

Heavy oil represents the greatest portion of the remaining oil and with the increasing demand for energy sources, the interest and efforts are directed toward producing from reservoirs with such kind of oil. The common method to produce the heavy oil is the thermal recovery method, but recently a new technology applied for enhancing the heavy oil recovery which is using Nano additives due to their ability to alter certain factors in the formation and in oil properties. In this study the catalytic effect of Nano-Fe_2O_3 in the viscosity of Sudanese heavy oil was studied and the result indicate that the Fe_2O_3 decreases the viscosity considerably at certain concentration and temperature, for this study 0.25% wt additive gave the maximum reduction in the viscosity. Also, this work investigated experimentally the effect of Nano-Fe_2O_3 in the oil recovery by steam injection and the result showed that when injecting a mixture of steam and Nano-Fe_2O_3 there is an increase in the oil recovery factor due to cracking reactions which convert the heavy component to lighter components, in this experiment there was an increase of 8% in the recovery factor.

Keywords: Heavy Oil Recovery, Steam Flooding, Nano- Fe_2O_3, Viscosity Reduction.

Introduction

Due to every year increasing in the population of mankind and the great development around the world, the global energy demands increase quite considerably. Therefore, oil and gas which represent the main and important sources of energy up to now, they are needed to be explored even further to meet those demands.

As a result of that the conventional oil production started declining; the interest is shifting towards the natural resource that has rarely been developed extensively before, which is unconventional hydrocarbon in the presence of heavy oil. Heavy oil has the greater percentage of the total remaining hydrocarbon resources. The term "heavy oil" is generally used to denote a crude oil having an API gravity of 25°, or less, and viscosity up to several thousand centipoises (S,M. Faroug Ali,1982).

Producing from heavy oil reservoirs and making benefits from them is very challenging as the oil viscosity is normally high that primary recovery is generally low and limited to a *few percent* of original oil in place (OOIP).

Heavy oil contains larger proportions of the heavy molecules such as asphaltenes with high natural viscosity, and this makes them particularly problematic for production. Enhancing oil recovery using thermal methods are the most advanced processes and contribute significant amount of oil to daily production. Thermal recovery has historically been the primary technique to improve the recovery from this type of reservoir. By injecting heat into the reservoir, oil viscosity could be greatly reduced yielding a significant improvement in recovery factor (You Wei *et al*, 2017).

One of these thermal techniques is the Steam flooding, in this process steam is forced continuously into specific injection wells and oil is driven to separate production wells (Roger M. Butler,1991). The zones around the injection wells become heated to the saturation temperature of the steam, and these zones expand toward the production wells.

In addition to the ordinary oil recovery methods, new technology of Nano additives in the oil and gas industry is just emerging. They are defined as particles with size ranges from 1 nm to 100 nm, and show some useful characteristics such as they have the ability to penetrate some pores where traditional injection fluids are unable to and thus, can contact more swept zones, and increase the macroscopic sweep efficiency (Xiaofei *et al*, 2017).

The recent research projects have shown that nanotechnology has the potential to solve or manage several problems in the petroleum industry. Nanoparticles have ability to change certain factors in the formation and in oil properties which can lead to enhance recovery. This involves introducing these nanoparticles into formations and studying its effect on oil recovery (N.A Ogolo *et al*, 2012). For the thermal recovery methods, these additives work as catalysts and have shown good improvement of oil recovery such as SAGD, CSS and steam flooding.

One of these additives that used with steam flooding process is Fe_2O_3 Nano powder due to its good thermal properties ability to work as catalyst in cracking process of oil with heavy component bonds and yield in light components and hence reduce the viscosity of oil. Also, Fe_2O_3 as a Nano-sized particles with large surface area Can penetrate small pores and give more contact with oil, in addition to that, adding Fe_2O_3 Nano powder increases the viscosity of injected fluid which increases the amount of oil swept.

There a number of researchers studied the catalytic effect of Fe_2O_3 on heavy oil, such as Hamidi *et al*, 2010, they worked on the effect of Nano sized metal on the viscosity reduction of heavy oil/bitumen during thermal applications. They used different metal types such as iron, nickel, and copper with different sizes. Their results showed that nanosized additives had a remarkable effect on heat transfer through heavy oil.

Another study conducted by Sahar Afzal *et al*, 2014, they investigated the effect of Fe2O3 additives on the recovery of heavy oil from the real core sample by the steam injection process. The results show that injecting a mixture of nano-Fe_2O_3 and steam increases recovery.

In Sudan there is a considerable amount of heavy oil that needs to be produced as in Fula North East (FNE) field and different thermal methods have been applied in this reservoir to produce oil. This work aims to investigate the effect of using nano-Fe_2O_3 in heavy oil viscosity and the oil recovery by steam flooding process in order to see the feasibility of applying such technology in the Sudanese heavy oil field.

Materials and Equipment

Fluids

The oil samples used in this study were heavy oil of Fula North East (FNE) reservoir from Sudanese fields. Figure (1) shows that oil viscosity changes with increasing the temperature of the heavy oil sample used in the experiments.

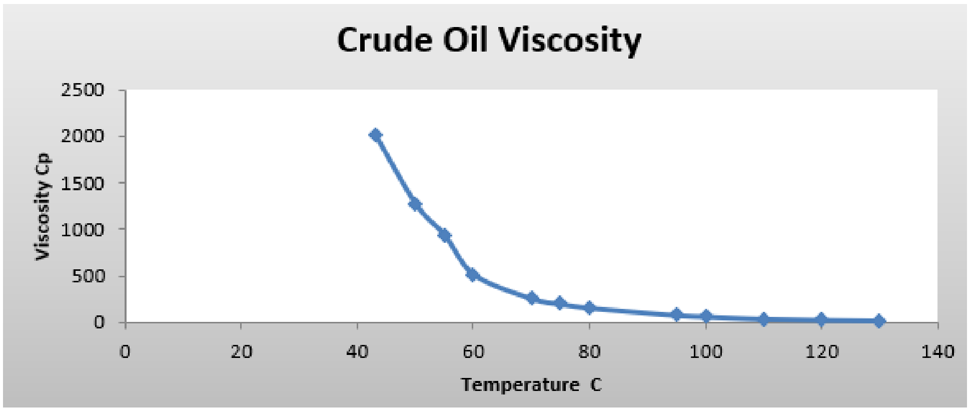

Figure 1: Viscosity of heavy crude oil versus temperature

Formation water was used to flush the core sample before saturating with oil. Also distilled water with a viscosity of 1 cp under ambient conditions was used for steam flooding process with and without Fe2O3 additives.

Rock Sample

A sandstone rock from real heavy oil Sudanese field (FNE) was selected in this study, and the core sample was cylindrical with a diameter of 3.757 cm and a length of 6.602 cm. Before being used, the core sample cleaned completely with toluene using Soxhlet device for 6 days and dried in an oven at high temperature for at 24 hrs. Then porosity of the core sample measured using manual saturator and the liquid permeability measured by flooding the core with formation water at several flow rate. Table (1) shows the measured porosity and absolute liquid permeability of the core sample.

Table 1: Core sample information

Length cm	Diameter cm	P V cc	Porosity, %	Kl mD
6.602	3.757	17.05	23.3	1607.8

Additives

Red Powder iron (III) oxide was selected to study the effect of such additives on the crude oil viscosity and oil recovery by steam injection process. These metal oxides were selected because of their role as a catalyst in cracking reaction and their heat properties. Table (2) shows the specifications of iron (III) oxide that were supplied by LOBA CHEMIIE Company for chemicals.

Table 2: Specifications of used Fe2O3 additives

Type	Formula	Form	Purity (wt %)	APS nm	SSA m2/g	Appearance
iron (III) oxide	Fe_2O_3	Nano powder	99	20-40	40-60	Red Powder

Apparatus

EV1000 electromagnetic viscometer was used for viscosity measurement. This apparatus is designed to provide high accuracy viscosity measurements at high pressure (up to 15000 Psi) and high temperature up to 200 Co as maximum. The electromagnetic viscometer is based on a simple and reliable electromagnetic concept that two coils move a small piston back and forth magnetically at a constant force. The motion of the piston is impeded by viscous flow in the annulus between the piston and the measurement chamber wall and when the piston 's two-way travel time analyzed, it gives a measure of absolute viscosity. The chamber is covered by a jacket and supplied with a liquid bath to provide required temperature and there is a built-in temperature detector (RTD) senses the actual temperature in the sampling chamber and a pressure transducer with its digital display. The system provided with a set of six calibrated pistons to cover viscosity ranging from 0.02 cP to 10000 cP. Fig (2) shows the EV1000 electromagnetic viscometer device.

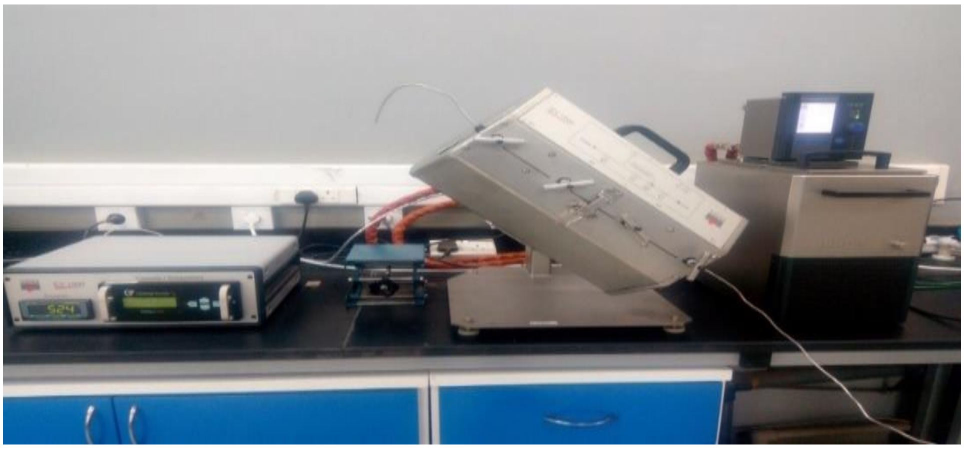

Figure 2: EV1000 electromagnetic viscometer device

Figure (3) shows a schematic representation of the Steam-flood 700 apparatus that used in these experiments. This system includes 3 double pumps, an oven, 4 piston accumulators, 2 gas regulators, a steam generator, core-holder, 2 back pressure regulators, a level tracker (graduated tube), and pressure measurement system and a gas meter.

Used fluids (oil, formation water) were injected and displaced into the core sample using syringe pumps with distilled water as displacing fluid.

HPLC pump with constant flow rate used to inject water into Steam generator, which heats water with an electrical element to vaporize water at designed pressure and temperature and the steam then injected in to the core sample to produce oil. The pump can provide a pressure up to 6000 psi and flow rate up to 10 cc/m.

The core holder was built from stainless steel which was capable of loading overburden and pore pressure up to 10000 psi and operating at temperatures up to 200 °C. Distell Water was used as the overburden fluid and the overburden pressure was always higher than the pore pressure. The core holder and measurement tools were placed in a thermostatic oven as shown by dotted line in Figure (3).

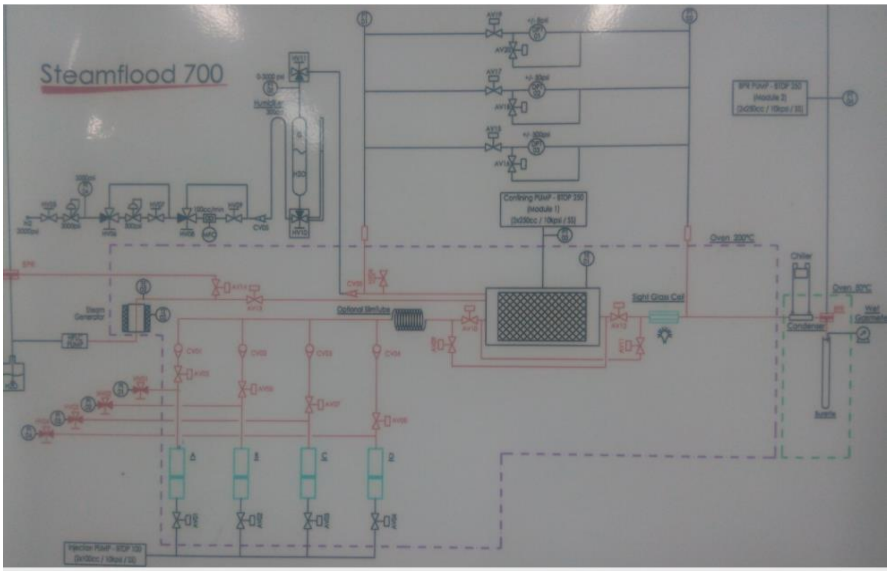

Figure 3:A schematic representation of the Steamflood 700 apparatus

The produced fluids were gathered in graduated cylinders for analysis and separation of oil and water in the system output. The produced fluid was cooled using a condenser attached to the flooding system before gathering.

All pressure, temperature, and pump calibrations were rechecked before each experiment to increase the accuracy of readings.

Operation of the system is controlled through a computer interface. The Applilab software included with the system is designed to allow for automated data acquisition and pump control, Fig (4).

Figure 4: Steam-flood 700computer interface

Ahigh speed mixer (Fig (5) used for adding and mixing the additives to the crude oil and the distilled water. For mixing additives with oil only the mixer with high mixing speed while for distributing additives with distilled water an ultrasonic bath (sonicator) was used.

Figure 5: A high-speed mixer

METHOD

For viscosity determination, Electro-magnetic Viscometer was used to measure viscosity of various mixtures of heavy oil and additives. The mixtures were prepared by adding certain amount of additive (Fe2O3) to the heavy crude oil sample and mixed together with high rotation speed mixer for 15 minutes to ensure mixing well. After that each mixture was imported into the Electro-magnetic viscometer, its temperature adjusted to the required value and after thermal stability the viscosity was determined.

Four concentrations of 0.1 ,0.25 ,0.5 ,0.75 wt.% of each additive were used and the viscosity of each mixture was measured at four temperatures of 43, 50, 80, and 100 ºC. The optimum concentration was then selected to be used in mixed steam flooding.

Before process of steam flooding without the additives, the selected core sample was saturated with formation water using manual saturator, then placed into the core holder and the required temperature (43 Co) and pressures (pore pressure 527 psi and confining pressure 2100 psi) were adjusted. After that the core sample was saturated with oil (by oil flooding) at irreducible water saturation (Swi). After reaching Swi the flooding system was put in aging period of 10 days, after that the steam generated and the test of the steam injection process then started, continued for 90 minutes and at the end of the experiment the volume of produced oil recorded.

The core sample will be cleaned with toluene and following the same steps that were mentioned in the previous paragraph and the 10 days aging period finished, the Swi is reached. The steam test repeated with a mixture of steam and Fe2O3 additives using the optimum concentration based on the viscosities test made for oil- Fe2O3 additive mixtures. The mixture prepared by adding the additive to water, mixed together with the mixer for 30 minutes and exposed to 90 minutes in ultrasonic bath. The mixture injected through the steam generator to provide the mixed stem for flooding. The test of the mixed steam injection process continued for 90 minutes and at the end of the experiment the volume of produced oil recorded. The produced volume of oil then determined and compared to that resulted without using Fe2O3 additive.

RESULTS AND DISCUSSION

As this study aim to investigate the effect of Fe_2O_3 additive on both the viscosity of heavy oil and the recovery of heavy oil from the real core sample by the steam injection process, the results were divided into two parts.

Effect on heavy oil viscosity

The resulted values of viscosity measurements for each mixture (oil/Fe2O3) at different temperature are presented in table (3). all viscosity measurements were repeated twice to confirm the results.

Table 3: Viscosity measurements for each oil/Fe_2O_3 mixture at different temperatures

	Viscosity CP				
Tem c	**Pure**	**0.10%wt**	**0.25%wt**	**0.50%wt**	**0.75%wt**
43	2019	1989.10	1907.03	1978.8	1968.07
50	1274	1241.72	1183.48	1231.9	1284.2
80	159	150.10	143.80	148.1	152.3
100	64.9	60.20	57.30	59.4	61.8

Table (3) above shows that for all concentrations the viscosity value decreased with the increase of temperature and follows the same trend as for pure heavy crude oil, this can be more illustrated in from Fig (6) to Fig (9).

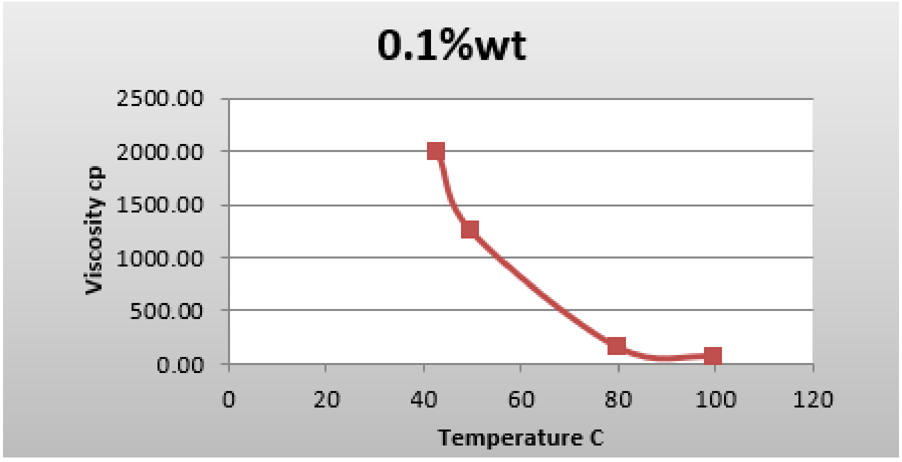

Figure 6: Viscosity of 0.1% wt oil/Fe2O3 mixtur

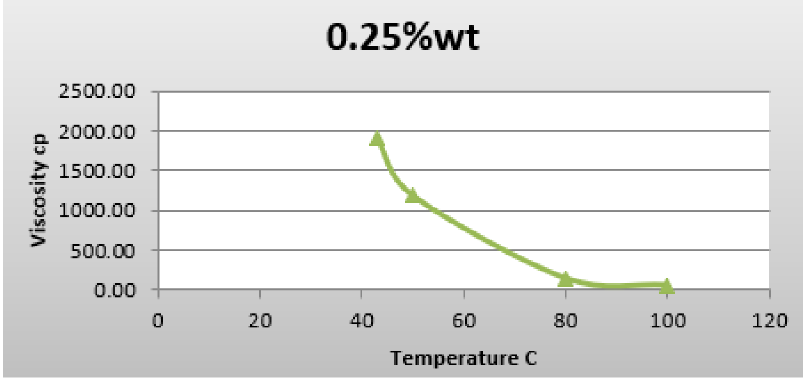

Figure 7: Viscosity of 0.25% wt oil/Fe2O3 mixture

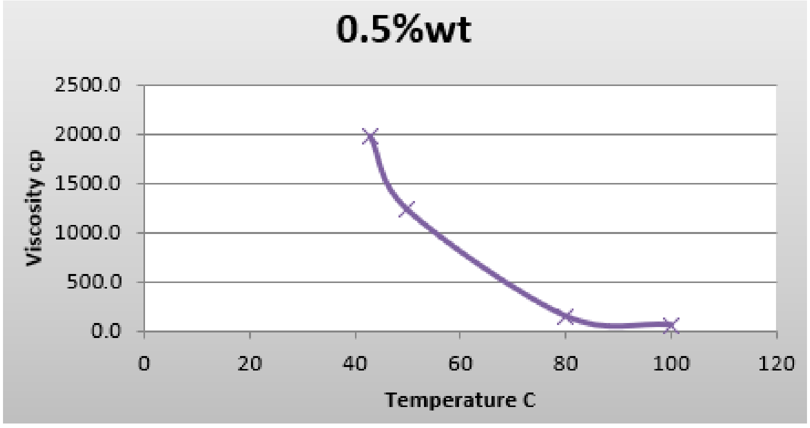

Figure 8: Viscosity of 0.5% wt oil/Fe2O3 mixture

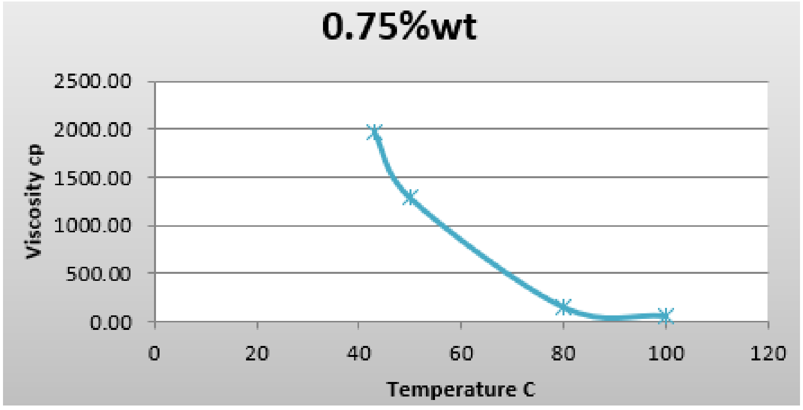

Figure 9: Viscosity of 0.75% wt oil/Fe2O3 mixture

In order to investigate which concentration of the Fe2O3 additive has the maximum reduction on the viscosity value or in other words to find the optimum concentration that has great effect on the viscosity, the percentage of viscosity deviation (Dev) of the different mixtures at different temperatures was calculated using the following equation: **Dev= ((u-u$_0$)/u$_0$) *100%**

Where (u0) is the viscosity of the pure heavy oil at certain temperature and (u) is the viscosity for any mixture at that certain temperature. The results of the viscosity deviation percentage are presented in table (4).

Table 4: viscosity deviation percentage for mixtures at different temperatures

	Deviation			
Tem c	**0.10%**	**0.25%**	**0.50%**	**0.75%**
43	-1%	-6%	-2%	-4%
50	-3%	-7%	-3%	-3%
80	-6%	-10%	-7%	-4%
100	-7%	-12%	-8%	-5%

Fig (10) compares the viscosity of pure heavy oil sample versus the viscosity of different mixtures (oil/ Fe2O3) at different temperature using the values of viscosity deviation percentage from table (4). It clear that the for different temperatures the reduction in viscosity increased at low concentration up to the concentration of 0.25% wt where the highest reduction was appeared and after that any increase in the concentration gave low reduction.

The highest reduction in the viscosity attributed to the fact that these Nano powder additives (Fe2O3) help in the cracking reaction and hence heavy oil sample component converted to the lighter component. Another reason is that these additives have large surface area which increase the contact area with the oil phase and can be placed within; this makes the movement of oil easy. At higher concentration of Fe2O3 additives more interaction with the oil sample increases the resistance against oil movement and lead to an increase in the oil viscosity.

These results are similar to the results of previous studies by Hamidi *et al*, 2010 which conclude that viscosity of heavy oil can be decreased by metal particles even at room temperature. Also Sahar Afzal *et al*,2014 found that Heavy oil viscosity could be decreased by adding Fe2O3nanoparticles even at different temperatures and the highest reduction in viscosity occurred with low concentration and high temperature.

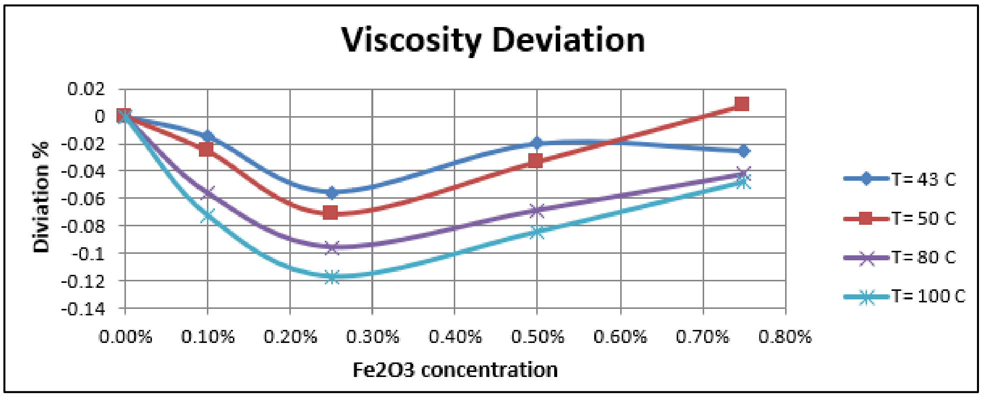

Figure 10: Percentage of viscosity deviation of mixtures at 43, 50, 80, 100 Co

Effect on oil recovery by steam flooding

To investigate the effect of Fe2O3 additives on oil recovery by steam flooding, two set of steam injection experiments were conducted on same sandstone core sample from a Sudanese oil field (FNE) under the reservoir conditions: confining pressure of 2100 psi, pore pressure of 527 psi, temperature of 43 Co and for steam generation a temperature of 248 Co selected.

In the first run only, steam was injected into the core sample that saturated by heavy oil at irreducible water saturation (Swi) with 15.5 cc as oil contained, while in the second run a steam-mixture with Fe2O3 (0.25% wt) was injected in to the core sample saturated with 15 cc of oil.

In both tests the duration was one hour and half, and tests were carried out with the same experiment's parameter under the same conditions; pressure and temperature. The volume of oil recovered from the two experiments recorded and the recovery factor was determined. Table (5) summarizes the results of experiments and the operation condition.

Table 5: Steam injection experiments results and operating condition

	Core Name	**Pore pressure psi**	**Total oil cc**	**Recovery %**
Without Additive	FNE-9B	527	15.5	29%
with Additive	FNE-9B	527	15	37%

Fig (11) comperes the results of the two runs, at the end of test duration the heavy oil recovery factors by injecting the steam and injecting the steam-mixture with Fe2O3 is 29% and 37% respectively.

This indicates that injecting steam mixture with additives lead to an increase of 8% in the oil recovery factor due to more reduction in oil viscosity and the easy flow with the present of additives. In addition to that, adding the additives causes an increase in the injected fluid and resulted in higher amount of oil swept from the core sample.

The result from these tests is similar to that result by the previous studies in this field. Hamidi *et al*, 2010 found that using metal nanoparticles with steam injection can cause an improvement in heavy recovery.

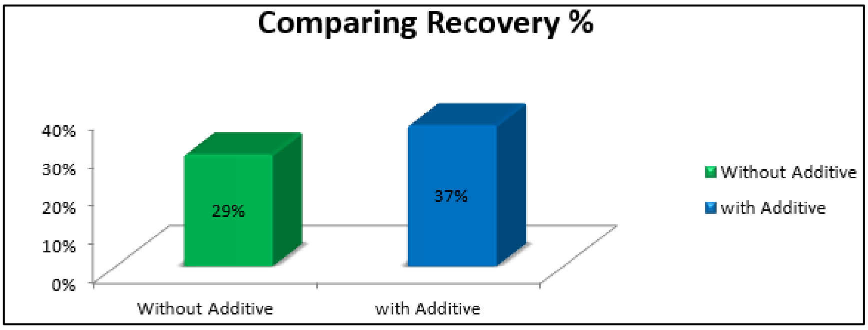

Figure 11: Comparing the oil recovery from steam injection experiments

CONCLUSION AND RECOMMENDATIONS

This experimental study aimed to investigate the effect of Fe_2O_3 additives on the viscosity of FNE heavy oil and the recovery of oil by steam flooding process. Four different mixtures (0.1%, 0.25%, 0.5% and 0.75% wt) were tested at different temperatures (43, 50, 80, 100 C^o) and the results of viscosity measurements were reported. for different temperatures, heavy oil viscosity could be decreased by adding Fe_2O_3 additives due to that it works as a cracking catalyst to crack the bond of heavy components of the heavy oil. The optimum concentration that gave the highest viscosity reduction obtained at 0.25% wt by comparing the percentage of viscosity deviation for various concentrations at different temperatures.

Two steam injection tests were performed on a real core sample from a Sudanese heavy oil field (FNE) under same reservoir condition, in the first test only steam injected while in the second one steam with additives was injected. The results indicate that there is additional of 8% in the oil recovery factor when steam with additives injected.

The additives used in this study cause an increase in the viscosity of the injected fluid and as a result increase the amount of oil swept from the core sample.

More investigations in the field of using such additives for viscosity reduction and increasing the recovery of oil from heavy oil field, such as studding the interaction of formation rock with the additives to know if there are any damages or side effect of such additives. Also, different types of additives can be investigated in order to reach to the suitable additives that not harmful to the field and economically wise.

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