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Oil Recovery by Using Electromagnetic Waves

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Abstract: This study describes electromagnetic heating of oil using curve transmitter with magnetic feeders in the radio frequency region. The transmitter was developed to focus the electromagnetic waves to the target. A series of experiments were done to find focus point of electromagnetic waves by using curve transmitter with magnetic feeders in water tank filled with brine at 15% salinity. The center of the transmitter has 184.4% higher magnetic field strength as compared to both end of the transmitter. Three magnetic feeders had resulted approximately 210% increased of magnetic field. The porosity and permeability of the core samples were also measured. Oil saturated core rock samples were kept in tank filled with brine of 15% salinity for efficient oil recovery. The EM waves emitted by the curve transmitter with 3 magnetic feeders were able to recover 43.71 (sample 1) and 59.26% of OIP (sample 2).

Key words: Electromagnetic waves, curve transmitter, magnetic feeders, enhanced oil recovery

INTRODUCTION

Today's major challenge for oil industry is to improve the oil recovery from the reservoir. There are many methods for the oil recovery such as thermal method, chemical methods and electromagnetic methods etc. (Hamouda and Karoussi, 2008) . Most famous method for oil recovery is steam injection method. In most cases such as very deep formation, thin pay-zones, low permeability formations, reservoir heterogeneity steam injection method is not feasible (Sahni *et al*., 2000; Rangel-German *et al.,* 2004). The alternative method for steam injection is electromagnetic heating of the reservoirs (Sahni *et al*., 2000; Gunal and Islam, 2000). In electromagnetic methods, electromagnetic waves in radio frequency and microwave region are use. The electrical energy from the electromagnetic waves transfers to the dielectric and resistive materials in the form of heat and reduce the oil viscosity which increase the mobility of the oil. The electromagnetic heating in the reservoir can be produce by two ways high frequency (Radio and microwave) and low frequency. In high frequency, heating take place due to the align movement of dipole of the molecules with electromagnetic waves. This molecular movement results in heating of the surrounding environment. The power dissipated due to high frequency electromagnetic is $P = \sigma E^2$. When electrical energy in low frequency (50 Hz) electromagnetic waves are use resistive heating take place and power dissipated is $P = I^2R$ (Chhetri and Islam, 2008; Vermeulen and McGee, 2000).

Several studies have been done theoretically and experimental by many researchers to use the electromagnetic method for enhanced oil recovery. A mathematical model for electromagnetic heating of the oil shales was developed by Jarvis and Inguva (1988). In this model, temperature, pressure, saturations, chemical reactions, mass conservation and source terms equations was used for the recovery of oil. A model for development of oil flow by microwave heating was presented (Soliman, 1997). The analytical and numerical solutions for microwave problem were obtained after assuming specific reservoir dimensions and oil properties. Radio frequency electromagnetic waves were used to recover bitumen from tar sand deposits when experiments were done in laboratory and field scale by Sresty *et al*. (1986). They obtained 50-80% recovery of bitumen and they also showed that the process was economical and energy efficient.

An electromagnetic heating laboratory model was developed for recovery of oil from thin pay zone by Chakma and Jha (1992). When combine with gas injection. They showed that minimum heat losses can be obtained when electromagnetic heating was confined to

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oil bearing zone. Effects of salinity, oil viscosity, pressure, frequency, temperature on the recovery of oil were studied. They reported 45% recovery of oil was obtained when combine with gas injection.

By using Maxwell's equations the simplified expression for average power dissipated in a volume V is given by Sahni *et al.* (2000).

$$P_{ave} = \omega\varepsilon_0\varepsilon'' E^2 V \text{ Watts} \quad (1)$$

where:

ω = Electromagnetic waves frequency
ε_0 = Free space dielectric constant
ε'' = Loss factor (proportional to the electromagnetic energy absorbed by the porous media)
E = rms electric field intensity in volts per meter

$$P = \sigma E^2 \text{ Watts cm}^{-3} \quad (2)$$

Where:

$$\text{Conductivity } \sigma = \omega\, \varepsilon_0 \varepsilon'' \quad (3)$$

After absorption of electromagnetic energy, the increase in temperature of the medium is calculated from the following equation:

$$\sigma E^2\, dt = \rho c_p\, dt \quad (4)$$

Where:

ρ = Mass density in kg m^{-3}
c_p = Specific heat at constant pressure

$$\frac{dT}{dt} = \frac{\sigma E^2}{\rho c_p} \quad (5)$$

For any electric field E, the rate of temperature increase depends on $\frac{\sigma}{\rho c_p}$.

The objective of this work is to develop an electromagnetic transmitter that can be used to focus the electromagnetic waves to recover oil from a core sample.

MATERIALS AND METHODS

An experimental study was conducted to evaluate the performance of the curve transmitter with and without magnetic feeders and its use in the enhanced oil recovery.

A curve aluminum transmitter and three magnetic feeders in the form of toroids having 20 turns of copper wire and two different core samples were used in this study.

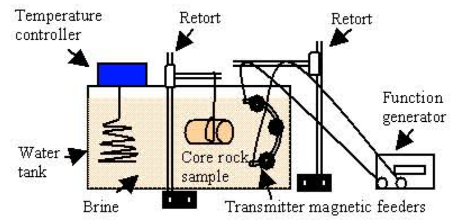

Fig. 1: Schematic diagram of the experimental setup

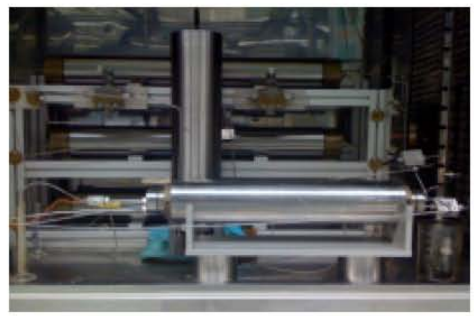

Fig. 2: Permeability test equipment for saturation of core rock sample with oil

Experiments were conducted in a physical scaled model (Fig. 1). The heart of the setup is the reservoir like model. It was essentially consist of a rectangular tank made of the thick Perspex sheet of the following dimension 20×30×20 cm. The tank was filled with brine at 15% salinity.

A series of experiments were done to find focus point of electromagnetic waves by using curve transmitter. The transmitter was placed in tank with brine and connected with function generator operating with square waves at 1 KHz and peak to peak voltage of 20 V both for transmitter and magnetic feeders as shown in Fig. 2. The magnetic field strength of the electromagnetic waves was measured by the fluxgate magnetic field sensors Model Mag-03MSS100 and magnetic field data was recorded by Decaport data acquisition system Model NI PXI-1042.

The permeability of the core sample was measured with help of Poroperm System. Two core samples with different properties were saturated with brine to determine its porosity and the absolute permeability. A crude oil having properties shown in Table I was injected at flow rate of 2 mL min^{-1} by using equipment Benchtop Permeator System (Fig. 2). After that water flooding was performed with brine.

Table 1: Properties of crude oil

Field name	Oil viscosity at reservoir temperature	Oil density at 20°C	API
Angsi 1-68	3cp	0.827 g cm^{-3}	40.17

These core samples with oil are placed in the tank with brine to replicating the reservoir environment. An aluminum curve transmitter with magnetic feeders was used to provide the electromagnetic waves. This transmitter is connected with function generator operating with square waves at 80 MHz and peak to peak voltage of 10 V. A temperature controller is used to control the temperature of the brine to replicate reservoir temperature which is at 55°C.

Percent of recovery: Percent of recovery is calculated as follows:

$$\%\text{ of recovery} = \left(1 - \frac{y}{x}\right) \times 100 \qquad (6)$$

Where:

x = Volume of oil in place in the rock sample

y = After electromagnetic heating, the volume of oil remains in the sample

$$\text{Volume} = \frac{\text{Mass}}{\text{Density}} = \frac{m}{\rho}$$

RESULTS AND DISCUSSION

Core sample characteristics: The characteristics of the core rock samples were measured by He Porosimeter system are summarized in Table 2. Core sample labeled 86 have high porosity and permeability than the sample labeled as 62. Due to curvature of transmitter it can focus EM waves at the center. The left and right end of the transmitter emits electromagnetic waves in approximately equal in magnitude. Effect of electromagnetic waves in the presence of core rock sample was measured and results are shown in the Fig. 4 . It has been observed that with the increasing number of magnetic feeders in the presence of core rock sample, the magnetic field strength increases up to 184.4%.

Effect of magnetic feeders: Figure 3 shows the magnetic field strength of EM transmitter with magnetic feeders. From the graph, it is cleared that as number of magnetic feeders increases the magnetic field strength also increases. By using three magnetic feeders 210% magnetic field strength was observed with respect to no magnetic feeders.

Effect of position of core rock sample: EM waves emitted from transmitter were used to focus on the core rock

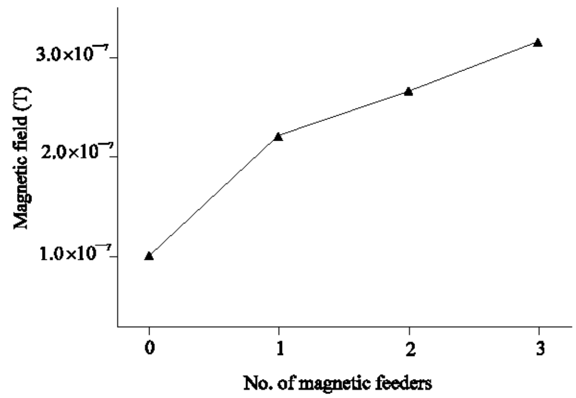

Fig. 3: Magnetic field strength vs. No. of magnetic feeders without core rock sample

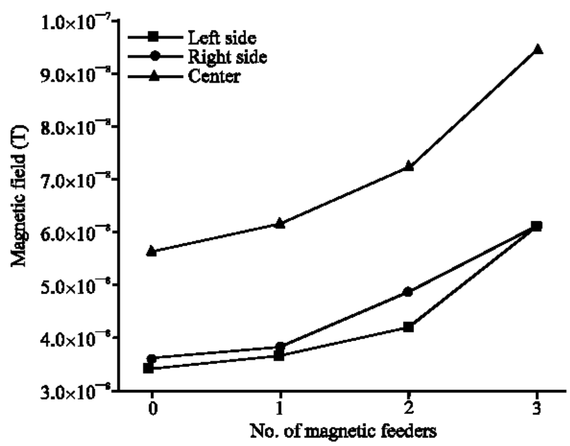

Fig. 4: Magnetic field strength vs. No. of magnetic feeders with core rock sample

sample. It was observed that curve transmitter can be use for the focusing of electromagnetic waves.

When core rock sample was placed at the center in the front of the transmitter, a decrease in magnetic field strength was observed. This shows that core sample can absorb EM waves. The transmitter emits EM waves in all directions.

Effect of field strength with and without core rock sample: The core rock sample was placed at the center position in front of transmitter. It was observed that magnetic field strength has larger value without core rock sample where as smaller field strength was observed with core rock sample. Seventy percent absorption of the EM waves was observed in the Fig. 5.

Oil recovery using EM waves: To analyze the effect of EM waves on oil recovery was done by using EM

Table 2: Characteristics of core samples

Sample No	Sample ID	Core dia (mm)	Core length (mm)	Weight (g)	Effective core porosity (%)	Air permeability (md)
1	62	37.98	50.09	117.56	20.67%	96.68
2	86	37.16	50.00	90.69	38.02%	2784.52

Table 3: Effects of electromagnetic wave heating for oil recovery

		Weight of core rock sample (g)			Volume of crude oil (cm^3)		
Sample No	Sample ID	Initially	Before EM wave radiation	After EM wave radiation	Oil in place	After EM wave radiation	Percent of recovery
1	62	117.110	127.3087	121.2651	12.3321	5.0243	59.26% of OIP
2	86	86.540	101.5656	94.9971	18.1688	10.2262	43.71% of OIP

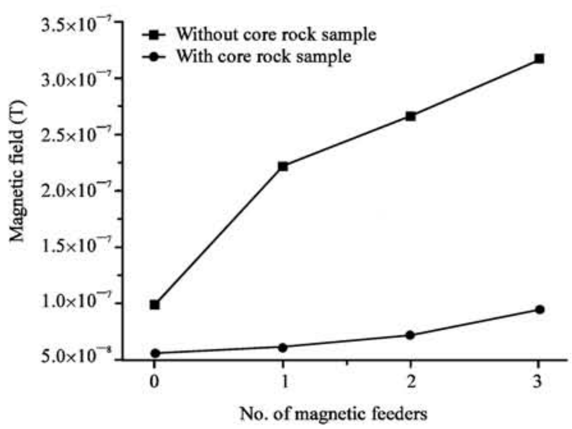

Fig. 5: Magnetic field strength vs. No. of magnetic feeders with and without core rock sample

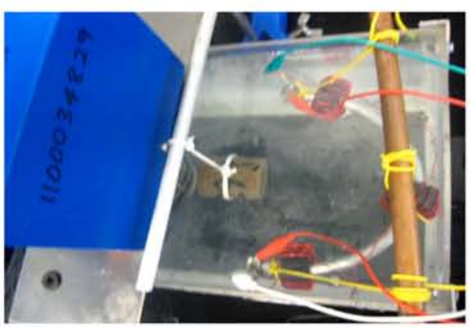

Fig. 6: Experimental setup before oil recovery

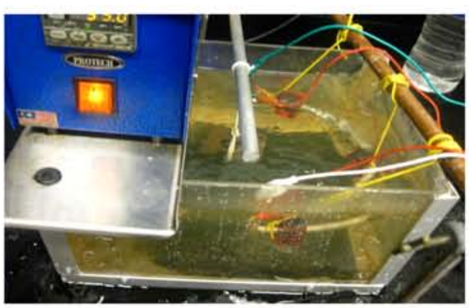

Fig. 7: Experimental setup after oil recovery

transmitter with three magnetic feeders. The core samples were placed in the brine at 5 cm from the transmitter for 24 h. Experimental setup before oil recovery is shown in Fig. 6.

EM waves irradiation on the core samples increases the temperature and viscosity of the oil decreases. The core sample depends on the absorption of the electromagnetic waves and on the material properties such as dielectric properties. Therefore different materials have different absorbing properties. Both samples show additional recovery due to absorption of the electromagnetic waves because with the absorption of the electromagnetic waves core sample heat up and reduces the oil viscosity. Table 3 shows the volume of the oil in the core samples before and after exposure to the electromagnetic waves and recovery of the oil in percentage. The core sample labeled as S-86 has high volume of the oil because it has high porosity as shown in Table 1. Porosity is the ratio of void space in the rock to matrix. This petrophysical property is important because it controls the amount of the oil in the reservoir. The more porous the reservoir is the more oil it will hold and vice versa. It was also observed that coalescence of the oil drop from the rock sample begin and these oil drops detach from the core sample and mix with brine. Due to mixing of the oil with brine, color of the brine changes as shown in the Fig. 7. The oil recoveries for the samples are ranges from 43.71 to 59.26% of OIP.

CONCLUSION

The effect of EM waves on core rock samples was successfully evaluated. EM transmitter with magnetic feeders was used for oil recovery. It was observed that with three magnetic feeders magnetic field was increases up to 210%. The electromagnetic waves emitted from the transmitter are absorbed by the core rock samples and heat the core samples which reduce the viscosity of the oil. It was observed that oil recovery for sample 62 59.26% of OIP and for the sample 86 43.71% of OIP was observed.

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