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Investigation of Water-Flooding Activity Using Radiotracer Technology in Commercial Core-Flood Set Up

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An intervention of radiotracer technology in the EOR program has been initiated using commercial core-flood set up. A commercial type of Berea core is used throughout the experiment. ^{99m}Tc is chosen as a radioactive tracer for this experiment, which has a half-life of 6 hours and emits gamma rays' energy of 0.104MeV. It is a liquid radiotracer with the activity of 10GBq (270mCi), eluted and prepared by Institute Cancer of Malaysia (IKN) before transporting it to the laboratory at Centre of Research in Enhanced Oil Recovery (COREOR), Universiti Teknologi Petronas. The experiment was conducted after 3.5 half-lives. Thus the activity has reduced to approximately (1.48GBq) 40mCi during injection inside the system. The results can be used to assist the reservoir engineer in determining the exact water-tracer breakthrough, localize the location of water-tracer concerning time, and determine the residence time distribution and mean residence time of the core flood where the hydrodynamics of the flow can be predicted. Moreover, the introduction of radiotracer inside the core flood rig can be translated as secondary oil recovery. The idea is to integrate radiotracer technology into the existing commercial core flood set up (FES350) to track the movement of fluid during water-flooding operation. Besides, it can be considered as the first interaction of radiotracer in the enhanced oil recovery application studies in Malaysia.

Keywords: Commercial core flood set up, EOR, Hydrodynamics, Radiotracer (^{99m}Tc), Water flooding

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INTRODUCTION

The hydrodynamics of fluid in most reservoirs are mainly anisotropic, where the character of the reservoir is usually multilayers with different homogeneity of sediments. Thus, the fluid movement inside the reservoir is difficult to predict, especially when flooding activities are introduced in Enhanced Oil Recovery (EOR) programs.

Recently, our group from Plant Assessment Technology has conducted a proof of concept (POC) using radiotracer technology for EOR activity. It showed that the significance of radiotracer in assisting reservoir engineers in understanding the characteristics of their reservoirs, which can lead to a better oil recovery procedure. Radioactive tracer or substance is capable of emitting radioactive rays such as gamma rays that can be tagged with fluid such as water, gas, surfactant, chemicals, to monitor the movement of fluid flow or hydrodynamics during EOR activities. Analyzed data from radiotracer study can provide rich information on reservoir such as the presence of channeling or homogeneity of the sand-rock, etc. Most of the information given by the tracer response curves cannot be obtained through other techniques.

The RTD model from radiotracer experiments will present the characterization of the reservoir such as flow abnormalities, to verify any parallel flows, and to provide information on sweep changes due to the injection of various types of EOR flooding agents (polymer, chemical, and surfactant). In this study, the sand column (artificial oil reservoir) is developed to qualitatively and quantitatively monitor the fluid hydrodynamics and model the flow field. Radiotracer in the form of ^{99m}Tc is added into injection fluid during water flooding and observed in the outlet whereby sodium iodide (NaI) scintillation detector is installed at the outlet to monitor the tracer movement. Tracer response is then used to describe the flow pattern and obtain a better understanding of the reservoir. It is essential knowledge to optimize oil recovery. Thus, this study's objective is to assess the fluid flow using radiotracer technology during water flooding.

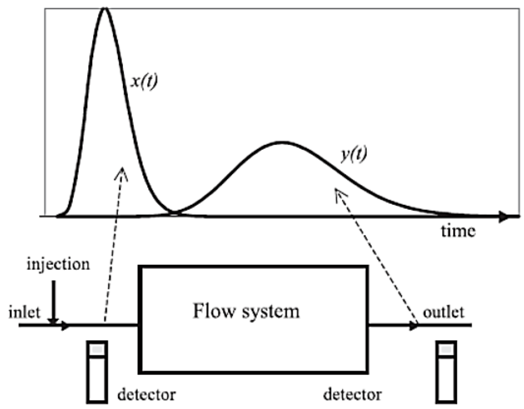

Fig. 1: The principle of radiotracer experiment by Furman et al. 2011

Figure 1 shows the fundamentals of an experimental tracer setup, as described by Furman et al. (2011). Two detectors are installed, in which a detector is installed upstream at the inlet, where the injection of radiotracer is located, and the second detector is located downstream (outlet of the column). The radiotracer signals from will be captured by scintillation sodium iodide (Tl) detector attached to the Data Acquisition System

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(DAS) for data collection and monitoring. The type of radiotracer used differs according to the phase of the process under study.

EXPERIMENTAL SETUP

Preparation of Berea core saturation

Porosity and permeability are the main parameters in EOR study. Porosity measurement is required to determine the volume of trapped hydrocarbon in s specific type of rock, whereas permeability will dictate hydrocarbon's capability to flow inside the reservoir.

In this study, the permeability is given as 300mDarcy, and porosity is calculated as shown in Equation (1).

$$\Phi = \frac{Vp}{Vb} \quad (1)$$

where ϕ is porosity, V_p is pore volume and V_b is bulk volume. Bulk volume is determined from the geometry of the cylindrical shape of Berea core. Berea Sandstone™ contains mainly of sandstone-quartz grains with pre-determined size which is bound by silica. In this study, the Berea core is a fine, compact and solid cylinder with d, diameter of 3.777cm (measured by Vernier caliper) and h, length of 30.455 cm as shown in Figure 2. Thus, the V_b is 341.27 cm^3 and calculated as Equation (2).

$$V_b = \pi \frac{d^2}{4} h \quad (2)$$

Moreover, the pore volume, V_p is measured as the difference of wet mass, to dry mass,   of column divided by density of water, as shown in Equation (3).

$$V_p = \frac{m_w - m_d}{\rho_w} \quad (3)$$

Fig. 2: Manual saturation & Buff Berea sandstone core

Fig. 3: Commercial core flood set up before intervention of radiotracer activities

The saturated water core is then attached to the core flood holder, which is wrapped by heating jacket that connects to the overall system, as shown in Figure 3. Initially, the core flood set up is purged using distilled water to ensure that there is no leakage present, and the system is running well. Once attached to the system, brine injection is carried out to ensure the column is fully saturated with water. The salinity of brine is 30 ml in 1litre of water (30,000ppm). When the electronic and data acquisition is on, the value of delta P is observed and has to be constant for initial permeability determination. P1 should be higher than P2 for the flow to occur or else backflow is predicted.

Radiotracer Setup

Figure 4 and Figure 5 are the schematic diagrams of radiotracer-core flood set up whereby Tapis oil is used as crude oil since it is less viscous; thus, no heating of the oil is necessary. The flow rate of injection is set independently at 1 cm^3/min for oil and tracer, while 0.5 cm^3/min for brine, respectively, and 100ml of oil is injected inside the system. Accumulators (beakers of water flooding activities) are assigned in which one bottle is meant for radiotracer container, and the rest are for fluid flooding in this study. During injection, the activity of ^{99m}Tc is 1.5 mCi/1.6 ml, and background dose rate is recorded. Since the tracer volume is minimal compared to the size of the accumulator (bottle), dilution of tracer to 5 ml is advised so that the injection of tracer is made possible to the core flood. The objective of the study is to inject 99mTc, a liquid radiotracer inside the core flood, followed with several brines PVs during water flooding operation, and let water sweep through the oil inside the column. The NaI detectors will detect each signal emitted from tracer, which shows the tracer's location at present (in-situ). NaI detectors are connected to the Data Acquisition system (DAS) attached to PC, which provides tracking of water movement (hydrodynamics flow) inside the core flood as this is never being considered and highlighted for any core flood studies before. Radiotracer experiments can also determine the actual and correct time of water breakthrough during water flooding activities. Figure 4 shows the arrangement of five (5) sodium iodide (NaI) scintillation detectors In contrast, Figure 5 comprised of seven (7) detectors installed in series at the designated point to ensure the tracer is detected and recorded in the system.

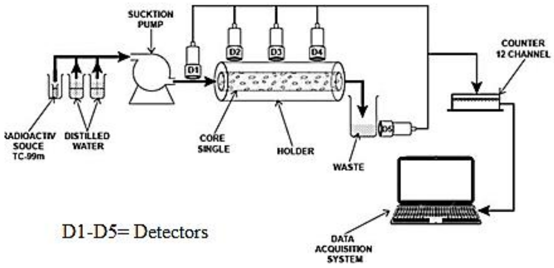

Fig. 4: Schematic diagram of radiotracer setup with five (5) detectors: First arrangement

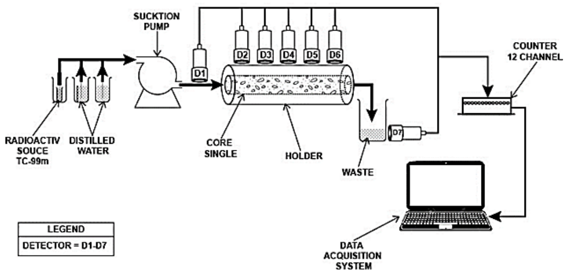

Fig. 5: Schematic diagram of radiotracer setup with seven (7) detectors: Second arrangement

Since radioactive source involved in this experiment, stringent SOP should be adhered by operators. Each operator should wear an OSL batch, and the area of core flood experiment is barricaded. Survey meter is always within reach to ensure the exposure of radiation from radiotracer is monitored, although the activity used is extremely low. After the experiment completes, the counts of dose rate should reach background reading so non-radiations workers can safely conduct the that subsequent investigation of the core flood.

RESULTS AND DISCUSSION

Berea core saturation is carried out by saturating the core with 5 L of distilled water for 3.5 hours at 2000 psi. However, the recommended time for water saturation is 6-8 hours (API RP40 Standard) using manual saturation equipment as shown in Figure 2. The standard is to ensure the core's porosity is at optimized condition and acceptable range of Berea core. Lower than that, there is no point in resuming the experiments since the saturation is not optimum. Hence, wet mass is obtained after time elapsed of 3.5 hours saturation. The values of all parameters are tabulated in Table 1.

Table 1. Calculation of PV

Parameters	Units
Wet mass, m_w	765.92g
Dry mass, m_d	690.32g
Density of water, ρ_w	1g/cm^3
Pore volume, V_p	75.6 cm^3
Porosity, Φ	22.15%
Grain density	2.609g/ cm^3

Thus, 1PV = 75.6 cm^3

Table 2. Oil recovery

Parameters	Oil recovery (ml)
V_{oil} (water flooding)	35.5
Total oil injected	100
Actual oil injected	100-7.5=92.5
Amount of water used	200ml = 2.5PVs
Recovery factor ,RF	$\frac{35.5}{92.5}\ x\ 100\% = 38.37\%$

The oil recovery is carried out during water flooding. The results are shown in Table 2. Seven point five ml is the amount of dead oil trapped along the tubing. The dead oil is calculated after completing the experiment. The rig, such as tubing, is dismantled and any trapped oil inside the tubes is measured.

The result of oil yield is the typical recovery range for secondary oil recovery using water as a flooding mechanism. It is clearly stated that about 200 ml of water is sufficient to push out 38.37% of trapped oil inside the Berea core. The tracer will provide the tracking method of water flooding hydrodynamics only.

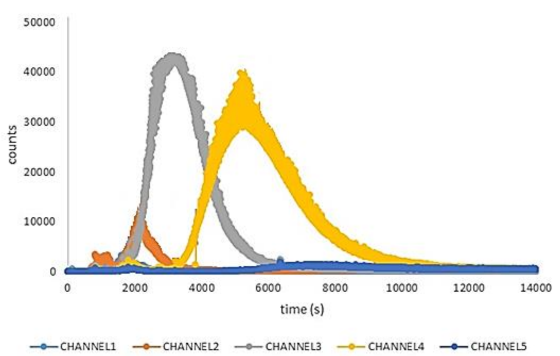

Fig. 6. Radiotracer experimentation: First arrangement

Figure 6 is the first arrangement of three detectors that show the radiotracer signals detected by the NaI detector once ^{99m}Tc gets into the system. The tracer emits a gamma-ray that converts into an electric signal by photomultiplier tubes (PMTs) inside the detector and produce the C-curves. The flowing movement of water flooding activities can be monitored continuously using radiotracer-NaI set up. From this arrangement, the peak at D1-D4 are clearly defined and highlighted. D1 indicates the tracer is entering the system, whereas D2-D4 shows the sequence of water movement from left to right as predicted.

Nevertheless, the peak of D2 is smaller compared to D3 and D4. The result shows that the detector is not on the top of the core but slightly arranged on the holder steel casing. Thus, it acts as shielding material, which reduce the counts of the emitted gamma rays from the 99mTc. The time of tracer arrival is assigned at every peak. Thus, the detector is collecting data at every 1000s for every detector. The radiotracer peaks can be monitored and observed using a data acquisition system connected to the laptop.

Moreover, for the second arrangement, the detector's location is arranged in alignment with Berea core to ensure the peaks obtained are significant and highlighted, as shown in Figure 7. This time five detectors are arranged side by side with a distance of about 1 cm from each other. All detectors are collimated to ensure peak consistency. Figure 7 indicates the gamma rays emitted from ^{99m}Tc, which is diluted in water flooding flow, is received well by the detector. No blockage is found in the system that designates the Berea core is homogeneous during fabrication. The counts seem to decrease in value gradually will be because the tracer is well diluted over time, and also the probable reason is the emitted tracer is farther from the detector. It is because radioactive tracer attenuation is directly proportional to the distance of the radioactive source.

The sequence of prompt signals shown indicates that radiotracer was enabling the tracking of water-oil during water flooding, whereby water is needed to push out oil from the trapped column. It determines the exact time and the water-oil whereabouts and provides the information on current state of reservoir. Since the distance between each detector is constant, any discrepancy in arrival or late breakthrough of the tracer will show a presence of anomaly such as flow channeling in that respective area.

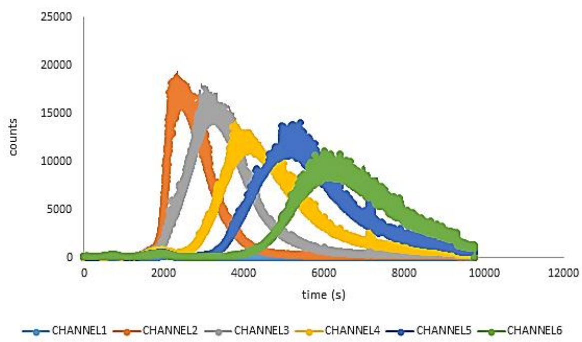

Fig. 7. Radiotracer experimentation: Second arrangement

RTD & MRT determination

The mean residence time (MRT), which is the mean time of tracer resides in the system, is calculated as 5973 s or 1.66 h for first arrangement and 6698 s or 1.86 h for second arrangement, respectively. The mathematical expression for the First Moment (M1) in discrete form or better known as MRT is calculated using the following Equations (4) as described by Danckwerts (1953).

$$Mi = \frac{\int_0^{\infty} t\ C_i(t)\,dt}{\int_0^{\infty} C_i(t)\,dt} \quad \text{and}$$

$$E(t) = \frac{C(t)}{\int_0^{\infty} C(t)dt} \tag{4}$$

where C(t) is the concentration of radiotracer, it is monitored by NaI scintillation detectors in counts per second (cps), as numerator and denominator is the area under the curve of plotted C(t). The detected signal is normalized by dividing it by the area under the curve.

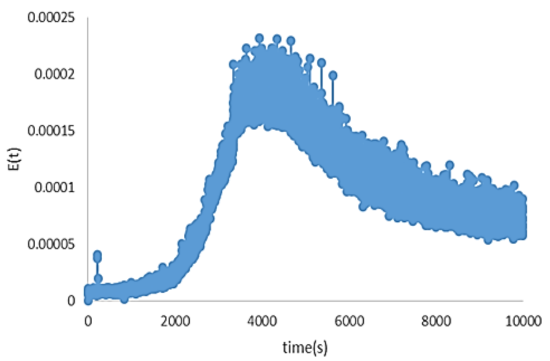

Fig. 8. RTD analysis: First arrangement

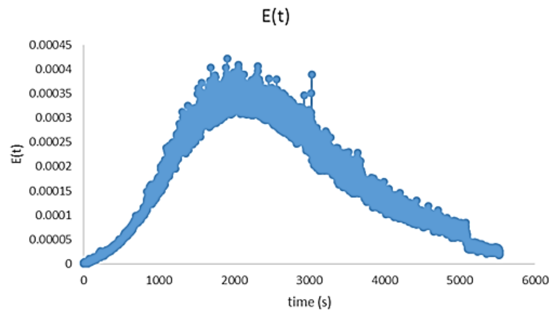

Fig. 9. RTD analysis: Second arrangement

Figure 8 and Figure 9 indicate the normalization of the curve to obtain RTD, which means E(t). Residence Time Distribution (RTD) or E(t) is a fundamental parameter in reactor design. It can give information on how long the substrate has been in the reactor, and the RTD analysis can characterize the extent of their deviation from ideal behavior. The MRT is shown that tracer resides in the second arrangement longer than first arrangement. It because the detector is at the tip of the outlet compared to the first, which is a bit off. Figure 8 also shows that the extrapolation of data is essential for RTD determination in which a complete RTD curve should start and end at zero (IAEA 2008 & Kasban et al. 2010). Besides, the long tail obtained after extrapolation is constructed, the porous media is experiencing a stagnant zone that elongates the residence time of tracer.

CONCLUSIONS

The intervention of radiotracer technology seems to be fruitful inside commercial core flood rig in which the tracer-water flooding movement can be tracked and monitored well using Tc-99m with minimum activity. Nevertheless, radiotracer technology will not enhance the yield of oil but assist reservoir engineers in providing information about the behavior and characteristics of the specified core.

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NOMENCLATURE

V_p	:	pore volume [m^3]
V_b	:	bulk volume [m^3]
h	:	Berea core length [m]
m_w	:	wet mass [g]
m_d	:	dry mass [g]
ρ_w	:	density of water [gcm^{-3}]
V_{oil}	:	volume of oil [ml]
$C(t)$	:	concentration of tracer [cps]
M_i	:	First moment
$E(t)$	:	RTD

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