TRACER TESTS FOR HETEROGENEITY CHARACTERIZATION AND SATURATION DETERMINATION ON CORE FLOODING

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ABSTRACT

Low sweep efficiency is the common problem in displacement process due to heterogeneity, high permeability streaks, fractures, and thief zones existing in the formation. Similarly, the success or failure of EOR implementations are always affected by those problems which causes displacing fluids fingering and early breakthrough. Factors of this type, unless properly identified and understood before the start of EOR process, will likely cause a project failure.

Core flooding as the model of small scale of fluids movements in reservoir undergoes similar circumstances. Approximately one foot long of four 3.5 inches stacked native and synthetic cores are normally used in core flooding experiment. Tracer test was performed to characterize the core in addition of CT scan analysis. On this experiment, lithium solution was selected as tracer solution to be then injected into core at constant rate, 4 ft/day. Afterwards, the effluents were collected by Gilson sample collector in each tube for further determinination its concentration using Atomic Absorption Spectrometry (AAS).

Response curves of lithium tracer were able to determine core heterogeneities and this should be done to avoid misleading interpretation of core flooding results. Besides, lithium concentration reported in some extent and subsequently analyzed by employing method of temporal moments. This method provides numerical calculation to estimate effective core pore volume (PV) and fluid saturation. Weighing method was also used to compare the PV with aforementioned method and the results were comparable.

Key Words: *Tracer, heterogeinity, fluid saturation, and core flooding*

I. INTRODUCTION

EOR is the only technology which is capable for producing the remaining of oil in the reservoirs after primary and secondary recovery processes. Success of secondary and tertiary oil recovery projects targeting the remaining oil in mature or partially depleted reservoirs strongly depends on adequate description of reservoir heterogeneity. Processes that are well-understood in a laboratory environment and those also should be properly designed for the reservoir scale. A number of procedures exist that can be used before implementation of an EOR process in attempt to describe the reservoir geology. One of these procedures is tracer test.

Tracer technology plays an important role in improving the reservoir characterization before the application of EOR methods by providing qualitative information on reservoir compartmentalization, preferential flow paths to improve understanding of fluid movement in the reservoir, stratification, and heterogeneities distribution. Basically, tracer is chemicals that can be added to fluids in small concentrations and used to follows their movement without affecting their physical properties. It also can be used as an effective tool to detect and estimate of remaining oil saturation using two different types of tracers. The two tracer types are differentiated into the conservative (ideal) tracer and the partitioning tracer. The ideal tracers do not have solubility in other substances, this case in oil or by definition they do not interact with the rock or other fluid phases present. Thus when ideals are injected in reservoir, they will flow only in the water phase adopting the velocity of this phase. Some examples that can be used as ideal tracer are iso-propyl alcohol (IPA), bromide and lithium.

In contrast, partitioning tracers are soluble in liquid hydrocarbon as well as water or gas phases. The molecules of the partitioning tracers are moving back and forth between the water and oil phase, because they have high partition coefficient (absorb into the rock) which determines the tracer solubility in other phases. Consequently, when a pulse of aqueous solution containing a suite of partitioning tracers is injected into an oil reservoir, the tracer will continuously partition into and out of the oil phase contacted by aqueous solution (injected gas). Hence the molecules of partitioning tracers are flowing with the water velocity when they are in the water phase and oil velocity when they are in oil phase[6]. Thus, partitioning tracers propagate more slowly in an oil reservoir than conservative tracers. This retardation of the partitioning tracer is analogue to chromatographic separation where this mechanism is utilized to estimate oil saturation in the reservoir. Several examples from this type of tracers are n-butanol, rhodamine, and propanol

Tracer test is necessary to be performed in core flooding experiment when we are deeply concerned with core properties and validation seeking. Besides

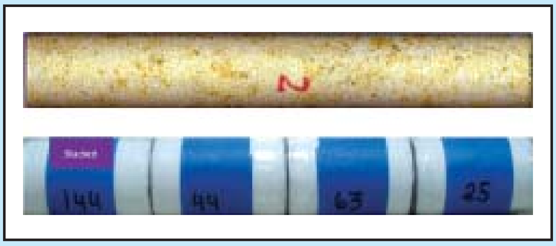

Figure 1
Top Synthetic and Bottom Wrapped Stacked Native Cores

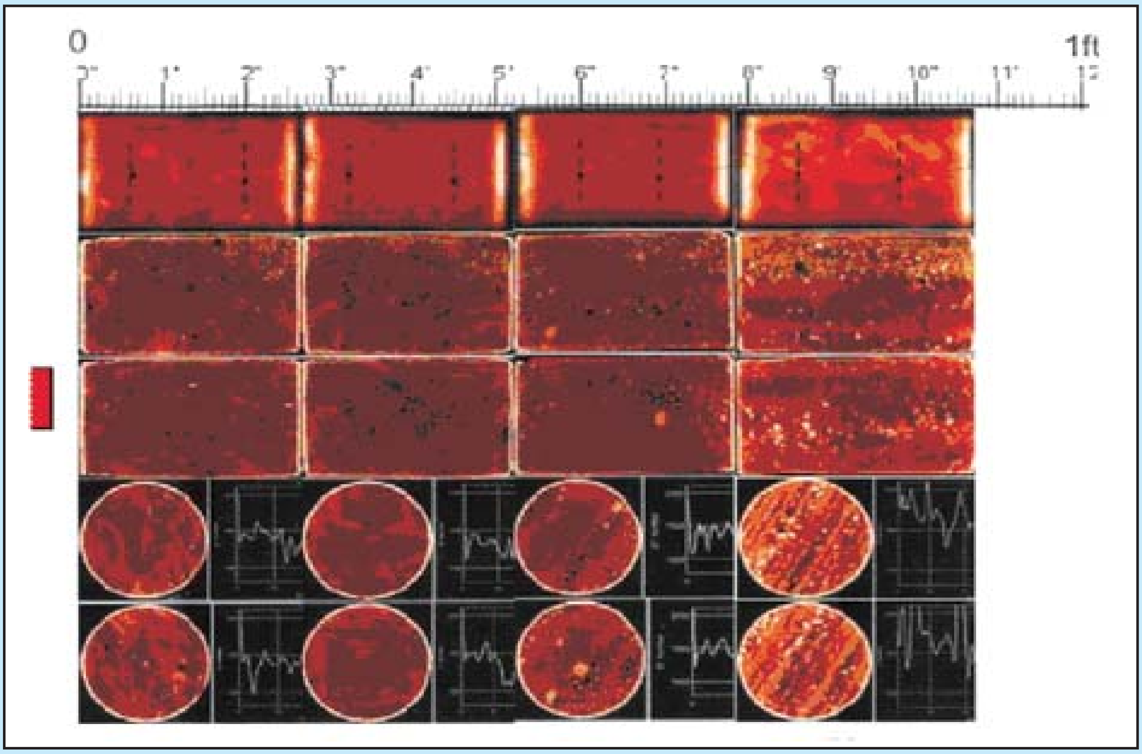

Figure 2
CT Scan on Stacked Core Plugs

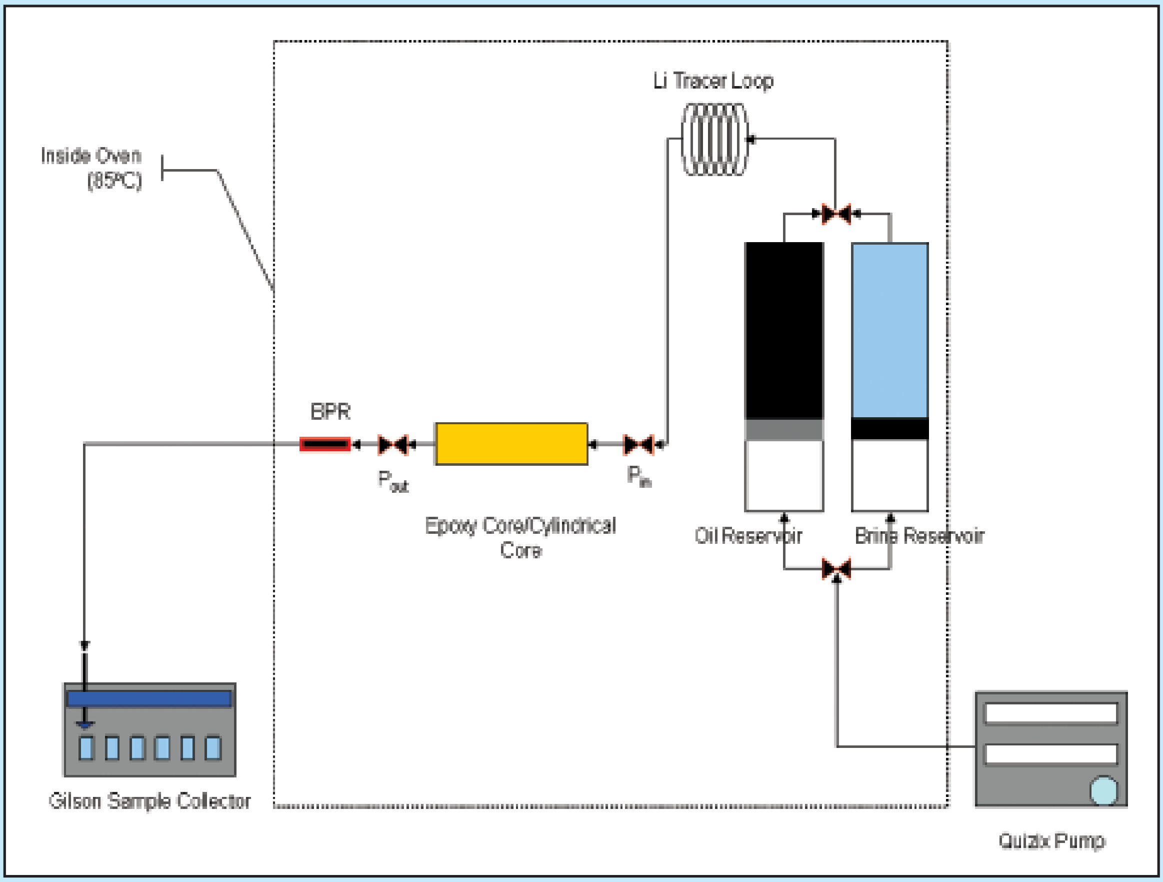

Figure 3
Coreflood Equipment Applied for Tracer Test

describing the heterogeneity within core including its connectivity, another advantage is as leak indicator in core set up. Moreover, we could obtain effective pore volume swept by the tracer.

This paper will describe the results of tracer test on several core flooding succinctly including how to use the method of temporal moment analysis from tracer response curve data to estimate effective core pore volume. A quick look observation on response curve to reflect core heterogeneity and experimental set up was also presented concisely.

II. CORE PREPARATION FOR TRACER TESTS

A native core sample was taken from the interest zone. Approximately one foot long of four 3.5 inches stacked native core are normally used for representing the reservoir rock. In case of unavailablity of native core, a standard or synthetic core such Classhach, Brial Hill, and Berea sands can be used just only for determining the efficiency of displacing material for EOR project without any results of fluid-rock interaction. Running core flood using stacked cores is much more crucial and common misleading interpretation of the core flood results occurs unless prior heterogeneity determinations by tracer test. Figure 1 shows the two types of core i.e. stacked native and synthetic cores.

Four 3.5 inches native core plugs were drilled for this core tracer test. Prior to performing core flood test, a CT scan must be done to sproperly select the cores for stacking which have similar qualitatively rock properties and avoiding fractures and shale lamination. Figure 2 is the CT scan results of the candidate cores for tracer test.

III. TRACER INTERPRETATIONS METHOD

A host of tracer analysis methods consider the temporal behavior of tracers. The methods were originally developed for closed reactor vessel, but have been applied to more general conditions of open boundaries, characterization of fractured media under continuous reinjection and to estimates flow geometry. The methods have rigorous mathematical basis. The methods and application mentioned above are all based on analysis of tracer residence times. The mean residence time or first temporal moment, is the most useful single property derived from tracer test, although other properties have been used as well. Levenspiel[10] shows the total pore volume swept by the tracer can be determined from its residence time.

The method of temporal moments is a very simple, fast and robust method to estimate swept pore volume and remaining oil saturation. As explained earlier, to calculate remaining oil saturation we need two different types of tracer where the ideal tracer behaves as the reference tracer and the partitioning tracer as the partitioned one. Because of the presence of oil, partitioning tracers are retarded compound to the non-partitioning. However, this paper aims merely on effective pore volume estimate.

Effective pore volume can be estimated using one tracer that is swept by tracer. The pore volume was determined from tracer mean residence time which required steps are summarized as follows:

- Normalize the tracer history
- Extrapolate the history to late time
- Calculate mean residence time and swept volume

Although this method provides some advantages but it is necessary to inform that moment analysis is a general method, and one that suffers from few limitations. Assumed conditions essentially state that the flow field is steady and tracers moves with bulk fluid flow such that the information obtained from the analysis is general bynapplicable. These conditions can be stated as follows:

1. Steady state injection and extraction
2. The tracer is ideal and conservative

IV. EXPERIMENTAL PROCEDURE

Several tracer tests were conducted by using high pressurized core cell with low dead volume. The experiment used both standard and native sandstone core that condition set to reservoir state (Table 1). The core was prepared to contain residual oil saturation using standard procedure by altering flow of brine and crude oil. The experiment configuration is illustrated in Figure 3.

Table 1
General Experimental Data

Core length	27.18 cm
Core diameter	3.8 cm
Pore volume	115.23 cc (?)
Porosity	30.08 %
Flow rate	0.3 cc/min
Velocity	4 ft/day
Temperature	85 ^{o}C
Mobile phase	Synthetic brine
Volume of tracer injected	24.36 cc

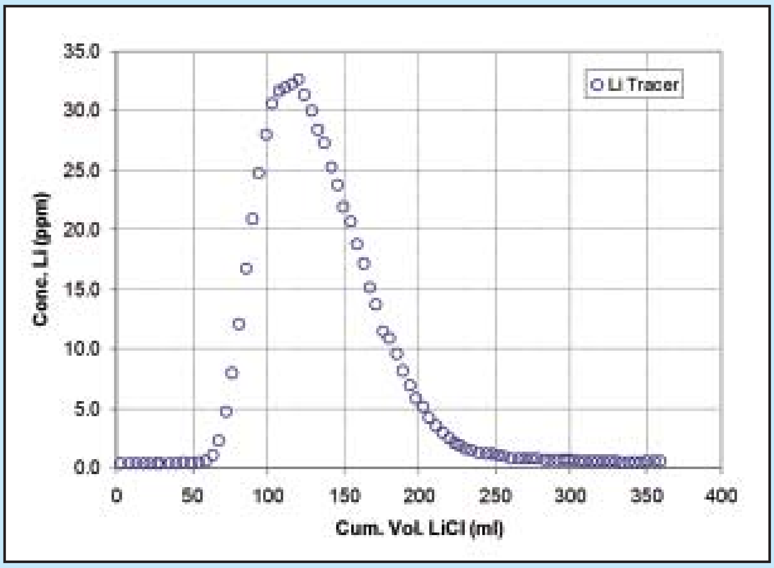

Figure 4
Tracer Response Curve

First tracer test was conducted when the core was saturated fully with the formation water. This first step of core flooding experiment is to identify the heterogeneity of fractures in the core. In this stage a small volume of tracer was injected into the flowing water phase close to the core inlet. On this experiment Lithium (Li), dissolved in LiCl solution, was selected as conventional tracer. The solution had been designed at 100 ppm Li^+ ion. Waterflood resumed at stable flow rate until the tracer chemical was eluted through the core plug, thus the majority of the injected tracer mass could be recovered.

Similarly, when residual oil saturation had been established to quantify the right residual oil saturation after water flood, the core was flooded also with synthetic brine at constant flow rate, 4 ft/day. During this period, a small volume of tracer was injected into the flowing water phase. The same tracer test was also performed after chemical flood, again to calculate the residual oil saturation after chemical flood and to recheck the oil recovery factor at chemical flood, although a dean stark could be run on core after flood to make a comparison.

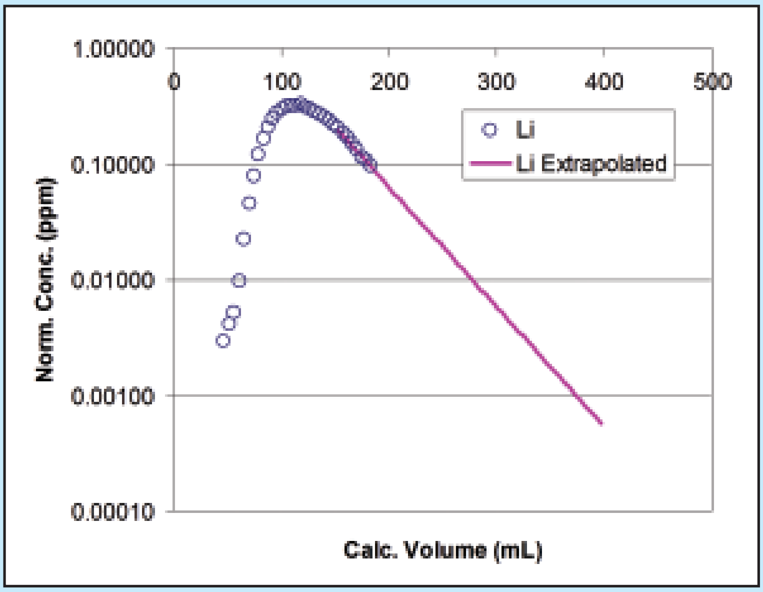

Figure 5
Li Extrapolated Curve

Aliquots of 5 ml of the effluent were continuously collected by Gilson sample collector fraction close to the outlet of the backpressure regulator valve. Then each sample fractions were analyzed for its content of Li by atomic absorption spectrometry (AAS).

V. RESULTS

Each sample concentration was plotted versus its volume, as depicted in Figure 4. The calculation of effective swept pore volume will be determined from temporal moment method. The first step is normalizing the concentration history by dividing measured Li^+ concentration to total Li^+ injected concentration.

Tracer response curves should be complete in terms of outflow measured concentration in order to estimate effective pore volume precisely, because much of the information is contained in the tails of the response curve. Unfortunately, the tracer response curve is often incomplete either due to dilution of the tracer concentration below detectable limit of apparatus or some other reasons. Therefore to overcome this difficulty is with extrapolating the history to long time. The tracer response curve can be extrapolated with an exponential function provided the derivation of the test is sufficient to establish this decline.

The first moment of the tracer response curves was obtained by dividing the data into two parts. The first part represents the data from zero to the time t_b where time becomes exponential, and the second covers the exponential part in which it goes from t_b to infinity.

After time t_b, the tracer response is assumed to follow an exponential decline given by:

$$C = C_b e^{-\left(\frac{t-t_b}{a}\right)} \quad \text{.......................................} \quad (1)^4$$

Where 1/a is slope of the straight line when the tracer response curves are plotted in semi-log scale and C_b is the tracer concentration at time t_b when curve becomes exponential. The extrapolated curve is seen in Figure 5.

The mean residence time, or first temporal moment, of tracer is determined directly from the normalized and extrapolated tracer history as:

$$t^* = \frac{\int_0^{t_b} tCdt + \frac{b}{a^2} e^{-at_b}(1+at_b)}{\int_0^{t_b} Cdt + \frac{b}{a} e^{-at_b}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)^4$$

The constants a, b and t_b are determined by curve-fitting late time tracer data in spreadsheet. Pore volume estimates follow directly from the mean residence time as describe from the equation below:

$$V_p = \frac{m}{M_{inj}} q_{inj}\, t^* \quad \ldots\ldots\ldots\ldots\ldots \quad (3)^4$$

Then each data was tabulated and plotted against cumulative volume as shown in figure 6. The effective pore volume calculation from temporal moments and weighing method is 118.14 cc and 115.23 cc respectively. There is a fair difference between the estimation of effective pore volume using temporal moments and weighing method.

A. Core Characterization

Figure 4 shows the tracer response and indicated that the core is homogeneous curving with the single peak and having almost similar front tail and end tail formation.

But Figure 7 is heterogeneous core reflected from two peaks which formed in tracer response curve. These peaks mean the core was stratified into different flow paths.

Another case depicted in Figure 8 shows scattered and varying noise in response curve that may indicate the leakage occurred during the flooding due to imperfect core set up particularly in core holder sleeve.

B. Saturation Determination

Tracer test can be used in validating fluid content during coreflood experiment. We can estimate effective pore volume from first tracer response curve which is obtained prior saturating the core with oil, this can be simplified by following simple term:

Effective Swept PV → *Tracer Response Curve.* ..(4)

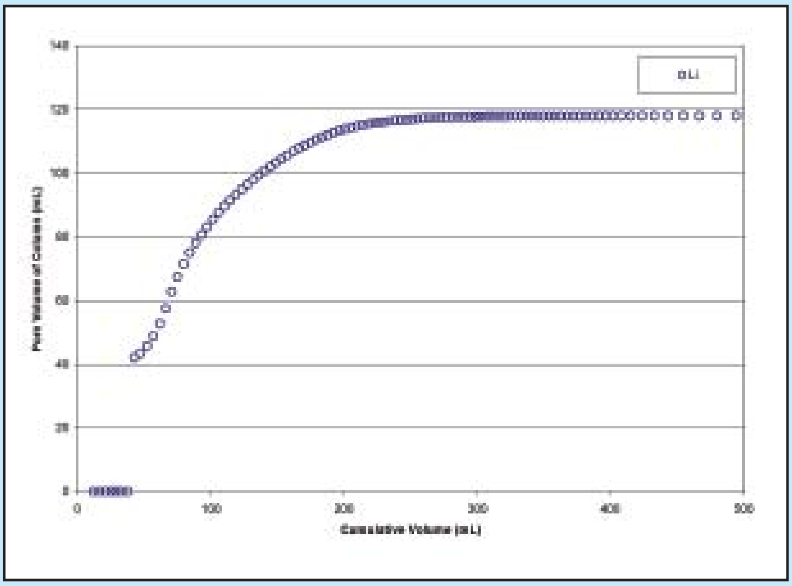

Figure 6
Pore Volume Estimation Curve

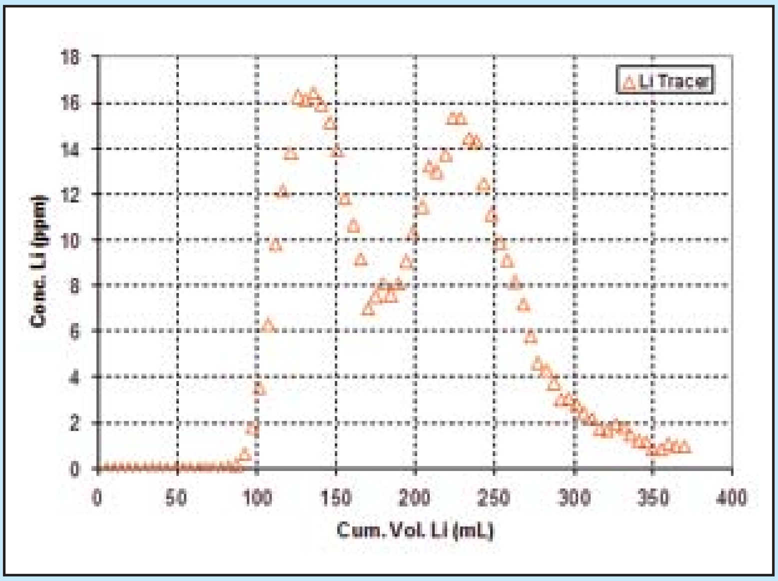

Figure 7
Heterogeneity Core Response Curve

Obtained effective swept PV form above term can be defined as effective PV 1.

Moreover, sequential tracer tests can give us estimates on residual oil saturation (Sor) and recovery factor. To obtain estimates on Sor secondary tracer test needs to be undertaken after waterflood. At this stage we obtain another tracer response curve, herewith can be defined as effective swept PV 2. By subtracting effective swept PV 1 with effective swept PV 2 we can obtain Sor. This can be simplified by following equation:

Sor Validation = Eff. PV1-Eff. PV2...................................... (5)

Recovery Factor Validation = Eff. PV3-Eff. PV2 .... (6)

Third tracer test conducted after chemical flood can be used also in validating oil recovery.

Figure 9 exhibits the three tracer tests responses running at initial condition, after water flood, and after chemical flood. Then the saturation on each flood step has been calculated precisely and shown in Table 2.

VI. CONCLUSIONS

1. Effective pore volume estimates from temporal moments and weighing method are 118.14 cc and 115.23 cc, respectively.
2. Tracer test provides helpful tools to improve core characterization by providing qualitative information on preferential flow, stratification, core connectivity, heterogeneities distribution and apparatus set up.
3. Method of First Temporal Moment Analysis is simpler and faster to interpret tracer response curve.

Table 2
Saturation Determination

Core Sample	Soi % PV	Swc % PV	ROS-WF % PV	RF-EOR % ROS
Synthetic	60.95	39.05	26.24	80.65
Native	61.54	38.46	27.59	95.76

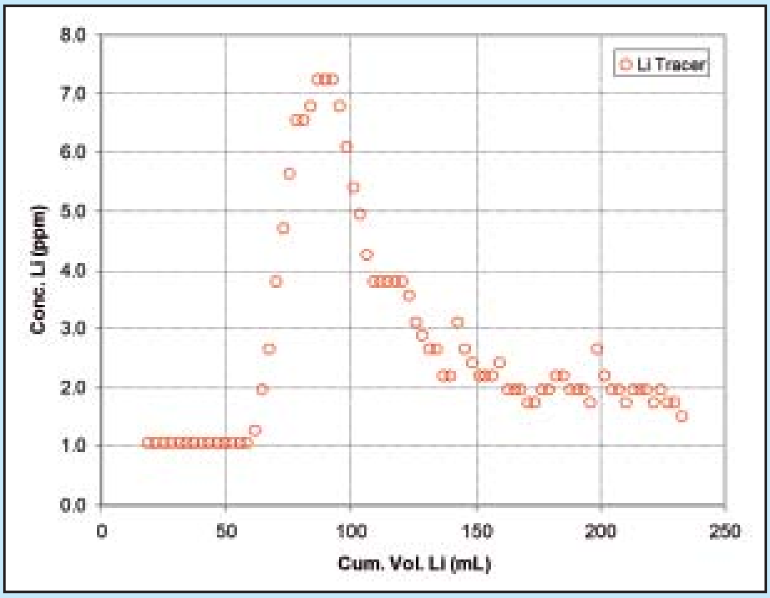

Figure 8
Leakage on Core Holder Set up Response Curve

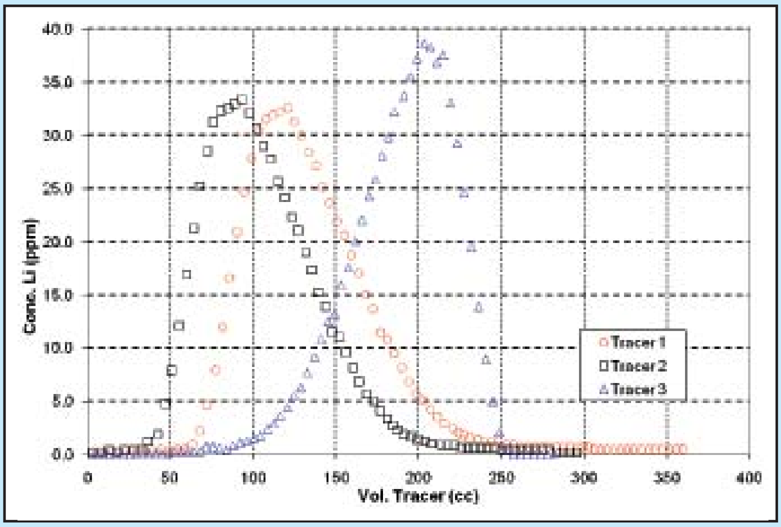

Figure 9
Tracer Response Curves at Each Step of Flood

4. Tracer test possible to be used as initial assessment to core before proceeding core flooding. Hence, it will save times and cost in experimental.

VII. NOMENCLATURE

C = tracer concentration, ppm
q = flow rate, cc/min
M = total tracer injected, cc
ROS = residual oil saturation
RF = recovery factor

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