Investigations of Au-198 as radiotracer in laboratory porous media using gamma camera: a preliminary study

N Othman1, W H B Wan Kamal2, N H Yusof3, E M F Engku Chik1, M A S Yunos1, M A K Adnan1, M R Shari1

1Plant Assessment Technology, Industrial Technology Division, Malaysian Nuclear Agency, 43000 Kajang, Selangor
2Medical Technology Division, Malaysian Nuclear Agency, 43000 Kajang, Selangor

noraishah@nm.gov.my

Abstract. Preliminary experiment has been carried out using irradiated Au-198 as radiotracer inside the laboratory porous media. The objectives are to check the compatibility of Au-198 as the radiotracer inside the porous media as well as to provide insights of fluid hydrodynamics inside the media using gamma camera. 198Au is gamma emitter isotope with half-life of 2.7 days and energy of 0.41 MeV (99%). The porous media consists of fine sandstone with grain size 850µm, lubricant as the mimic of original oil in plant (OOIP) or trapped oil and a layer of cement on top of the rig as the bed rock. Gamma camera is arranged next to the porous media in order to capture the movement of radiotracer which has been set to 1 minute per frame. Initially, the gold wire which has isotope of 197Au was irradiated inside the rotary rack of Reactor Triga PUSPATI (RTP) to produce 198Au. RTP is located in Nuclear Malaysia, Bangi has energy of 750kW and neutron flux of 5 x 102 n/cm2/s. 198Au, which is in liquid form, is injected inside the porous media and monitored and recorded by gamma camera. The gamma camera gives a quantitative determination of local fluid saturations over the area of observation.

1. Introduction
Crude oil development and production of oil reservoirs can include up to three distinct phases: primary, secondary, and tertiary recovery. During primary recovery, the natural pressure of the reservoir or gravity drives oil into the wellbores, combined with artificial lift techniques which bring the oil to the surface [1]. The expected initial extraction rate of available hydrocarbons reservoir's original oil in place is around 10-15% typically produced during primary recovery. This will leave around 85% of hydrocarbons in the reservoir. Secondary recovery techniques extend a field's productive life generally by injecting water or gas to displace oil and drive it to a production wellbore [2]. Pump jacks for water flooding and initial gas injection can increase the recovery up to 25-30% of the original oil in place. However, producers have attempted enhanced oil recovery (EOR) techniques, techniques that offer prospects for ultimately extracting another 10-15% of the initially available hydrocarbons or producing 30 to 60 % or more, of the reservoir's original oil in place [3].

The petroleum potential in Malaysia is mainly fractured basement rock reservoir located offshore and characterized by a fracture system of very high heterogeneity in porosity and permeability. The complexity of the reservoir structure introduces a considerable uncertainty in the reservoir model and fluid flow simulation. The extraction of residual oil requires modification in reservoir characteristics in
which water flooding is most commonly used for enhanced oil recovery. In this operation, the water is injected through the residual oil under high pressure to extract the oil. This situation calls for more application of tracer technique and challenges to tracer technology. In view of rising energy consumption, the use of advanced technologies to boost oil recovery from mature oil fields in Malaysia is most welcomed [4]. In addition, the innovative application of the gamma-camera-imaging system as a quantitative method for investigating the physics of oil displacement within a thin slab of porous medium has been successfully carried out using radiotracing medium [5]. The gamma camera can provide the behavior of the water and oil movement in the porous media during water flooding. In this paper, preliminary result is shown on the intervention of radiotracer in porous media which mimics the reservoir with gamma camera as a tool in quantitative determination of local fluid saturations over the area of observation. Thus, the objectives are to investigate the compatibility of Au-198 as radioactive tracer in porous media and to visualize the water-oil movement inside the porous media using gamma camera. The selection of Au-198 is made based upon assumption that the particle of irradiated Au-198 is tagged with hydrocarbon inside the laboratory porous media. The radiation from Au-198, in this case gamma ray emission is detected and captured by NaI scintillation detectors and provide data monitoring and profile of oil movement.

2. Materials and Methodology
About 2 mg of gold wire with 99% purity from Goodfellow Cambridge Limited is sent to research reactor for irradiation and produce about 1mCi of activity. \textit{Aqua regia} solution with ratio of 3:1 (HCl: N\textsubscript{2}O\textsubscript{3}) is prepared beforehand to dissolve the irradiated Au-198 to liquid form. The volume of 10ml gold solution is prepared for this study. All preparations of gold radiotracer are carried out inside the radioactive fume hood for safety. The survey meter is always available to monitor the dose rate level is at the permissible level which is 10 µSv/hr or 1 mR/h at all time. Gamma camera Hamamatsu model BHP6602 is used for imaging and monitoring the flow of fluid inside the porous media.

A lab-scale rig for porous media consist of water reservoir which can accommodate about 2L of water, is attached to porous media container using Teflon uniform tubing. In this preliminary study, tap water is used to supply continuous water as source of water flooding. The water reservoir is located about 50 cm above the oil reservoir and gravity is used to push the water flow from water reservoir to the oil reservoir respectively. The outlet from the porous media is then connected to separator as the outlet and also to assess the oil recovery as well as the water as shown in figure 1. The porous media consists of fine sandstone with grain size 850µm, 20ml lubricant as the mimic of original oil in plant (OOIP) or trapped oil and a layer of cement on top of the rig as the bed rock. The dimension of oil reservoir is 20 cm in diameter and height respectively.

The water from the reservoir will be pushed inside the porous media using the gravity pull for fluid displacement activity. Prior to that, the gold radiotracer is mixed inside the water reservoir and this is called as tracer dilution technique. This means that radiotracer is further diluted and this may affect the sharpness of the image. Gamma camera is set to capture image of one frame per minute and once the gamma camera is ready for dynamic study, the experiment is on. The half-life of gold is 2.7 days and emits gamma ray with energy of 0.41MeV (99%).
3. Results and Discussions

3.1. Determination of actual activity
The dose rate recorded was 100µSv/h at surface of uncollimated liquid gold and 3µSv/h at 1m distance. Therefore, actual activity is calculated using the equation below for 1meter distant:

\[
Dose\ rate \left( \frac{mR}{h} \right) = 0.55 \times Energy\ (MeV) \times Activity\ (mCi) \tag{1}
\]

\[
Activity\ (mCi) = \frac{0.3mR}{0.55 \times 0.41} = 1.3\ mcI/48.1MBq \tag{2}
\]

Thus, the actual activity for radiotracer injection is 1.3mci or 48.1MBq throughout the study.

3.2 Flow visualization using gamma camera
Figure 2a shows the hotspot of radioisotope Au-198 inside the vial. The bright red and yellow colors indicate the high intensity of highly concentrated Au-198 which is measured as 1,825,192 counts for 10ml gold solution before injection inside the rig. It shows that activity of 48.1MBq is sufficient and capable for image detection using gamma camera. Figure 2b displays the image intensity of gold solution as soon as water is added to the concentrated gold solution for dilution of radiotracer. The intensity of Au-198 is gradually decreased as depicted in blue greenish color.
Figure 2. The images of Au-198 intensity (a) 10ml gold solution, (b) diluted gold solution.

The hydrodynamics of fluid inside the oil reservoir can be observed once Au-198 is injected inside the porous media as shown in figure 3 where the intense green colour is recorded and monitored. At earlier minutes (t=2-3min), it seems that the liquid radiotracer is dispersed inside the media where continuous water is pushing the radiotracer inside the oil reservoir. It seems that the water containing radiotracer is occupying the porous media which contains oil and therefore, oil recovery is expected at the outlet. This is due to the fact that water reservoir is meant to push the trapped oil inside the media as water flooding mechanism. Nevertheless, after 20 minutes, no oil was collected at the collector pot. Figure 3 shows that the accumulation of Au-198 occurs inside the media and the reading are around 2200-2300 counts and remain plateau. There is no significant tracer breakthrough at the outlet as expected although additional of water is carried out. Besides, the media’s dose rate is recorded as 2mR/h which is equivalent to 0.8mCi or 29.6MBq. This indicates higher intensity of radiotracer is trapped inside the media. These preliminary results show that Au-198 is adsorbed onto the sand and does not behave as water tracer.

Figure 3. Image of dynamic flow of Au-198 recorded at 1frame per minute for Experiment 1.
In order to rebut with the previous experiment, second experiment is carried out in which the modification is done to the tracer injection mechanism. Instead of injecting the radiotracer Au-198 inside the water reservoir which is causing higher dilution of radiotracer, the radiotracer which is 3ml in volume (concentrated) is injected to the system by Dirac pulse. Prior injection, the dose rate of radiotracer was measured using survey meter and it was recorded as 100µSv/hr and the flow rate of water supplied was 180ml/min. The monitoring of the process took about an hour. (OOIP) or trapped oil and a layer of cement on top of the rig as the bed rock. The dimension of oil reservoir is 20 cm in diameter and height respectively. Figure 4 shows the flow of radiotracer inside the reservoir and it can be seen clearly that the impact of concentrated radiotracer without dilution provides more distinctive image of injection process. It shows that, once the injection starts, the detector captures small green area (1,1) to indicate the tracer has already entered the reservoir and the injection has just commenced. Only small green area is observed which shows the Dirac pulse method of injection is implemented. The blue area is the reservoir or porous media which has not been touched by Au-198 yet. From coordinate (1.2) to (1,8), the distribution of radiotracer covers about two-third of the overall circle. Thus, it can be deduced that the dispersion of Au-198 as radiotracer is not homogenous and still remain and stuck inside the sand although continuous water injection is exerted and sufficient time of water flooding is given. To improve the hiccup of this experiment, the researcher should monitor and record the dose rate reading of the collected water to confirm the presence of Au-198 at the outlet if any.

Figure 4. Image of dynamic flow of Au-198 recorded at 1 bit per minute for Experiment 2.

4. Conclusions
From this preliminary result, a conclusion can be made that Au-198 is not recommended for oil-tagging tracer but more for sand tracing application. This is because, both results from different set of experiments show that most Au-198 tracer is trapped inside the oil-laden sand and the rest is...
distributed on the sand particles although water flooding is introduced continuously. Nevertheless, gamma camera can be used to study about the hydrodynamics of oil inside the Laboratory Porous Media provided the selection of oil tracer is correct. This is because, for lab study, the movement of water or oil can be traced accordingly (static or dynamic) and monitor respectively.

5. References

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