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# Monitoring Water Alternate Gas Process using Streaming Potential

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Spontaneous potential (SP) is commonly measured during reservoir characterisation. SP signals are also generated during hydrocarbon production due to the streaming potential occurrence. Measurement of SP has been proposed as a method to detect and monitor water encroachment. In principle, SP signals could also be monitored during production from a single well, with pressure support provided by a water alternate gas (WAG) process. The objective of this study is to monitor WAG process by using streaming potential measurement. SP signal will be measured during production by WAG injection. Measurement of streaming potential has been previously proposed to detect the water encroachment towards a production well. The peak of the signal corresponds to the waterfront where there is a change of saturation from ionic water to non-polar hydrocarbon. Similar trend is predicted in the case of WAG where we have several interfaces between the injected water and the injected gas. This project involved experimental work. The investigation comprised physical model design for WAG process, model characterisation, and correlation between SP signals WAG performance. WAG displacement process could be monitored indirectly from the signal acquired. SP measurement is a promising method to monitor the effectiveness of a WAG process. This study is significant because monitoring the progress of water and gas in a WAG process is a key in the effectiveness of this enhanced oil recovery method. Measurement of the streaming potential provides another method besides using tracers to monitor the WAG profile. Better monitoring will lead to more efficient displacement and great benefits in term of economy and environment.

## 1. Introduction

Primary and secondary recovery can leave up to 60 - 70 % of oil in the reservoir. The productions of hydrocarbon need to be more proactive. Technology development is required in order to improve and maximise the oil recovery. The best way is by applying an enhanced oil recovery (EOR) method (Memon and Shuker, 2011). EOR process can improve recovery about 30 - 60 % or more compared to just 20 - 40 % using primary and secondary methods.

Some amount of residual and heavy oil will remain in the reservoirs after the conventional recovery process. Although secondary recovery such as water flooding has been implemented in many oils field to recover more oil, many of them suffer from an unstable displacement problem. This is due to the generally lower viscosity of injected water compared to the oil in the reservoir. The main reason for low volumetric sweep efficiency is the unfavourable mobility ratio. Several techniques have been introduced after natural depletion stage and water flooding.

Water alternate gas (WAG) process is a process where a gas slug is followed by a water slug and also can be referred as combined water/gas injection. WAG injection is recommended to improved gas injection sweep efficiency by using water to control the displacement mobility and also to stabilise the front. Besides that, produced hydrocarbon gas also can be re-injected into the water injection wells to improve oil production and to maintain the reservoir pressure or pressure maintenance. WAG injection process has become an imperative method in EOR throughout the suitable fields/reservoirs because it is capable to control gas fingering and also enhance the vertical sweep efficiency (Memon and Shuker, 2011).

WAG process need to be monitor to prevent viscous fingering which can lead to early breakthrough. Tracer have been used successfully to monitor and retrieve flow parameters, inter-well formation heterogeneity such as high permeability region and inter-zone communication regime. By using the tracer system, the understandings of fluid flow and WAG injection efficiency have been improved. Tracers are best described as a unique reservoir compatible species that is foreign to the system. Once the reservoir has been injected by any fluid, the tracer will monitor the injected fluid and allows important information to be retrieved. Tracer can be divided into three categories which namely as radioactive, chemical and fluorescent (Abdullah et al., 2011). By using tracer, it takes too long to get the data. The alternative method to monitor WAG process is by using streaming potential measurement.

In the exploration and production segment of the oil industry, streaming potential is usually encountered as a component of the spontaneous potential (SP) log. The electromotive force measured by the SP log arises mainly from two types of phenomenon, electrokinetic and electrochemical (Doll, 1949). The electrochemical component is generally considered to be dominant phenomenon (Wyllie, 1949), the electrokinetic or streaming potential component is sometimes important. Streaming potentials in porous media arise from the electrical double layer which can forms at solid-fluid interfaces (Hunter, 1981). Streaming potential measurements have been proposed as a method to characterise flow in fractures, adjacent to a borehole, and the pressure response of a reservoir during transient production test (Jaafar et al., 2009). This research will be focused on the use of the streaming potentials to detect and characterise water and gas encroaching on a well during production.

The objectives of this study are to quantify the magnitude of the streaming potential during production by WAG process.

### 1.1 WAG process

Since 1950, the use of carbon dioxide for improving oil recoveries in petroleum reservoirs has been investigated. It is not surprising that the idea of using $CO_2$ to remove oil from underground reservoir is becoming more popular as carbon dioxide is one of the most plentiful and useful compounds on the planet (Holm, 1982). Hence the use of $CO_2$ for enhanced oil recovery becomes popular.

The major advantages of $CO_2$ miscible process are low MMP (Minimum Miscibility Pressure), swelling of reservoir oil and the reduction in viscosity of reservoir oil. Despite the advantages of $CO_2$ flooding, the poor sweep efficiency and high operation cost are two main disadvantages of using $CO_2$. The poor sweep efficacy results in the early breakthrough of gas. The low viscosity of $CO_2$ compared to reservoir oil causes viscous fingering that results in early breakthrough. The operation cost of $CO_2$ flooding is high compared to the oil price. Controlling the mobility of $CO_2$ to improve sweep efficiency and incremental oil recovery is a solution to reduce the unit costs of incremental oil due to $CO_2$.

The main problems affecting the effectiveness of $CO_2$ WAG process are early breakthrough, gravity segregation, viscous fingering, heterogeneity effects and phase behaviours (Stone, 1982), hence resulting in poorer sweep efficiency, and therefore inefficient oil recovery. To improve WAG process, breakthrough and viscous fingering should be controlled. A schematic of typical $CO_2$ WAG flooding process by alternate water and $CO_2$ is presented in Figure 1.

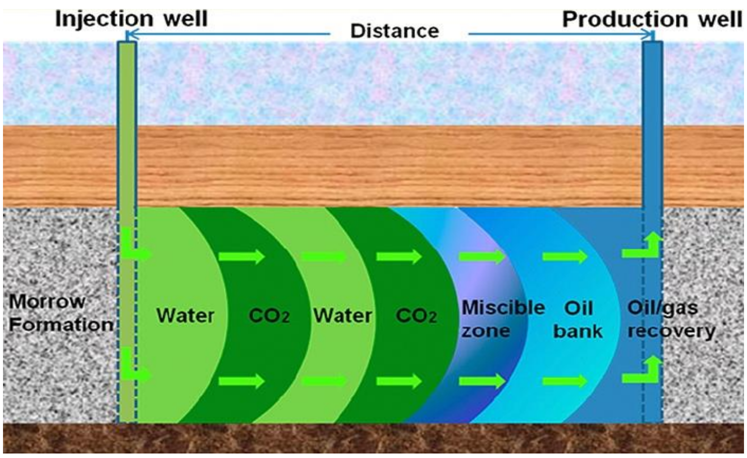


*Figure 1: Schematic of WAG process (Dai et al., 2013)*

### 1.2 Streaming potentials theory

The electrical double layer which forms at solid (mineral)-fluid interface was created streaming potentials in porous media (Hunter, 1981). A diffuse layer in the adjacent fluid (contains an excess of countercharge) was formed when the solid surfaces become electrically charged. If more than one fluid phase is present in the pore space, additional double layers may format fluid-fluid interfaces (Jaafar et al., 2009). If the fluid is persuaded to flow tangentially to the interface by an external potential gradient, and then some excess charge within the diffuse layer is transported with the flow, giving rise to a streaming current. Streaming potential is an accumulation of charge associated with divergence of the streaming current density establishes an electrical potential.

Measurements of streaming potential by using electrodes permanently installed downhole have recently been proposed as a promising new reservoir monitoring technology (Jackson et al., 2005). There are still significant uncertainties associated with the interpretation of the measurements, particularly concerning the magnitude and sign of the streaming potential coupling coefficient at high salinity (Saunders et al., 2008). Streaming potential measurements have been proposed as a method to characterise flow in the fractures adjacent to a borehole, and the pressure response of a reservoir during transient production test. In this research will focus on the use of streaming potential measurements to detect water and gas encroaching on a well during WAG process.

## 2. Monitoring WAG process

Implementation of tracer application in the reservoir system had been applied in various applications throughout the world. The tracer has been used successfully on many oil field systems to monitor and retrieve flow parameters, inter-well formation heterogeneity such as high permeability region and inter-zone communication regime (Abdullah et al., 2011). By using the tracer system, the understandings of fluid flow and WAG injection efficiency have been improved.

Tracers are best described as a unique reservoir compatible species that is foreign to the system. Once the reservoir has been injected by any fluid, the tracer will monitor the injected fluid and allows important information to be retrieved. Tracer can be divided into three categories which namely as radioactive, chemical and fluorescent (De Melo et al., 2001).

Radioactive tracer is the most commonly used system in the reservoir due to low detection level. Besides that, radioactive tracer is a molecule which contains one or more atoms that are radioactive. These atoms may emit radiation in extremely low energy beta particles. This radiation can be absorbed by even thin layer of plastic to more penetrating electromagnetic gamma radiation which can penetrate into several inches of metal.

Halogen is the most widely used in chemical tracer. Its detection level requires larger volumes as compared to radioactive tracer. Fluorescent tracer is safe and can be easily detected visually and affordable to purchase. This tracer can react with reservoir rock and it is limited to the noticeable fault or channel reservoir.

By using tracer, its take too long to know the performance of WAG process. Since the tracer was injected to the reservoir, we need to wait the tracer solution comes out at the producer. The process takes long time to finish since we need to wait the tracer comes out from the producing well. To save the time and cost, other alternative method for monitoring the WAG process is streaming potential signals.

## 3. Experimental set-up for streaming potential measurement

Glass bead was used as porous media. The range selected for the glass bead is 90 – 150 µm. The advantage of using glass beads is enhancing visual observation and providing consistent permeability and porosity (represent homogeneous reservoir). Glass beads also provide clear visual observation of displacement front.

The linear model is designed to simulate flow in a horizontal cross section of the reservoir. The model is made of Perspex which permits visual observation of the displacement behaviour. The perspex was glued to the cover by using araldite glue. The model is designed in order to have a packing volume (bulk volume). Mesh screens are placed at the inlet and outlet to prevent glass beads from coming out together with the fluid during injection experiments.

The quizix pump can be used to set any desired injection rate. The displacing fluids were pumped into one end of the model through injection port and the produced fluids were collected by collector tubes. The displaced fluids were displaced out through the other end of the model, collected, and measured in collectors. The fluids produced are water and oil. A few non-polarising Ag/AgCl electrodes are used to measure the voltage across the model. The electrodes are installed along the WAG model. Streaming potential signals are measured by using National Instrument Data Acquisition System (NIDAS). A pair of pressure transducers will be measured the pressure differences across the WAG model and the voltage across the model will be measured by using Ag/AgCl electrodes. The liquid system used in this study is paraffin oil to represent oil, brine to represent formation and injected water, and nitrogen represent gas phase. The liquid system and background around the model were adjusted to have a clear visual observation. The liquid used in the study were dyed. The oil in red colour, water in green and nitrogen will be left colourless. These colours allowed visual observation of the shape of the displacement front.

## 4. Results and discussion

The experiments are performed with brine solution, paraffin oil and nitrogen. Experiment are conducted by injected the brine solution and nitrogen alternately with ratio 1 : 1, 3 : 1, and 7 : 1. During the experiments, the electrokinetic signal are recorded and stored in the NIDAS.

At t = 0 s, pressure difference and voltage are at the initial value (Figure 2). Water is pumped at first. Since the pumping will starts, the pressure difference increases and slowly drop. It happens because of changing the phase from water to gas. For all the ratio of WAG, the pressure slowly drop at t = 2,400 s based on desired of slug size. The application of WAG does not only improve in terms of gas mobility reduction and oil recovery, profound effect can be too observed in terms of pressure maintenance as shown in Figure 2. Nitrogen was pumped to the model after the desired slug of water obtained. Since gas is compressible, higher pressure needed to continue displacement. Consequently, improves reservoir condition. The voltages also change, stabilising at the same as the pressure. The voltage reading changes close to the initial value because gas acts as a non-polar hydrocarbon.

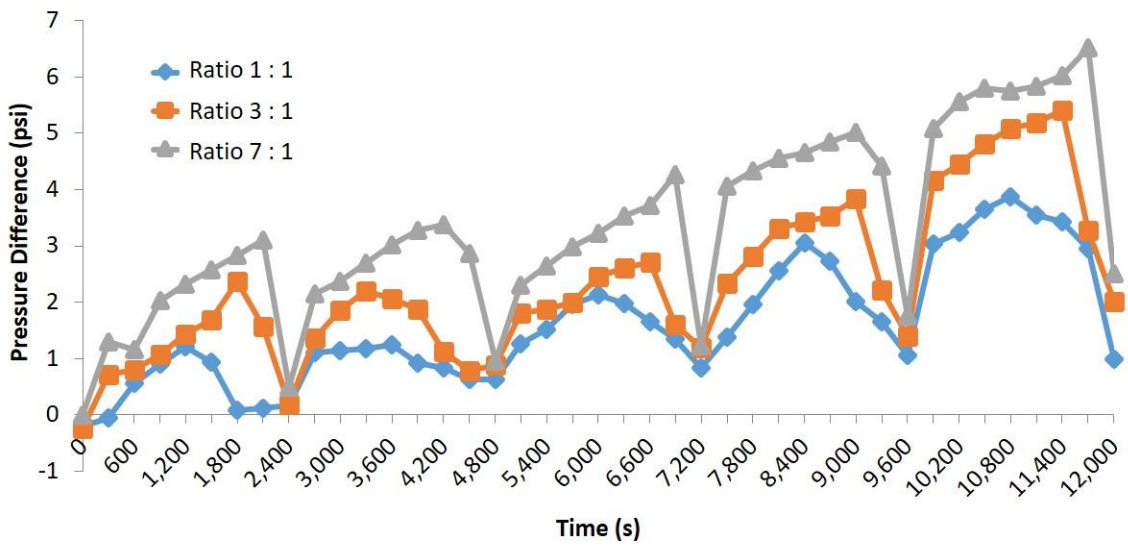


*Figure 2: Pressure difference during WAG Process*

Streaming potential signals will increase in the present of water and lower in the present of gas. Figure 3 shows the illustration for experimental result. WAG process with the ratio 7 (water) : 1 (gas) give a higher streaming potential reading compared to the ratio 1 : 1. It is because there a lot of free ion moving through porous media. Basically, when brine moves from high pressure region to a low pressure region through porous media, ions which are located in the diffuse layer of inside the pores are transported downstream. The movement of ions generates a streaming current in the direction of the flow and a streaming potential in the opposite direction. The coupling coefficient is the key parameter controlling the magnitude of the electrokinetic potential. It is simply the ratio of the streaming potential to the pressure gradient, when the total current density is zero.

The value streaming potential can be used to predict the early water fingering which can affect the performance of WAG process. Figure 4 shows the relationship between streaming potential with time during WAG process with ratio 1 : 1. At t = 0, the brine was pumped first until t = 1,200 s, followed by gas until t = 2,400 s. The value of voltage would be up and down when the time was increased. For the first slug of brine, the voltage for the electrode 1 higher than the voltage at electrode 2, because of the presence free ion at electrode 1. After a few slug, t = 3,600 s, electrode 1 measured the higher voltage, even though gas was pumped at that time. So, water fingering happened at t = 3,600 s. There are a few reasons that contributed water fingering such as heterogeneity and permeability of the porous media. Based on streaming potential reading, the effectiveness of WAG process can be monitored.

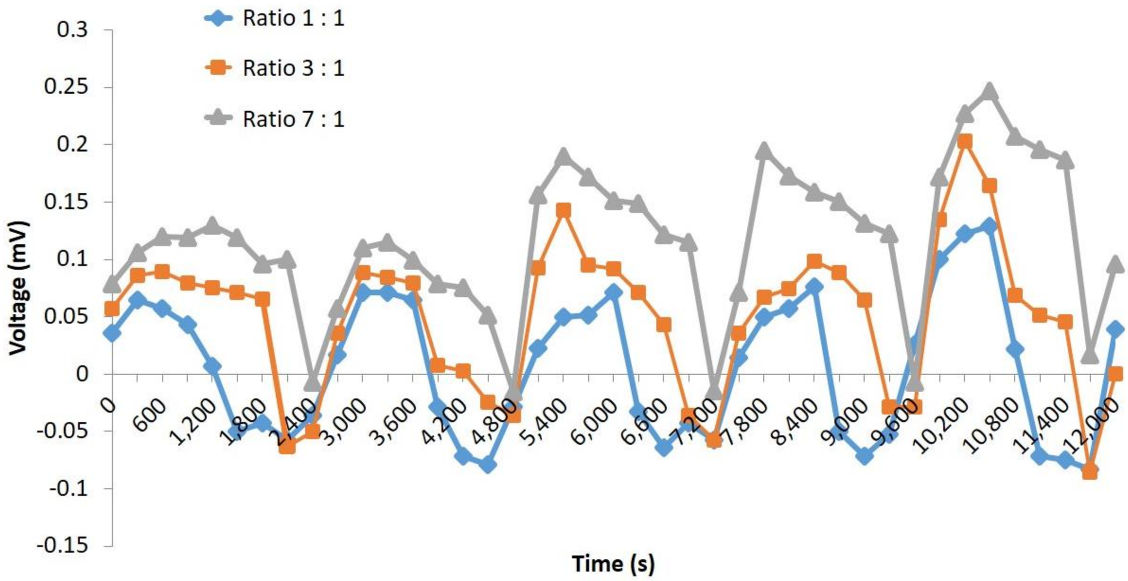


*Figure 3: The trend of voltage during WAG process*

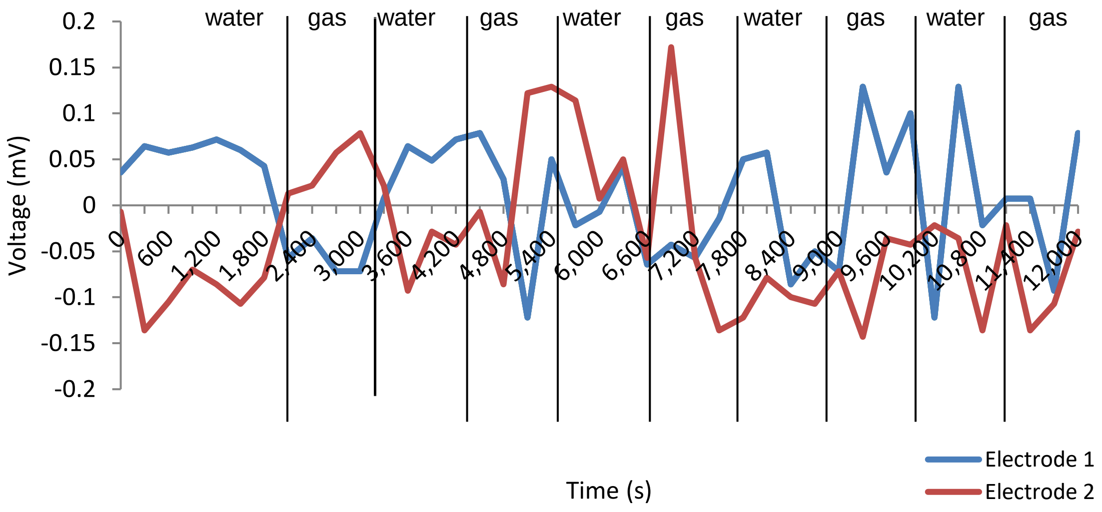


*Figure 4: The relationship between streaming potential and time*

## 5. Conclusion

This project could present new findings in the correlation study between streaming potential signal and waterfront progression during WAG process. This fundamental knowledge could lead to monitoring the progress of water and gas in a WAG process is key in the effectiveness of this enhanced oil recovery method. Measurement of the streaming potential provides another method besides using tracers to monitor the WAG profile. Better monitoring by using streaming potential will lead to more efficient displacement and great benefits in term of economy and environment.

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