Effect of Drag Reducing Agents (DRA) in Water Injection Well

By

Iz'aan 'Irfan bin Abd Rahman

Dissertation submitted in partial fulfilment of
the requirements for the
Bachelor of Engineering (Hons)
(Petroleum Engineering)
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CERTIFICATION OF APPROVAL

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Petroleum Engineering Programme
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(PETROLEUM ENGINEERING)

Approved by,

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MAY 2012

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

(_______________________________________)

IZ'AAN 'IRFAN BIN ABD RAHMAN

ABSTRACT

Applying drag reducing agent (DRA) into water injection system has improved injection capacity of wells by reducing the friction that occurs inside the well tubing. Many studies were conducted to understand the behaviour and optimise the performance of DRA when applied in multiphase flow. However, less study is being done to evaluate the effect of DRA on the formation, especially in the near wellbore zone. It is expected that DRA in injected water will cause permeability reduction, albeit the factor and exact percentage of reduction are subject to the current study. A water injection system using core flood equipment was used in this work. Polyacrylamide (PAM) and polysaccharide (Xanthan Gum) were mechanically degraded under high shear rates before injected into the core to simulate field condition. Injection rates were varied so that the relationship between permeability reduction and the rates could be established. It is found that low injection rate of 1cc/min gives more permeability reduction compared to high injection rates at 5cc/min, while Xanthan gum DRA solution gives more permeability reduction compared to polysaccharide DRA solution. Backflow was performed to restore core permeability, but the permeability restored was less than initial permeability. CT scan was run to study the permeability reduction of the core. However, no significant difference was observed. It is suggested that the injection rates need to be considered when designing the water injection wells with DRA additives.

ACKNOWLEDGEMENT

Bissmillahirrahmanirrahim,

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CHAPTER 1

INTRODUCTION

1.1 Background Study

The study of friction drag reducer is one of the most important knowledge in catering the hydrodynamic problem of flow, especially when dealing with the real field application. In that sense, drag reducing agents was one of the way to treat such problem. Drag reducing agents (DRA) are one of the most beneficial additives which reduce the friction force, particularly in improving the flow of fluid inside the pipeline. It was spotted in the literature by Toms in 1948, while he was studying the mechanical degradation of polymer molecules at high Reynolds number in a simple pipe flow apparatus. After that, the usage of DRA was vastly developed, and used in several applications such as:

1. Fire fighting hoses

   Polyethylene oxide (PEO) was shown in the 1960s to be very effective in fire hose streams, providing spectacular increases in hose stream pressure, reach, and volume.
2. Agriculture and Industrial Waste

   Transported waste in agriculture industry was improved and proven most cost effective way just by using a small amount of insoluble drag reducing polymers.
3. Possible Medical Application
   a) Kamenva et al. 2004 "Blood soluble drag-reducing polymers prevent lethality from hemorrhagic shock in acute animal experiments," Biorheology vol 41 p.53-64
   b) Unthank et al. 1992 "Improvement of flow through arterial stenoses by drag reducing agents," J. Surg. Res. vol 53 , p. 625–630

In oil and gas industry, knowing the fact that DRA could decrease the frictional force inside the pipeline, thus most of the problem associating with limitation in hydrocarbon volume transported could be fixed, without having to upgrade the whole pipeline system. In such case, the Trans-Alaska Pipeline System case, one of the largest pipeline systems in the world, has proven the DRA capability in solving the problem. (Adrian, 2008) The pipeline was constructed in 1977 to move oil from the North Slope of Alaska to the northern most ice-free port in Valdez, Alaska. Due to the attribute of DRA in the oil flow inside the pipeline, the flow increase from 1.44 MMSTB/day to 2.136 MMSTB/day, which around 48 % increase in oil volume transported per day.

Figure 1: Trans-Alaska Pipeline System

The latest development in DRA was the usage in water injection wells, in order to increase volume of water capacity injected into the reservoir, thus maintaining the pressure of the formation. The application of DRA in the water injection water was also a success, and proven by several case study. The author will discuss the case study later in this paper.

1.2 Problem Statement

Majority of the study regarding the application of DRA in the water injection wells, focussed on the effect of DRA inside the pipeline, and the working principle of polymer towards the wall of the pipe. Unfortunately, DRA which is mixed together with the water in injection wells will flow to the formation, thus creating some reduction towards the permeability. However, less study was done to evaluate the behaviour of DRA entering the reservoir rock.

Current literatures suggest that permeability reduction is a function of DRA concentration, in which the evaluation was made towards high permeability and low permeability core samples using the core flood experiments. Nonetheless, it is also expected that permeability reduction can be affected by injection rate of DRA towards the formation. This paper will study the effect of injection rate towards the permeability reduction using two different type of polymer DRAs which is polyacrylamide (PAM), and polysaccharide (Xanthan gum). The author will try to simulate the real field situation in which the DRA efficiency will be affected, and the coreflooding experiment will be evaluated over two different sets of permeability value; a high permeability core, and a low permeability core.

1.3 Objectives and Scope of Work

1. To study the effect permeability reduction of DRA in injection wells. The parameters are:
    a. Effect of injection flow rates.
    b. Effect of different DRA polymers.
2. To study the extend of permeability damage via visualisation method. (CT Scan).
3. To measure the permeability recovery after reverse flow technique.

1.4 Project Relevance and Feasibility

Relevance

- Polymer is widely used in oil and gas industry
- Studies will govern the behavior of very dilute polymer solution (DRA).
- Results will be beneficial to the industry as DRA is more cost effective.

Feasibility

- Project can be finished within timeframe of FYP 1 and FYP 2.
- Equipments are available
- Both polymers are also already available in the lab.

CHAPTER 2

LITERATURE REVIEW

2.1 DRA in General

Drag reducing agents can be used as flow improvers in pipeline, in either oil or water based system. Perhaps, the usage is most typical in increasing the oil transport capacity, by addition of small amount of high molecular weight polymer. Oskarsson (2005), gives justification on the usage of polymer as flow improvers inside the pipeline. With a small amount of polymers (10ppm-30ppm) injected into the flowing system of pipeline, significant pressure drop can be achieve, thus increasing the transported volume of oil. However, the fact is that polymer cannot withstand the high temperature and high mechanical degradation, and current literature suggest for a change from using the polymer towards using another DRA alternative, which is surfactant. Nonetheless, for the sake of this study, the author will limit the study on the usage of polymer as DRA, and will be studying on two types of polymer which are polyacrylamide (PAM) and polysaccharide (Xanthan gum)

Figure 2: PAM (left) and Xanthan gum (right) in powder form.

In early days, the drag reducing agents was first written in the literature, when Toms accidently observe the effect in his study of mechanical degradation of polymer inside a flow of a pipe. (Toms, 1948) In his experiments, he found it is a fascinating fact that in a single phase turbulence flow, an addition of small amount of long-chain polymer into the flowing fluid, can give a very large decrease in the frictional resistance near the wall of a pipe. However, the extend of polymer effectiveness inside the turbulence flow was handicapped through the circulation into the pump, and also the disturbance of injection probe towards the flow in the pipe. (Warholic et al., 1999) This is a result in the high degree of mechanical shear rate, which most polymers cannot withstand. Later, more detailed study was conducted on the subject of drag reducer on different type of pipe geometry, and ways to evaluate the polymer degradation system. Previous studies done by Rudd (1972) and Logan (1972) in square pipes and by Reischman and Tiederman (1975) in a rectangular channel (1975) found that by using laser-Doppler velocitymetry, flow intrusion can be eluded. On the other hand, Willmarth (Willmarth et al. 1987; Wei and Willmarth 1992) in the recent studies conducted found that injection of polymer DRA through slots near to the wall at the inlet could actually avoid degradation of the polymer, when looping flow inside the pipe. With this improvement in knowledge of DRA behaviour inside the pipeline, more application of DRA was develop to be efficient, and cost effective.

In the oil and gas application, the works on drag reducer was first written by Savins (Savins, 1964). He defines the drag reduction theory as the increase in pump-ability of a fluid caused by the addition of small amounts of another substance, such as high molecular weight polymers, to the fluid. His works agree to the fact of previous study but more subtle for the study of transported hydrocarbon inside the pipeline, with the effect of macromolecules injection such polymers to reduce the drag, thus increase the pump efficiency.

With the application of DRA which are immense in the oil and gas industry, instead of applying DRA in the transportation pipeline, engineers start to apply the DRA in the water injection system, with the same hypothesis of increment in volume of water transported into the formation, and the results is bright. Nelson (Nelson, 2003), define the application of DRA in the pipeline system, as the reduction of pressure drop over a length of pipeline due to traces of dissolve polymer inside the fluid transported. Towards his research of application of DRA inside pipeline, he found 4 factors which govern the degree of drag reduction, which are the solubility of polymer in continuous phase, effectiveness of dispersing the polymer DRA, the molecular weight of the polymers, and the concentration of the polymers. The author will discuss the findings in details later in the chapter.

2.2 DRA Working Principles

2.2.1 In Pipeline

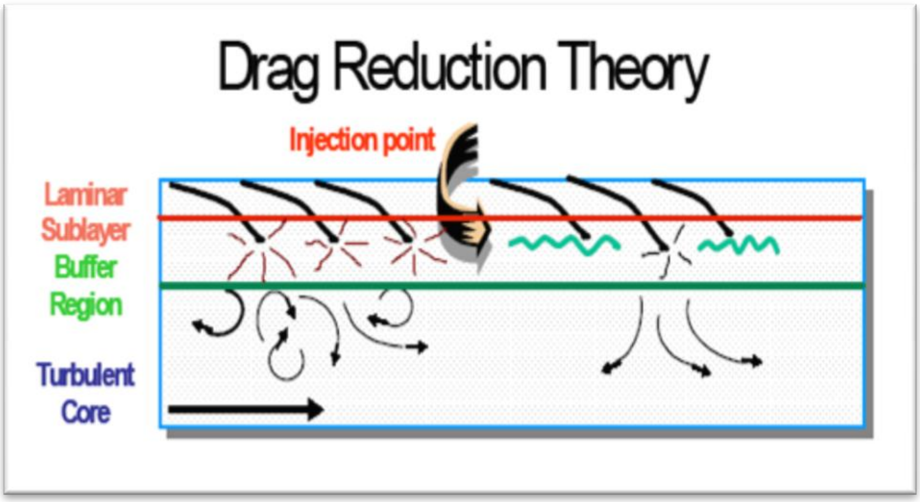

Figure 3: Drag reduction in pipeline.

In a transported fluid pipeline, turbulent flow increased the friction force of fluid flow inside the tubing, hence lowering the transported fluid flow rate. The phenomenon occurs as the flow velocity increase, which bring the friction between the boundary layer near to solid surface of the pipeline to also increase. Due to the turbulence flow, energy losses will be encounter, and can be in a very high magnitude. For a liquid flow, there exists a viscous sub-layer of laminar flow near the pipe wall. Next to this is an intermediate or elastic sub-layer (buffer region), and in the middle is the turbulent core. (Bewersdoff and Berman, 1988). DRA work by reducing the frequency of eddy burst from the pipe wall sub-layer, which helps to modify and stabilize this flow region, thus the rate of energy dissipation within the eddy flow can be reduced. Hence the pressure drop will also reduce. (Ohlendorf, 1986). However, drag reduction occurrence only happen in a turbulent flow system. (Al-Anazi, 2006)

Following the same working principles as in transported pipeline, DRA can be applied in the water injection system. In a water injection system, the maximum water flow rate that can be injected to maintain the reservoir pressure might be limited by the capability of water injection pump, injection well tubing size, and the reservoir characteristic. (Nelson, 2003). The problem can be solved by injecting DRA downstream into the injection tubing, which then will help to reduce the pressure drop. As a result, the water injection rate can be increased until the maximum allowable operating pressure of the injection system is reached.

In another point of view, DRA can also increase the water disposal rate, especially in a mature field, which normally produce high volume of water. Injection of DRA into the produce water will help the increasing the rate of water disposal into the aquifer, or abandoned reservoir. (Nelson, 2003)

2.2.2 In Formation

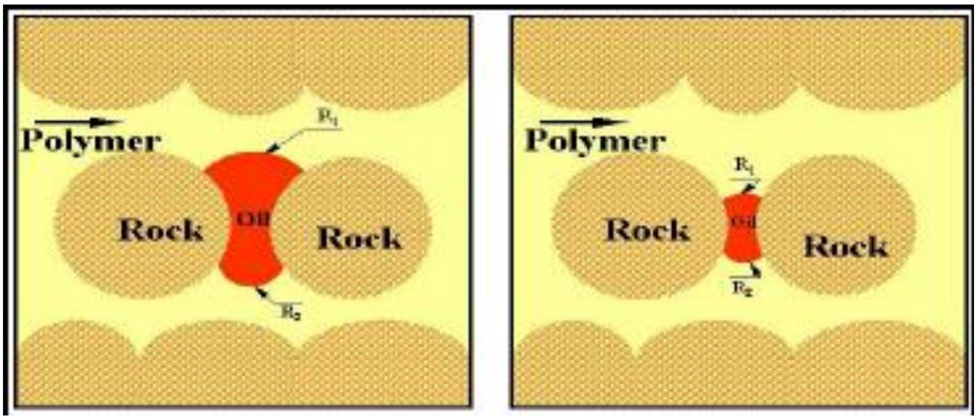

Figure 4: DRA application in water flooding.

Researches suggest using DRA in water flooding system, in order to increase the sweep efficiency of water towards the oil. (Nelson, 2003) Water flooding is an almost the same process of water injection system, but having different objective. In water injection system, the water is injected continuously to maintain the reservoir pressure; however, in water flooding, the water is injected in a large slug, in order to form a vertical water front, and pushed the oil towards the production system.

The concept behind water flooding is that the mobility ratio of water must be less than the mobility ratio of driven fluid, which is oil in the formation. In most cases, the problem of water flooding occurs as the viscosity of driven fluid (oil), is high enough, creating channel or finger of water through hydrocarbon, that will simply bypassing the oil inside the pore space. In order to solve the problem, DRA is apply into the water flooding system, and will act as a viscosifier, and as a result, hydrocarbon is more likely to be sweep towards the producing wells.

2.3 Field Case Study using DRA

2.3.1 Ukpokiti Field, Niger Delta

Located in Western Niger Delta offshore, Ukpokiti is found to have around 500 MMSTB recoverable oil reserve, and was first drilled in late 1992. The first discovery well drilled was found to have one gas bearing zone, and two oil bearing formation. In the field development project, the field was supposed to flood the reservoir with 40,000 bbl/day, however during the initiation of the project, the facilities installed could only deliver up to 31,000 bbl/day. Looking through all aspect of the problem, the solution which the company choose was to use the Conoco Drag Reducer (CDR).

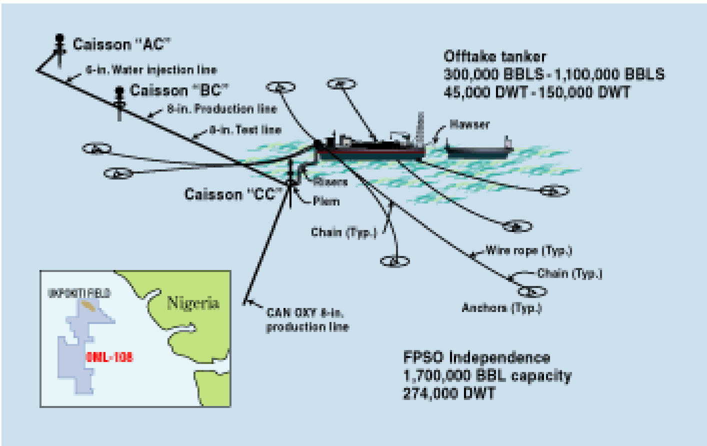

Figure 5: Ukpokiti Field, Niger Delta

Before the CDR was applied, several test was done to evaluate the solution. The first test was the fluid incompatibility test to determine the reason behind loss of injectivity. Some of the water from the injection water treatment system was taken, and they found several factor causing the lower injection rate. The first conclusion that they have made is that they is fluid incompatibility, which produce a heavy emulsion at 95°F. They also found that acid which they had been used in the previous treatment to restore the injectivity produces solid mixture when added to the emulsion, and they decided not to use acid in further treatment.

The second test was pressure fall-off test, and the analyzed result shows no skin or damage problem. Salinity from the injection water and the formation aquifer was also found to be different, eliminating the possibility of water breakthrough. Using the Watson test, the company concluded that, the CDR is compatible with other chemicals used in this project, and shows no negative impact on both the operation, and the environment.

The lab test showed that injection of 15-20 ppm of CDR could achieve the optimum injection rate. Once the commencement of the project, the CDR was pump with 20 ppm of CDR for 24 hours, following with 15 ppm of CDR in the next 24 hours, the results shows that injection of water with CDR decrease drag reduction up to 11%, which an indicator that water injection rate is increasing. (Joseph, and Ajienka, 2010)

2.3.2 Chevron Texaco Galley Field

The Galley field, situates in east-north-east of Peterhead, Scotland has an estimated of 57.5 MMBBL, and 80.4 Bcf in place, while recoverable reserve of 28 MMBBL, and 40.2 Bcf. Field production was begin in 1998 and reached its peak of 43,000 boe/day in 2000.

The water injection system consist of 2.2 km of 6 inch tubing from the platform to the subsea manifold, continued with 4.8 inch of injection tubing from the subsea manifold to the injection wells with depth of 5500 metres. Initially, the water injection rate without DRA was found to be around 29,000 bbl/day and thus results in an average 39,000 bbl/day of production rate. In late 2000, the pressure of reservoir falling thus lowers the oil production rate, and there is a need to re-pressurize the reservoir. The result from calculation shows that the reservoir need to be injected with 40,000 bbl/day of water, and could be achieve with injection of 45ppmv of DRA. Once the project was implemented, Chevron Texaco proved that they are able to re-pressurize back the reservoir, and continue with 39,000 bbl/day of production rate. In addition to that, the expected life of the reservoir also has been extended by 3 years, and the recoverable reserve is also increase. (Nelson, 2003)

2.4 Evaluation of DRA in Core Sample

Studies shows there are several impact of DRA upon the formation, and evaluation of DRA in core sample is crucial. Nelson (Nelson, 2003) in his study, reported that there are small permeability reduction occurs on the core after injecting 100ppm of DRA, and concluded that it was within the acceptable limit which was set by Chevron Texaco. More detail study was conducted by Al-Anazi (Al-Anazi, 2006), which concluded that permeability reduction is a function of DRA concentration, and can be restored by backflowing through the core, with the same volume of water initially injected. Another important finding is that, the broken DRA gives less impact on permeability reduction compare to the fresh DRA. Broken DRA was used to simulate the real condition of DRA which mechanically degraded after flowing through pumps, and elbow of the piping before injected to the reservoir, while fresh DRA considered being in the worst case scenario. However, the test did not mention about the injection rate used in the test, and the injection rate used in the recovering process, limiting the conclusion of the degree permeability reduction by other factors.

2.5 Performance of DRA

Performance of drag reduction in pipelines can be evaluated using the following formula (Savins, 1964), given that ΔP is the initial pressure drop of the untreated fluid, and ΔP_{DRA} is the pressure drop during fluid treated with DRA,

$$\%DR = \frac{\Delta P - \Delta P_{DRA}}{\Delta P} \times 100$$

The flow increase also can be estimated using a formula designed by Lescarboura (Lescarboura, 1971), relating the %DR design by Savins. The formula is as follow

$$\%FI = \left[\left(\frac{100}{100 - \%DR}\right)^{0.556} - 1\right] \times 100$$

In order to evaluate the permeability reduction, the author going to use the formula built by Chauveteau (Chauveteau, 1995), given that K_b is the initial brine permeability to the core, while K_f is the final permeability of brine after the injection of DRA towards the core.

$$Permeability\ Reduction = \frac{K_b}{K_f}$$

CHAPTER 3

METHODOLOGY

3.1 Research Methodology

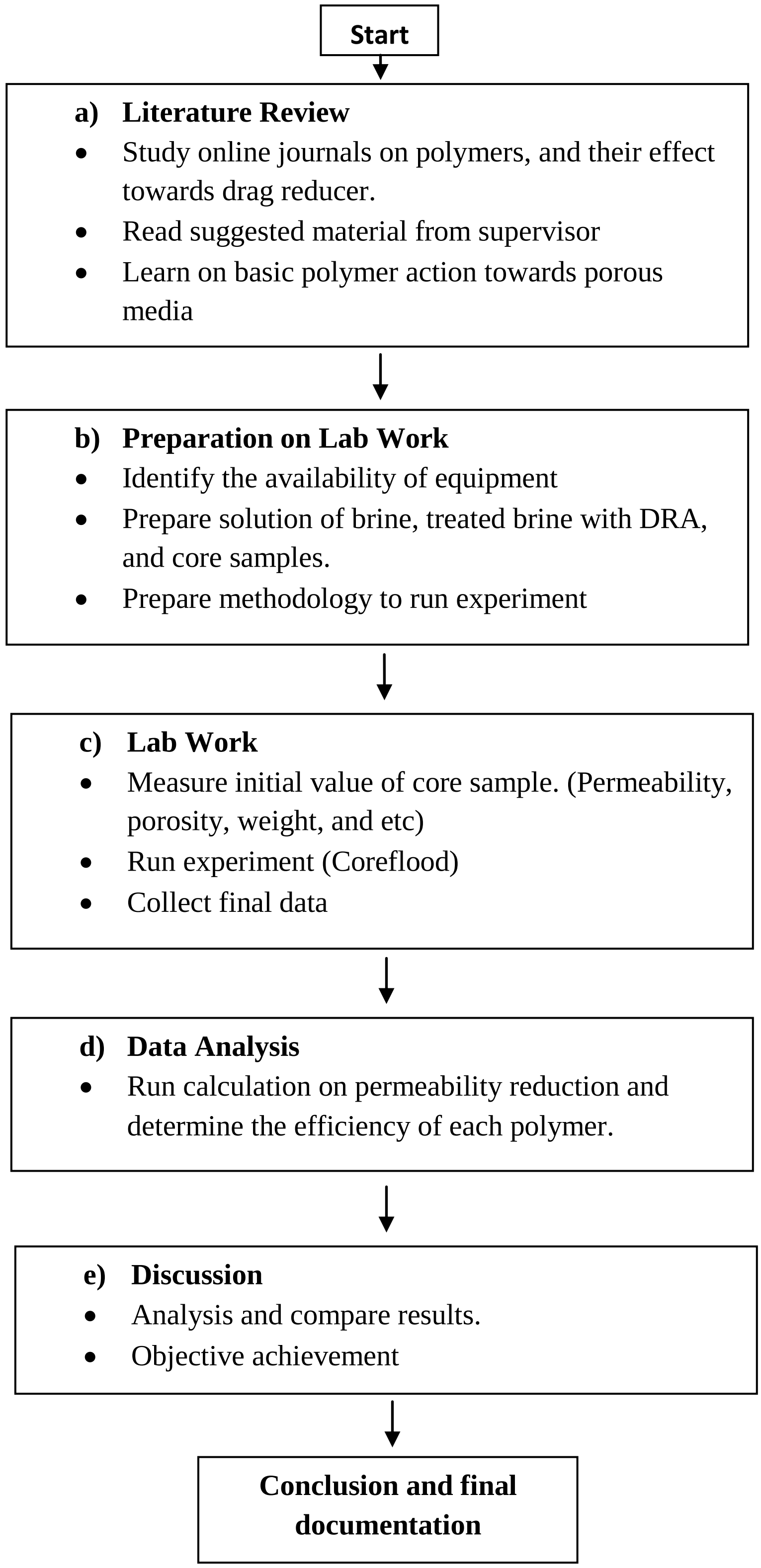

Figure 6: FYP flow chart on research methodology

3.2 Gantt Chart

	2011					2012			
Activity	**Jan**	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**
Selection of FYP title	■	■								
Literature Review		■	■							
Submission of Peliminary Report			■							
Lab Work Preparation			■							
Submission of Interim Report				■	■					
Experimental Work					■	■	■			
Submission of Progress Report						■	■	■		
Discussion and Calculation on the outcomes						■	■	■		
Oral Presentation									■	
Report Documentation										■

	2011						2012			
Milestone	**Jan**	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**
Completion of Interim Report (FYP 1)					■					
Experiment with high permeability core					■	■				
Experiment with low permeability core						■	■			
Report Documentation								■	■	■

3.3 Project Activities

Task	**Objective**	**Expected Result**
Effect of injection rate	To measure optimum injection rate between two DRAs	Increasing injection rate will increase permeability reduction
Effect of different polymer type	To study the different DRA effect in core sample.	Polysaccharide DRA shows more damage in permeability compared to polyacrylamide DRA
CT Scanning upon core with highest permeability damage	To visualize and assess the characteristic of permeability reduction	Justify the above expected results
Measure permeability recovery	To assess the percentage of permeability recovery after each run.	High permeability core under low flow rate recovers more permeability than low permeability core under high flow rates.

Table 1: Summary of project activities

3.4 Equipments and Consumables

There are 2 main equipments used in the experiments, which are POROPERM, and FDS, and 3 type of consumables needed for the testing which are, polyacrylamide, polysaccharide, and 11000 ppm brine. The author will discuss the used of the equipment and consumables later in this chapter.

3.4.1 POROPERM

Figure 7: POROPERM in GPE laboratory

The POROPERM instrument is a permeameter and porosimeter used to determine properties of plug sized core samples at ambient confining pressure. All the parameters measured will then transferred to the software, and users can gather the data of the core without hassle. Below are the parameters which the equipment able to measure.

Direct measurements:

- Gas permeability (mD)
- Pore volume
- Core length and diameter

Calculated parameters:

- Klinkenberg slip factor "b"
- Klinkenberg corrected permeability
- Inertial coefficients

- Sample bulk volume
- Sample porosity

Grain volume

Grain density (assuming sample is weighed)

3.4.2 Benchtop Permeability System

Figure 8: Benchtop Permeability System

The Benchtop Permeability System (BPS) is designed for permeability testing of core samples, at ambient conditions of temperature. Tests that can be performed with the system include initial oil saturation, secondary water flooding, and before-and-after permeability measurement. Brine, oil, drilling mud, gels, or other fluids can be injected into and through the core sample.

BPS is the equipment needed for the formation damage experiment. As the core will be flooded with treated brine and polymer, there is expected to be a significant permeability reduction, and this reduction will be measured by BPS. On the other hand, the permeability restoration will also be measured by BPS after the backflow of the brine.

3.4.3 InspeXio SMX 225 CT Scanner (CT Scan)

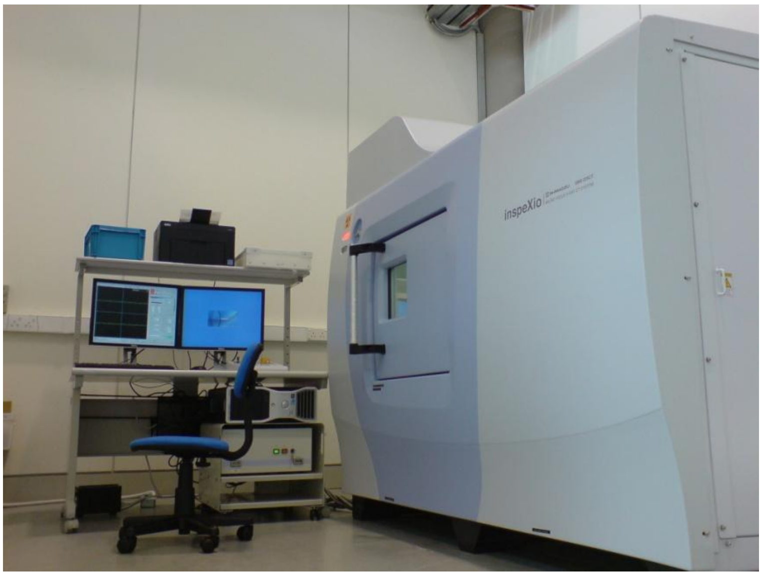

Figure 9: InspeXio SMX 225 CT Scanner

InspeXio SMX 225 CT Scanner is the most advance technology of CT scanning available in the market. As for its name, CT Scan emits a series of X-ray to scan anything, within its acceptable size limit. The CT scan works by calculating different in density inside the core. The CT scan will be used to scan the core after being damage by the DRA, in order to see the extend of the permeability reduction, occurs inside the core at different injection rate.

3.4.3 Brine

The brine is prepared by diluting 11g of normal salt (NaCl) into 1 litre of distilled water, and mixed with a magnetic stirrer. This would result in 11000ppm of brine, which considered to be low salinity brine. In this experiment, the salinity of the brine will be fixed at 110000ppm at each run.

3.4.4 Polyacrylamide

The solution is prepared according to the methods by Al-Anazi et al. [2], and Ogunberu A.L et al. [k] The fresh DRA was prepared by mixing 0.05g polyacrylamide (powder form) into 1 litre of prepared brine, and mixed gently with a magnetic stirrer for 4 hours. Then the solution is kept overnight for complete hydration. Each time before each run, the fresh DRA will be broken at high shear rate using a blender to simulate the real condition of DRA in the field use. All run will be conducted at the same concentration of 50ppm polyacrylamide, with the broken condition.

3.4.5 Polysaccharide

Polysaccharide used in this experiment is Xanthan gum, which oftenly used to thicken the mud. The solution follows the same steps as in preparing the solution of polyacrylamide, with the same concentration of 50ppm.

3.5 Experiments Procedures

The experiment is divided into two section, the coreflooding test, and CT scanning technique.

3.5.1 Coreflooding Test

For coreflooding test, we are using only low permeability core. We define low permeability core as core which having permeability 50md or less.

The procedure are as follow:

1. Clean the core with core cleaner, and dry the core inside the oven overnight.
2. Scanned the core with CT Scan for base condition view of core sample.
3. Measure initial K, Φ, weight of the high permeability core with POROPERM.
4. Saturate the core with brine using desiccators, for at least one day.
5. Flood the core using BPS with brine at constant injection rate, to get the initial brine permeability in the core.
6. Inject the core with 100ml solution of broken polyacrylamide DRA using BPS at constant injection rate of 1.0ml/min
7. Take out the core from the core holder, and let some brine passing through BPS system to clean the tubing from DRA solution.
8. Reverse the core position in BPS core holder, and start to inject 200ml of normal brine at the injection rate of 10ml/min to restore the permeability
9. Record the data at all injection steps, and produce permeability versus time graph for each steps.
10. Repeat step 1 until step 9 using injection rate of 3ml/min, and 5ml/min.
11. After finished the first section, repeat the whole experiment using Xanthan DRA solution.

The summary of the coreflooding experiment is as follows:

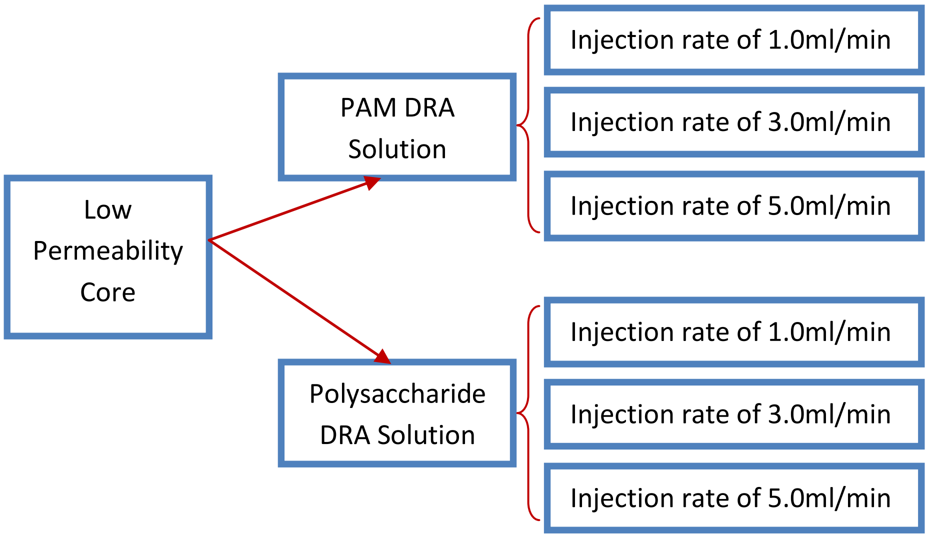

Figure 10: Summary of core flooding experiments

3.5.2 CT Scanning Technique

For the experiment, the test is conducted only for the core which having the highest permeability reduction. The coreflooding experiment will be repeated again for the condition of highest permeability reduction, but this time the core will be scanned several times. Below is the schedule for core scanning test:

1. Initial dry core cross-section view
2. Core cross-section view after water flooding
3. Core cross-section view after DRA flooding

The core permeability reduction behaviour will be evaluated in the middle of the core using computer software.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Effect of Injection Rates and Recovery

The permeability and pressure difference versus time was recorded using BPS, and the initial permeability was averaged. The reduction on permeability was calculated by the dividing the permeability reading during DRA flooding with the average initial permeability. The author sets to constantly flood the core with only 100cc of DRA solution in brine, in order to see the effect of permeability reduction at different injection rate. For permeability recovery, backflowing process was done by flooding 200cc of brine at constant rate of 10cc/min in reverse direction. The final permeability after recovery process was collected and averaged, and the percentage of permeability recovered was calculated by dividing the averaged permeability after recovery with the initial permeability.

4.1.1 Effect of Injection rate on PAM DRA Solution

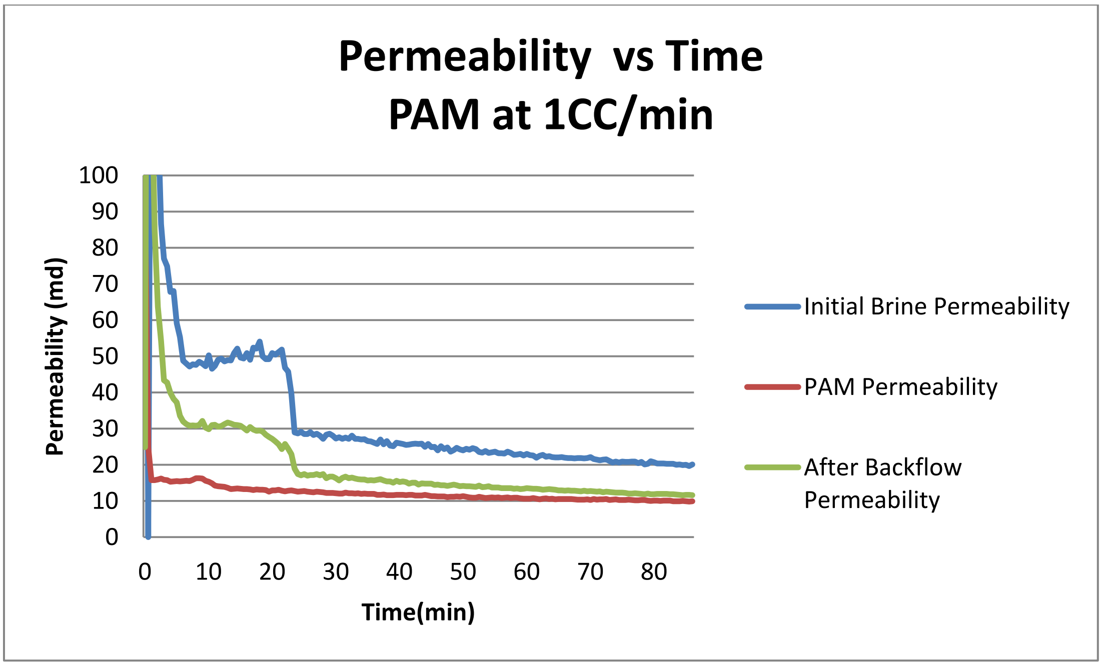

Figure 11: Permeability versus time of PAM DRA at 1cc/min

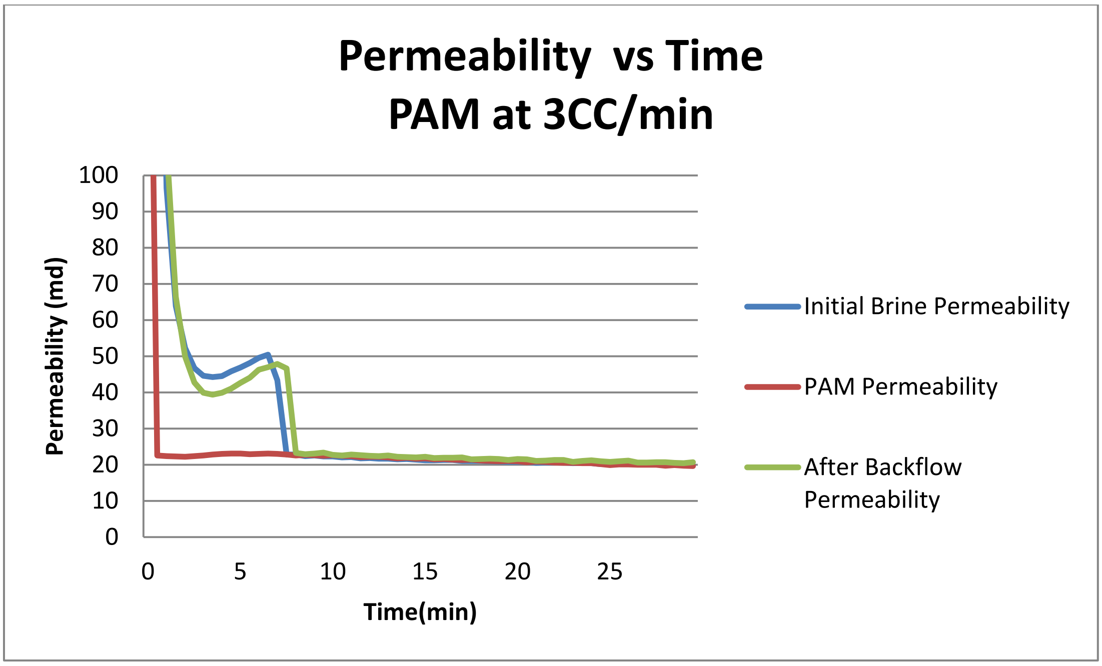

Figure 12: Permeability versus time of PAM DRA at 3cc/min

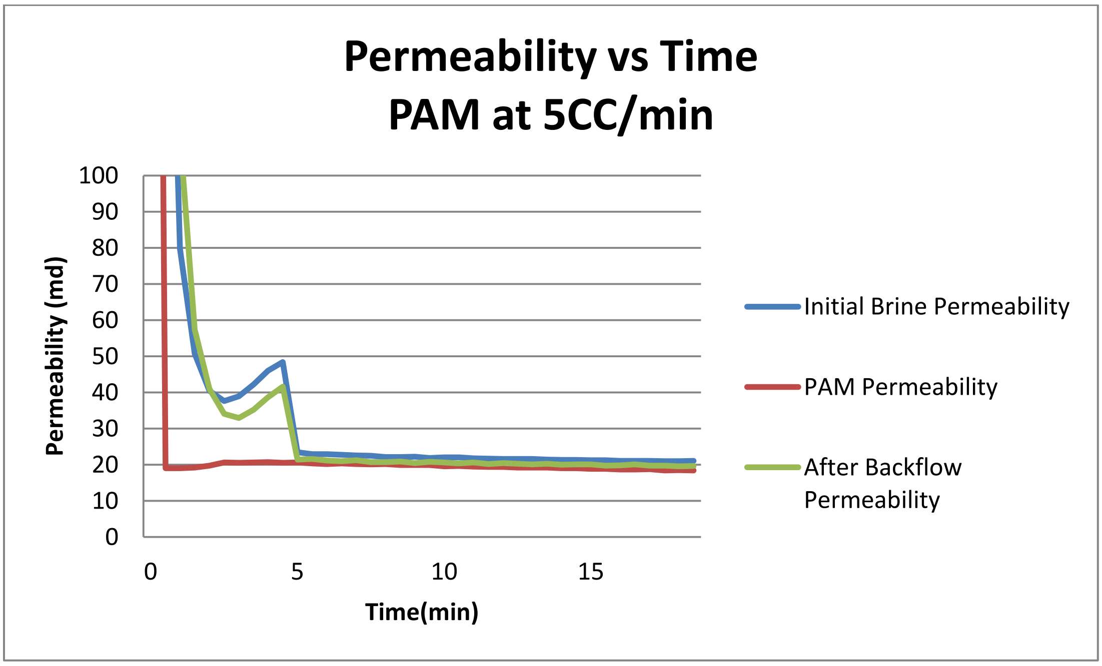

Figure 13: Permeability versus time of PAM DRA at 5cc/min

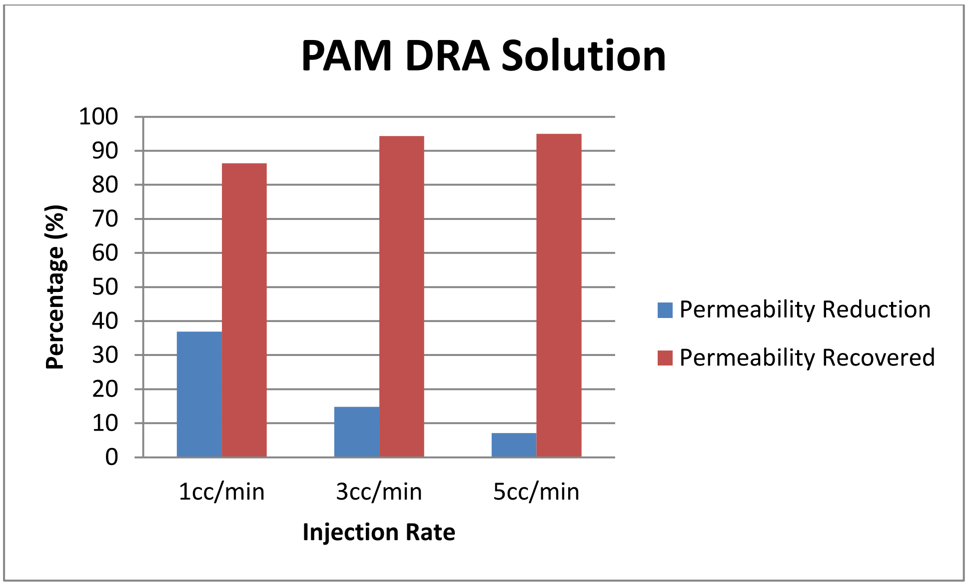

Figure 14: Permeability reduction and recovered versus injection rate of PAM DRA Solution

Experiment results shows permeability reduction of 36.89% for 1cc/min injection rate, 7.93 % for 3cc/min injection rate, and 7.08% for 5 cc/min injection rate. While for recovery process, permeability recovered was found to be 86.32 % for 1cc/min injection rate, 94.31 % for 3cc/min injection rate, and 94.9% for 5cc/min injection rate.

4.1.2 Effect of Injection rate on Xanthan DRA Solution

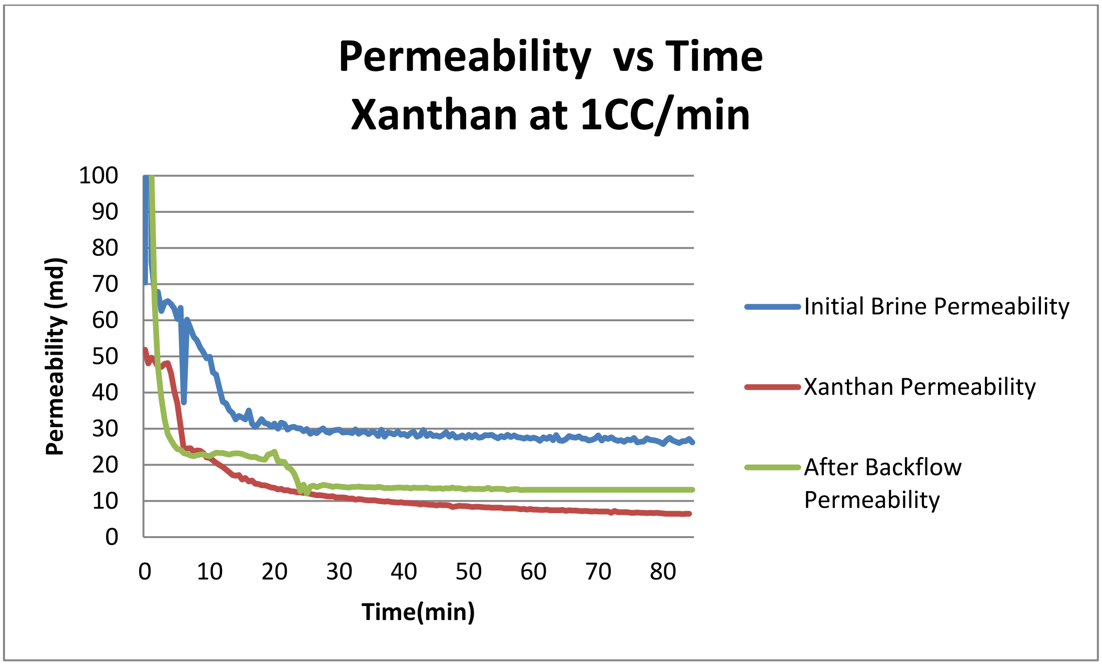

Figure 15: Permeability versus time of Xanthan DRA at 1cc/min

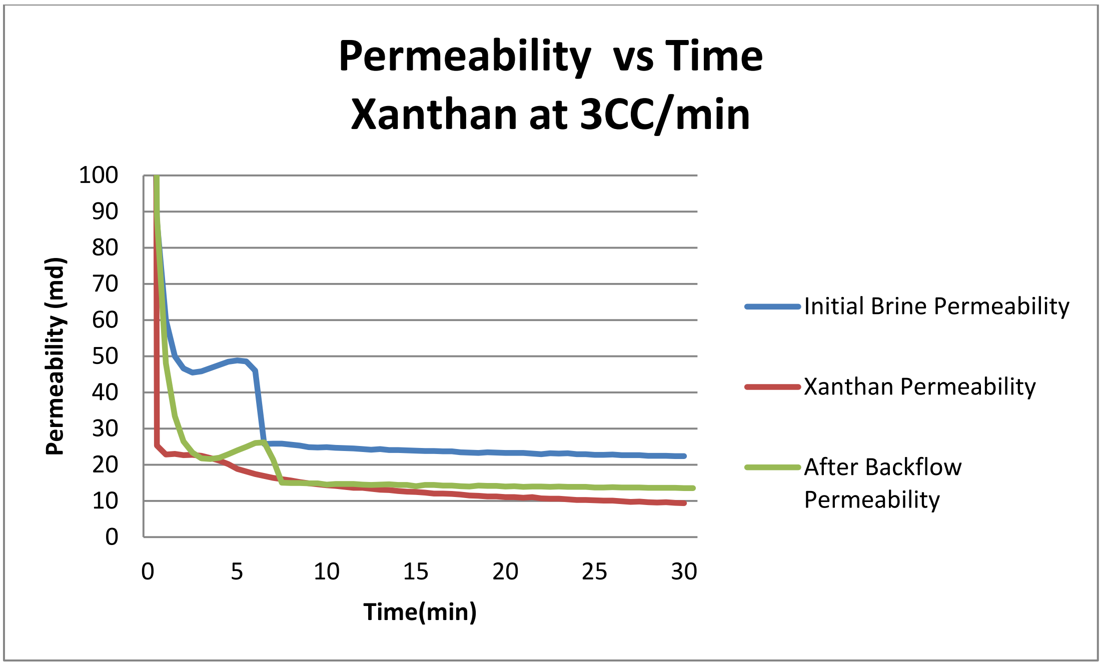

Figure 16: Permeability versus time of Xanthan DRA at 3cc/min

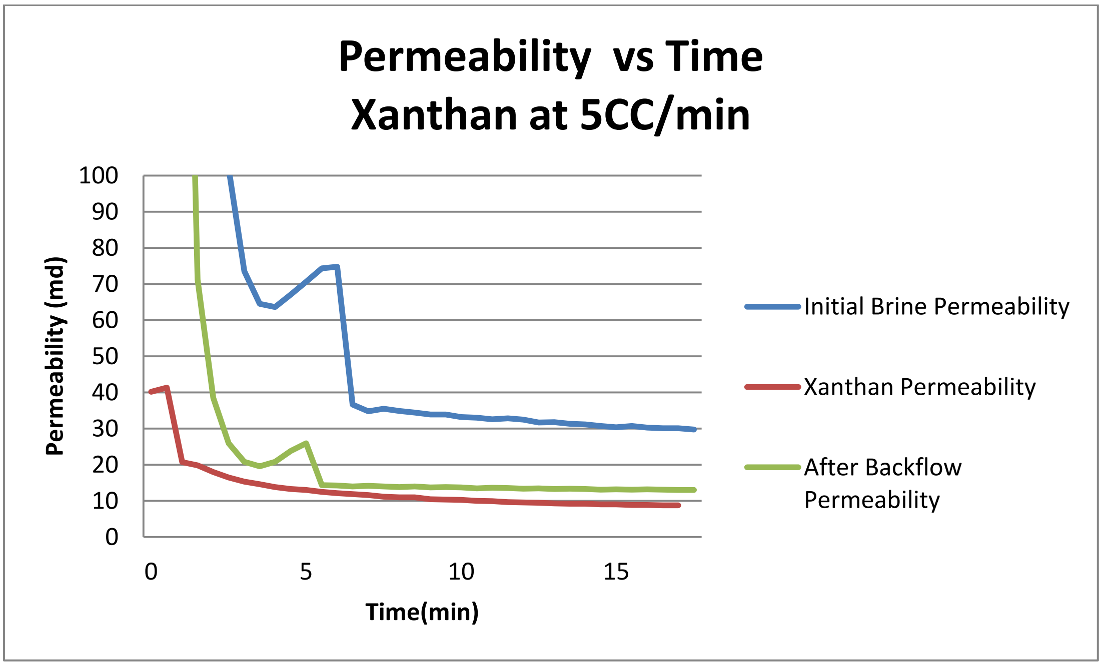

Figure 17: Permeability versus time of Xanthan DRA at 5cc/min

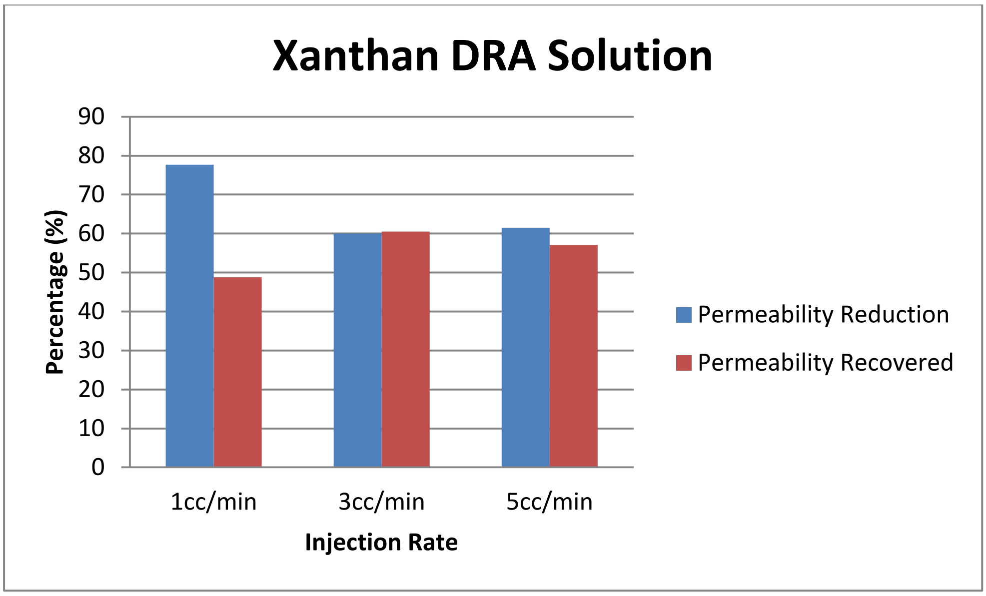

Figure 18: Permeability reduction and recovered versus injection rate of Xanthan DRA Solution

Experiment results shows permeability reduction of 77.63% for 1cc/min injection rate, 59.98 % for 3cc/min injection rate, and 61.46% for 5 cc/min injection rate. While for recovery process, permeability recovered was found to be 48.76 % for 1cc/min injection rate, 60.49 % for 3cc/min injection rate, and 57.06% for 5cc/min injection rate.

4.2 Effect of Different Type of Polymer

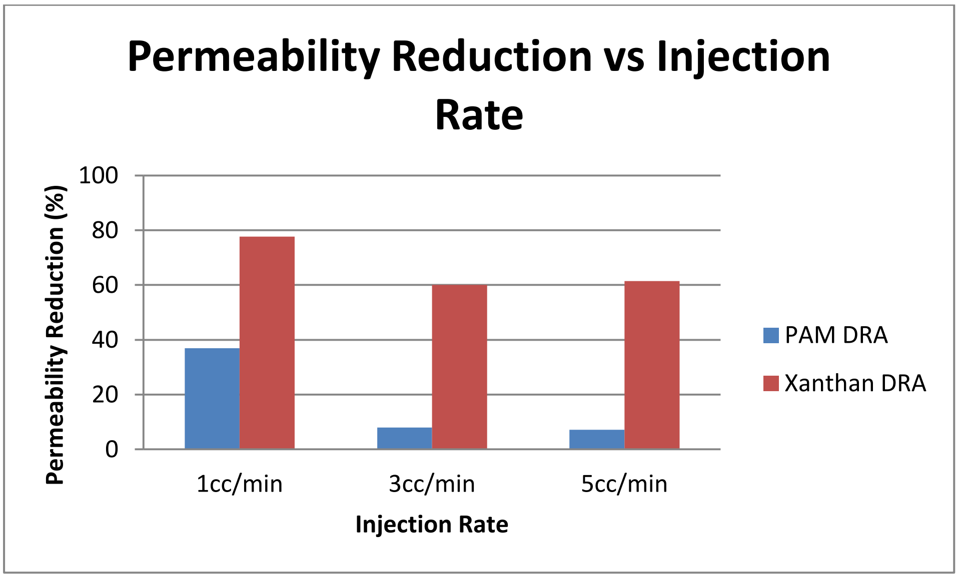

Figure 19: Comparison between permeability reduction of PAM DRA and Xanthan DRA

4.3 CT Scanning Technique

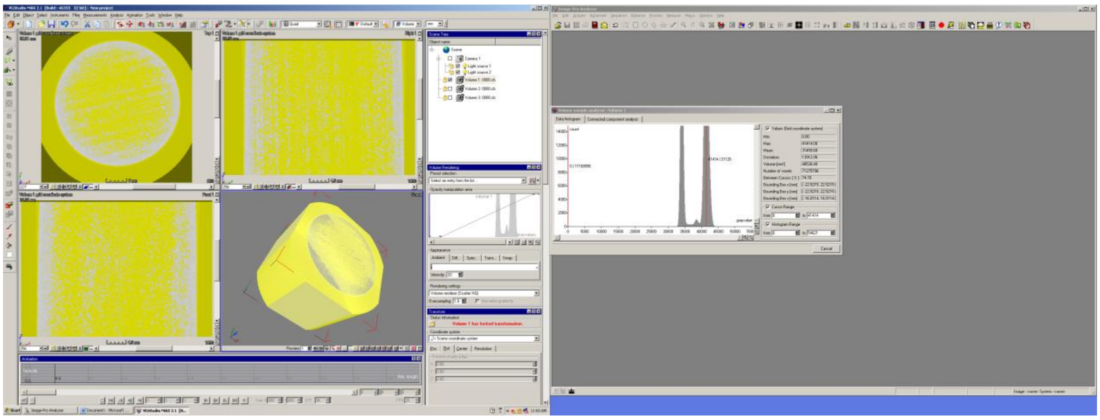

Figure 20: CT Scanner Software Interface

The author had run some visualization technique using CT Scanner in order to investigate the behaviour of permeability reduction. The test will be conducted such that the core will be scanned twice; in the beginning of core flooding process, and after the DRA flooding. Figure 21-A, Figure 21-B, and Figure 21-C are the results from the core which having the highest permeability reduction.

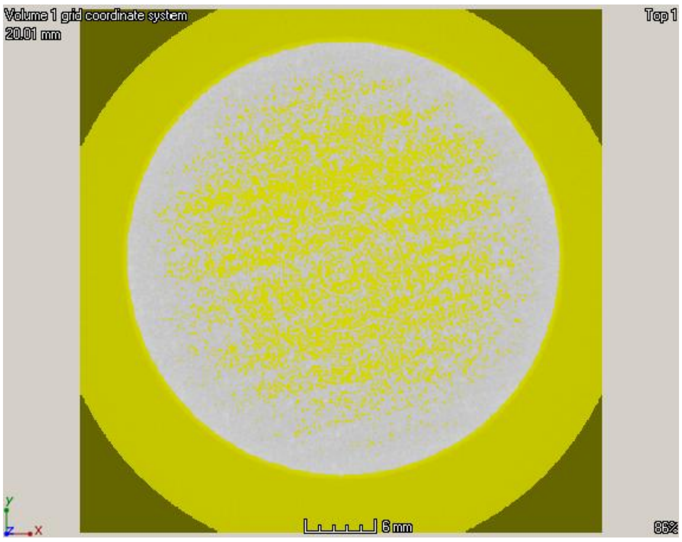

Figure 21-A: Initial Core cross-section view before flooding

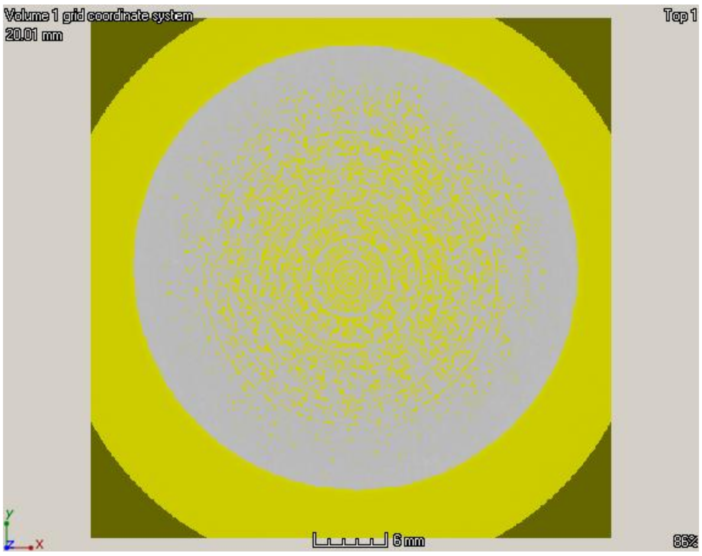

Figure 21-B: Core cross-section view after water flooding

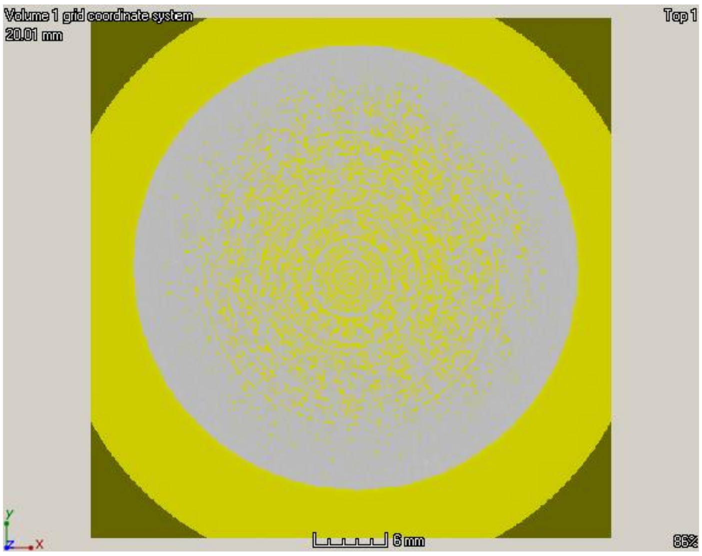

Figure 21-C: Core cross-section view after DRA flooding

Yellow zone shows a less density point, while grey zone shows high density point, in the core. From the results, we can see that the core view after both water and DRA flooding are almost the same; both having less yellow zone from the initial core cross-section view, but at almost the same intensity. At this point, we cannot distinguish the different in which the permeability channel captured by the CT scanner is filled with water or plugged with DRA polymer. This happen because CT

Scanner only captured the density of the core at each scan. However, the brine and the polymer DRA solution having almost the same density, hence no different can be analyzed at each core cross-section view.

4.4 Discussion

For both case of PAM and Xanthan DRA solution, it is clearly displayed that the permeability reduction is a function of injection rate. Higher injection rate gives less permeability reduction compared to lower injection rate. This is due to the fact that at lower injection rate, the shear rate of the fluid flowing at the inlet of the core is small. Small shear rate tends to make the polymer molecules plug at the inlet face of the core. However at higher shear rate, more polymer chain is broken, thus easing the fluid flow through inlet and the permeability channel inside the core. Furthermore, results at 3cc/min and 5cc/min of injection rates show almost the same percentage of permeability reduction. Thus we can conclude that the critical shear rate for both polymers DRA occurs at 3cc/min.

On the other hand, the core which flooded with DRA at higher injection rate shows higher percentage of recovery when backflow with brine compared to the core flooded at lower injection rate. The permeability channels which consist of highly sheared polymer chain, which a result from flooding at higher injection rate, make it easy to be flushed backwards. At low injection rate, the permeability channel plugged with bigger polymer molecules, thus make it hard to flush out in backflow process.

Different polymer type also gives impact on percentage of permeability reduction. PAM DRA solution shows a lower permeability reduction compared to Xanthan DRA solution. The reason behind this is that the Xanthan molecules are bigger compares to PAM molecules. Bigger polymer molecules will severely plug the permeability channel, while small molecules tend to pass through it. Although Xanthan DRA can reduce more friction compared to polyacrylamide because of its higher molecular weight, but reduction in permeability around the wellbore of injection well need to be look into. Using higher injection rates can reduce the permeability reduction when using Xanthan DRA solution, while backflowing process can recover the permeability, although not 100 percent restored to initial permeability.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Injection of water with DRA polymer do bring good and harm to the injection wells; however with some precaution assessed from time to time, the reduction of permeability can be insignificant. As a summary, injection of water with DRA polymer helps to increase the well's injection capacity. However this work shows that it can reduce the permeability around the wellbore. The permeability reduction depends on the injection rates and higher molecular weight polymer such as Xanthan gives more permeability reduction compared to less molecular weight polymer. The extent of permeability reduction is studied using CT scan. The results are not conclusive since the density difference between brine and water with DRA solution is too small and almost negligible.

5.2 Recommendation

In addition, the author would like to recommend further studies to be conducted at different core permeability range, in order to find the relationship between the permeability of the core with the permeability reduction. The experiments also can be conducted at reservoir temperature, to correlate the data to closed reservoir condition. Further studies on the comparison between drag reduction percentage in pipeline and permeability reduction inside the formation would bring a bright optimization point to take in consideration during the designing of water injection system. The visualization technique, on the other hand, can be improved using Scanning Electron Microscope (SEM), which might bring knowledge on the performance of the DRA and permeability reduction occurrence, on the surface of the core inlet.

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