Effect of Drag Reducing Agent on Core Sample in Injection Well

by

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Geosciences and Petroleum Engineering Department
Universiti Teknologi PETRONAS
in partial fulfillment of the requirement for the
Bachelor of Engineering (Hons.)
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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.

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(SHAHRUL NIZA BIN ABD RAHMAN)

ABSTRACT

The usage of sea water treated with Drag Reducing Agent in injection well has become phenomenon in oil and gas industry. Numerous case studies have reported the successful story of the DRA usage in order to maximize injection rate. Using DRA as additive in injection water was believe can increase the injection rate, increase the production rate, extend the field life, reduce energy cost. Several studies have proven that DRA only reduce the permeability of core with very small amount and can be negligible. However, there are lack of study on specific effect of Polyacrylamide DRA was conducted. Previous study mostly did not mention specific type of DRA that they used. This project was setup in objective to study the effect of Polyacrylamide, water-soluble polymer. This project will study the effect of Polyacrylamide on core sample in term of permeability losses. Apart from that, this project also will study the method the recover the permeability losses. Project methodology and activities also included. The project experiment design and procedure is explained. All the result data, analysis and findings presented at the end of this report.

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Oil recovery has become so popular these daysin the oil and gas industry. What is Oil recovery actually mean? Generally, oil recovery is easy to be understood as extracting out the oil from the reservoir. It has three stages, whichcategorized according the mechanism and also the percentage of oil that they can produce from the reservoir.

The three stages or categories which are:
1-Primary Oil Recovery
2-Secondary Oil Recovery
3-Tertiary Oil Recovery

Primary Oil recovery is the natural reservoir pressure drive that initially occurs at the early age of the reservoir. Recovery factor during the primary recovery stage is typically 5-15% [1]. After a period of time, natural reservoir pressure depleted so that the oil cannot rise to surface. Hence external driving force needed to supply pressure to the reservoir to make sure more oil can be extracted. The implementing of external force is called secondary recovery. The most common method for secondary recovery is water-flood and water injection. Typical recovery factor from water-flood operations is about 30%. Thermally enhanced oil recovery methods (TEOR) or enhanced oil recovery methods are tertiary recovery techniques that heat the oil, thus reducing its viscosity and making it easier to extract. Tertiary recovery allows another 5% to 15% of the reservoir's oil to be recovered. [2]

The Secondary recovery is most widely used recovery method. As reservoir become mature it will produce the byproduct which is water. Hence the management of the produce water which included its treatment and disposal system is needed which result in increasing operating cost. Well developer has to manage the produce water in safe and proper way because it is related with environment protection issue. Re-inject the produce water into the reservoir is functioning as the secondary oil recovery method which is practical and save cost. This is why water injection and water flooding is the most commonly used recovery method in hydrocarbon production well.

Nowadays, water flooding/ injection technology have become more sophisticated and evolved with current technology. Recently the usage of DRA (Drag Reducing Agents) in the injected water for injection well was reported. The usage of DRA in injection water was claimed can increase the water injection rate hence increase the production rate which lead to the extensionthe field production life.

1.2 Problem Statement

Nowadays, DRA application in oil and gas industry has widened and recently it is applied in injection application. Many fields were reported treats their injection fluid with DRA.Hence, the study of DRA effect on core sample in injection well seems so crucial and beneficial. DRA was claim has reduced the permeability of formation rock. Reservoir rock properties such as permeability and porosity are very important characteristic to ensure hydrocarbon fluid flow. Any changes to those two properties will affect the fluid flow hence will affect the hydrocarbon production. As result, maximum production rate cannot be archived and also maximum secondary oil recovery was not optimal.Due to that, the study of the effect of DRA on reservoir formation in injection well is so significant. Hence, this project is designed to make sure that the water injection method using DRA have no significant effect on the formation that will affect the production and reservoir formation itself.

However, the problem is the DRA technology is still new and still in research and development. In addition to that, all field cases that use DRA in their injection well were not mentioning specifically the type of DRA used in their report or in journal. As we know, DRA itself have many types and was categorize into two main categories which are oil-soluble and water-soluble. Under each main category have many type DRA itself. (Taylor,2009). Hence, variety type of DRA has its own characteristics and properties which will lead to different reaction and effect, especially on the rock formation. Because of that, it is crucial that every journal or research on the effect of DRA on reservoir formation in injection application has to refer to specific types of DRA.

As (Weilin 1992) said,Polyacrylamide has been extensively used in the oil and gas industry. Unfortunately, there were no distinctive paper and journal that reporting on the effect of DRA (which specifically refer to Polyacrylamide) on reservoir formation in injection well. That is why, the author proposed to design the experiment that studies the effect of Polyacrylamide to the reservoir formation in injection well.The objective and the scope of study of this project will be discussed.

1.3 Objectives and Scope of Study

1.3.1 Objectives

1. To analyze the effect of the injection of brine water treated with Polyacrylamide on the permeability of core sample

2. To analyze the core sample permeability recovery method

1.3.2 Scope of Study

The experiment has twooutputs, permeability losses and method of permeability recovery.

The scope of study will be in area of characteristics and properties of rock properties and polymer which in this project using Polyacrylamide (PAM). The author will observe if any effect of the polymer toward the core sample. Then the author will discuss the experiments result by analyzing the data and result with background understanding of reservoir rock and Polyacrylamide characteristics and properties and in term its reaction if any.

The author will conclude the finding of this experiment with adequate data and result with accurate and critical inference and discussion.

1.4 Project Relevancy and Project Feasibility

1.4.1 Project Relevancy

Polyacrylamide is most used polymer as DRA that have been used in many oil and gas industry applications. Polyacrylamide is the most important DRA in the industry. The usage of DRA in injection well is the current latest technology in the industry. Hence the study of the effect of Polyacrylamide as DRA on reservoir formation will lead to significant effect as it is related with DRA manufacturing industry, injection well system technology and also to the well developer. This project is very relevant with today's technologies and oil and gas current situation. This study will bring contribution in knowledge and technology beneficial to the many party.

1.4.2 Project Feasibility

Abide by the suggested milestone, the project scope has been narrowed down to make it feasible and accomplished within 14 weeks. The cost for this project is affordable as the author have to purchase only brine water and Polyacrylamide. While core sample, core flooding, porosity and permeability measurement equipment is provided by the university. All the equipment and consumable that will be used for this experiment will be discussed later in the methodology chapter.

CHAPTER 2

LITERATURE REVIEW

2.1 Drag Reducing Agent

Drag Reducing Agent or in short known as DRA was a popular additive used in oil and gas industry in many applications such as fracturing [3], acid stimulation,drilling fluid, water injection [4], coiled tubing operation [5] and oil transportation. The latest usage is in multiphase flow [6]. The usage of DRA nowadayshas been so broad and commercialize worldwide.

Drag Reducing agent in old days was called turbulent drag reduction. Turbulent drag reduction in fluid flow by additives has been an exotic field of research ever since its reported discovery in 1949[7].Contrary in other fact,it is reported the research of turbulent drag reduction with the function to reduce the frictional resistance at wall has started a year earlier that was on 1948."One of the most fascinating advances in single-phase turbulenceis the finding that the introduction of small amounts of long-chainpolymers into a liquid flow can cause large decreases in thefrictional resistance at the wall". (Toms, 1948).Further research on the effect of several solution and polymer to the turbulence flow was continued on 1991, 1992 and 1999 by using laser dopplervelocitymetry. (Harder and Tiederman, 1991; Wei and Willmarth, 1992; Warholic et al., 1999) have revealed how the turbulence properties differ from those of the solvent. Some study also start using Polyacrylamide and Percol 727 as the continuation of the DRA research saga.Warholic and Hanratty used a solution of a co-polymer of polyacrylamide and sodium-acrylate (Percol 727) in water. They realized significant drag-reduction with a concentration as low as 0.25 ppm. [8]

Until nowadays the study and research on Drag reducing Agent(DRA) sometimes known as friction reducers or flow improvers, although the latter term also called as wax inhibitors or pour-point depressants is still keep going on and improving by days.

According to Savins, (1964)

> Drag reduction is 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.(p. 203)

Other definition of Drag reduction was refined by other author by including the length of pipe and molecular weight aspects.Nelson (2003) said that "Drag reduction is a reduction in the pressure drop over some length of a pipeline when traces of high molecular weight polymer are dissolved in the pipeline fluid." (p.1).This two drag reducing definition have mentioned about several elements in drag reduction technology used nowadays. Both of them mention about additional substance with some amount of concentration with high molecular weight polymer.

Hence, we already have the clear definition of the drag reducing agent (DRA). How about how its work? How the long chain molecules can reduce the pressure drop in the pipeline hence increase the flow rate of the fluid? We will discuss about the principle theory of the drag reduction mechanism in the next topic.

2.1.1 Drag Reducing Mechanism

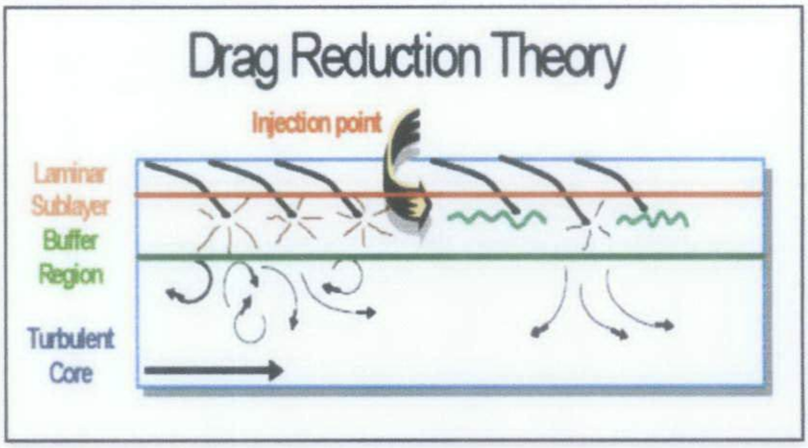


Figure 1: Drag reduction theory (Ibrahim, 2005)

Figure above is the cross-sectional image parallel to the pipeline, shows the principle theory behind the drag reduction phenomenon. In every center of a pipe is a turbulent core where one finds the eddy currents located at the largest region.Nearest to the wall is the laminar sub layer, fluid move laterally in sheets.Buffer zone located between these two zones. Before we want to discuss how drag reduction occur, we have first to understand how the formation of turbulent flow happened.

Portion in laminar sub layer called "streak" move to buffer zone. Then it begins to vortex, oscillate, moving faster as it get closer to turbulent core. Next, the streak become unstable and breaksup as it throws fluid into the core. As result it ejects fluid. The ejection of fluid called turbulent burst. So how DRA work?

DRA interfere with bursting process, reduce turbulence in core.First, the Drag reducing polymer absorb energy in the streak (act like shockabsorber) so it reduce the subsequent turbulent burst. As result, the Drag effect was reduced. Drag reducing polymer most active in buffer zone.[9]

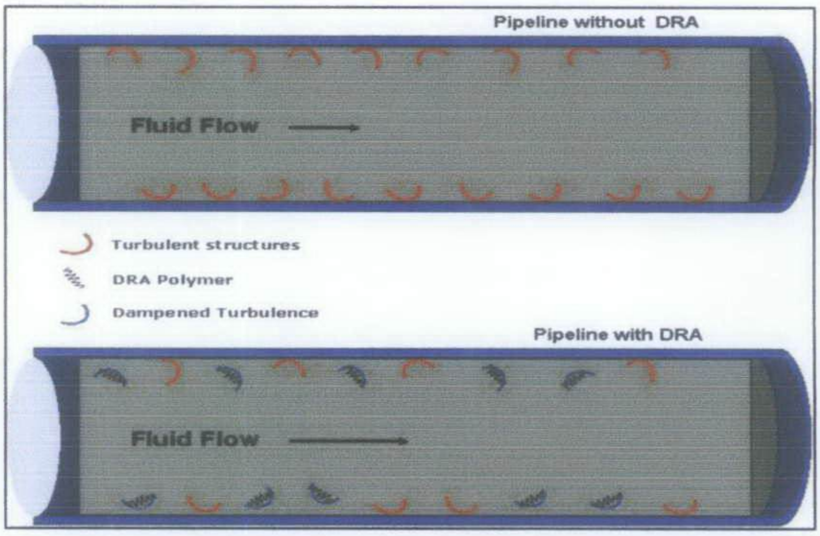


Figure 2: Dampening effect of DRA

For further understand on how the drag reducing agent reduce the drag effect, or the turbulence flow, see the figure above. When DRA dissolves in crude oil the polymer molecules begin to uncoil and outspread as they interact with the pipeline flow. This interaction is complex; the long chain molecules dampen turbulent bursts near the pipe wall as if they were acting as tiny shock buffers. This dampening effect reduces frictional pressure loss resulting in a decrease in energy consumption or an increase in flow rate. [10]

So, now we have understand how actually DRA can reduce the turbulance flow as it function as energy absober or turbulent bursts dampener.As the turbulance flow in pipeline was reduced, the pressure drop decrease hence it will increase the flow rate or injection rate of the fluid in the pipeline. After we understand the basic principle on how DRA works, we must be wandering what are the factors that contribute to the drag reducer perfomance? As we know its perfomance or its effectiveness may varies in some situation or conditons.The author will detail about the factors in the next topic.

2.1.2 DRA perfomance factors.

Nelson (2003) mentioned that there are four key factors governing the amount of drag reduction achievable in a given system which are;

- solubility of the polymer in the continuous phase
- effectiveness in dispersing the polymer
- molecular weight of the polymer
- concentration of the polymer

They are another four factors if according to Berge (2006) which are cloud point, degradation, and flow turbulence and injection location of polymer. These eight factors were the main factors that influence the drag reduction amount in a system. After we know the key factor and elements that lead to the DRA effectiveness or performance, we need some parameter to indicate the DRA performance.

2.1.3 DRA performance parameters.

Savins (1964) come out with the definition of percent drag reduction(%DR), as the difference between the pressure drop of the untreated fluid (ΔP, as baseline) and the pressure drop of the fluid containing DRA (ΔP_{DRA}) divided by the pressure drop of the base line.

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

Another parameter used to indicate the DRA performance is flow increase (%FI). Lescarboura (1971) come out with equation to show the relationship between the percent of drag reduction with percent of flow increase (%FI). Flow increase (%FI) equation as below;

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

2.1.4 DRA applications.

After we have already known about the definition of DRA, the mechanism, the performance key factors and the performance indicator, we must realize that DRA technology has rapidly spread and has been applied many oil and gas industry application recently.

According to Taylor (2009), there have been a number of uses for DRAs in the oil and gas industry including fracturing, acid stimulation, drilling fluid, water injection, coiled tubing operation, and oil transportation.

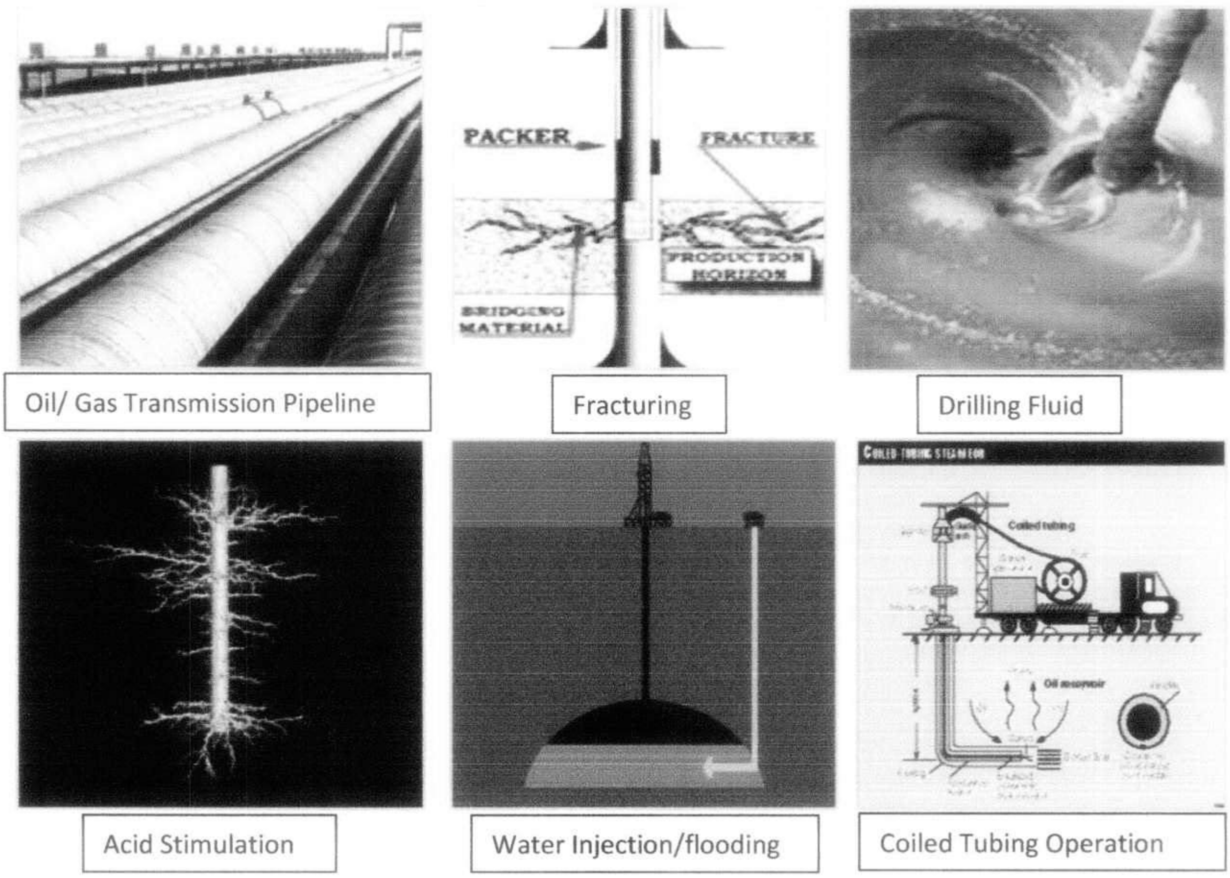


Figure 3: DRA applied in many oil and gas application

2.2 DRA usage in injection well

Injection well method was first discovered in Texas in 1930.According to EPA (United State Environmental Protection Agency) under the UIC (Underground Injection Control) program, the first documented project for the disposal of oil field brine into the originating formation begins in Texas in 1930s. 1930s was officially enhancing the recovery of oil by injecting water or other fluids into a formation to extract additional oil and gas begins. [11]Since then the injection method was spread worldwide as one of practical and reliable approach of secondary hydrocarbon recovery.

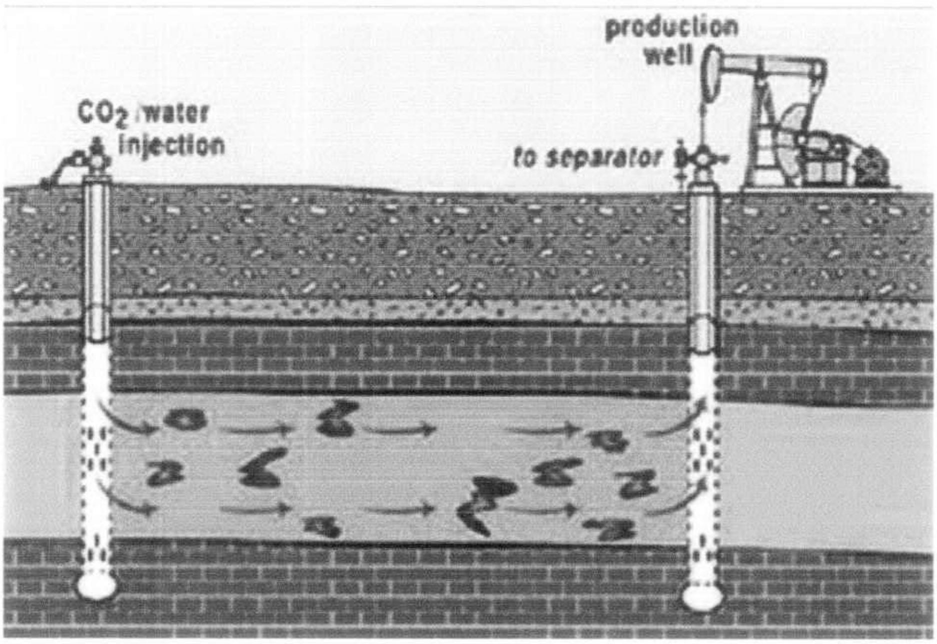


Figure 4: Water injection illustration

2.2.1 Conventional well injection method.

According to Schlumberger Oilfield Glossary (2011)

> Injection well is a well in which fluids are injected rather than produced, the primary objective typically being to maintain reservoir pressure. Two main types of injection are common: gas and water. Separated gas from production wells or possibly imported gas may be re-injected into the upper gas section of the reservoir. Water-injection wells are common offshore, where filtered and treated seawater is injected into a lower water-bearing section of the reservoir.

Conventional injection method without using DRA has it limitation. The maximum amount of water that maybe injected is limited by the capacity of water injection pump(s), the capacity of the injection tubing and the reservoir characteristics. By injecting DRA downstream of the injection pumps, the differential pressure drop in the water injection tubing may be reduced. As a result, the water injection rate may be increased until the maximum allowable operating pressure in the injection system is again reached. (Nelson, 2003, p.1)

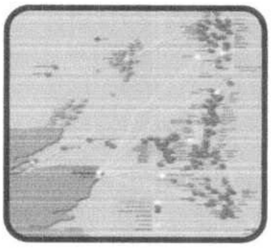
This is among the reason why many oilfield developers nowadays use DRA in their injection well. Injection fluid that treated with DRA will have lesser pressure drop due to the friction and turbulence flow reduction in the injection tubing in the injection well. Hence it will increase the injection rate and as result maximum reservoir fluid recovery can be reached that lead to maximizing the production rate.

2.2.2 Injection well using DRA technology

Produced water from reservoir was treated with DRA before it is re-injected into the reservoir has become famous and getting in place around the world as it reported can increase the injection rate so that reservoir pressure can be maintain beyond the ability of conventional injection well method. Furthermore, it will save cost because it saves the pumping and energy cost. There are many fields reported has successfully using the DRA technology in their injection well. There are Brent Alpha Offshore in Britain, Gyda Oilfield in Norway and also Galley Field in Scotland.

Brent Alpha Offshore, Britain

34 % injection rates increase up. [4]



Gyda Oilfield, Norway

65% increase total volume of seawater injected [4]

Galley field, Scotland

Increase injection rate up to 38 % [12]

Figure 5: Example of Fields that uses DRA to increase injection rate.

Figure above shows example of three field that use DRA in their injection system. At Brent Alpha, they manage to increase the injection rate up to 14% and in Galley field by 38%. While at Gyda Field they manage to increase the total volume of seawater injected by 65%. Next, will be the detail cases that happed at Galley field.

2.2.3. ChevronTexaco Galley Case Study.

A case study of ChevronTexaco Galley is one of many successful case of the usage of DRA to increase the injection rate to a targeted rate in order to meet certain amount of production rate. The Galley field is situated 145km east-north-east of Peterhead, Scotland, in block 15/23a of the UK sector of the North Sea. The field is operated by Petrofac (UK) Ltd using the Northern Producer floating production facility. The water injection system consists of approximately 2.2km of6in tubing from the platform to the sub-sea manifold, situated150m below the platform. The injection tubing from the sub-sea manifold to the injection well has an ID of 4.8in and a measured depth of 5500 meters. The bottom hole flowing pressure is 430bar and the injectivity index is 73.8m3/d/bar. Seawater is injected at a baseline flow rate, without Flow Improvers, of around 29,000b/d. At this water injection rate, the average oil production rate is 39,000b/d.

In late 2000, the pressure in the Galley reservoir was seen to be falling, resulting in reduced oil production rates. To maintain oil production rates, the reservoir needed to be re-pressurized. To achieve this, it was decided to increase the water injection rates. It was estimated that by increasing the water injection rate to40,000b/d, re-pressurisation could be achieved. [12]

After some predictive performance calculation using ConocoPhillip's in-house simulation model and real field test they be able to achieve water injection rate of 40,000b/d by injecting 40ppmv DRA into the injected sea water. Apart from that, they also manage to reduce the effect of corrosion by up to 30%, increased the field production rate, increased the production life, increase the overall recoverable reserves.

They also have conducted the laboratory core analysis before using the DRA in their injection well system in order to make sure no significant effect of DRA onto the reservoir that will harm the reservoir system and affect the production.

2.3 DRA Effect on Core Sample

Back to ChevronTexaco Galley study case, they perform a laboratory core analysis to study the effect sea water treated with DRA on core sample. First is the permeability test where they prepare untreated water and water with 100ppmv DRA concentration. From the result, they have found out that small permeability reduction was recorded.

According (Nelson, 2003) the small reduction in permeability seen with DRA was well within the acceptable limit set by ChevronTexaco. Apart from permeability test they also study the compatibility of DRA with all process chemicals, including corrosion inhibitor, oxygen scavengers, biocides, antifoam, etc. Amazingly they found out that DRA has no effect on any of the process. [12]

Another experiment was also conducted lately in 2006 relating DRA effect on core permeability by H.A Al-Anazi et al. The core flood experiments study the effect of DRA on core permeability with manipulating the degraded degree (fresh, degraded), and also manipulating the core permeability. Al-Anazi et al. also conduct study on restoring the core permeability by reversing the flow direction of treated water and also by diluting Hydro chloric acid (HCL). They have found out both methods successfully restore the core permeability but using treatment solution was the most effective.

2.3.1 Manipulating the DRA degraded degree.

The impact of shear on DRA performance was studied by repeating each experiment on cores with similar permeability, where one experiment performed using a fresh DRA solution and the other using a sheared (broken) DRA. The fresh DRA was prepared using a magnetic stirrer with gentle mixing, while the sheared DRA was prepared using a blender at very high mixing speeds. The use of fresh DRA presumes the DRA will be injected into the formation in the form as injected into the pipeline. In a practical point of view, however, there is a booster pump, which supplies seawater to injection wells, at the end of the transfer line and many valves and elbows.

Thus, it is expected that the DRA will be sheared (broken) before it reaches the formation. In other words, the fresh DRA represents the worst case, while the sheared DRA is close to field situation. In their experiment, the have found out the broken DRA gave less permeability reduction than the unbroken (fresh) DRA.

The overall permeability loss caused by the broken DRA in these high permeability cores is very small (up to 5%). The broken DRA is more representative to the field situation since there are many restrictions, elbows, booster pumps, and valves that degrade the injected DRA before it reaches the formation. It is also expected that the shear in the field is more and the DRA will be degraded more.[4]

2.3.2 Manipulating core permeability.

In their experiment, (Al-Anazi et al.) they used constant DRA concentration that is 10ppm DRA. They manipulate the core permeability which in their experiment they use tight core (ki=27.8 mD), medium core (ki= 94.6 MD) and higher permeability core (ki=643 md). After they performed the core flood experiments, they have found out that the low permeability cores gave the least return permeability.

The tight core (ki=27.8mD) lost 21% of its initial permeability, while for medium core (ki=94.7MD) and higher permeability core (ki=643mD) lost 7 % and 97 % of their initial permeability. This result is expected since the DRA is a very long chain polymer that cannot pass through the small pores of smaller permeability cores (tight core).

2.3.3 Restoring the core permeability.

In Al-Anazi et al. experiment also, there were several attempts were tried to restore core permeability after injection of the DRA. One way was to reverse the flow direction to emulate flow back of water injectors. Reversing the flow direction helped to clean the core from the injected DRA and eventually restore the initial permeability. This means that the DRA caused an external damage (face plugging) on the core face.

Accordingly, flowing back water injectors may help to clean the injected DRA in case of injectivity decline during field application. However, it was also found the volume of flow back is a function of the DRA concentration. More volumes of seawater were required to restore core permeability after an injection. A dilute HCl acid (5 wt%) was also found effective in removing the slight damage caused by DRA and restoring core permeability.[4]

2.3.4 Researchers experiments conclusion

As from these previous two research, it is can be conclude that first, they have found out that the effect of DRA on the core permeability is too small and can be negligible. Second, the small permeability reduction can be recovered by back flow and also dilute with HCL. Unfortunately, both of the projects were not mentioning specifically the DRA polymer that they used in their experiments. As we know, as presented by (Taylor, 2009) DRA can be classified into two which are oil-soluble DRA and water-soluble DRA.

Water-soluble DRA can be specified into several polymers such as PAM(Polyacrylamide), PHPA (Partially Hydrolyzed Polyacrylamide), copolymer of acrylamide, PEO (Polyethyleneoxide), polyvinyl alcohols, polysaccharides and its derivatives.[13] As Morgan (1990,p. 507) mentioned that many classes of water-soluble polymer exhibit drag-reducing properties, including cationic, anionic, or nonionic polymers.

Each and every of the DRAs has its own properties and characteristics that make the effect of DRA on core sample differ. As throughout this project, we will only focus on PAM (Polyacrylamide) as the DRA. The author tended to carry up this project that will study the effect of PAM on core sample in term of permeability, porosity and formation damage and also the method to recover the permeability losses. The methodology to carry out this project will be discussed in the next chapter.

CHAPTER 3

METHODOLOGY

This chapter is about the project methodology, the project activities and the milestone planned to achieve the due date. The injection fluid is single-phase as the injection fluid used is only water and it is non-Newtonian fluid. In this experiment, the author will use brine water as represent the brine water, Polyacrylamide as the DRA, core sample representing the formation rocks.

In this chapter, the author will present the methodology if the project where the method and procedures of this experiment will be conducted. Next, the author will present the key milestone of this project. After that, the author will discuss about the equipment, the consumables that will be used in the experiment. The author also has summarized the activities that will carry out in this project as the draft design of the experiment. At the end of this chapter, the author will present the experiment design and procedure.

3.1 Project Methodology

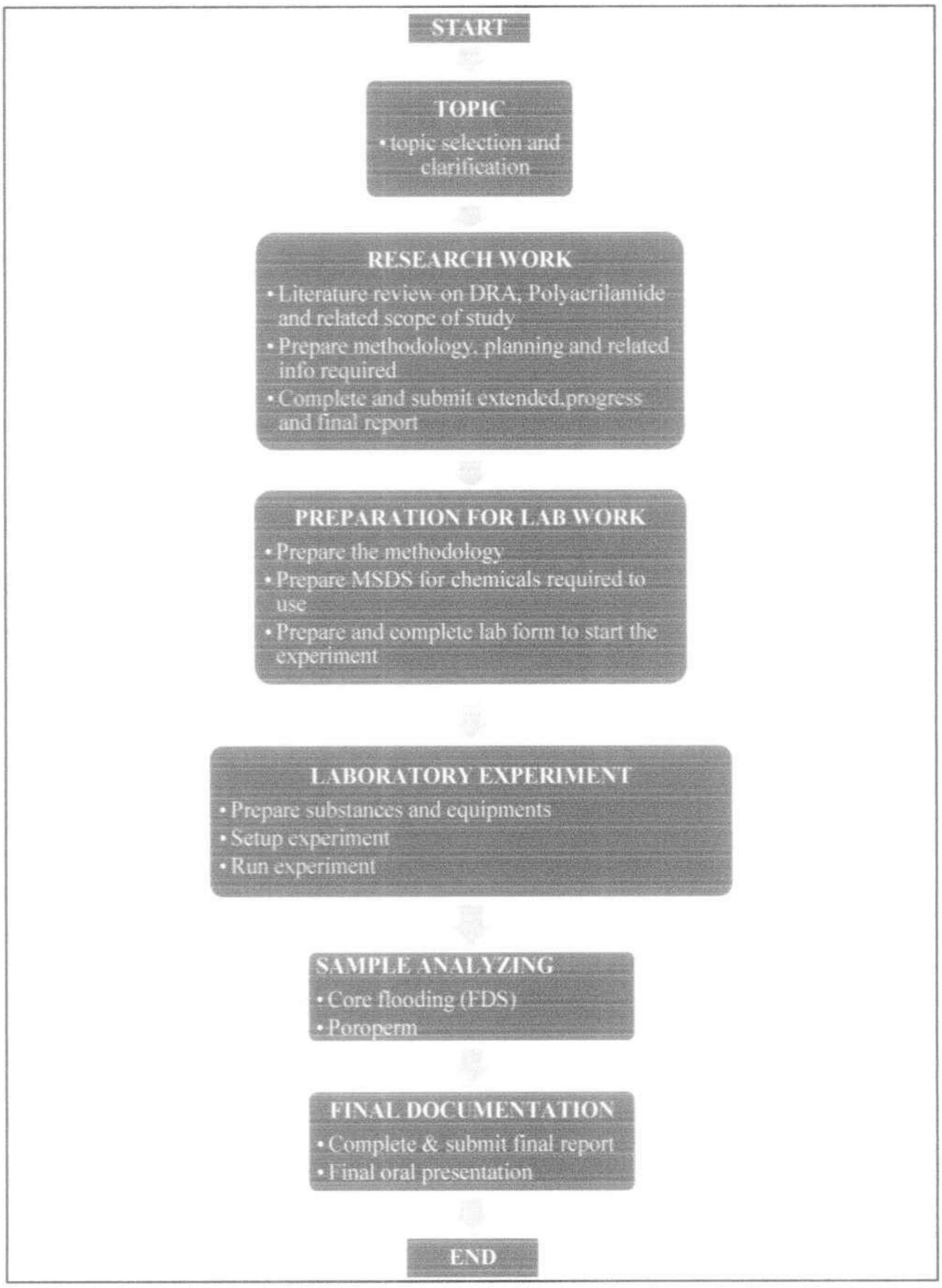


Figure 6: Project methodology flow chart

3.2 Key Milestone (Gantt chart)

No.	Detail/ Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Purchase Consumables and Tools															
2	Laboratory Equipment Setup															
3	Experimental Work Continues							Mid-semester break								
4.	Submission of Progress Report															
5.	Project Work Continues															
6.	Pre- EDX															
7.	Submission of Draft Report															
8.	Submission of Dissertation (soft bound)															
9.	Submission of Technical Paper															
10.	Oral Presentation															
11.	Submission of Project Dissertation (Hard Bound)															

Figure 7: Project Gantt chart

3.3 Equipment and Consumables

Below are brief descriptions on the equipment and consumables that will be used in this project. Among equipment that will be used arePoroperm and Formation Damage System (FDS). While for consumables the author need Polyacrylamide (PAM) and also brine water.

3.3.1 Poroperm

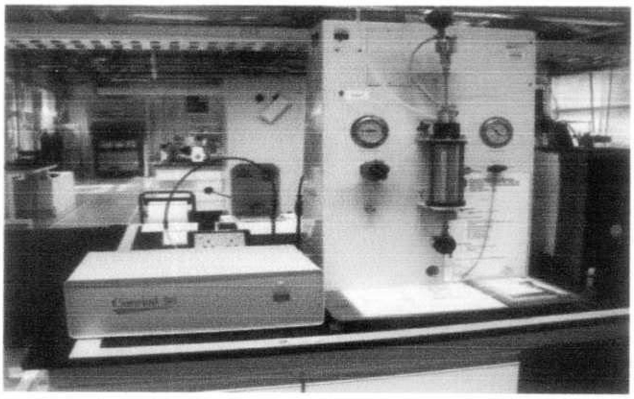


Figure 8: Poroperm instrument in university laboratory

The POROPERM instrument is a permeameter and porosimeter used to determine properties of plug sized core samples at ambient confining pressure. In addition to the direct properties measurement, the instrument offers reporting and calculation facilities thanks to its user-friendly Windows operated software.

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) [14]

3.3.2 Formation Damage System (FDS)

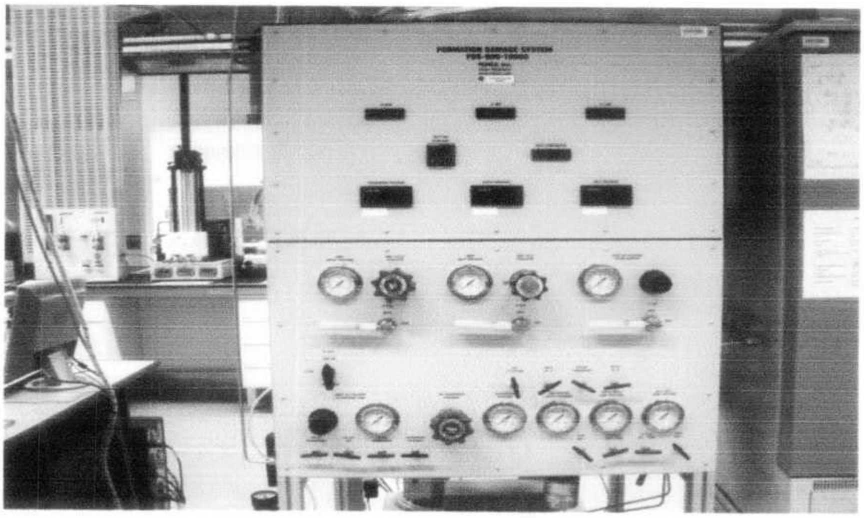


Figure 9: HTHP Formation Damage Test System (FDS)

The TEMCO FDS-800-10000 HTHP Formation Damage Test System is designed for formation damage testing of core samples, at in-situ conditions of pressure and temperature. Tests that can be performed with the system include initial oil saturation, secondary water flooding, formation damage testing with leak-off through the core, and before-and-after permeability measurement, in both forward and reverse (backflow for damage clean up) directions. Brine, oil, drilling mud, gels, or other fluids can be injected into and through the core sample.[14]

FDS is the equipment needed for the formation damage experiment. The author will measure the permeability reduction and backflow method to restore permeability of the core sample after running the experiment using FDS.

3.3.3 Consumables

Consumables that will use for this project are Polyacrylamide (PAM) and brine water. Polyacrylamide need to be brought from outside with the help of university lab technician and supervisors. Brine water can be produced using diluting salt with distilled water.

3.4 Project Activities

Table 1: Project activities summary

Process	Equipment	Objective	Parameter Used
Effect on porosity	Poroperm	1. To measure the	Porosity
		porosity reduction	
		1.1 before and after DRA injection	
Effect on Permeability		2. To measure the permeability reduction	Permeability
	Poroperm	1.1 before and after DRA	
	FDS	1.2 Varies DRA concentration	
Method of permeability restore	FDS	2. Proving backflow can restore permeability reduction	Permeability

3.5 Experiment Procedure

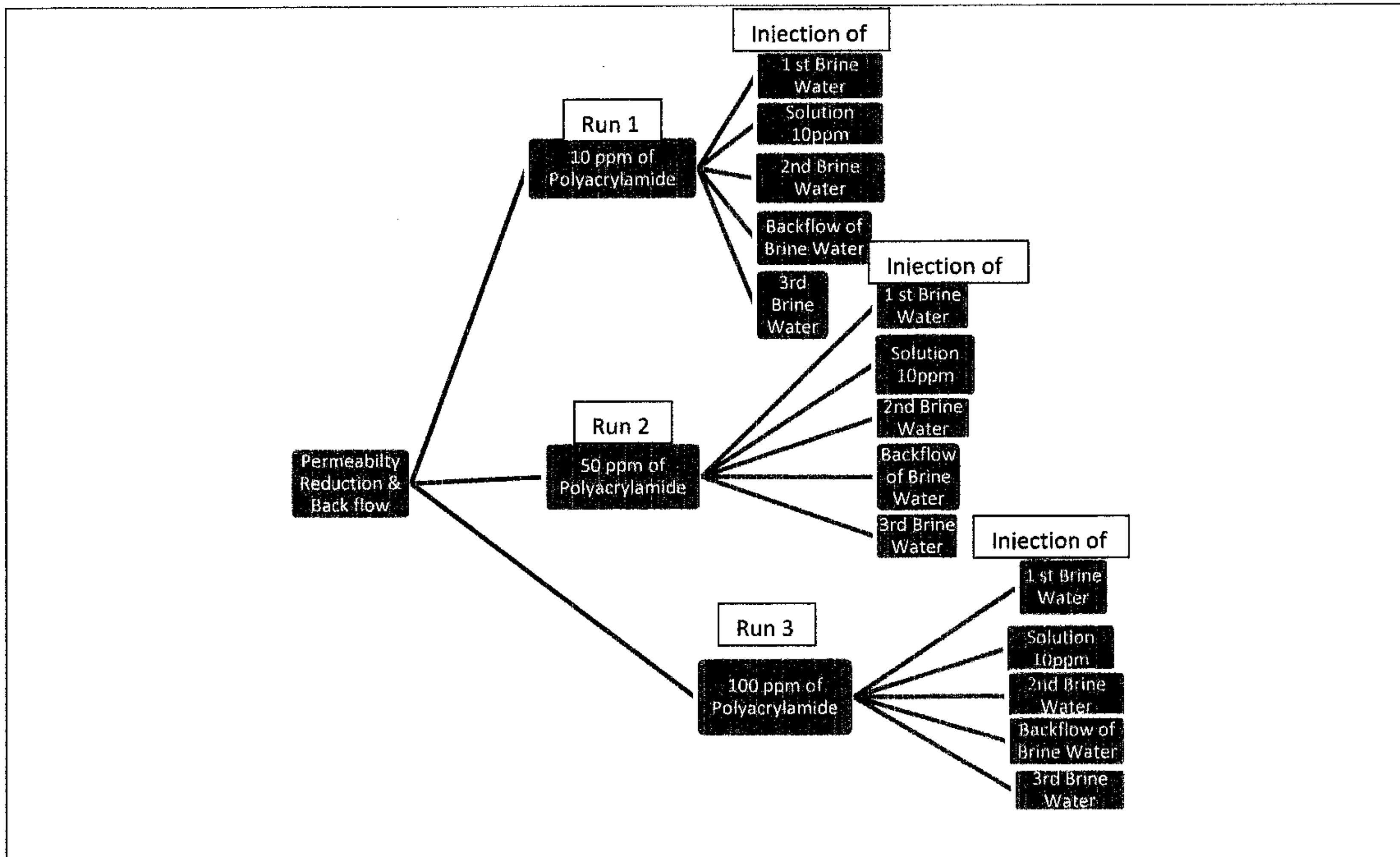


Figure 10: Experiment procedure outline diagram

3.5.1 Experiment Procedure

The figure above is describing the experiment procedure outline. Where what we can understand that this experiment has 3 stages or run. Run 1, Run 2 and Run 3. Where Run 1 is the injection of Brine water that treated with DRA with 10 ppm concentration, Run 2 is for 50ppm DRA and Run 3 is for 100ppm DRA. Each Run has 5 times injection onto the core sample. First we inject with pure brine water, (for this experiment we use standard salinity for all with 35000ppm), then we inject the DRA solution, next we re-inject with the pure brine water. At this stage, it is supposed to be that the permeability of the core has loss due to the DRA solution.

Then, we continued the run by injecting the pure brine water in reverse direction (backflow). This backflow injection is the method of restoring the core permeability that has been losses during the injection of DRA earlier. And lastly, the pure brine water once again injected in normal direction to measure the permeability that successfully restore. In summary, Injection one, two and three (brine water, DRA solution, brine water) are for the measurement of the permeability that has been losses. While the injection four and five (Brine water backflow, brine water normal direction) are for the measurement of the permeability losses that has been restore by the backflow method. After that the core sample being cleaned and dried. Then we measured the porosity and permeability of the core sample using Poroperm. This one whole cycle is for one Run. Then, repeat Run by using 50ppm and 100ppm.

One Run Cycle

1. Prepare 35000 ppm Brine Water and (10, 50, 100) ppm DRA solution.
2. Measured core sample porosity and permeability with Poroperm.
3. Saturate core sample with brine water for one day.
4. Setup FDS equipment for the run.
5. Run 6 injection onto the core (Brine, DRA, Brine, Brine Backflow Brine, Brine)
6. Collect recorded data.
7. Dismantle and clean FDS equipment
8. Clean and Dry core sample for next Run.
9. Proceed with next Run with same steps above.

3.5.2 Experiment Setup

This experiment setup (FDS setup) is to imitate the reservoir condition and closed to real situation in subsurface. The core that we used is the same which is the medium range permeability core. The reservoir conditions that will be imitate using the FDS setup as below;

FDS condition;

- Flowing Temperature: 54 °C
- Overburden Pressure: 1000psig
- Flowing Pressure: 500 psig

2 core sample we used along this experiments;

- Core name: L7
- Diameter: 3.751 cm
- Length: 3.725 cm
- Initial Permeability: 118.05mD
- Initial Porosity: 19.106 %

- Core name: NG
- Diameter: 3.788 cm
- Length: 3.882 cm
- Initial Permeability: 126.785 mD
- Initial Porosity: 20.192 %

CHAPTER 4

RESULT AND DISCUSSION

In this chapter, the author will present the experiment finding and data result from the experiment. The data has been redefined and modify in term of interface, and presentation for easier understanding and presentable for the reader. However the result data and reading is has not been changed at all and was keep its originality to make sure this experiment is authentic. The author will also present the data calculation that will lead to the parameters that we need to anlyze the result. Lastly the author will present the Data Analysis. The data analysis is where the data result will be discussed to prove the initial experiment expectation hypothesis.

4.1 Data Gathering

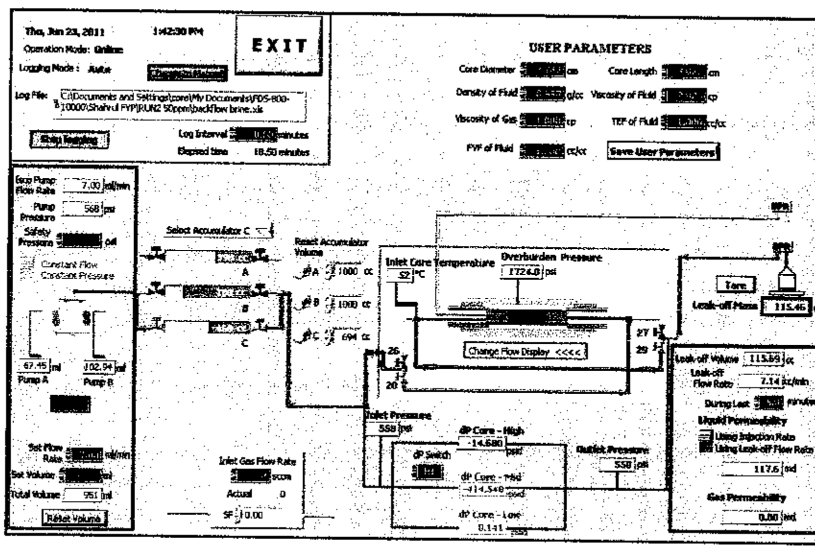


Figure 11: Screenshot of the interface of the Formation Damage System (FDS)

Figure above is the interface of the FDS. The interface is where we can control the FDS. In the FDS interface we can see the inlet pressure, outlet pressure, the injection flow direction and other essential data inputs. Before begin the injection of the run, we firstly insert the system condition desired for example the overburden pressure, the flow pressure and temperature. It is also required to put the core diameter and length.

After the system has been setup, the injection started. A data log was recorded for each half minute for every injection. In the data log, the most useful data was the pressure at inlet and pressure at outlet. The pressure difference (inlet – outlet) was the most important data that will be used to calculate the core permeability. The pressure difference (inlet –outlet) is the key indicator either the permeability of the core was affected of not. If there is no pressure differences recorded, it means that the core was not plug and no permeability was losses.

However, if there is pressure differences recorded, it shows that there are plug happened at the core which causes the permeability to reduce. Pressure difference for injection first brine water, second brine water and the last brine water for every run was recorded. The data that obtain from the experiment is presented in the graph below is extracted from a table that was tabulate from the log record from the FDS for every half minute.

4.1.1 Data for Run 1 (10ppm DRA)

4.1.1.1 1st Brine Injection

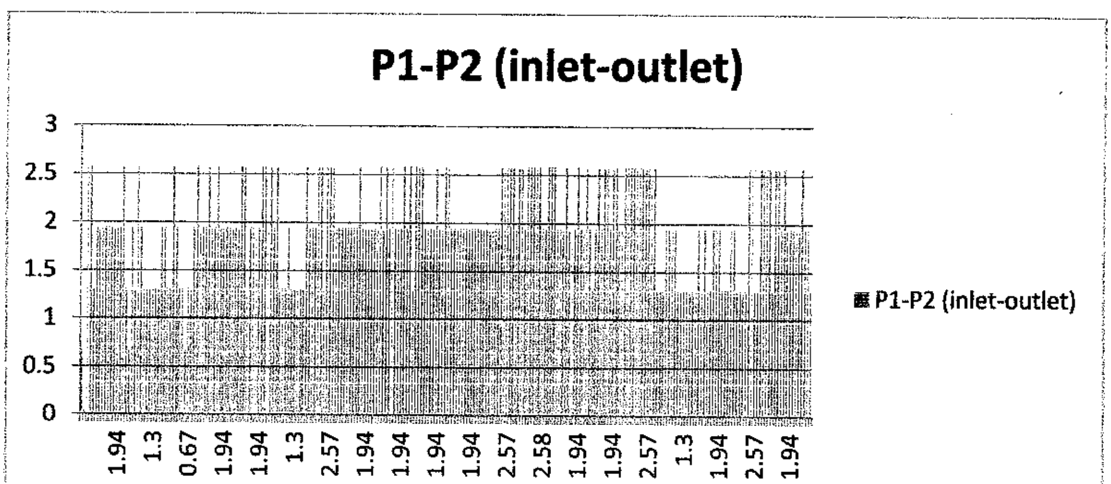


Figure 12: Pressure difference versus time for 1st Brine Injection for Run 1

From this figure, the value taken for the pressure difference (P1-P2) for the first brine is **2.57**

4.1.1.2 2nd Brine Injection (after DRA Solution)

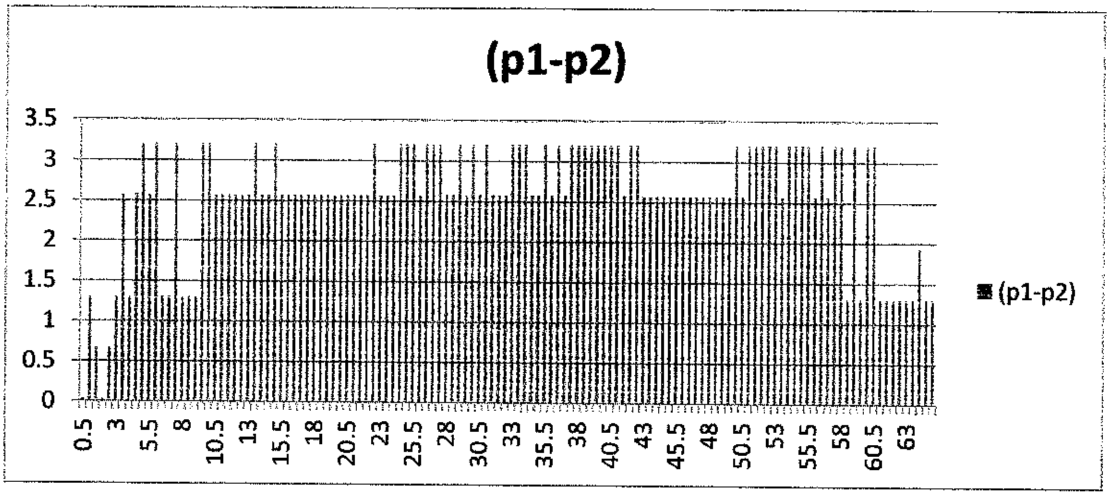


Figure 13: Pressure difference versus time for 2nd Brine Injection for Run 1

From this figure, the value taken for the pressure difference (P1-P2) for the second brine is **3.21**

4.1.1.3 3rd Brine Injection (after backflow)

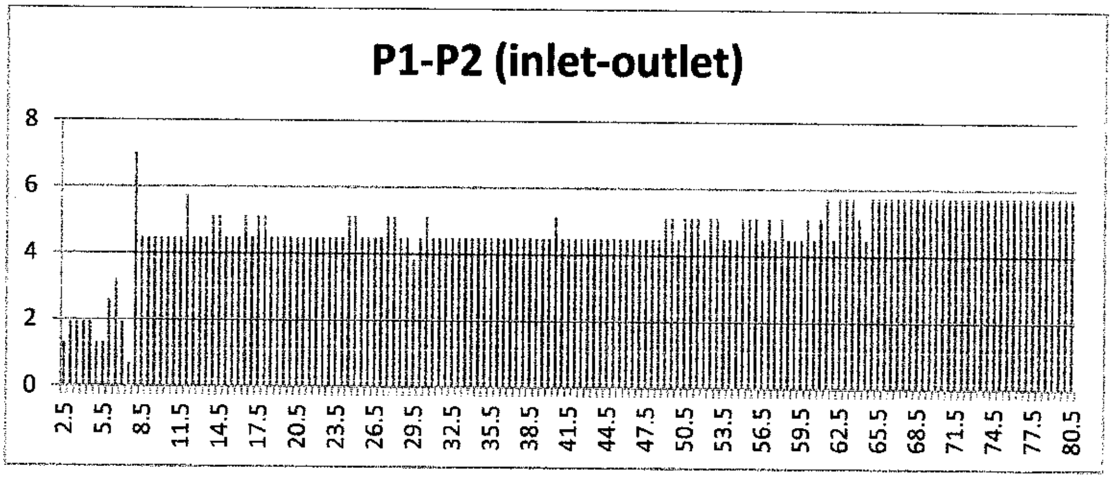


Figure 14: Pressure difference versus time for 3rd Brine Injection for Run 1

From this figure, the value taken for the pressure difference (P1-P2) for the last brine which is after the backflow is **5.57**

4.1.2 Data for Run 2 (50ppm DRA)

4.1.2.1 1st Brine Injection

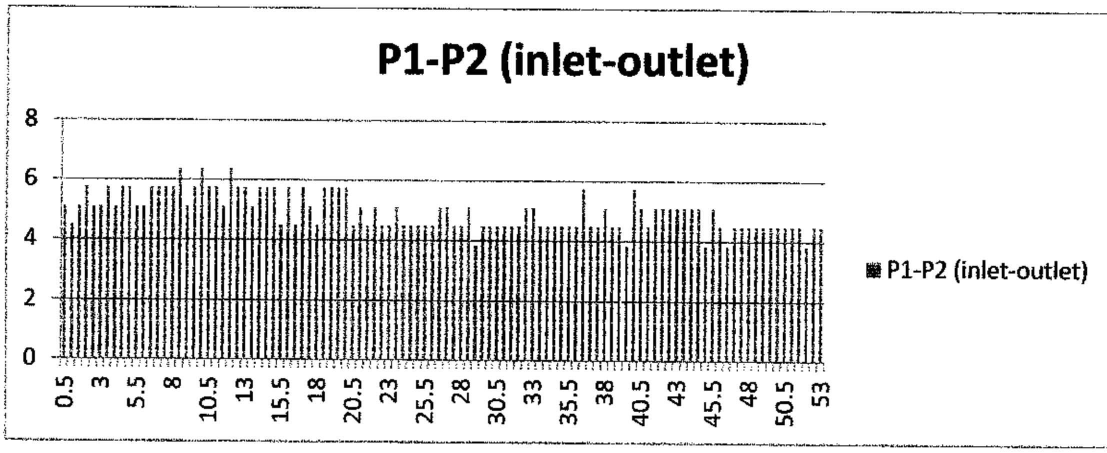


Figure 15: Pressure difference versus time for 1st Brine Injection for Run 2

From this figure, the value taken for the pressure difference (P1-P2) for the first brine is **4.48**

4.1.2.2 2nd Brine Injection (after DRA Solution)

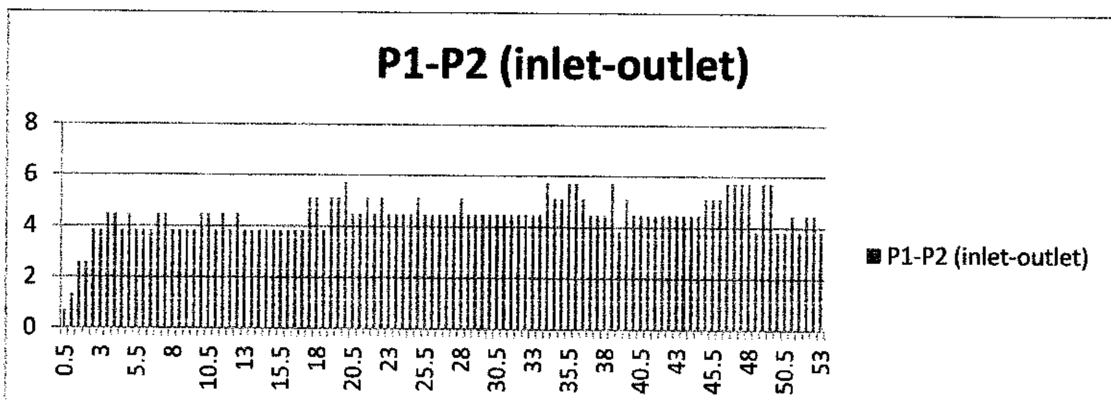


Figure 16: Pressure difference versus time for 2nd Brine Injection for Run 2

From this figure, the value taken for the pressure difference (P1-P2) for the second brine is **5.74**

4.1.2.3 3rd Brine Injection (after backflow)

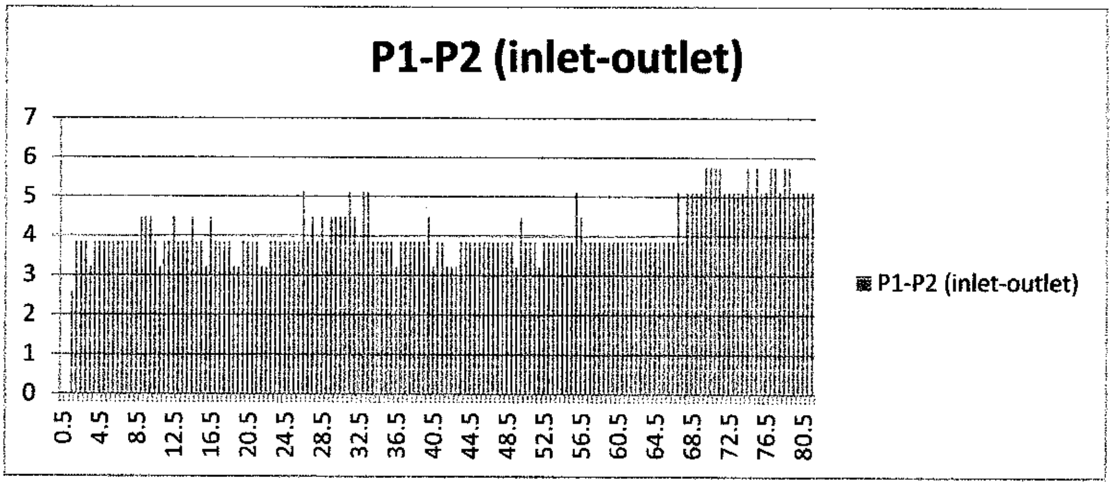


Figure 17: Pressure difference versus time for 3rd Brine Injection for Run 2

From this figure, the value taken for the pressure difference (P1-P2) for the last brine which is after the backflow is **5.11**

4.1.3 Data for Run 3 (100ppm DRA)

4.1.3.1 1st Brine Injection

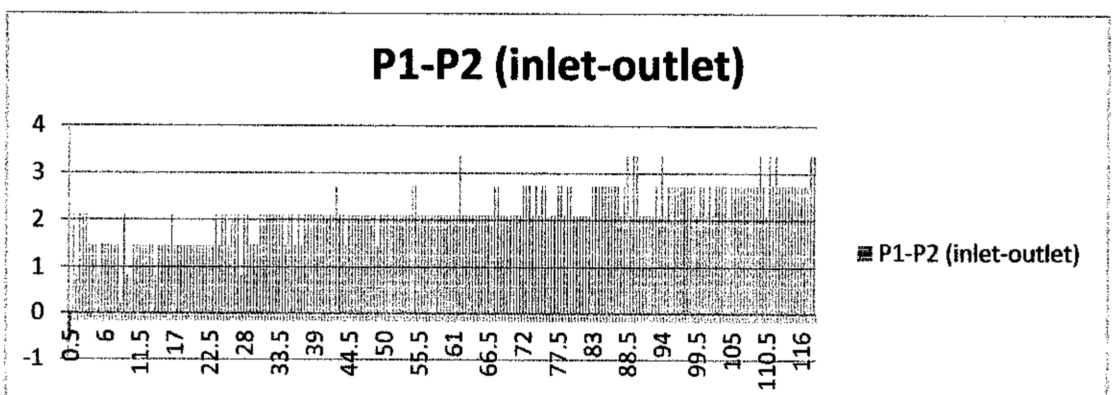


Figure 18: Pressure difference versus time for 1st Brine Injection for Run 3

From this figure, the value taken for the pressure difference (P1-P2) for the first brine is **2.7**

4.1.3.2 2nd Brine Injection (after DRA solution)

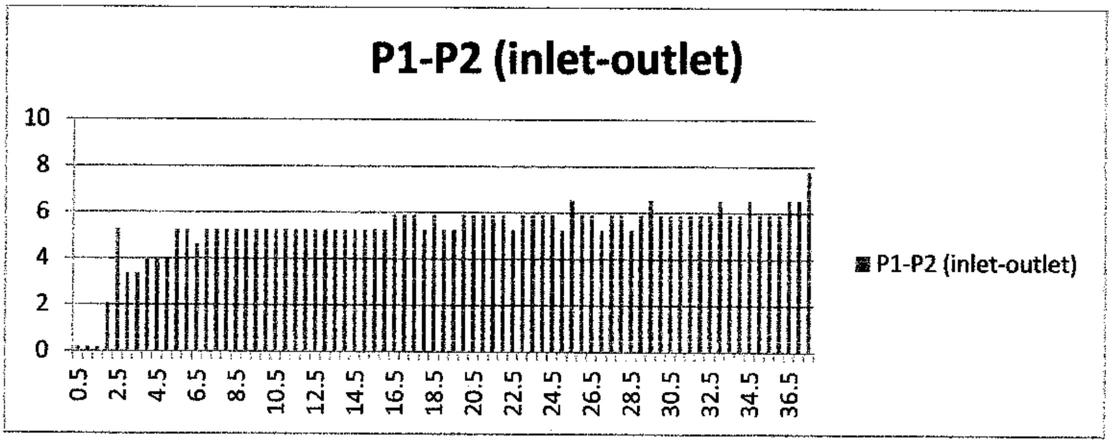


Figure 19: Pressure difference versus time for 2nd Brine Injection for Run 3

From this figure, the value taken for the pressure difference (P1-P2) for the second brine is **5.91**

4.1.3.3 3rd Brine Injection (after DRA backflow)

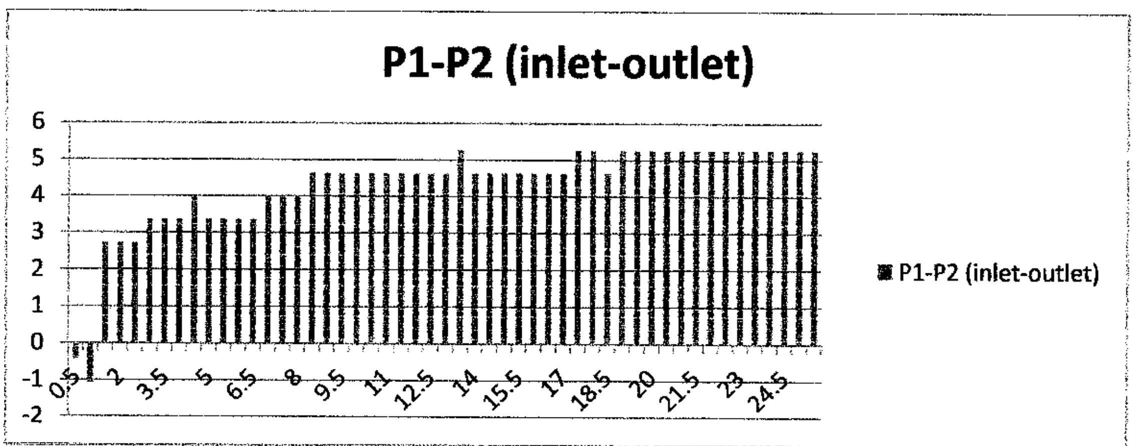


Figure 20: Pressure difference versus time for 3rd Brine Injection for Run 3

From this figure, the value taken for the pressure difference (P1-P2) for the last brine which is after the backflow is **5.27**

4.1.4 Data result summary

Table 2: Summary of the data result from the injection

Run	Injection	Pressure Diff. Data (p1-p2) (psi)
Run 1 10 ppm PAM	First Brine Water	2.57
	PAM solution 10ppm	
	Second Brine Water	3.21
	Backflow Brine Water	
	Last Brine Water	5.57
Run 2 50 ppm PAM	First Brine Water	4.48
	PAM solution 10ppm	
	Second Brine Water	5.74
	Backflow Brine Water	
	Last Brine Water	5.11
Run 3 100 ppm PAM	First Brine Water	2.73
	PAM solution 10ppm	
	Second Brine Water	5.91
	Backflow Brine Water	
	Last Brine Water	5.27

This table above shows the summary of the data result that gathered from the FDS for each injection in every run. This pressure difference will be used as the input into the permeability formula in order to calculate the permeability after the injection of DRA solution and after the backflow. The permeability calculation was used in this experiment is the Darcy permeability formula.

4.2 Data Calculation

All the data above is to get the pressure difference that will be used in the calculation of the permeability of the fluid using Darcy permeability formula. The fluid permeability before the injection of the DRA solution is compared with the fluid permeability after the injection of the DRA solution. Hence the fluid permeability reduction can be calculated. The fluid permeability after the backflow also compared to the last fluid permeability to calculate the permeability that successfully restored.

4.2.1 Run 1(10ppm) Data Calculation

Analysis

Run	ΔP (p1-p2)	Remarks	Inference
Brine 1st	2.57	indicate fluid permeability before injection of DRA solution	
Brine 2nd	3.21	indicate fluid permeability after injection of DRA solution	face plug by DRA happened
Brine 3rd	5.57	indicate fluid permeability after backflow with brine water	backflow restore core permeability

Calculation	for Run 1 using DRA solution 10 ppm					
Core Name	L7					
Permeability Formula	$k = (q \mu L) / 1.127(\Delta P)(A)$					
Parameter						
Symbol	Name	Value measured	data unit	value calculated	calculation unit	assumption
k	Permeability				Darcy	
q	injection flow rate	3	mL/min	0.02717194	bbl/day	
μ	fluid viscosity	1.8	cp	1.8	cp	Viscosity used in the calculation is the viscosity of the brine water.
L	core length	3.725	cm	0.12221129	ft	injection length or flow distance is equal to core length
d	core diameter	3.751	cm	0.1230643	ft	
A	core area	11.05198579	cm^2	0.01189626	ft^2	injection area or flow area is equal to core area
ΔP	pressure difference		psi		psi	

Run	ΔP (p1-p2)	Permeability (Darcy)
Brine 1st	2.57	0.173475081
Brine 2nd	3.21	0.138888149
Brine 3rd	5.57	0.080041465

Permeability drop/increase	Calculation	value	(%)	conclusion
after DRA solution injection	K (brine 1st)- K (brine 2nd) (drop)	0.034586932	19.9377	20% permeability drop after injecting DRA solution 10ppm
After brine water backflow	K (brine3rd)- K (brine 2nd) (increase)	-0.058846684	-73.52	error occurs. Issue will bring to discussion

4.2.2Run 2(50ppm) Data Calculation

Analysis

Run	ΔP (p1-p2)	Remarks	Inference
Brine 1^{st}	4.48	indicate fluid permeability before injection of DRA solution	
Brine 2^{nd}	5.74	indicate fluid permeability after injection of DRA solution	face plug by DRA happened
Brine 3^{rd}	5.11	indicate fluid permeability after backflow with brine water	backflow restore core permeability

Calculation	for Run 2 using DRA solution 50 ppm					
Core Name	NG					
Permeability Formula	$k = (q\ \mu\ L) / 1.127(\Delta P)(A)$					
Parameter						
Symbol	Name	Value measured	data unit	value calculated	calculation unit	assumption
k	Permeability				Darcy	
q	injection flow rate	3	mL/min	0.02717194	bbl/day	
μ	fluid viscosity	1.8	cp	1.8	cp	Viscosity used in the calculation is the viscosity of the brine water.
L	core length	3.882	cm	0.1273622	ft	injection length or flow distance is equal to core length
d	core diameter	3.788	cm	0.12427822	ft	
A	core area	11.27109551	cm^2	0.01213211	ft^2	injection area or flow area is equal to core area
ΔP	pressure difference		psi		psi	

Run	ΔP (p1-p2)	Permeability (Darcy)
Brine 1^{st}	4.48	0.101694075
Brine 2^{nd}	5.74	0.079370985
Brine 3^{rd}	5.11	0.089156449

Permeability drop/increase	Calculation	value	(%)	conclusion
after DRA solution injection	K (brine 1st)- K (brine 2nd) (drop)	0.02232309	21.9512	22.2% permeability drop after injecting DRA solution 50ppm
After brine water backflow	K (brine3rd)- K (brine 2nd) (increase)	0.009785464	10.9756	11% permeability was restore successfully after the backflow

4.2.3Run 3(100ppm) Data Calculation

Analysis

Run	ΔP (p1-p2)	Remarks	Inference
Brine 1st	2.73	indicate fluid permeability before injection of DRA solution	
Brine 2nd	5.91	indicate fluid permeability after injection of DRA solution	face plug by DRA happened
Brine 3rd	5.27	indicate fluid permeability after backflow with brine water	backflow restore core permeability

Calculation	for Run 3 using DRA solution 100 ppm					
Core Name	L7					
Permeability Formula	$k = (q\ \mu\ L) / 1.127(\Delta P)(A)$					
Parameter						
Symbol	Name	Value measured	data unit	value calculated	calculation unit	assumption
k	Permeability				Darcy	
q	injection flow rate	3	mL/min	0.02717194	bbl/day	
μ	fluid viscosity	1.8	cp	1.8	cp	Viscosity used in the calculation is the viscosity of the brine water.
L	core length	3.725	cm	0.12221129	ft	injection length or flow distance is equal to core length
d	core diameter	3.751	cm	0.1230643	ft	
A	core area	11.05198579	cm^2	0.01189626	ft^2	injection area or flow area is equal to core area
ΔP	pressure difference		psi		psi	

Run	ΔP (p1-p2)	Permeability (Darcy)
Brine 1^{st}	2.73	0.163308044
Brine 2^{nd}	5.91	0.07543671
Brine 3^{rd}	5.27	0.084597905

Permeability drop/increase	Calculation	value	(%)	conclusion
after DRA solution injection	K (brine 1st)- K (brine 2nd) (drop)	0.087871333	53.8071	54% permeability drop after injecting DRA solution 100ppm
After brine water backflow	K (brine3rd)- K (brine 2nd) (increase)	0.009161194	10.8291	10.8% permeability was restore successfully after the backflow

4.2.4 Data Calculation Summary

Table 3: Summary of the data calculation

Run	**Injection**	**Pressure Diff. Data (p1-p2)(psi)**	**Permeability calculated (Darcy)**	**Permeability reduction/ restore (%)**
Run 1 10 ppm PAM	First Brine Water	2.57	0.173	
	PAM solution 10ppm			19.93(reduction)
	Second Brine Water	3.21	0.138	
	Backflow Brine Water			-73.52 (error)
	Last Brine Water	5.57	0.080	
Run 2 50 ppm PAM	First Brine Water	4.48	0.101	
	PAM solution 10ppm			21.95(reduction)
	Second Brine Water	5.74	0.079	
	Backflow Brine Water			10.97(restore)
	Last Brine Water	5.11	0.089	
Run 3 100 ppm PAM	First Brine Water	2.73	0.163	
	PAM solution 10ppm			53.80(reduction)
	Second Brine Water	5.91	0.075	
	Backflow Brine Water			10.82 (restore)
	Last Brine Water	5.27	0.084	

This table shows the summary of the data calculation. From the calculation, we manage to come out the core permeability or the fluid flow permeability for each injection and also the percentages of the permeability losses and restore. The permeability reduction percentage was calculated from the permeability difference of the first brine and the second brine (which indicate after the injection of DRA solution) over the second brine. While for the permeability restore percentage was calculated from the permeability difference of the last second and the last brine (which indicate after the backflow injection) over the second brine. The permeability losses and restore in the data analysis.

4.3 Data Analysis

Table 4: Permeability reduction and restore

DRA Concentration	Permeability Reduction (%)	Permeability restore (%)
10ppm	**20**	-
50ppm	**22**	**11**
100ppm	**54**	**10.8**

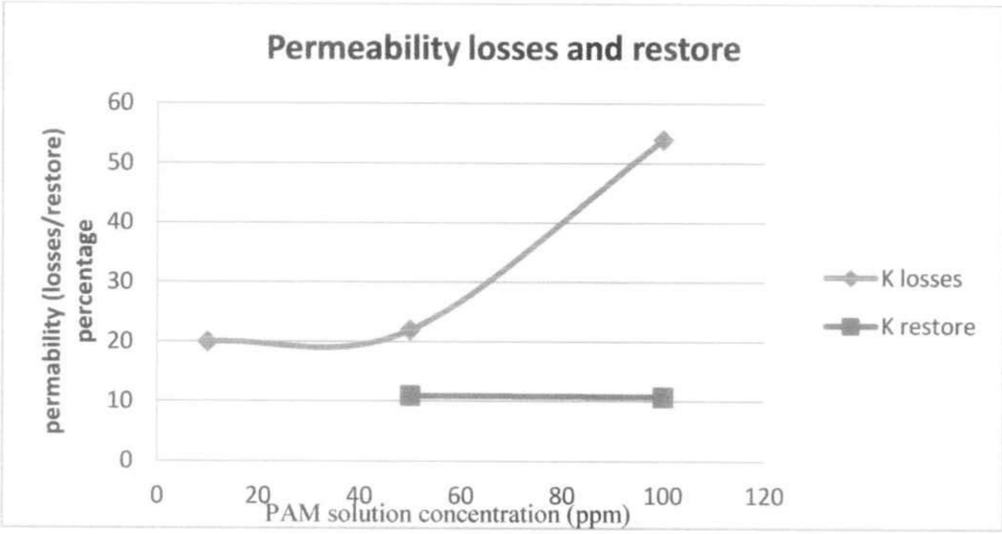


Figure 21: Permeability losses and restore across DRA concentration.

Table and figure above shows percentage of permeability losses and permeability restore in percentage across the DRA concentration. In the figure above, there are two lines that assemble the permeability losses (blue) and the permeability restores (red). This figure shows the percentage of permeability losses across the DRA concentration which represent by the blue line, and the percentage of permeability restore across the DRA concentration which represent by the red line.

4.3.1 Permeability losses

From the result above we see that 10ppm DRA causes 20% permeability losses while 50ppm causes 24% and 100ppm causes 54% permeability losses. DRA solution injection onto the core sample proves the permeability losses. The permeability losses increase with the DRA solution concentration. More concentration of the DRA solution more permeability losses recorded. Greater increment of DRA solution concentration predicted to be greater permeability losses.

4.3.2 Permeability restores

From the result above we see that permeability losses can be restored by backflow method. This finding proves that the permeability losses are because of face plugging of the DRA long chain polymer on the core face. However, from the experiment, the author fail to observe the permeability restored for 10ppm DRA solution injection. This is maybe because of some reasons. Maybe 10ppm DRA solution polymer form smaller polymer chain that plug far into the core so that backflow method only cause more permeability losses rather than being restored. Fortunately, for 50ppm and 100ppm DRA solution, it is successfully record the permeability restore by 10.8% for 100ppm and 11% for 50ppm. The permeability restored increase when the DRA concentrations decrease. Lesser the DRA concentration, higher the permeability can be restored.

4.3.3 Face Plugging

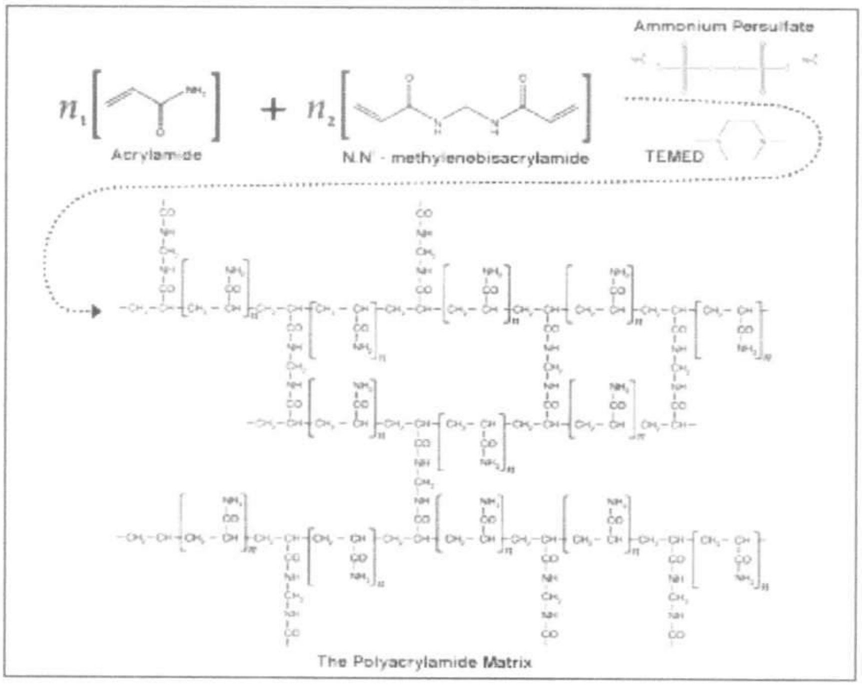


Figure 22: The polymerization of a Polyacrylamide matrix with methylenebisacrylamide cross-linking [15]

The figure above is an example of Polyacrylamide (PAM) molecule structure. Polyacrylamide is a synthetic (man-made), potassium-based, long-chain polymer (same molecule repeating it many times) designed to attract either positively charged particles (organic materials, such as carbon or human waste) or negatively charged particles (inert materials, such as sand or clay). [16] So as we now understand that PAM causes the core permeability losses is due the PAM molecule structure itself. PAM molecule long chain structure causes plug in the core. When PAM solution is injected through the core sample, the PAM molecule stuck in the tiny core pores and causes plug. However, since the PAM injection is one direction (inlet to outlet), the PAM molecule only stuck at the face of the core sample (injection inlet). That is why the PAM only causes the face plugging on the core sample that resulting the permeability losses. In addition, the increment of the PAM concentration resulting more plugs at the core face and resulting higher permeability losses.

4.3.5 Backflow method prove permeability losses is only external damage

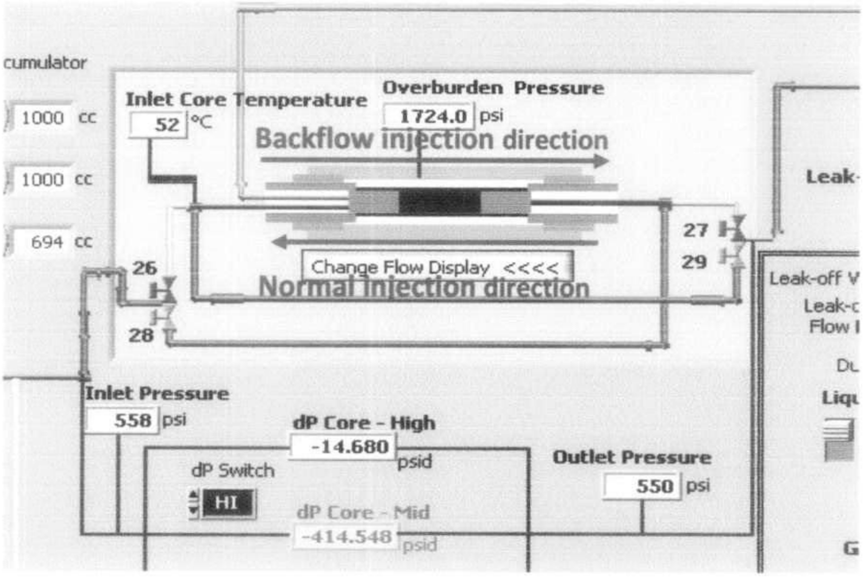


Figure 23: The backflow injection direction

This figure above shows the direction of backflow injection which is reverse to the normal injection direction. The backflow injection is still using the brine water but only reverse to the normal injection direction. From the result, the author manages to prove the backflow method can restore the permeability losses that occur after the injection of the PAM solution. As per discussion before, the permeability losses is due to the PAM long-chain molecule that plug at the face of the core sample. However, after the brine water was injected in reverse direction, the permeability increment was measured. The successful of restoring the core permeability is because the backflow brine water injection easily unplugs the PAM molecule from the core. This proves that the plug only happened at the face of core and not deep inside the core. In other words, there is only external damage that happened to the core.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The introduction of this project has been discussed by the author at early chapter of the report whereby the author mention about the background study, problem statement, the project objective, scope of study and the relevancy and feasibility of this project. The author also has explained about the DRA in all aspect in term of the definition, mechanism, application. The author has also analyzed and concludes several previous researches that related with the project in chapter two. The last chapter is about the project methodology and activities to summarize how this project was conducted. All the key milestone for this project has been summarize in the Gantt chart. The author also gave a brief description on the equipment and consumables that has been used in this project. The author also has described the experiment procedures and design and has been conducted successfully. All the data result from the experiment has been presented in this report includes the data calculation. The result findings has been analyzed and discussed. In conclusion, the experiment was successfully achieve its objective when the result met its expectation in its initial hypothesis.

5.2 Recommendation

In this recommendation section, the author would like to express and give his idea and opinion on the further research extension and continuation from this project. As we can see the scope of study of this project only covers certain area of field. This project only covers the permeability aspect of the effect of the PAM. Furthermore, in this project, the effect of permeability onto the core only was further analyzed by manipulating the PAM concentration by using three different concentrations. Hence wider and various scope of study can be cover in this project that will be discussed below.

5.2.1 Future Work for Expansion and Continuation

5.2.1.1 New scope of study (porosity, precipitation).

In this project, the author was only study the effect of Drag Reducing Agent (DRA) which in this project was using Polyacrylamide (PAM) on core sample in term of permeability only. It means that the outcome of the project is to prove that PAM does reduce the core permeability and backflow method manages to restore the permeability reduction. There are other scope of study can be covered for this topic which are the porosity, precipitation and rock alteration. This project can be extended by study the effect of PAM on core sample in term of porosity. The study is about to approve if there are any porosity reduction after the injection of PAM on core sample. This project are also can be extended by study about the precipitation in the core sample that might happen after the injection of PAM.

5.2.1.2 Analyzing the permeability reduction effect for different type of core sample.

In this project, the author only manages to use the different types of the PAM concentration in order to see the relationship between the concentration and the amount of permeability reduction upon injection. However, this project can be extend by doing the study on the relationship between the different type of core sample and the amount of permeability reduction of the core sample due to the injection of PAM. This time the PAM concentration used will be the same but the core samples that will be use is the tight core (permeability below 100 mD) medium core (100-200 mD) and also large permeability core (permeability above 200 mD). This is to show the effect of DRA on different types of reservoir formation from tight reservoir to the large permeability reservoir formation. The expected result should be the tight core will result more and higher permeability reduction than others.

5.2.1.3 Analyzing the permeability reduction effect between fresh DRA and broken DRA.

Fresh DRA is the DRA is that is not damage, not been sheared while the broken DRA is the DRA that been sheared. The fresh DRA is prepared using a magnetic stirrer with gentle mixing, while the sheared DRA was prepared using a blender at very high mixing speeds. The fresh DRA presume that DRA will be injected into the reservoir formation in the form as injected into the pipeline. However, in the real situation that usually practiced, there is booster pump the end of the transfer line, and it has also elbows, valves too. Thus, it is expected that the fresh DRA will be sheared (broken) before it reaches the formation. It can be conclude that the fresh DRA represent the worst case scenario, while the broken DRA (being sheared) is close to the field situation. [4] Thus, this project can be further expand by analyzing between fresh and broken DRA, which one give greater permeability losses to the core sample. It is expected that the fresh DRA will give greater permeability losses.

5.2.1.4 Study the effect of oxidizer treatment solution to restore initial core permeability

According to Al-Anazi 2006, a treatment solution (an oxidizer) was a very effective in degrading the DRA and restoring the initial core permeability. They used 3,000 ppm oxidizer treatment that which was prepared in seawater was injected it to the core after the DRA injection. They manage to prove the pressure drop after the injection of the oxidizer treatment drop and reached to the initial value measured before the DRA injection. Hence, this project can be carry on to study and prove the claim that the oxidizer treatment can restore the initial core permeability.

In conclusion, there are wider and bigger aspect and scope to further study of the effect of DRA on core sample. Hence, all the recommendations that explained by the author do base on his ground understand and future perspective of this project since it has been started for almost 8 months. The author hope the potential of this project can be expanded and continued for the knowledge and betterment of oil and gas industry practices.

REFERENCES

1. Spectraseis Ag. 2007 <http://www.spectraseis.com/jahia/Jahia/spectraseis/technology>
2. E. Tzimas, 2005 <http://ie.jrc.ec.europa.eu/publications/scientific_publications/2005/EUR21895EN.pdf. Retrieved 2008-08-23>
3. R. A. Woodroof and R. W. Anderson, "Synthetic Polymer Friction Reducers Can CauseFormation Damage," SPE 6812 (paper presented at the 52nd Annual Fall TechnicalConference and Exhibition, Denver, CO, 9–12 October 1977).
4. H. A. Al-Anazi, M. G. Al-Faifi, F. Tulbah, and J. Gillespie, "Evaluation of Drag ReducingAgent (DRA) for Seawater Injection System: Lab and Field Cases," SPE 100844 (paper presented at the SPE Asia Pacific Oil & Gas Conference and Exhibition, Adelaide,Australia, 11–13 September 2006).
5. M. Ke, Q. Qu, R. F. Stevens, N. Bracksieck, C. Price, and D. Copeland, "Evaluationof Friction Reducers for High-Density Brines and Their Application in Coiled Tubingat High Temperature," SPE 103037 (paper presented at the SPE Annual TechnicalConference and Exhibition, San Antonio, TX, 24–27 September 2006).
6. R. L. J. Fernandes, B. M. Jutte, and M. G. Rodriguez, "Drag Reduction in HorizontalAnnular Two-Phase Flow," International Journal of Multiphase Flow 30 (2004): 1051.
7. Prakash Singh, R. 2002, Drag Reduction, New York, John Wiley & Sons
8. Al-Sarkhi, A. 2010,*Drag reduction with polymers in gas-liquid/liquid-liquid flows in pipes*, Amsterdam, Netherlands, Elsevier B.V.
9. ConocoPhillips. 2010 <http://www.liquidpower.com/EN/productsolution/whataredragreducers/Pages/index.aspx>
10. FloQuest GmbH.2010 <http://www.flo-quest.com/mechanism.php>

11. EPA Science& Technology. 10 December 2010
<http://water.epa.gov/type/groundwater/uic/history.cfm>

12. Nelson, J., 2003,*Optimising production using drag reducing agents in water injection wells,* Offshore Engineer.(October 2003) 1-4.

13. Malcolm A. Kelland, June 25, 2009 *Production Chemicals for the Oil and Gas Industry, University of Stavanger, Norway,* CRC Press.

14. UniversitiTeknologiPetronas, 2011
<http://www.utp.edu.my/COE/EOR-Center/index.php?option=com_content&view=article&id=98&Itemid=88>

15. National Diagnostics, 2010
<http://www.nationaldiagnostics.com/article_info.php/articles_id/6>

16. Hydrosob, November 2002.
<www.hydrosorb.com/docs/PowerofPolyacrylamide.pdf>

Tom B.A., 1948. Some observations on the flow of linear polymer solutions through straight tubes at large Reynolds numbers. In: Proceedings of the First International Congress on Rheology, vol. 2. North Holland Publication Company, Amsterdam. 135–141.

Harder, K.J., Tiederman, W.G., 1991.Drag-reduction and turbulent structure in two-dimensional channel flows. Phil. Trans. R. Soc., Lond. A 336, 19–34.

Wei, T., Willmarth, W.W., 1992.Modifying turbulent structure with drag-reducing polymer additives in turbulent channel flows. J. Fluid Mech. 245, 619–641.

Warholic, M., Massah, H., Hanratty, T.J., 1999. Influence of drag-reducing polymers on turbulence: effects of Reynolds number, concentration and mixing. Exp. Fluid 27, 461–472.

Savins, J.G.: "Drag Reduction Characteristics of Solutions of Macromolecules in Turbulent Pipe Flow," SPEJ (September 1964) 203-214.

Nelson, J., 2003. " Optimising production using drag reducing agents in water injection wells," *Offshore Engineer*.(October 2003) 1-4.

Berge, B.K. and Solsvik, O.: "Increased Pipeline Throughput using Drag Reducer Additives (DRA): Field Experiences," SPE 36835 presented at the 1996 SPE European Petroleum Conference held in Milan, Italy,October 22-24.

Lescarboura, J.A., Culter, J.D. and Wahl, H.A.: "Drag Reduction with a Polymeric Additive in Crude Oil Pipelines," SPEJ (Sept. 1971) 229-234.

S. E. Morgan and C. L. McCormick, "Water-Soluble Copolymers: XXXII. Macromolecular Drag Reduction. A Review of Predictive Theories and the Effects of Polymer Structure," Progress in Polymer Science 15 (1990): 507

John U. Ibrahim and Lucky A. Braimoh, "Drag Reducing Agent Test Result for ChevronTexaco, Eastern Operations, Nigeria," SPE 98819 presented at the 29th Annual SPE International Technical Conference and Exhibition in Abuja, Nigeria, August 1-3, 2005.