Experimental Study on the Effect of Different Injection Rates of Biopolymer Extracted from Natural Waste Material (Coconut Residue) as Drag Reducing Agent (DRA) in Water Injection Well: Formation Permeability Reduction

By

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Dissertation submitted in partial fulfillment of

the requirement for the

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(Petroleum)

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CERTIFICATION OF APPROVAL

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Approved by,

_____

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January 2015

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 here have not been undertaken or done by unspecified sources or persons.

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(Mohamad Nor Rafie bin Jainuddin)

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. However, the synthetic polymer that is widely used in the industry have raised the environmental concern as its chemical content are believed to be harmful to the environment. This has generate the idea of using natural biopolymer DRA instead of the synthetic polymer. In this study, grated coconut residue has been chosen as the source of biopolymer to produce the natural DRA due to its high content of cellulose. Many studies were conducted to understand the behavior and optimize the performance of DRA when it is being applied in the pipeline. However, the effect of DRA on the reservoir formation has been less studied, especially in the near wellbore zone. A water injection system using core flood equipment was used in this work. 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 synthetic DRA solution gives more permeability reduction compared to natural DRA solution. In conclusion, natural DRA is believed to have a full potential as an alternative to save cost on energy needed to drive the water injection system by eliminating the need to install new injection well.

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ABBREVIATIONS AND NOMENCLATURES

DRA	Drag reducing agent
CMC	Carboxymethylcellulose
CR	Coconut residue
PAM	Polyacrylamide
NaOH	Sodium Hydroxide
NaCl	Sodium Chloride
POROPERM	Permeability and Porosity Meter
BPS	Benchtop permeability system

CHAPTER 1

INTRODUCTION

1.1 Project Background

Drag can be define as forces that oppose the relative motion of an object through a fluid. In oil and gas industry, drag had caused several problems to the flow line such as power pumping losses, decreasing in production capacity and pipelines corrosion. In the production stage of the well, hydrocarbon is displaced by sufficient pressure provided by natural reservoir drives. However, the natural energy will depleted after the production of hydrocarbon begin and it will affects the capacity of production rate.

Secondary recovery will then be introduced to continue produce the well at the optimize production rate. Water injection system is secondary oil recovery method normally be used to increase the reservoir pressure by injecting the water into the reservoir through a number of injection wells. However, the frictional pressure loss will reduce the performance of the liquid flow as a result the flow capacity will reduce. The implementation of water injection will reach poor efficiency after times due to drag problem which occurs in pipeline.

In fluid flow inside pipeline, the fluid in contact with the inner surface of pipe (pipe wall) tends to stick to the surface due to the viscous effect. This layer of fluid will slow down the movement of the adjacent fluid layer by dragging that fluid layer due to friction. Due to this frictional drag, it will cause pressure drop along the pipeline. With the increasing distance, more pressure will be reduced and directly affect the flow rate of the fluid transportation.

In oil and gas industry, to cope with the pressure loss, equipment such as booster pump is installed at specified location. The installing, operating and maintaining this equipment can cost millions or maybe higher. Thus, presence of DRA has proven to reduce the friction and increase the flow rate which can be considered as reliable and economical solution for the problem.

Since the famous successful usage of first DRA in field application for Trans-Alaska Pipeline during late 1970s, DRA have been improved tremendously, both in reliability and effectiveness. 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 [1]. Since then, drag reduction applications have brought a lot of improvement in crude oil transportation and water injection for last few decades.

Figure 1.1: Trans Alaska pipeline (Source: www.breakingenergy.com)

The usage of DRA was vastly developed and used in several applications such as:

1. Medical Application
   a). Improve blood flow through clinically significant arterial stenosis [2].
   b). Clinical treatment for hemorrhagic shock and microcirculatory disorders [3].
2. Firefighting hoses
   DRA is very effective in increasing the hose stream pressure, reach and volume [4].

DRA reduces the loss of energy due to friction as fluid travels through the pipeline. Significant drop in pressure loss can be achieved without the need to increase the pumping pressure. Different types of DRA are being introduced to the industry with improved characteristic and suitability to different type of fluid. Over the years, there are three main types of DRA that have been widely used in industry which are polymers, surfactants and fibbers. Polymers DRA can be divided into two categories: synthetic polymers and natural polymers. However, the study area of natural polymer

remains grey since the availability of natural polymers DRAs is quite limited in industry.

To give contribution to the oil and gas industry, this project is purposely done to explore the usage of Coconut Residue as natural polymer DRA in water injection well. The effect of DRA will be tested at different injection rate towards flow rate and pressure loss in water injection tubing. The CMC will be extracted in the lab and the experiment is conducted using the setup in the lab.

1.2 Problem Statement

Turbulent flow regime of water in water flooding system and pipeline induced drag along the inner wall of the pipeline making it difficult to flow thus increased the pressure drop along the injection tubing and the pipelines respectively. Many techniques for reducing drag were suggested by many researchers for large number of applications and one of that is by using DRA. However, most studies regarding the application of DRA is focused on its effect and also the working principle of the biopolymer towards the pipeline. There are very less focus given on the effects of DRA on the formation or wellbore itself. Current literatures suggest that injection rate of DRA may cause the reduction of permeability towards the formation.

According to Abdulbari et al. (2014), there are questions and concern raised on the environmental impact of synthetic polymers as DRA. Excessive use of the synthetic polymers will harm the environment due to their chemical content [5]. The cost of repairing the damage inflicted by the DRA to the well might even outweigh the benefits of the DRA usage at the first place. Thus, the DRA might not be economically feasible to be utilized in the oilfield if it does a damage to the formation.

This is where the idea to use a natural polymers came as a replacement to the existing synthetic polymers as a DRA. Phukan et al. (2001) studies suggest that purified bio-polymer works as better DRA than commercial grade. The removal of protein and fat impurities actually has a huge impact on drag reduction performance [6]. This paper is therefore very important to clarify whether this DRA is commercial enough to be use in the industry. The author will try to simulate the real field situation in which the DRA efficiency will be affected.

1.3 Objectives

The objectives of this project are as outlined below:

1. To extract carboxymethylcellulose (CMC) from coconut residue (CR) and justify its effectiveness as a drag reducing agent (DRA) in reducing the frictional drag and pressure loss in the pipeline.

2. To study the effects of various injection rate of extracted CMC as natural DRA compared with commercialized DRA on permeability reduction.

1.4 Scope of Study

The scope of study for this project is focused on justifying the effectiveness of biopolymer extracted from coconut residue to function as DRA in water injection well. This project also evaluating various injection rate of the natural DRA compared with the commercialized DRA and study its effects on reduction of formation permeability. Reduction in permeability of formation can cause by plugged DRA particles inside the pore of the core.

This study will be an experimental-based research in which the results will be obtained through lab experiments. The type of water will be used to simulate water injection in the flow meter test is tap water. However, the particles size, molecular weight and densities of the DRA were not covered in this studies. This study were also not cover the effect of DRA within the formation or reservoir, the dynamic changes in reservoir temperature and pressure with depth, as well as the chemical reaction between DRA and the reservoir formation.

There will be three stages of experiment for this study which is the extraction process of CMC from the CR, flow meter test to study the efficiency of the CMC, and benchtop permeability test to study the effects of various injection rate of DRA on the formation permeability.

CHAPTER 2

LITERATURE REVIEW

2.1 Water Injection Wells

Water injection which is known as secondary oil recovery method used to maintain the reservoir pressure by injecting the water into the reservoir through the injection wells. The water is injected using the pumps located upstream the injection flow line and it will pass through the small diameter pipe (6-8 inch) [10]. The water injected will push the oil towards the production wells, thus it helps to boost the production rate of the reservoir

In a research paper entitled "Modelling and Operation and Flow Control of Large Water Injection Systems" by Miaoxin, C et. al. (1995), they stated that for high water cut fields, the operational cost for injecting water inside the reservoir is expensive due to higher electrical power consumption (EPC) [11]. The suitable pressure and flow rate determine whether water injection is a success, and with a successful water injection, there will be higher amount of oil to be recovered.

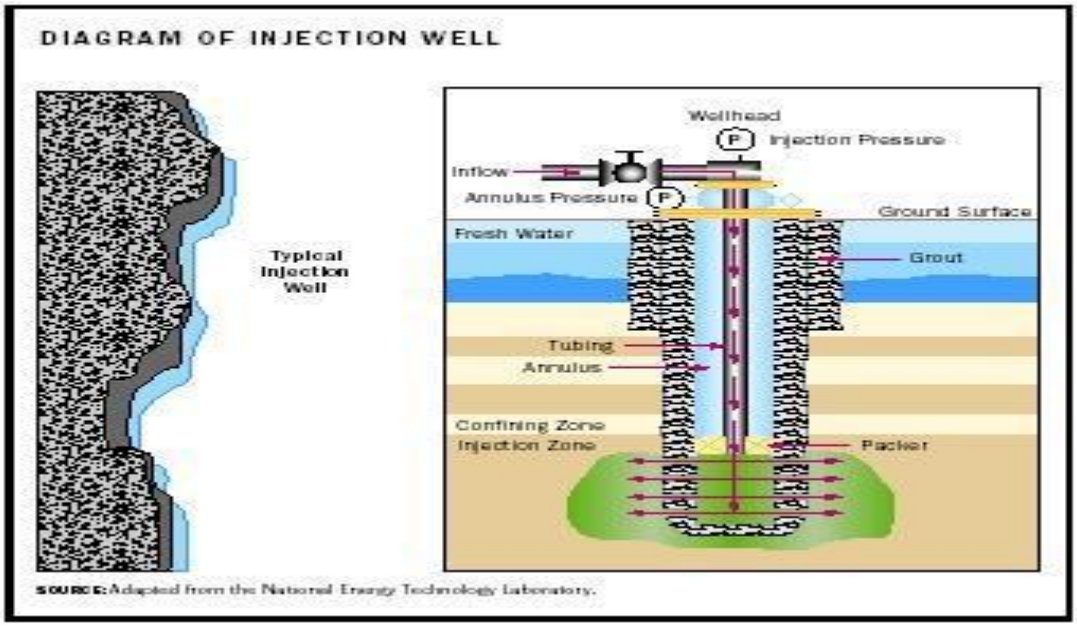

Figure 2.1: Overview of Water Injection Well
(Source: www.stateimpact.npr.org)

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. According to Nelson, J. (2004), the problem can be solved by injecting DRA downstream into the injection tubing, which then will help to reduce the pressure drop [10]. As a result, the water injection rate can be increased until the maximum allowable operating pressure of the injection system is reached.

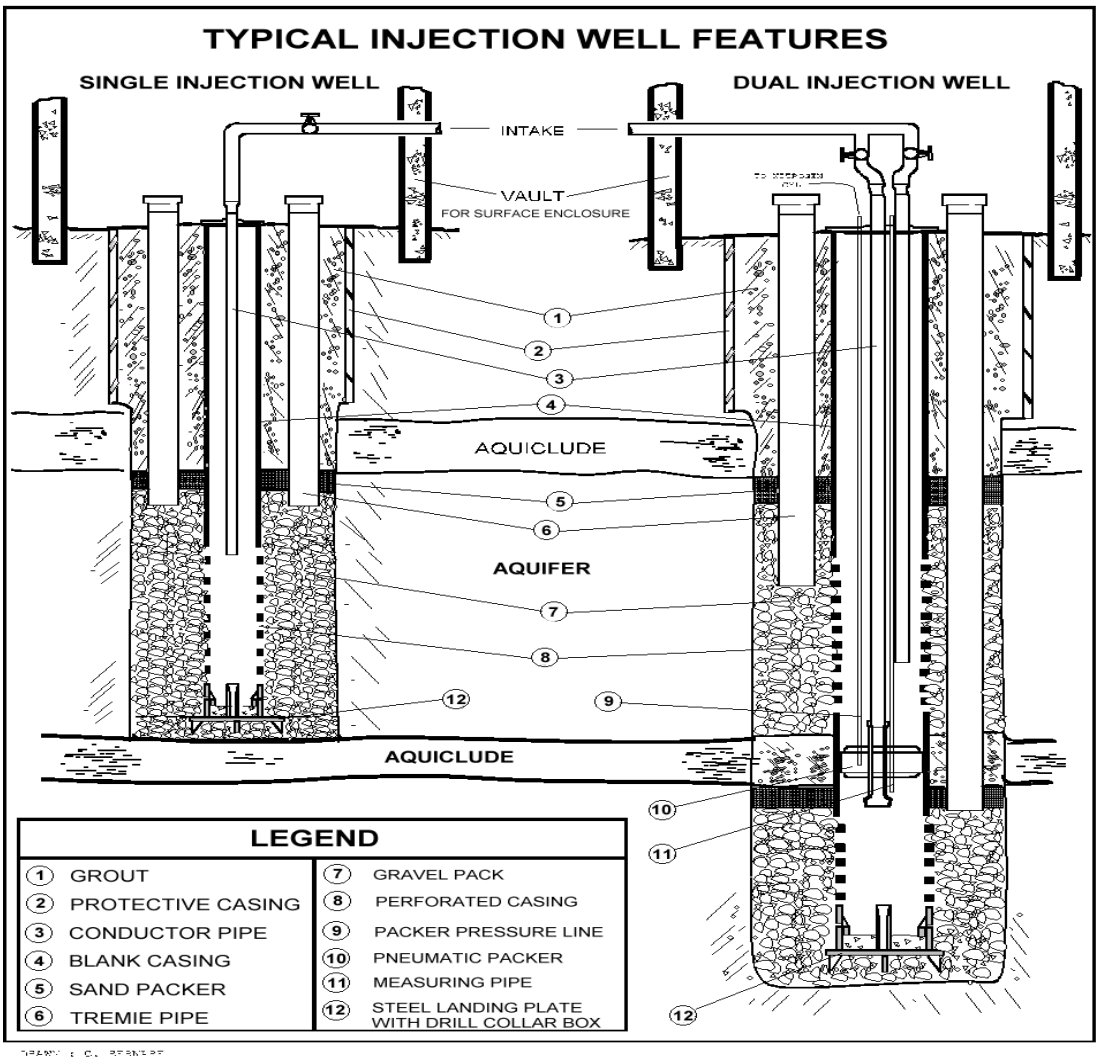

Figure 2.2: Typical Injection Well System (Source: www.dispatch.com)

2.2 Turbulent Flow Regimes

According to Ezaty et al. (2012), the long chain polymer of DRA helps in lessening the frictional pressure loss by wetting the turbulent strike and controlling the flow regime of the fluid flowing via the conduit pipe [15]. This statement also supported by Henaut et.al (2009), by stating that the DRA is able to reduce the pressure drop of the fluid if it is categorized as turbulent flow, DRA also helps to boost the tubing capacity [16]. In a transported fluid pipeline, fluid flow produce the friction force 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 thus creating a turbulence flow regime.

Due to the turbulence flow, energy losses will be encounter, and can be in a very high magnitude. According to Berman et al. (1988), 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 [19]. Ohlendrof, (1986) stated that the 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 [20].

To ensure that the DRA works effectively in reducing the drag, the flow inside the flow meter must be in turbulent regime. Turbulent flow is categorized by having Reynolds number greater than 4100 (N_{Re} > 4100). The Reynolds number of the flow in the flow meter is calculated using the formula below:

$$N_{Re} = \frac{\rho v D}{\mu} \qquad \text{(Eqn. 1)}$$

Where,

ρ = Density (kg/m3) v = Velocity (m/s)

D = Diameter (m) μ = Viscosity (kg/m.s)

2.3 Drag Reduction Agent (DRA)

In early days, the drag reducing agents was first written in the literature by Toms (1948), where he accidently observe the effect in his study of mechanical degradation of polymer inside a flow of a pipe. 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 [7]. However, the extended 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) stated that, this is a result in the high degree of mechanical shear rate, which most polymers cannot withstand [8].

In the oil and gas application, the works on drag reducer was first written by 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 [9]. His works has justified the effect of macromolecules injection such polymers to reduce the drag, thus increase the pump efficiency.

One of the most impressive successes in polymer applications for drag reduction was the use of 10ppm oil-soluble polymers in the trans-Alaska pipeline system which increased pipeline flow rates significantly (Burger et al., 1982) [1]. In oil industry, oil soluble and long-chain polymers had been identified as the effective chemical to reduce the frictional pressure drop caused by turbulence in a pipeline. The operating pressure can be diminished while keeping the same flow rate or the throughput can be increased while applying the same pressure.

With the application of DRA which are immense in the oil and gas industry, engineers start to apply the DRA in the water injection system. Nelson (2004), has defined 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 [10].

DRA is a type of additive made up of high molecular weight polymers that is used to reduce the pressure drop and improve the flow of the oil in the transportation tubing and the flow of water in the water injection system [17]. The effectiveness of the polymer type DRA can be determined by many factors:

1. Solubility of the polymer in the fluid.
2. Molecular weight of the polymer.
3. Concentration of the polymer.
4. Turbulence flow.
5. Length of tubing.
6. Injection Location.
7. Degradation.

The increase in the flow capacity and declining of pressure drop has eliminate the need for the bigger number of injection wells for water flooding system. The target flow rate can be reach using lesser number of injection wells with the application of DRA. According to Al-Anazi et al. (2006), the performance of DRA can be assessed by determining the percentage of drag reduction (%DR) at a given flow rate and concentration which can be calculated by using the following equation [14].

$$\%DR = \frac{\Delta P - \Delta P_{DRA}}{\Delta P} X\ 100\% \qquad \text{(Eqn. 2)}$$

Where;

ΔP = pressure drop of untreated fluid, psi

ΔP_{DRA} = pressure drop of fluid containing DRA, psi

2.4 Formation Permeability Reduction

Permeability is the measurement of a rock's ability to transmit fluids, typically measured in darcies or millidarcies. Formations that transmit fluids readily, such as sandstones, are described as permeable and tend to have many large, well-connected pores. While impermeable formations, such as shales and siltstones tend to be finer grained or of a mixed grain size with fewer or less interconnected pores. Permeability in petroleum-producing rocks is usually expressed in units called millidarcys (one millidarcy is 1/1000 of a darcy). Most oil and gas reservoirs produce from rocks that have ten to several hundred millidarcys.

The permeability decrease of sandstone reservoirs is caused by the interaction of many physicochemical parameters and processes which characterize the fluid and the porous medium. The particles available in the injected fluid can migrate and plug the pores in the reservoir thus reduce its permeability, depending on their size and its concentration (Ochi et al., 1998) [18]. The particles with higher molecular weight and density will result in more permeability reduction in the reservoir. Particles with higher densities will resulting in higher gravitational sedimentation where the particles will be easier to deviate from fluid streamlines and collide thus deposited in the grain.

The release of particles from pore surfaces occurs as a result of two different phenomena. The first, regarded as a chemical phenomenon and named 'water sensitivity of sandstones'. Secondly, the phenomenon regarded as mechanical, is induced by the hydrodynamic force of the fluid [18]. However, the rate of particle release cannot be related to the fluid velocity alone because it is also related to the mechanisms of release and deposition of particles occurring in the porous medium and to the amount of the unblocked particles available for mobilization at the pore surface.

2.5 Carboxymethylcellulose (CMC)

Carboxymethylcellulose was produced from the modification of natural polymer known as cellulose. Cellulose is a natural type of polymer. CMC can also be defined as the derivative of cellulose group formed by the reaction of acid and alkali such as sodium hydroxide (NaOH) and monochloroacetic acid [11]. According to Hong (2013), higher concentration of NaOH increases the degree of substitution of carboxymethyl group on the cellulose backbone. This subsequently results in higher molecular weight as well. Besides, the substitution process also creates strong inter-molecular bond between caboxymethyl group and hydroxyl group, thus it results in higher mechanical properties. In conclusion, higher concentration of NaOH yields higher molecular weight and better mechanical properties [12].

2.6 Coconut Residue

Coconut residue has been chosen as a sample for CMC extraction due its high content of cellulose. According to research done by Mirhosseini, H. et al. (2010), cellulose content of the grated coconut is 72.6% [13]. Hence, the content of cellulose plays an important role in choosing the suitable natural polymer as DRA. Cellulose content is one of the deciding parameters that can be taken into account in choosing a natural polymer to be used as DRA. The higher the cellulose content, the more effective the natural or organic polymer as a DRA. Apart from that, coconut residue is an abundant resource in which we can find it in almost all places in Malaysia, along with the fact that it is a relatively cheap material.

Figure 2.3: Grated Coconut Residue

CHAPTER 3

METHODOLOGY

3.1 Research Methodology

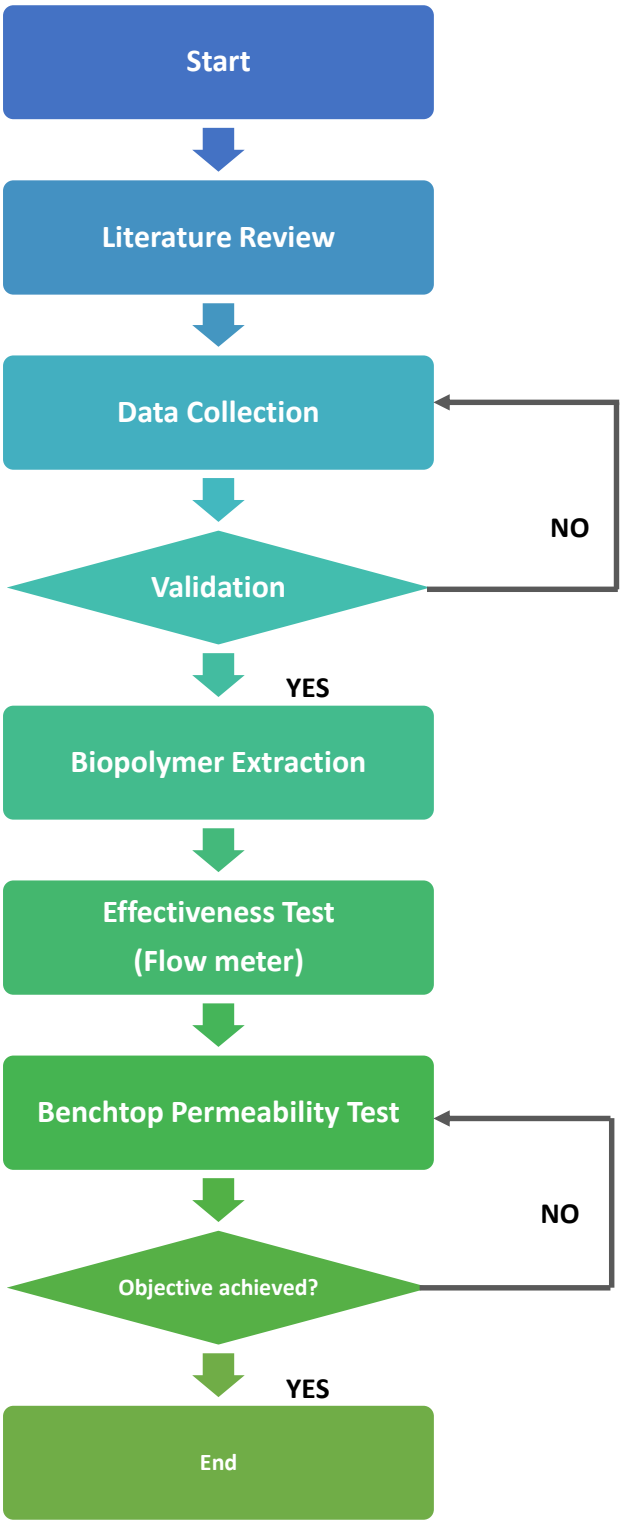

Figure 3.1: Project Workflow

3.2 Experimental Setup

The experimental investigation of this research are divided into several subsections, which are preparation of the DRA, the effectiveness test, and sample evaluation on the permeability reduction effect.

3.2.1 Synthesizing the biopolymer

CR is the leftovers of grated coconut meat after the coconut milk is extracted by subjecting the coconut residue to physical treatment such as compression. The process of synthesizing the biopolymer from grated coconut residue is adapted from previous research by Kaur, H. (2013) of The Study of Drag Reduction Ability of Naturally Produced Polymers from Local Plant Sources [11].

The original idea of extracting the CMC from natural by-products is formulated by the Center of Excellence for Polysaccharides Research, Friedrich Schiller University of Jena, Germany [11]. This method is discovered to be more feasible hence chosen due to the minimal requirement on the amount of chemicals used besides of it relied mostly on the raw organic material available on the CR itself.

3.2.2 Materials

Coconut residue used in this experiment were collected from local source that selling the coconut milk at Taman Maju while the needed chemicals for synthesis process of carboxymethylcellulose (CMC) were purchased from a chemical company, Irama Canggih Sdn Bhd. The required chemicals for synthesizing CMC are as listed below:

i. Sodium hydroxide pellets AR QREC S5158-1-1000
ii. Isopropanol AR QREC PR141-1-2500
iii. 96% Ethanol denatured AR QREC E7045-1-2500
iv. Methanol AR QREC M2097-1-2500
v. Chloroacetic acid MERCK 412
vi. Acetic Acid AR QREC A1020-1-2500

3.2.3 Cellulose Extraction

i. CR is rinsed with tap water until cleaned before oven-dried for 24 hours (or more until completely dried). The tap water is acquired from the laboratory to ensure consistency and repeatability with other raw materials later on. Weighted the mass of CR before and after the drying process.

Figure 3.2: Oven-dried Process of Coconut Residue

ii. Dried CR was then mix and cooked with 1M of NaOH in a 2L beaker at 100°C hot plate temperature for 1 hour utilizing a magnetic stirrer. The amount of CR added to the NaOH solution should not too much which will be troublesome for the magnetic stirrer to stir the thick mixture.

This step was carried out to ensure there is no contamination and undesirable items from the CR. After the mixing process, it was observed that the mixture will turn from earthy color to a reddish-purple mixture and this progressions happened quicker when heated on the magnetic stirrer.

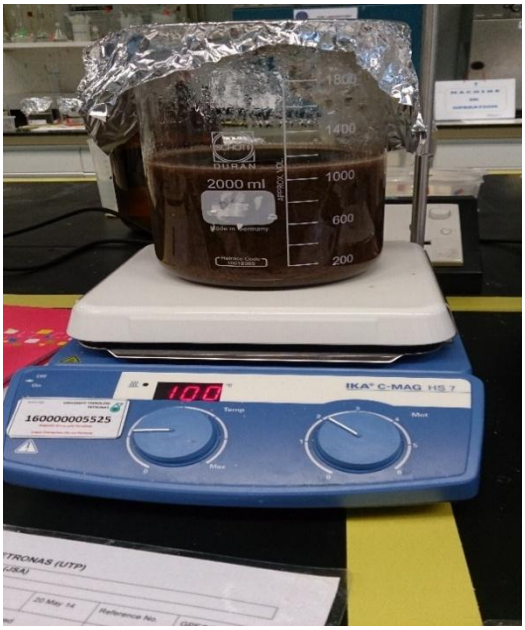

Figure 3.3: CR cooked with 1M NaOH mixture at 100°C temperature

iii. After the red slurry is obtained, it will be filtered to remove the powder from the liquid phase. The suspended powder will be washed with plenty of water until the red color is gone and it nearly turns to its originated color.

Figure 3.4: CR before and after being rinsed with tap water

iv. The obtained residue will be dried in an oven at 60°C for some time (24 hours or more until it completely dried) so it will be ready to be synthesized to obtain the CMC. The mass of the residue before and after drying process will be measured. This drying process is to ensure the moisture has been eliminated completely. The dried powder will be kept in a tight container before synthesizing CMC.

3.2.4 Carboxymethylcellulose (CMC) Synthesization

The synthesizing process of CMC mainly affected by three main parameters which are the reaction temperature, reaction time and concentration of NaOH. As recorded in the table beneath is the parameters set for this experiment:

Table 3.1: Used parameters for synthesizing the CMC

Parameters	Range
Reaction Temperature (°C)	60
Reaction Time (min)	240
NaOH Concentration (m/v %)	60

Preparation of CMC Consist of 2 reactions which is alkalization and carboxymethylation. The procedure of the experiment are as follows:

i. 40g of cellulose obtained in the previous step, 100ml of NaOH of 60% concentration, and 900ml of isopropanol were mixed in a beaker using a magnetic stirrer for 30 minutes. 36.0g of monochloroacetic acid was added into the beaker to initiate the carboxymethylation reaction and stirred for another 30 minutes. This step is essential to ensure the biopolymer are mixed thoroughly with water as the solvent until the polymer solutions are visibly homogeneous.

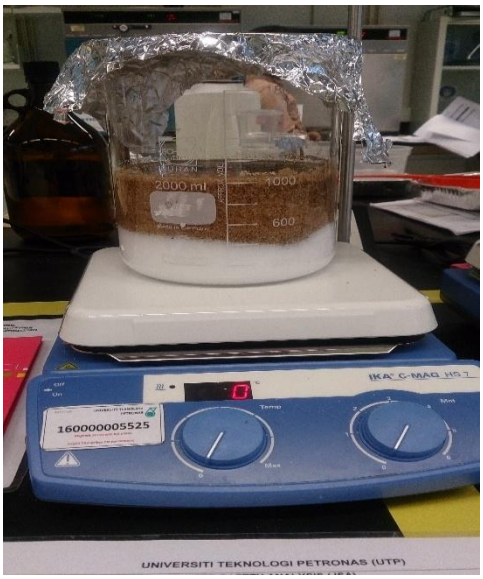

Figure 3.5: CR were mixed inside 100ml NaOH + 900ml Isopropanol + chloroacetic acid

ii. Prior to heating the mixtures of polymer solutions prepared in the previous step at 60ºC for 240minutes, the beakers were covered with aluminum foil to avoid evaporation during the entire heating process.

iii. Separate and remove the solution phase while the solid phase is kept aside and suspend it into 100ml of methanol (70%v/v) for overnight. Glacial acetic acid was poured into the beaker to neutralize the suspended solids in methanol solution.

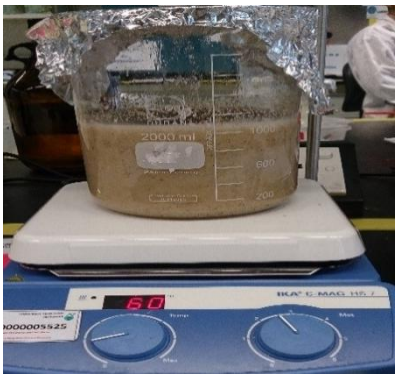

Figure 3.6: CR were heated in the solution at 60°C for 4 hour

iv. The sample is suspended in 300ml of ethanol of 70% v/v for 10 minutes to remove the unwanted products. Afterward, the solid phase will be washed with 300ml methanol until it looks clean. The product will undergo a drying process in an oven for 24hours at 60°C and then will be grinded to very fine powder and finally CMC is produced.

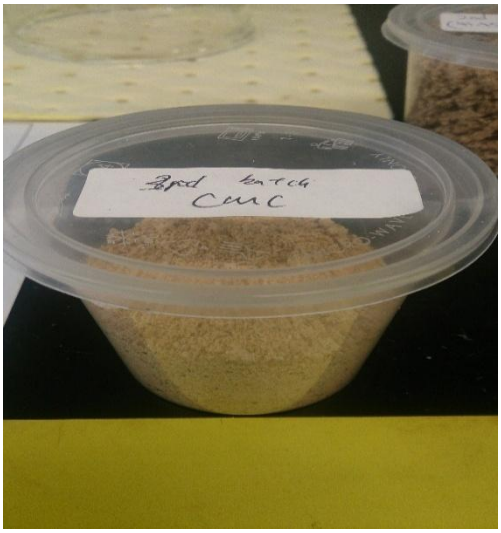

Figure 3.7: CMC produced

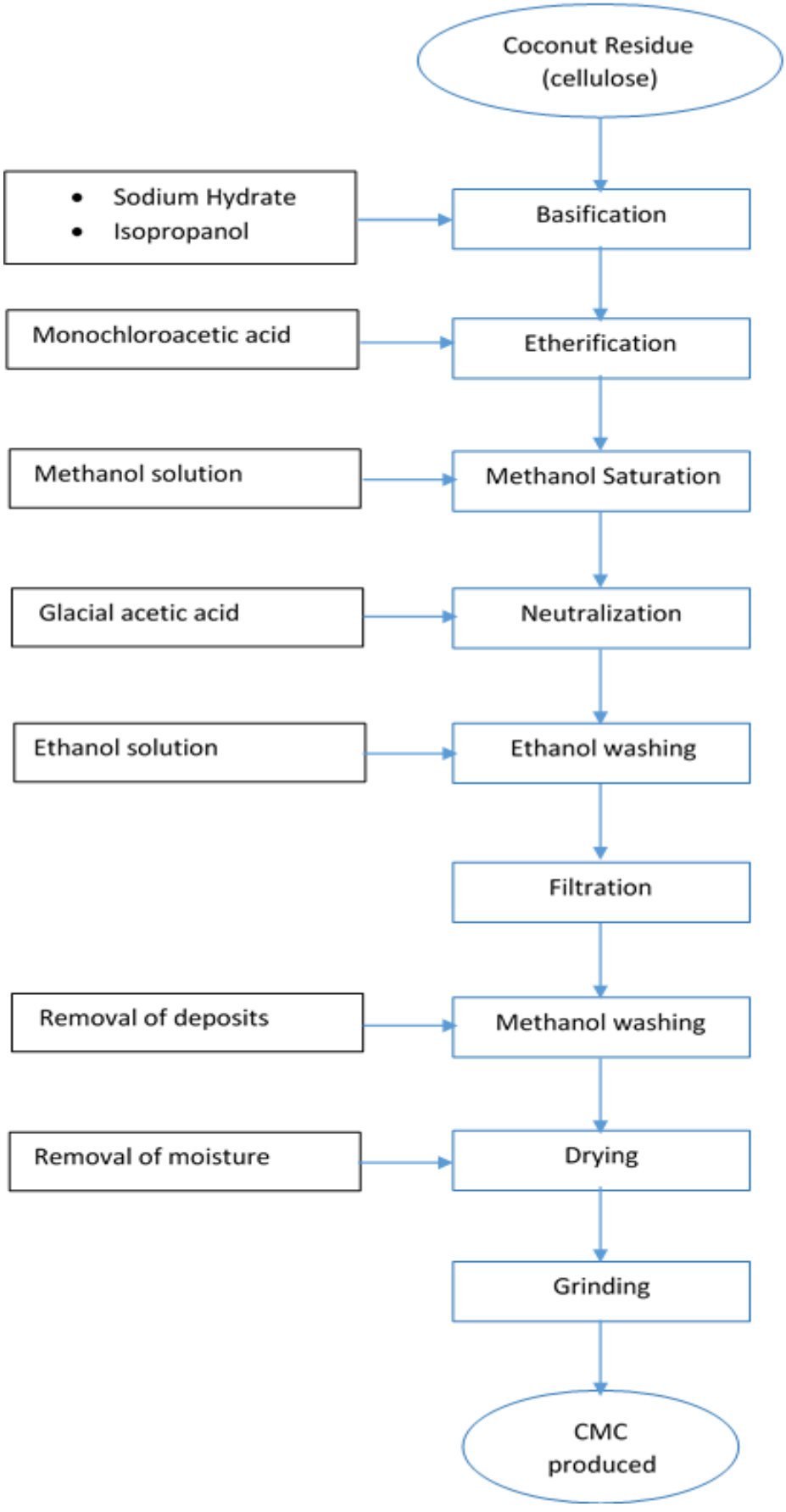

Figure 3.8: Flow chart of CMC preparation

3.2.5 Materials and Sample Preparation

Table 3.2: Materials and Equipment used

Materials	Equipment
• Barea sandstone core	• Cole Parmer mortar grinder • Flow loop apparatus • POROPERM • Desiccator with vacuum pump • Benchtop permeability system

DRA solution that has concentration of 200 ppm and 100ppm will be prepared in order to be used in the flow meter test and benchtop permeability test respectively. The following formula can be used to create the DRA solution with desired concentration:

$$Concentration\ (ppm) = \frac{mass\ of\ DRA\ (g)}{volume\ of\ solution\ (ml)}\ x\ 10^6 \qquad \text{(Eqn. 3)}$$

i. DRA solution for flow meter test:

$$Concentration\ (ppm) = \frac{8g}{40{,}000ml\ tap\ water}\ x\ 10^6$$

$Concentration\ (ppm) = 200ppm$ of DRA solution

ii. DRA solution for benchtop permeability test:

$$Concentration\ (ppm) = \frac{0.1g}{1{,}000ml\ brine\ solution}\ x\ 10^6$$

$Concentration\ (ppm) = 100ppm$ of DRA solution

While Brine solution that has salinity of 10000ppm was prepared for the use to simulate the water used in the water injection system. Brine will be used in benchtop permeability experiment. The following formula can be used to calculate the salinity of brine:

$$Concentration\ (ppm) = \frac{mass\ of\ NaCl\ (g)}{volume\ of\ distilled\ water\ (ml)}\ x\ 10^6 \qquad \text{(Eqn. 4)}$$

$$Concentration\ (ppm) = \frac{10g}{1{,}000ml\ distilled\ water}\ x\ 10^6$$

$Concentration\ (ppm) = 10000ppm$ of brine solution

The DRA solution is mixed under a medium shear rate using magnetic stirrer for 8 hours to create a homogenous solution of DRA solution. New DRA solution is prepared before each run of the experiment to avoid any effects caused by shift time degradation between each run.

Three core sample that is chosen in this experiment are Barea sandstone cores. Diameter of the core samples is 1.5 inches with length of 3 inches. The core samples were saturated around 8 days using Dessicator equipment to ensure that the core is fully saturated. The core samples are immersed in 600ml brine with 10,000ppm salinity before the pump is switched on to start the saturation process.

3.2.6 Flow Meter Test

Flow meter test is conducted to test the effectiveness of CMC as DRA to reduce the pressure drop inside the turbulent tubing. Theoretically, the flow after the orifice plate in the flow meter equipment is assumed as turbulent as it flow in high velocity and there is pressure drop. In this experiment, the horizontal flow loop is assumed will gives the same effect of drag reduction as in vertical flow loop.

8 grams of CMC powder is mixed with 1 liter of water using magnetic stirrer for half an hour until it dissolves completely. Any impurities or solids are filtered out using filter paper. The prepared DRA solution is mixed with 39 liters of water, which totaled up to 40 liters of DRA solution with 200ppm concentration in the tank before the procedures begin. The flow loop equipment need 40 liters of water for each run.

Figure 3.9: Flow loop equipment

3.2.7 Benchtop Permeability Test:

For benchtop permeability test, polyacrylamide (PAM) and coconut residue is the DRA chosen. The injection rate is varied to compare the effect of different injection rate on permeability reduction. In the beginning of the experiment, the properties of the core samples such as porosity, permeability, pore volume, bulk volume, grain volume, grain density are tested and identified by using the POROPERM instrument. While the effect of DRA injected at different injection rate will be tested using the benchtop permeability equipment.

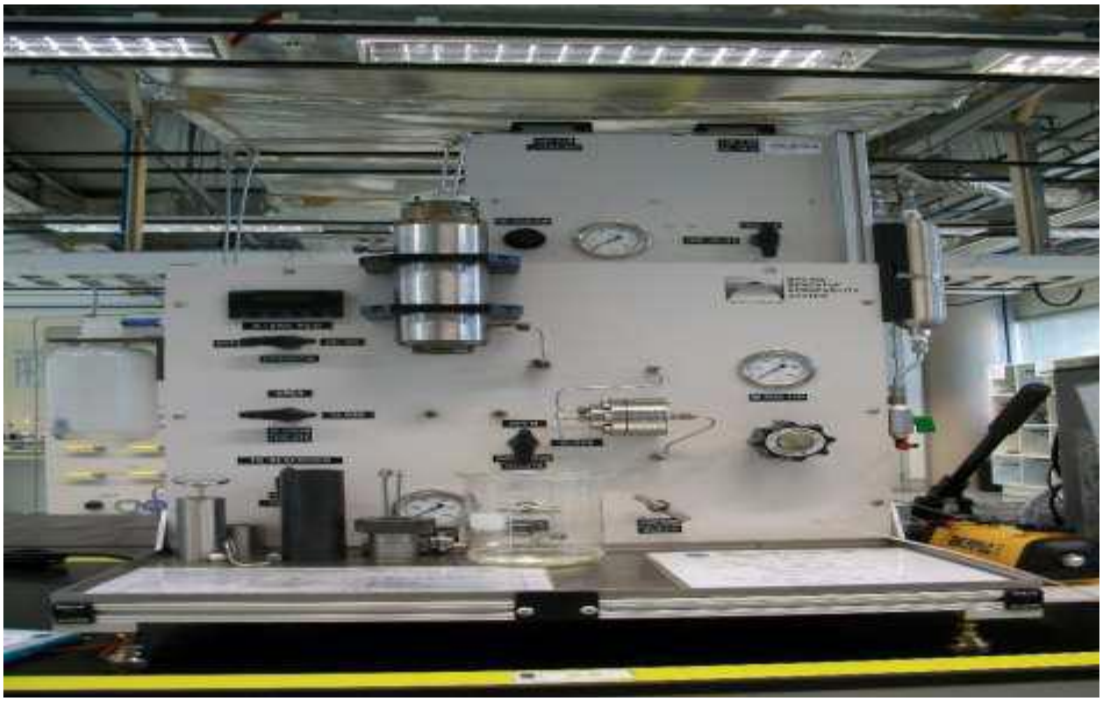

Figure 3.10: Benchtop permeability equipment

To evaluate the permeability damage caused by different injection rate here is the steps need to follow:

i. The three core samples were saturated in brine solution containing salinity of 10000ppm. The saturation process was conducted by using desiccator equipment and positive displacement pump to ensure that the cores are fully saturated with brine. For a better result core samples were saturated for 8 days.
ii. Natural DRA solution is prepared by mixing 0.1g of natural DRA with 1000ml of brine to create a DRA solution with 100ppm concentration. After mixing the DRA with brine, the solution undergoes mixing process for at least 8 hours using magnetic stirrer in order to generate a broken solution that can be categorized as homogenous solution.

iii. The core will be deposited into the core holder in the system, and then it will be flooded with brine at three different flow rates 1cc/min, 3cc/min, and 5cc/min for some times until the stable permeability is achieved for each run.

iv. First core sample is placed in the core holder and then the pump is switched on to flood the core with brine solution at 1cc/min until the stabilized permeability is recorded.

v. The second run will be executed right after the first run at which the core sample will be flooded with brine containing 100ppm of DRA at the same flow rates.

vi. After that, the core will be flooded with brine in reverse direction (backflow process) at a flow rate of 8cc/min to restore the permeability back and then it will be flooded again with brine at 1cc/min in order to achieve the final permeability of the core.

vii. To continue the test for the remaining two core samples, step 5, 6, and 7 should be repeated only injection rate will be changed to 3cc/min for the second core sample, and 5cc/min for the third core sample. Final permeability vs time plot will be generated on PC screen for each run.

viii. After all the three core samples is done, the experiment should be repeated with the natural DRA is replaced with synthetic DRA which is polyacrylamide. The difference in permeability reduction cause by both natural and synthetic DRA will be analyze later in Chapter 4.

3.3 Gantt Chart

Table 3.3: Gantt chart for FYP 1

No.	Details\Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Selection of Project Topic														
2	Prelimenary Research Work														
3	Submission of Extended Proposal														
4	Proposal Defence														
5	Project Work Continues: -Chemical purchasing -Lab booking														
6	Submission of Interim Draft Report														
7	Submission of Interim Report														

Table 3.4: Gantt chart for FYP 2

No.	Details\Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Project work continues: -Synthesizing the biopolymer -Sample preparation -Coreflooding test															
2	Submission of Progress Report															
3	Project work continues: -Tabulate data and result -Plotting graph -Data analysis and conclusion															
4	Pre-SEDEX															
5	Submission of Draft Report															
6	Submission of Dissertation (soft bounded)															
7	Submission of Technical Paper															
8	Oral Presentation															
9	Submission of Dissertation (hard bounded)															

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Variables

Before conducting any test, it is very essential to define the variables to be used in the experimental studies in order to target the study to the desired objectives effectively. It is important to be firm on the variables used in the experiment to make comparison on every experimental run. Hence, the variables of the experiment conducted by the author are as follow:

4.1.1 Constant Variables

i. Volume of brine used during permeability test (1000ml)
ii. Mass of DRA added to the brine solution (0.1g)
iii. Concentration of brine 10000ppm (1%)
iv. Concentration of NaOH (60%)
v. DRA reaction time (240 minutes)
vi. DRA reaction temperature (100°C)

4.1.2 Manipulated Variables

i. Injection rate in permeability system (1cc/min, 3cc/min, 5cc/min)
ii. Type of DRA solution (Natural DRA from CR and polyacrylamide)

4.1.3 Responding variables

i. Mass of CMC yielded from the extraction (in grams)
ii. Pressure drop in the flow meter
iii. Permeability before and after introducing the DRA

4.2 Assumptions

i. The DRA solutions prepared prior to flow meter test were mixed completely with the water in the tank. This assumption is important because complete solubility of DRA in the solution is required to ensure drag reduction.

ii. It is vital that the flowing fluid is flowing in the whole pipe, in which there is no gap between the fluid and the inner wall of the pipe. This is to ensure that a buffer region is created to give way for the DRA to absorb the turbulent burst

iii. The flow inside the flow loop is turbulent flow regime. The water flowing at high velocity after the Orifice plate opening due to constriction in size. The fluctuation of the manometer reading across and away from the Orifice plate indicate the existence of pressure drop from turbulent flow.

4.3 CMC Extraction

The extraction process of CMC is explained in detail inside the methodology part. This chapter is going to show the obtained results after finishing the extraction process using the 60% concentration of NaOH, reaction temperature of 60°C, and reaction time of 240 minutes. It has been proven in previous study by UTP student, the stated condition used in this experiment is the optimum concentration, reaction temperature and also the optimum reaction temperature for extracting the CMC. The results of the extraction process summarized in the table below:

Table 4.1: Extracted mass of CMC

Sample No.	Initial mass of CR (g)	Concentration of NaOH (%)	Reaction Temperature (°C)	Reaction Time (min)	Extracted Mass of CMC (g)
1	40	60	60	240	28.77
2	40	60	60	240	27.35
3	40	60	60	240	27.18
4	40	60	60	240	27.83
5	40	60	60	240	28.59

The average mass of extracted CMC from coconut residue is 27.94 g. This shows around 69.86% from initial mass, 40g of coconut residue has successfully extracted to CMC.

4.4 Flow Meter Test

In this result section, the manometer readings from the flow meter test of water and DRA solutions are recorded in table below. The manometer readings data were recorded at point X and point Y. Point X means the pressure drop or difference in manometer reading across the Orifice plate while point Y is located further at 1m away after the point X.

Table 4.2: Manometer reading recorded at point X and Y

No.	Type of Fluid Tested	Manometer Reading (mm)	
		X	Y
1.	Tap water	49.5	37.3
2.	DRA (200ppm)	48.2	39.5

The drag reduction percentage (%DR) were calculated for the samples run within the flow meter test by using the differential reading from the manometer itself without calculating the amount of pressure drop. This is because the amount of pressure drop is equal to the differential reading from the manometer liquid level and thus pressure drop can be replaced directly with the liquid level from manometer readings only in the formula. The drag reduction percentage can be calculated using the following formula:

$$Drag\ Reduction\ (\%DR) = \frac{\Delta P_{water} - \Delta P_{DRA}}{\Delta P_{water}}\ x\ 100\% \qquad \text{(Eqn. 5)}$$

Where:

ΔP_{water} = Differential manometer liquid level without DRA (tap water)

ΔP_{water} = 49.5mm – 37.3mm

ΔP_{water} = 12.2mm

ΔP_{DRA} = Differential manometer liquid level with DRA

ΔP_{DRA} = 48.2mm – 39.5mm

ΔP_{DRA} = 8.7mm

Therefore, the %DR natural DRA inside the flow loop equipment is:

$$Drag\ Reduction\ (\%DR) = \frac{12.2-8.7}{12.2}\ x\ 100\% \qquad \%DR = \mathbf{28.7\%}$$

4.5 Benchtop Permeability Test

The permeability versus time was recorded using benchtop permeability system (BPS-805), and the initial permeability was averaged. The 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, it is expected for the core to experience 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.

The reduction on permeability was calculated by the dividing the permeability reading during DRA flooding with the average initial permeability. In this section, first core sample was flooded with brine at 1cc/min injection rate until the permeability is stabilized, afterward it was flooded again with natural DRA solution at the same injection rate, and then back flow process was run at high injection rate of 8cc/min for some time. Followed by brine injection rate at 1cc/min in order to obtain the final permeability reading. Same procedure will be repeated for core 2 and 3 but at different injection rate 3cc/min and 5cc/min respectively. After all three core sample is done, the experiment is repeated again by replacing the natural DRA with synthetic DRA which is Polyacrylamide. The same procedure is followed for testing the reduction effect by PAM DRA solution. After the stabilized permeability is achieved, all permeability readings against time will be recorded automatically by benchtop permeability system. The reduction and recovered permeability can be calculated using the following formula:

$$K_{reduction} = \frac{K_{initial} - K_{DRA}}{K_{initial}} \text{ X } 100\% \qquad \text{(Eqn. 6)}$$

$$K_{recovered} = \frac{K_{final} - K_{DRA}}{K_{initial} - K_{DRA}} \text{ X } 100\% \qquad \text{(Eqn. 7)}$$

Effect of Different Injection Rates of Natural DRA

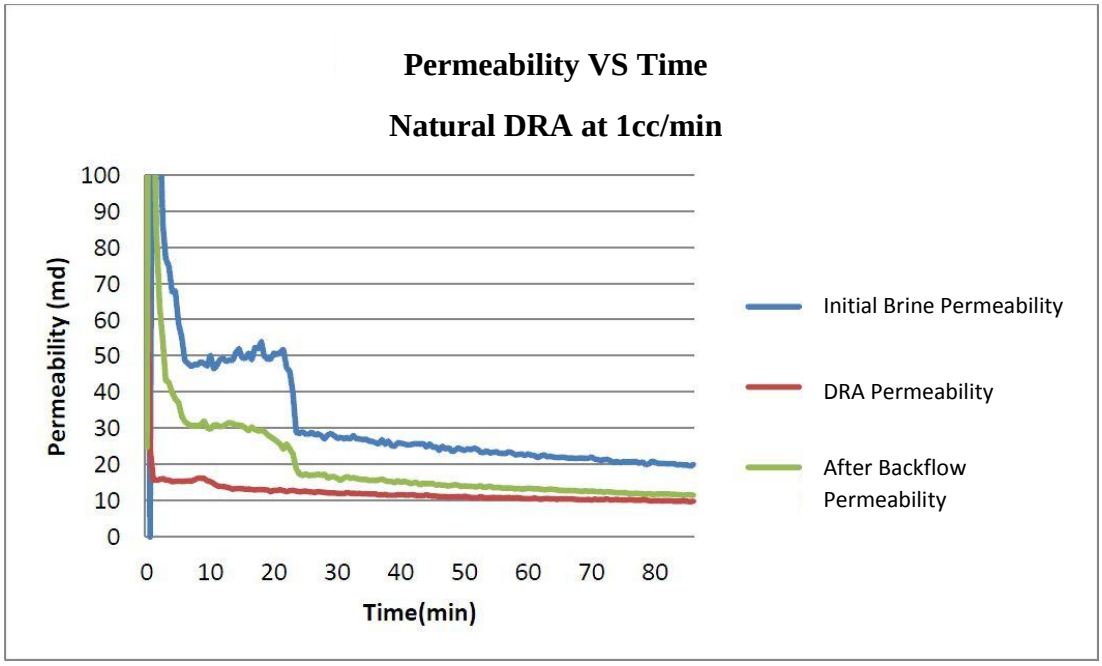

Figure 4.1: Natural DRA performance at 1cc/min

Figure 4.1 shows that, when the core is initially flooded with brine at 1cc/min, the stabilized permeability is recorded at 19.565md. However, after flooding with natural DRA solution at the same injection rate it reduces to 9.112md. This shows a permeability reduction of 53.42%. The core is then reverse and back flow process is carried out at 8cc/min in order to restore the permeability. The core is then flooded with brine again and the final permeability is recorded at 12.122md. This shows that 28.79% permeability restoration is managed to be obtained. The pressure profile shows that the pressure increases in the beginning of each run and becomes constant as the permeability reaches a constant value.

$$K_{reduction} = \frac{19.565 - 9.112}{19.565} X\ 100\%$$

$$K_{reduction} = \mathbf{53.42\%}$$

$$K_{recovered} = \frac{12.122 - 9.112}{19.565 - 9.112} X\ 100\%$$

$K_{recovered}$ = **28.79%**

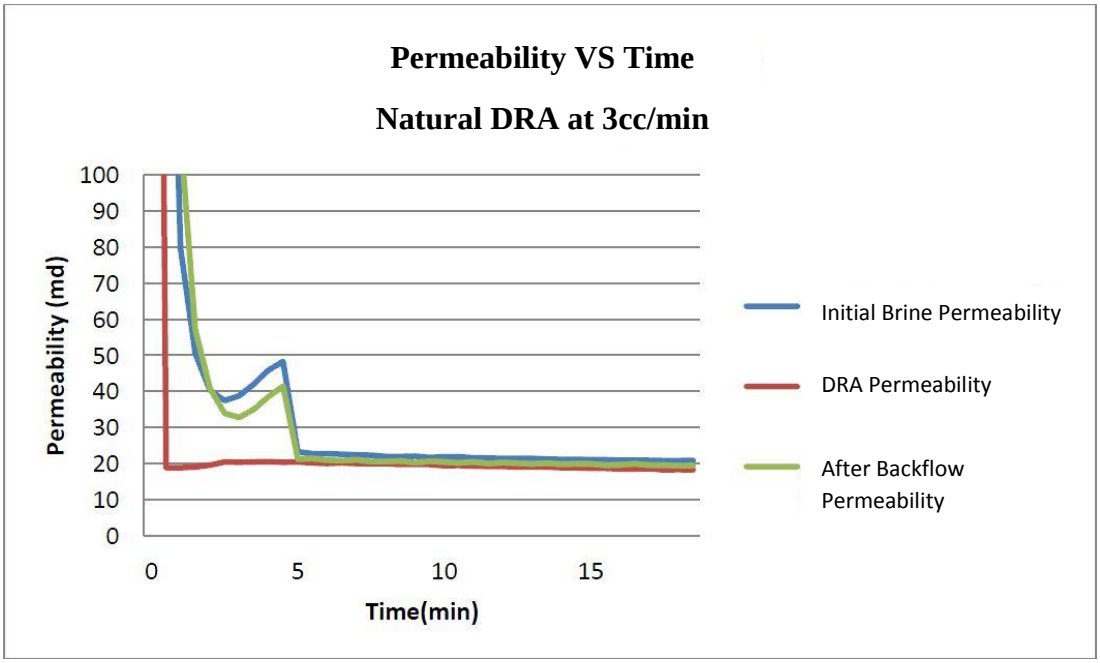

Figure 4.2: Natural DRA performance at 3cc/min

Figure 4.2 shows that, when the core is initially flooded with brine at 3cc/min, the stabilized permeability is detected at 21.739md. After flooding with natural DRA solution at the same injection rate, the stabilized permeability reduces to 18.760md. This shows a permeability reduction of 13.7%. The core is then reverse and back flow process is carried out at 8cc/min in order to restore the permeability. The core is then flooded with brine again and the final permeability is stabilized at 19.947md. This shows that 39.84% permeability restoration is managed to be obtained. The pressure profile shows that the pressure increases in the beginning of each run and becomes constant as the permeability reaches a constant value.

$$K_{reduction} = \frac{21.739 - 18.760}{21.739} X\ 100\%$$

$$K_{reduction} = \mathbf{13.7}\%$$

$$K_{recovered} = \frac{19.947 - 18.760}{21.739 - 18.760} X\ 100\%$$

$K_{recovered}$ = **39.84%**

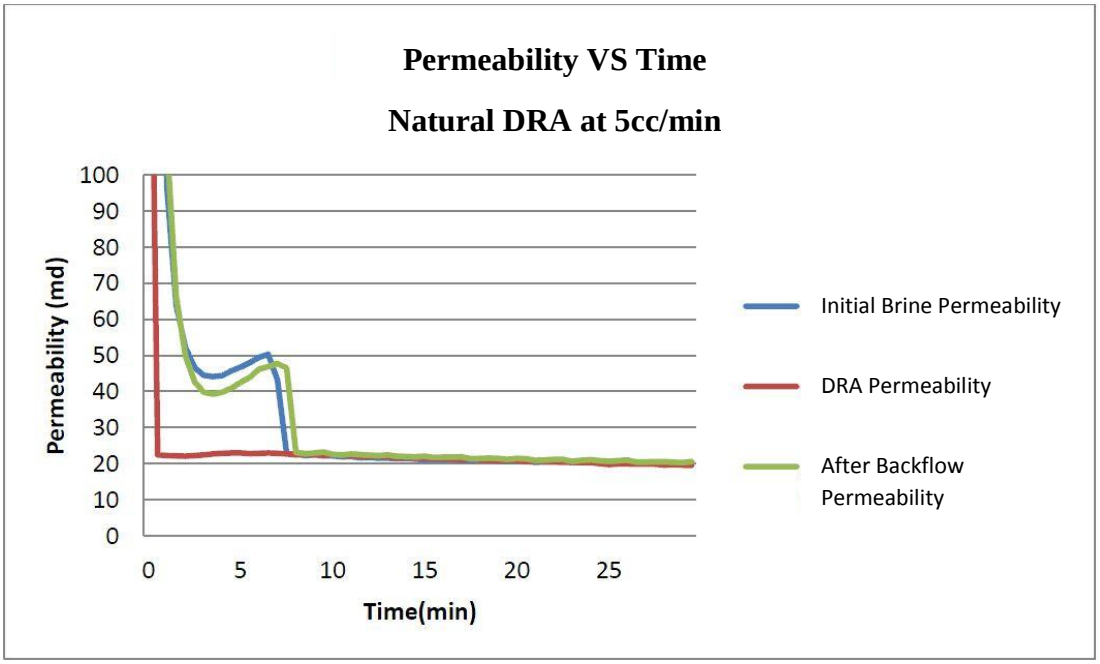

Figure 4.3: Natural DRA performance at 5cc/min

Figure 4.3 shows that, when the core is initially flooded with brine at 5cc/min, the stabilized permeability is recorded at 20.131md. After flooding with natural DRA solution at the same injection rate, the permeability reduces to 18.65md. This shows a permeability reduction of 7.36%. The core is then reverse and back flow process is carried out at 8cc/min in order to restore the permeability. The core is then flooded with brine again and the final permeability is stabilized at 19.347md. This shows that 47.06% permeability restoration is managed to be obtained. The pressure profile shows that the pressure increases in the beginning of each run and becomes constant as the permeability reaches a constant value.

$$K_{reduction} = \frac{20.131 - 18.65}{20.131} X\ 100\%$$

$$K_{reduction} = \mathbf{7.36\%}$$

$$K_{recovered} = \frac{19.347 - 18.65}{20.131 - 18.65} X\ 100\%$$

$K_{recovered}$ = **47.06%**

Effect of Different Injection Rates of PAM DRA

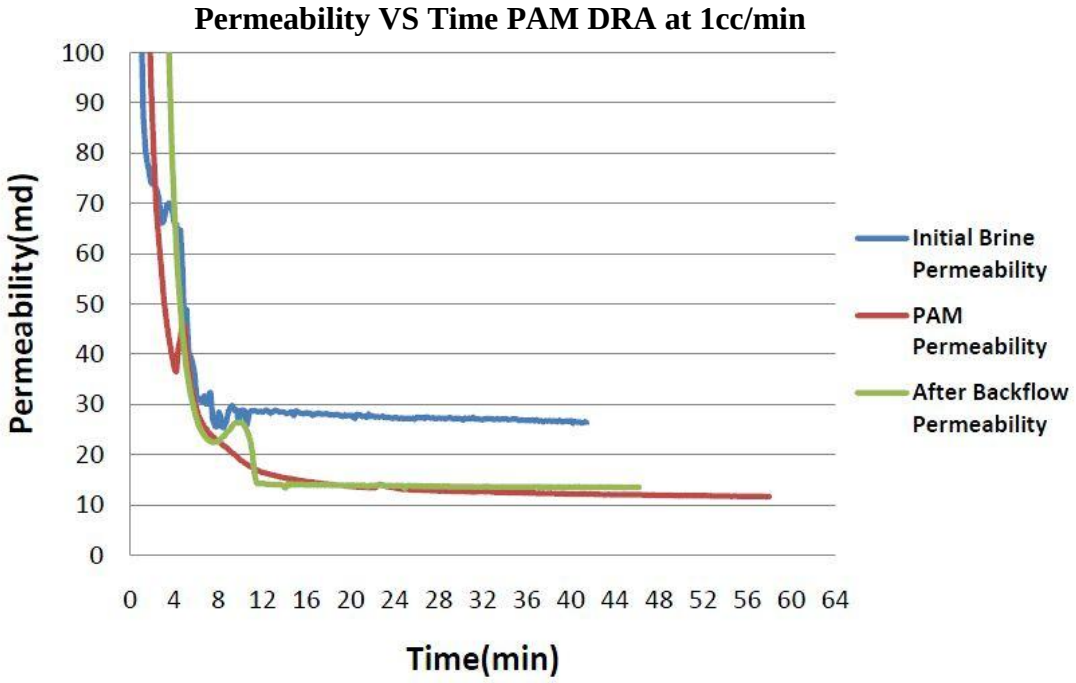

Figure 4.4: PAM DRA performance at 1cc/min

Figure 4.4 shows that, when the core is initially flooded with brine at 1cc/min, the stabilized permeability is recorded at 26.344md. After flooding with DRA solution at the same injection rate it reduces to 11.659md. This shows a permeability reduction of 55.74%. The core is then reverse and back flow process is carried out at 8cc/min in order to restore the permeability. The core is then flooded with brine again and the final permeability is recorded at 13.504md. This shows that 12.56% permeability restoration is managed to be obtained. The pressure profile shows that the pressure increases in the beginning of each run and becomes constant as the permeability reaches a constant value.

$$K_{reduction} = \frac{26.344 - 11.659}{26.344} X\ 100\%$$

$$K_{reduction} = \mathbf{55.74}\%$$

$$K_{recovered} = \frac{13.504 - 11.659}{26.344 - 11.659} X\ 100\%$$

$K_{recovered}$ = **12.56%**

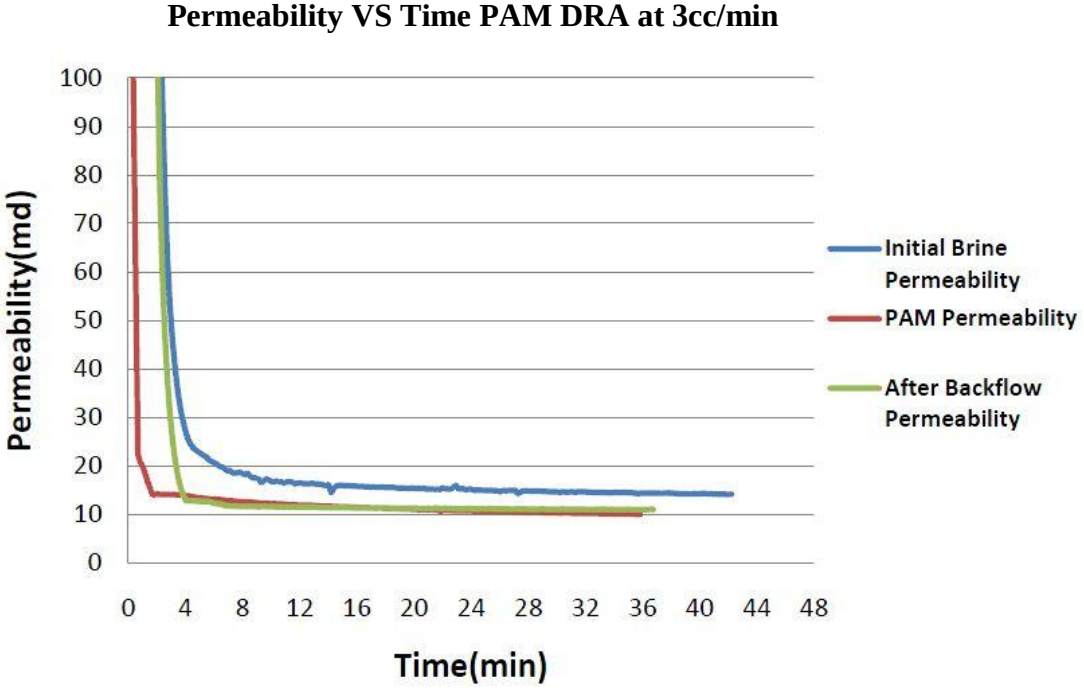

Figure 4.5: PAM DRA performance at 3cc/min

Figure 4.5 shows that, when the core is initially flooded with brine at 3cc/min, the stabilized permeability is recorded at 14.199md. After flooding with DRA solution at the same injection rate it reduces to 10.007md. This shows a permeability reduction of 29.52%. The core is then reverse and back flow process is carried out at 8cc/min in order to restore the permeability. The core is then flooded with brine again and the final permeability is recorded at 11.024md. This shows that 24.73% permeability restoration is managed to be obtained. The pressure profile shows that the pressure increases in the beginning of each run and becomes constant as the permeability reaches a constant value.

$$K_{reduction} = \frac{14.199 - 10.007}{14.199} X\ 100\%$$

$$K_{reduction} = \mathbf{29.52}\%$$

$$K_{recovered} = \frac{11.024 - 10.007}{14.199 - 10.007} X\ 100\%$$

$K_{recovered}$ = **24.73%**

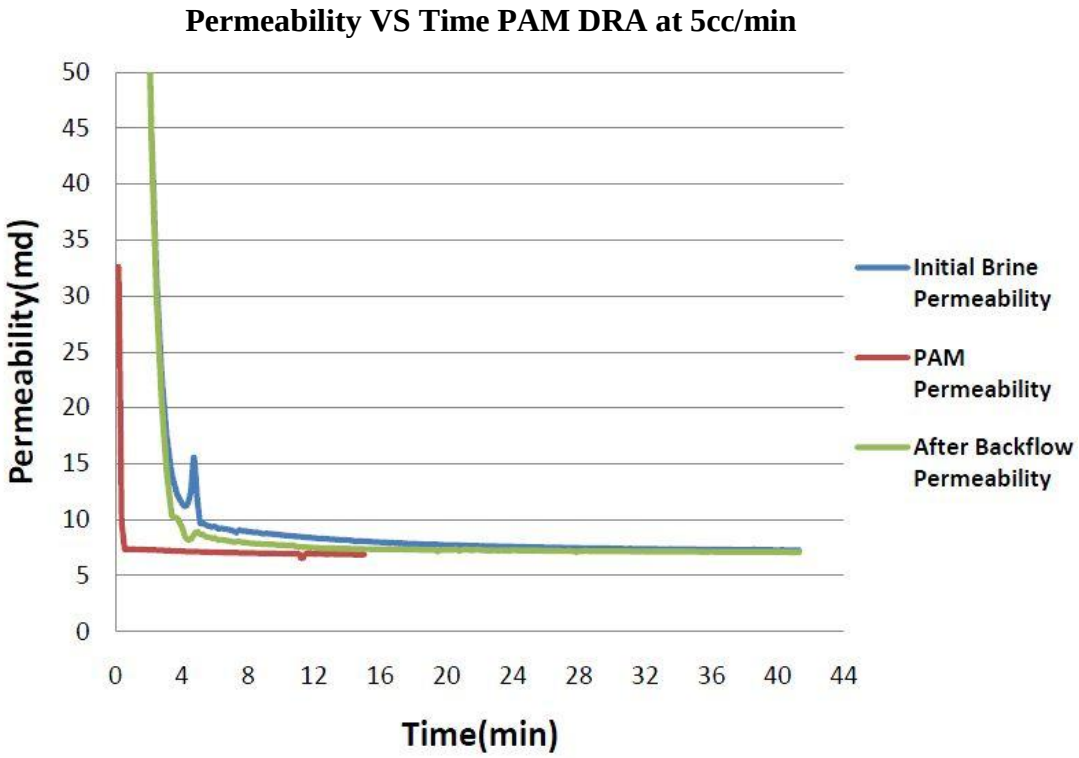

Figure 4.6: PAM DRA performance at 5cc/min

Figure 4.6 shows that, when the core is initially flooded with brine at 5cc/min, the stabilized permeability is recorded at 7.288md. After flooding with DRA solution at the same injection rate it reduces to 6.879md. This shows a permeability reduction of 5.61%. The core is then reverse and back flow process is carried out at 8cc/min in order to restore the permeability. The core is then flooded with brine again and the final permeability is recorded at 7.109md. This shows that 56.23% permeability restoration is managed to be obtained. The pressure profile shows that the pressure increases in the beginning of each run and becomes constant as the permeability reaches a constant value.

$$K_{reduction} = \frac{7.288 - 6.879}{7.288} X\ 100\%$$

$$K_{reduction} = \mathbf{5.61\%}$$

$$K_{recovered} = \frac{7.109 - 6.879}{7.288 - 6.879} X\ 100\%$$

$K_{recovered}$ = **56.23%**

Table 4.3: Observed permeability for natural DRA

	Injection Rates		
	1cc/min	3cc/min	5cc/min
K_Brine, (mD)	19.565	21.739	20.131
K_DRA, (mD)	9.112	18.760	18.650
K_Backflow, (mD)	12.122	19.947	19.347

Table 4.4: Permeability reduction and recovered by natural DRA

Injection Rates (cc/min)	K_reduction (%)	K_recovered (%)
1	53.42	28.79
3	13.7	39.84
5	7.36	47.06

Experiment results shows, for natural DRA performance, permeability reduction for 1cc/min injection rate is 53.42%, 13.7% for 3cc/min injection rate, and 7.36% for 5cc/min injection rate. While for recovery process, permeability recovered was found to be 28.79% for 1cc/min injection rate, 39.84% for 3cc/min injection rate, and 47.06% for 5cc/min injection rate.

Table 4.5: Observed permeability for PAM DRA

	Injection Rates		
	1cc/min	3cc/min	5cc/min
K_Brine, (mD)	26.344	14.199	7.288
K_DRA, (mD)	11.659	10.007	6.789
K_Backflow, (mD)	13.504	11.024	7.109

Table 4.6: Permeability reduction and recovered by PAM DRA

Injection Rates (cc/min)	K_reduction (%)	K_recovered (%)
1	55.74	12.56
3	29.52	24.73
5	5.61	56.23

While for natural PAM DRA performance, permeability reduction of 55.74% for 1cc/min injection rate is recorded, 29.52% for 3cc/min injection rate, and 5.61% for 5cc/min injection rate. While for recovery process, permeability recovered was found to be 12.56% for 1cc/min injection rate, 24.73% for 3cc/min injection rate, and 56.23% for 5cc/min injection rate.

4.6 Discussions

For both case of Natural DRA and PAM 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 5cc/min of injection rates for both solution show almost the same percentage of permeability reduction. Thus we can conclude that the critical shear rate for both natural DRA and PAM DRA occur at 5cc/min.

On the other hand, the core which injected with DRA at higher injection rate shows higher percentage of recovery when backflow with brine compared to the core injected 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. Natural DRA solution shows a lower permeability reduction compared to PAM DRA solution. The reason behind this is that the PAM DRA molecules are bigger compares to coconut residue molecules. Bigger polymer molecules will severely plug the permeability channel, while small molecules tend to pass through it. Although the natural DRA can reduce more friction compared to PAM DRA 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 natural DRA solution, while back flowing process can recover the permeability, although not 100 percent restored to initial permeability.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

From this research, CMC has been successfully extracted from the grated coconut residue. By implies the optimum parameters which is 60% concentration of NaOH, 60°C of reaction temperature and 240minutes reaction time, 69.86% or 27.94g of CMC has successfully extracted from the initial 40g of raw coconut residue. However, the purity and degree of substitution of the produced CMC from CR which are affected by the reaction parameters such as temperature, time and concentration of NaOH were not covered and identified from this research. The natural DRA also able to reduce 28.7% of drag reduction inside a flow loop.

Besides that, the formation permeability reduction depends on the injection rates with higher injection rate gives less permeability reduction compared to lower injection rate. On the other hand, the core which injected with DRA at higher injection rate shows higher percentage of recovery when backflow with brine compared to the core injected at lower injection rate. Different type of polymer also gives an impact on percentage of permeability reduction with natural DRA solution recorded a lower permeability reduction compared to PAM DRA solution. In conclusion, all the objectives of this research had been successfully achieved. Coconut residue has shown a very good potential to be a replacement for synthetic DRA.

5.2 Recommendations

i. The natural polymer DRA extracted from the grated coconut residue should be tested to study its mechanical and chemical properties. Besides, the research should be expanded to increase its temperature stability when it is pumped into the wellbore. The dynamic changes of reservoir condition should also be taken into account.

ii. Further studies to be conducted on the molecular weight and size of the coconut residue particles. Scanning Electron Microscope (SEM), can be used as a visualization technique, which might bring knowledge on the performance of the DRA and permeability reduction occurrence.

iii. Further studies on the chemical reaction between DRA and inner wall of pipeline, also the effect towards the reservoir formation. This part of the study should consider several other factors such as pH values, temperature and materials reactivity which may lead to the reaction between the DRA and the inner wall of the tubing thus causing less effective drag reduction performance.

iv. 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.

v. 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.

CHAPTER 6

6.1 References

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