ROLE OF PERMEABILITY ON FOAM FLOW

by

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10983

Dissertation

Submitted to the Petroleum & Geoscience Engineering Department

in partial fulfilment of the requirements for the degree

Bachelor of Engineering (Hons)

(Petroleum Engineering)

Universiti Teknologi PETRONAS

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CERTIFICATE OF APPROVAL

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Approved by:

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Project Supervisor

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
MAY 2011

CERTIFICATE OF ORIGINALITY

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

Shameer bin Mumtaz Ali

ACKNOWLEDGEMENT

First of all, I would to express my deepest thanks to Mr Saleem Qadir Tunio, my supervisor for his never ending support throughout the duration of my Final Year Project. His support and assistance has been a vital component in helping me complete this project. He was always there to entertain my questions during the weekly meetings and had never pushed me away despite his busy schedule. His guidance truly proved to be important in enabling me to complete this project.

My heartfelt gratitude and appreciation are extended especially to Mr Shahrul, Lab Technician, Building 15, UTP as well as Mr Redzuan, Lab Technician, Building 15, UTP. They have greatly assisted me throughout the course of my project especially during the experimentation sessions. They have always been there to lend a helping hand which has proven to have a significant impact in ensuring that the project was completed within a short duration of time.

My acknowledgement is not complete without giving credit to Universiti Teknologi PETRONAS (UTP), especially Department of Petroleum Engineering that allowed me to use their equipments as well as apparatus without any hassle or complications. It is also vital that I mention the hands on experience I have had with the equipments at the lab in UTP has certainly improved my knowledge and has exposed me to handling machines that I thought were really complicated prior to my Final Year Project. Last but not least, to everybody who has assisted me in completing this project, I am truly grateful.

ABSTRACT

Foam has been used for decades as an application in enhanced oil recovery (EOR) and well stimulation operations. Foam is employed to improve the sweep efficiency by which the displacing fluid recovers residual oil in a reservoir [1]. Foam is used in various reservoirs with different permeabilities and the effect of this on foam flow has not been thoroughly researched. This project discusses the effects of changes in formation on foam flow as well as methods to optimise the effect of foam flow in varying permeabilities. Evaluating the usage of foam in EOR as a method of increasing oil production and reducing water cut shall be studied as well as the resulting foam flow in different permeabilities [1]. A comparison of foam flow in high formation permeability and low formation permeability shall be carried out by running tests using cores with different permeabilities and injecting foam into them. One major aspect shall be to understand the effects of changes in formation permeability on foam flow. Factors such as surfactant type, quality, liquid and gas velocities will be kept constant during the experiment. The results shall then be analysed. The methodology for the entire paper has been included to enable the approximation of the duration for the entire project. Finally, low permeability results shall be compared to higher permeability results as to identify the changes in foam flow.

LIST OF FIGURES, TABLES & EQUATIONS

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Presently, the world is basically addicted to oil and therefore a massive importance is given to ensuring that every drop of oil is being produced from a reservoir[2]. Given that crude oil prices had already breached USD 100 per barrel about a year ago and given the uncertainty shadowing oil producing countries in the Middle East, which is not expected to decline soon. It is important for oil companies to maximize production economically as this would lead to maximum profit. The task of producing crude oil is not as simple as drilling a hole in the ground with hope that oil will surge to the surface. Oil recovery is categorised into three different categories which are primary, secondary and tertiary recovery. Primary and secondary recovery contributes to about 40 percent of total recovery. Tertiary recovery which is also called EOR describes a set of techniques used to increase the amount of oil that can be extracted from and increases recovery to about 60 percent [3]. There are studies indicating the usage of foam may be applicable as a restrictive agent in reducing gas flow in the reservoir. Foaming agents are commonly employed in various aspects of oil recovery including drilling, gas production and EOR which inadvertently increases crude oil production. Despite foam being a vital component of the FAWAG process, very little has been done to investigate effects of permeability on foam flow [4]. Since permeability is an important factor of oil recovery process and the effect of it on foam flow has to be investigated.

In order to proceed with my project, I had to construe a problem which I could solve during the entire duration of my project. Finally, I decided to work on the problem stated below.

1.2 Problem Statement

Formation permeability and gas permeability vary in each reservoir. Due to the changes in permeability, the effect of foam flow varies in each reservoir. A proper evaluation needs to be conducted to enhance our knowledge on the effects of permeability on foam flow.

1.3 Objectives of the Study

- To understand the effects of high and low formation permeability on foam flow.
- To understand the effects of high and low gas permeability on foam flow.
- Detailed understanding of the effects of permeability on foam flow to optimise the function of it in Enhanced Oil Recovery.

1.4 Scope of Study

Evaluation of foam usage in EOR and the resulting foam flow. Next I studied up on FAWAG for all the issues faced with the presence of foam during EOR. This was followed by the effects of permeability on oil recovery in a reservoir and lastly, the effects due to formation and gas permeability on foam flow.

1.5 The Relevance of the Project

Surface agents are used for various reasons. One of the more evident reasons would be to increase the recovery of oil. The usage of foam has increased and many production companies are looking to inject foam in reservoirs to enhance recovery of older fields. As a future petroleum engineer, the project would give me a better understanding of the resulting foam flow in reservoirs with different permeability.

1.6 Project Feasibility

The project would be broken into two main parts namely be FYP1 and FYP2. In FYP 1, my main task would be to understand greater the aims and solutions to my project as well as to plan out my experimental setup. In FYP 2, my main tasks would be to complete the experiments. As stated later in this report, the experiment would take a couple of weeks and shall be completed in due time prior to the dateline for FYP 1 and FYP 2. The methodology and planning of my project shall be elaborated later on in this report.

The usage of foam is widespread in the oil industry and the technology to use it certainly available. The benefits attained from using foam in the recovery of oil are greater than the cost of using foam. By being able to produce more oil, companies are looking at a higher profit margin and the cost of foam is much lower than the profit gained from the oil recovered. Oil companies do have the technology and the resources to use foam in the recovery of oil therefore making this project viable.

CHAPTER 2

LITERATURE REVIEW

Prior to conducting the experiment, various project papers and articles were read in order to gain more knowledge on the topic discussed. Books, journals and websites were scrutinised which allowed the development of the literature review below.

2.1 Foam Assisted Water Alternating Gas (FAWAG)

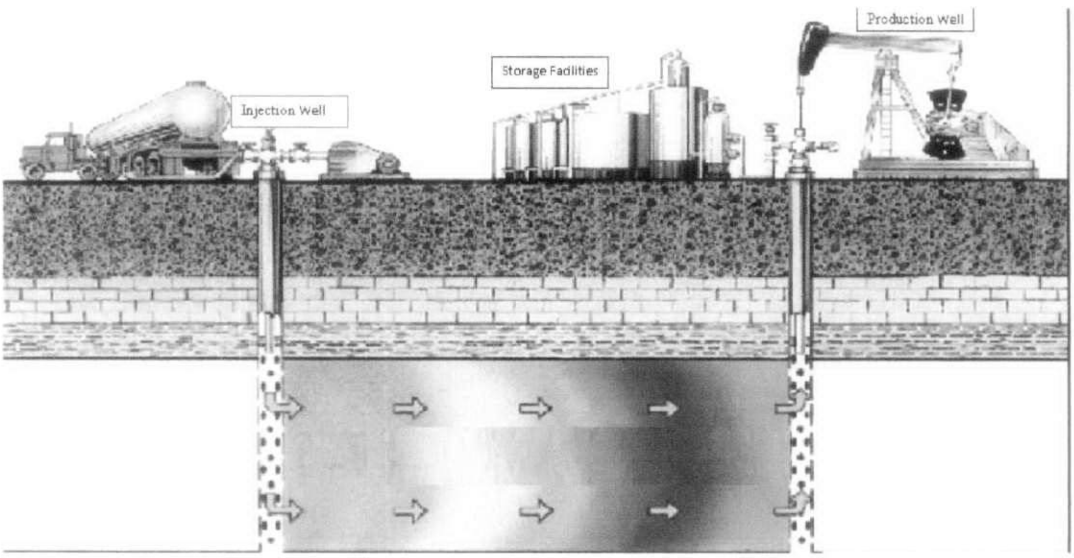


Figure 1: Basic schematic diagram of EOR [5]

Normally, after undergoing the primary and secondary oil recovery process, a significant amount of oil remains in the reservoir. Some of this oil can be produced using FAWAG which is an EOR method where gas is injected alternating water into the reservoir. As the IFT between gas and oil is less than the IFT between gas and water which results in gas entering pores of reservoir filled with oil rather than filled with water. When water is injected, then it enters the pores filled by gas and inevitably the gas displaces the oil that were in the pores as the gas channels become narrower as the content of water increases. Consequently, the gas channels are observed to become narrower as the water filaments grow [6]. Foam is injected into the reservoir to displace residual oil in porous oil structures that is unrecoverable using conventional water or gas drives [7].

Foam colloidal dispersion in which a gas is dispersed in a continuous liquid phase. Furthermore, the significant viscosity of foam improves the mobility ratio and contact efficiency [8]. The reason that foam is injected into the reservoir is due to the improvement in the efficiency by which the displacing fluid sweeps the reservoir and comes into contact with residual reservoir oil. Sweep efficiency is defined as the volume of formation swept by the displacing fluid over the total volume of the formation. [9]

Permeability has a significant impact on foam flow. This includes formation permeability, gas permeability as well specific permeability of the fluid. Below are materials I have attained on the effects of permeability on foam flow.

2.2 Functions of Foam in Oil Production

Foam is a colloidal dispersion in which a gas is dispersed in a continuous liquid phase [9]. The addition of surfactants is used to reduce the interfacial tension and also used to stabilize foam. Many studies demonstrated that surfactant stabilized foam could drastically reduce the gas mobility in the porous media, consequently improving volumetric sweep efficiency and oil recovery. Foam is used in FAWAG to improve the efficiency by which the displacing fluid mobilizes the residual oil towards the production well [10]. Since foam has a much lower mobility, it is effective in heterogeneous reservoirs with higher formation permeability than formations with a low permeability. It also counteracts the high mobility and low density of water as well as gas [11].

In some formations, foam is used to reduce the water cut which results in more oil being produced. It is used to plug the high permeable zone and this reduces the amount of water produced from high permeable zones. The action of plugging high permeable zone ensures that oil from lower permeable zones has lesser resistance in their path to the wellbore resulting in a higher production of oil [12].

2.3 Effects of Formation Permeability on Foam Flow

Formation permeability is defined as the ability of a rock to transmit or flow fluids is measured in Darcie's [13]. In high formation permeability, foam flow increases due to foam being used to plug the high permeability streaks [13]. Foam is used to divert fluid from high permeability streaks to the low formation permeability layer in order to increase production. Hence in low formation permeability zones, foam flow is decreased.

2.3.1 Mobility Reduction Factor

The equation for mobility reduction factor is given as:

$$\boldsymbol{MRF} = \left[\frac{\Delta P\ surfactant{-}gas}{\Delta P\ brine{-}gas} \right]$$ Equation 1 : Equation of Mobility Reduction Factor [14]

This formula is defined as the ratio of normalised pressure drop during foam flow over normalized pressure drop without foam flow [15]. The mobility of higher formation permeability layers is much higher than the mobility of lower permeability layers. Thus for the highest formation permeability layer, the MRF is lowest [16]. In the lowest formation permeability layer, the MRF is highest.

As formation permeability increases, the foam flow becomes more unstable thus requiring a higher foam flow injection rate [17].

2.4 Effects of Gas Permeability on Foam Flow

Gas permeability is defined as the ability of gas to flow through a porous medium such as a reservoir formation. Foam is used to reduce gas permeability. Irrespective to formation permeability, gas permeability is effectively reduced significantly [18]. A foam bank which is essentially a formation injected with foam in order to reduce its permeability can be maintained indefinitely as long as small amount of foam is injected continuously[18]. In cases where brine is present, it does not have an effect on gas permeability therefore foam flow remains the same.

In gas reservoirs, it is interesting to observe that the greater the specific permeability of a formation, the greater is the effectiveness of foam in reducing gas permeability [19].

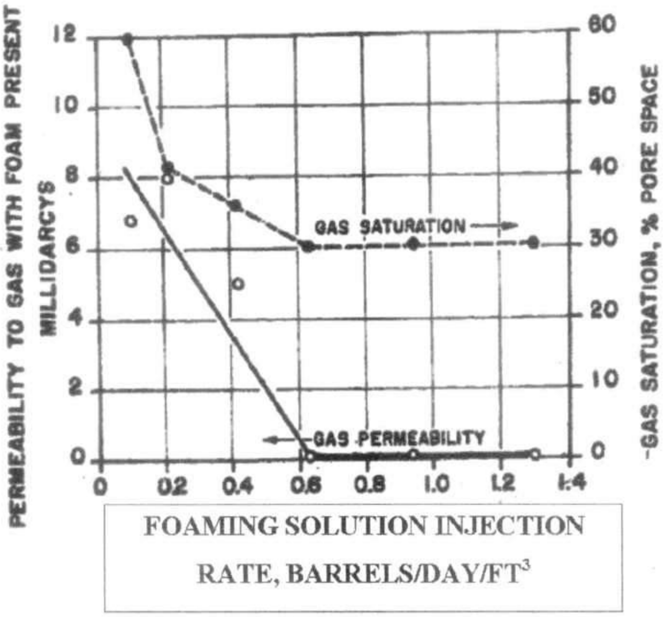


Figure 2: Effectiveness of foam in reducing gas permeability at all foaming injection rates [20]

2.5 Resistance Factor

Resistance factor, RF is the ratio of normalized pressure drop across the core during foam flow over the normalized pressure drop across the core during brine flow [14]. With increasing pressure drops, the effectiveness of foam deteriorates.

CHAPTER 3

METHODOLOGY

As I got started with my project, I firstly had to come up with a methodology on how to proceed and complete it. The project is broken up into two major stages consists of literature review and experimental work. Finally upon acquiring results, a detailed evaluation shall be conducted with a discussion. The methodology of my project would be as follows:

3.1 Research Methodology

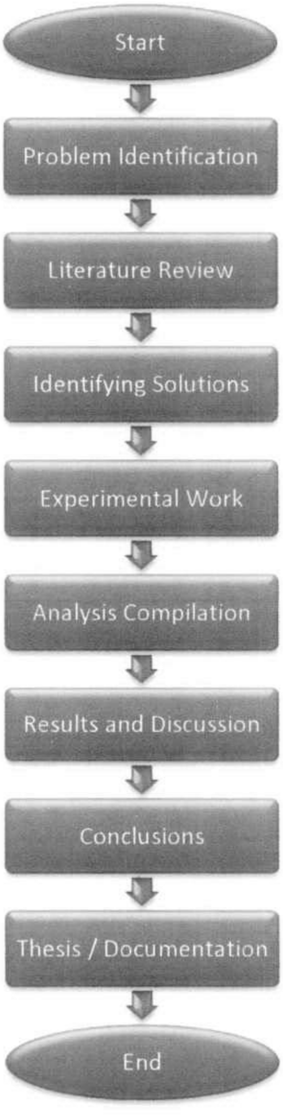


Figure 3: Methodology of the Project

3.2 Project Activities

Phase 1 : Literature Review

Read and analyse theories on the effects of permeability on foam flow.

↓

Phase 2 : Identification of method

Identify the method to complete the project (Experimental Work)

↓

Phase 3 : Experimentation

A couple of experiments to be conducted to validate this project

↓

Phase 4: Compilation of data

Data from the experiment shall be compiled and submitted in the format of a report.

3.3 Experimental Set-up

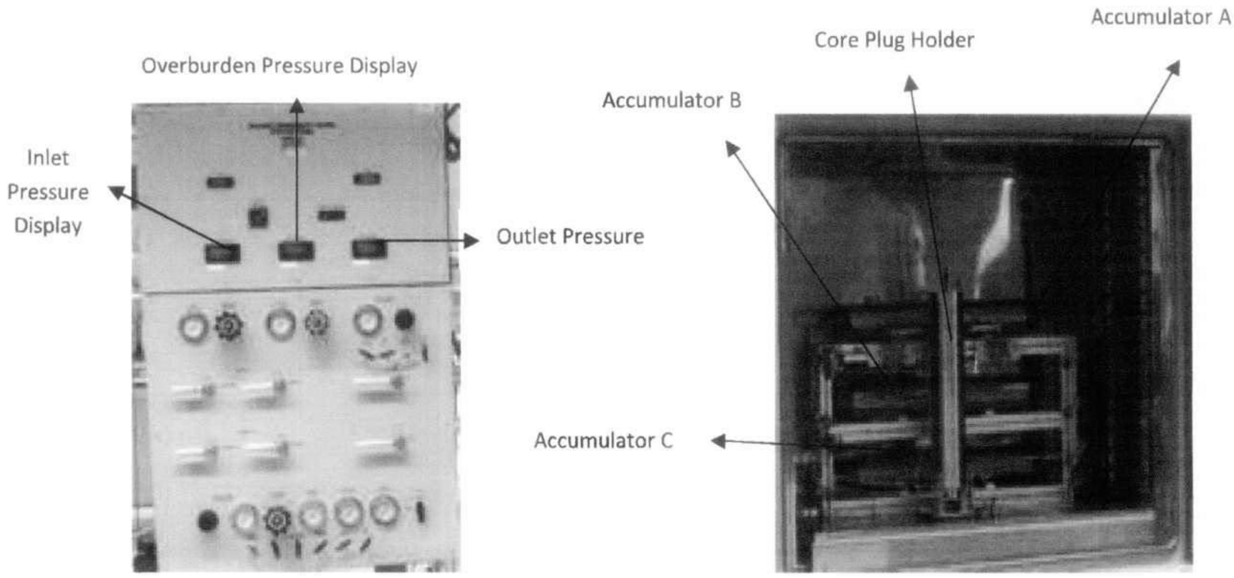
To determine the effects of varying formation permeability on foam flow, tests are conducted to see the resulting foam flow through a reservoir rock. I plan to use different reservoir rock samples with varying permeabilities and record the resulting foam flow. For the experimental setup, I would need a unit capable of injecting water, oil, gas, surfactant solution, and foam into a core simultaneously.

From the oil reservoir, a cylindrical rock sample is cut with a hollow drill. Then a syringe pump introduces a fluid into the rock core holder. Depending on the EOR process, core flooding may require hours to days of fluid injection at high pressures and low flow rates for the newly introduced fluid to displace the oil from the rock sample. From the data obtained from rock core flooding, we will able to acquire data on the flow rates through the core.

To conduct the experiment, I used 3 cylindrical cores plus, a steady state PoroPerm machine, a RPS machine, 2 beakers, a mechanical stirrer, an industrial oven, 9 measuring cylinders, 1000cc of light crude oil, 1000cc of 30,000 ppm brine solution, 1000cc of 2 wt% surfactant and 1000cc of CO_2 gas.

3.4 Description of Experimental Equipment and Chemicals

Relative Permeability System (RPS)



Display System

Core Holder and Accumulators

Figure 4: TEMCO RPS-800-10000 HTHP Relative Permeability Test System

- Tests that can be performed with this system include initial oil saturation, secondary water flooding, tertiary water flooding, permeability and relative permeability.

- Brine, oil or other fluids can be injected into and through the core sample.

- Since in my experiment we would need the injection of surfactant, brine, crude oil and CO_2 gas, we would need to replace the accumulator containing CO_2 gas with surfactant as we proceed with the experiment.

- The equipment uses an external ISCO pump as well as an external heater at the backpressure gauge to ensure a continuous flow of fluid and low temperature.

Steady State Gas Permeameter and Porosimeter (PoroPerm)

- Used to measure steady state gas permeability, Klinkenberg permeability, pore volume and grain volume of plug sized core samples at room conditions.

- The instrument is provided with a permeameter console, a hassler coreholder, a matrix cup and a data acquisition computer station to be operated in manual and automatic mode.

- An optional hydrostatic coreholder can be used to perform measurement at overburden pressure

Sodium Dodecyl Sulphate (SDS)

Figure 5: Sodium Dodecyl Sulphate (SDS)

- Sodium dodecyl sulfate (SDS or NaDS), is an anionic surfactant used in many cleaning products.
- SDS is a highly effective surfactant and is used in any task requiring the removal of oil.
- The reason behind the selection of SDS instead of Sodium Lauryl Sulphate is due to the availability as well as the cost of the product itself.
- SDS is easily available and the cost for it falls within our budget.

3.5 Experimental Conditions

The conditions for this experiment were set to try and simulate an actual reservoir. 3 cores with differing permeabilities were used throughout the duration of this experiment

- Core dimensions :

Table 1: Dimensions of Cores

Properties	Core Plug 1	Core Plug 2	Core Plug 3
Weight , g	93.293	94.393	93.246
Length , mm	38.563	33.752	36.594
Diameter , mm	37.923	38.765	37.621

- Longer cores were not used to minimise pressure drop

- Confining pressure : exceeding 500 psi

- Oil conditions :

Table 2 : Crude Oil Properties

Characteristics	Value
API No	37.8°
Viscosity (initial) , μ_{oi}	0.82 cp
Pressure at Bubble Point, P_b	1550 psi
Density, ρ	0.8256 g/cm3
Oil Formation Volume Factor, B_{oi}	1.279 rbbl/STB
Specific gravity of Oil at 60 °F	0.83976

3.6 Experimental Procedure

3.6.1 Core Preparation

I. Three separate cylindrical core samples were attained from the lab.

II. Core samples were dried in the oven for 24 hours at 250 ^{o}F

III. Once the cores were dried, they were placed in the PoroPerm machine and the data was recorded.

IV. This is followed by the saturation of the cores in a brine solution using desiccators for an entire day.

3.6.2 Steady State Gas Permeameter and Porosimeter (PoroPerm)

I. The cylindrical core plugs are dried and prepared.

II. It is then loaded into the PoroPerm holder by removing the covers for the core holder and inserting the cores.

III. Ensure the PoroPerm machine is tightened to ensure no leakages.

IV. Measurements such as weight, diameter and length are inserted into the software and the PoroPerm machine is allowed to run.

V. Data would automatically be uploaded onto the computer and results are then saved.

VI. Experiment is then repeated using the remaining cores.

3.6.3 Preparation of Surfactant

I. 1,000ml of distilled water is poured into three separate beakers.

II. 20gm of SDS is added to the distilled water in each beaker.

III. Beakers are then placed on a mechanical stirrer until all surfactant particles have disintegrated and mixed well.

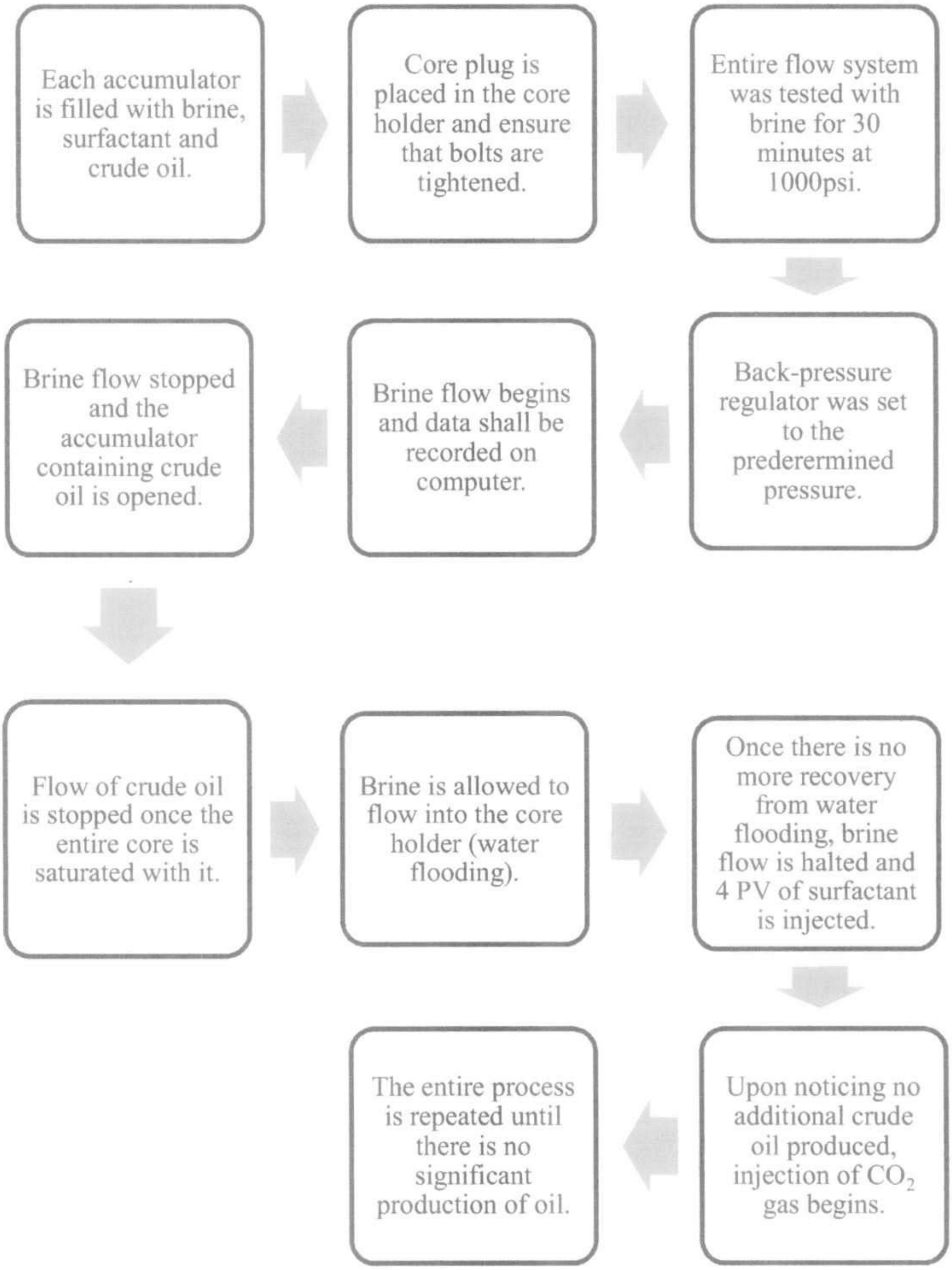
3.6.4 Preparation of Brine

I. Distilled water is filled into three different beakers up till 1,000cc each.

II. 30gm of NaCl is then weighed and added into each individual beaker.

III. This is followed by placing the beakers on a mechanical stirrer till the salts have completely dissolved.

3.7 Coreflooding Procedure (RPS Machine)



3.8 Gantt Chart of Project Flow

Table 3 : Gantt Chart of FYP 2

No	Detail / Week	1	2	3	4	5	6	7		8	9	10	11	12	13	14	15
1	Project Work Continues																
2	Submission of Project Report								M	X							
									I								
3	Project Work Continues								D								
									-								
4	Pre -SEDEX								S				X				
									E								
5	Submission of Draft Report								M					X			
6	Submission of Dissertation (soft bound)								B						X		
									R								
7	Submission of Technical Paper								E						X		
									A								
8	Oral Presentation								K							X	
9	Submission of Project Dissertation (Hard Bound)																X

X Suggested Milestone

Process

CHAPTER 4

RESULTS & DISCUSSIONS

4.1 Results

4.1.1 PoroPerm Results

The results obtained from the PoroPerm machine have been copied down and transferred onto the table below. This data is vital in allowing us to ascertain the core properties such as permeability, pore volume, permeability and bulk volume.

Table 4 : PoroPerm Core Plug Measurement Results

PoroPerm System Computer Calculation Results			
Properties	Core Plug 1	Core Plug 2	Core Plug 3
Pore Volume, Vp (cc)	14.82	7.438	7.738
Permeability, md	156.243	83.744	24.328
Porosity, Φ (%)	19.834	17.915	18.126
Bulk Volume, V bulk (cc)	74.523	68.37	44.036

4.1.2 Results of FAWAG on Different Cores

Table 5: Results of FAWAG on Different Cores

Core Sample	1	2	3
Formation Permeability, md	156.243	83.744	24.328
Surfactant Concentration, wt%	2.0	2.0	2.0
Duration of the FAWAG process, minutes	264	324	285
Maximum Oil Recovered through FAWAG, %	63.8	51.6	24.6

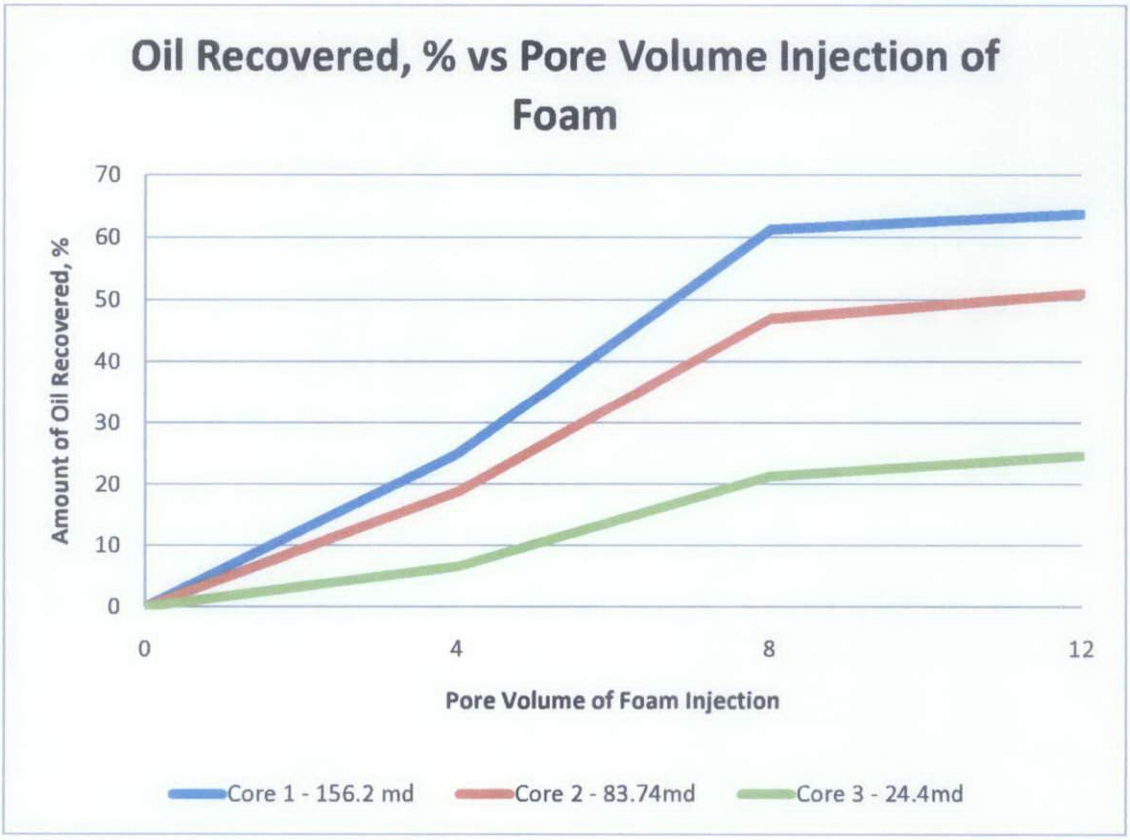


Figure 6: Graph of Amount of Oil Recovered vs Pore Volume of Foam Injection

- Table 5 is a summary of the effects of permeability on foam flow with the assumption that the oil displaced is due only to the foam flow effect as a displacing fluid. Figure 6 shows the surfactant injection and the amount of oil recovered from the core with regards to OOIP.

- Based on the figure we can surmise that core 1 which has the highest permeability results in highest return of oil from the FAWAG process. Core 2 is in the middle followed by core 3 which recovers the least. The amount of foam that flows through the core inadvertently displaces the oil. This effectively shows that run 1 has the highest amount of foam flow as the percentage of oil recovered is the highest at 63.8% followed by run 2 and run 3.

- It can be seen that foam is mostly effective during the 4PV-8PV injection span and this is due to the effective of foam increases with time. Foam takes time to coalesce with the oil in the core and this happens during the early duration of the foam injection. The graph becomes horizontal towards the 12PV of foam injection as most of the oil that can be recovered through FAWAG has already been recovered therefore the recovery percentage is at a minimum.

- In high permeability formations, foam is able to move freely therefore it works more efficiently in displacing the oil in the core as compared to lower permeability formations.

4.1.3 Resistance Factor

Table 6: Resistance Factor for each core

Core Plug	1	2	3
Resistance Factor	1.88	2.33	15.28

Based on the calculation of resistance factor, we can summarise that in higher formation permeability with higher foam flow mobility, the resistance factor is lower than in formations with lower permeability and low foam flow mobility.

4.2 Discussions of results

During the foam flow experiment, crude oil was used at residual oil saturation. In order to establish similar saturation conditions, the core was flushed each time with brine, followed by crude oil and finally brought to residual oil saturation by injecting the same number of pore volumes of the surfactant solution.

I would also like to mention that there was barely any foam present during the experiment for third core. This shows that oil has a negative implication on foam and the surfactants are not as effective is generating foam in low formation permeability especially in the presence of oil.

It can also be seen that mobility is highest for the core having the highest formation permeability and it is lowest when having lowest formation permeability. This basically means that the total mobility has a strong dependence on absolute permeability. The mobility reduction factor is highest in the lowest permeability and lowest in the highest permeability core.

To make sure that foam generation was successful, I flowed the foam through the bypass line for certain duration of time to ensure it had not turned into precipitates which would have had a disastrous effect on my experiment.

During the lab experimentation, I had encountered a couple of issues. The main problem I had encountered was the lack of an external heater at the back pressure gauge which caused the freezing of fluids due to the low temperature of carbon dioxide gas.

The other issue was the need for a stable power supply line throughout the length of the experiment. During one of our runs, the power went off and that caused the RPS machine to be down for a couple of minutes. This resulted in the results of the entire run being void and invalid.

Last but not least, the overburden pressure has to be maintained at a pressure of 300 psi above the outlet pressure to ensure no accidents occur.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The experiments were conducted using different cores with different formation permeability. The effect of the changes in formation permeability on foam flow were analysed and compared with one another.

From my thorough research and experimentation, I have concluded that varying permeability have varying effects on foam flow. Formation permeability dictates the effects that foam flow would have on oil recovery. Based on the results acquired, I have been able to conclude that:

- In low formation permeability layers, the foam flow is decreased compared to high permeability layer.
- Mobility reduction factor is dependent on the absolute formation permeability.
- Reduction factor is dependent on the formation permeability and is higher in high formation permeability as the mobility of foam flow increases.

5.2 Recommendations

In order to optimise foam flow, various aspects of the reservoir has to be studied first. By knowing the formation permeability of a reservoir, we would be able to minimise the wastage of foam which would eventually lead to greater savings in the production of oil.

Further studies should be conducted on higher permeability cores to ascertain the effects of formation permeability on it since lower formation permeability have different effects on foam flow as compared to higher formation permeability.

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