DECREASING GAS MOBILITY TO ACHIEVE BETTER SWEEP EFFICIENCY IN FAWAG PROCESS

by

ISKANDAR BIN MHD NASIR

10677

Dissertation
Submitted to the Petroleum & Geoscience Engineering Department
in partial fulfilment of the requirements for the
Bachelor of Engineering (Hons)
(Petroleum Engineering)

Universiti Teknologi PETRONAS
Bandar Seri Iskandar
31750 Tronoh
Perak Darul Ridzuan

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CERTIFICATE OF APPROVAL

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Approved by:

Saleem Qadir Tunio

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, is my original work except as specified in the references and acknowledgements, and the original work contained herein have not been undertaken or done by unspecified sources or persons.

Iskandar Bin Mhd Nasir

ACKNOWLEDGEMENT

In the name of Allah, the Most Gracious, the Most Merciful. Praise to Him the Almighty that His blessings and guidance in giving me strength, courage, patience and perseverance to endure and complete my Final Year Project (FYP) within the appointed time.

My sincere appreciation and gratitude goes to my supervisor Mr. Saleem Qadir Tunio for his guidance, never-ending supports and for the knowledgeable moments we shared throughout the FYP period. His availability, time and support have been invaluable to me.

Heartfelt appreciation is extended to Mr. Shahrul and Mr. Redzuan, lab technicians in block 15 in UTP, for their assistance and input especially during the experiment sessions. Their contribution in providing the expertise, help and cooperation during completing my tasks is very much appreciated.

Throughout this experience, I would also like to thank the Petroleum & Geoscience Department of Universiti Teknologi PETRONAS (UTP) for providing me with an excellent opportunity to expose myself to the machines and apparatus provided in the laboratory. I have gained a lot of knowledge theoretically and practically to prepare myself for the working environment in the future.

Thank you.

ABSTRACT

The alternation of slugs of gas and water injection i.e. Water Alternating Gas (WAG) has been a common practice to obtain better mobility ratio and improve sweep efficiency [6].Eventually, WAG can suffer from viscous instability and gravity overriding and therefore has not always been a successful method on controlling gas mobility. Therefore, foams are then introduced to WAG for mobility control in enhanced oil recovery operations. This paper aims to prove it by lowering gas mobility better sweep efficiency can be achieved resulting in better oil recovery. Experiments on different gas mobility ratio will be conducted using the same core properties for each experiment and kept to reservoir conditions. The alteration of gas mobility is done by using sodium dodecyl sulphate (a type of surfactant) as a mobility control agent. Furthermore, the optimum concentration of surfactant is obtained for optimal oil recovery. This is done by varying the concentration of surfactant. To determine the outcome of this project, fluid collection of each experiment is observed for volume of oil accumulated. Simulation of the project is also conducted to make a comparison the experiment data in order to have a precise and accurate data thus making a solid conclusion. The methodology of the paper is included to show the organized process that is being followed and approximate duration of the project can be determined. In a nutshell, the experiments will lead to a conclusion whereby decreasing gas mobility better sweep efficiency can be achieved in a foam assisted water alternating gas (FAWAG) process.

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CHAPTER 1

INTRODUCTION

1.1 Background of Study:

There has been a growing interest and research towards maximizing oil recovery in the petroleum industry due to the increasing demand of energy. Enhanced Oil Recovery (EOR) is a method that is used to increase the amount of crude oil that can be extracted from an oil field. On average, primary and secondary recovery methods extract about 20% - 40% of the oil originally in place in the reservoir [1]. Meanwhile, Enhanced Oil Recovery can achieve up to 30% - 60% [2]. Foam has been extensively used in improved and enhanced oil recovery processes in the petroleum industry over decades [16]. There are two uses for foam in the process of oil recovery. The first use of foam is for gas shut off to reduce the gas/oil ratio (GOR) at the production wells. The second one is to control gas mobility in depth of oil reservoirs. In the applications of gas injection or water-alternating-gas (WAG) injection techniques, the high mobility and low density of the gas lead the gas to flow in channels through the high permeability zones of the reservoir and to rise to the top of the reservoir by gravity segregation. As a result, the sweep efficiency decreases and the residual oil in the reservoir will be more. Foam has been used to control the gas mobility and improving sweep efficiency by increasing the viscosity and decreasing the relative permeability of the gas. Hence, a method called Foam assisted Water Alternating Gas (FAWAG) is introduced due to the foam's ability to improve sweep efficiency by stabilizing the mobility of injected gas [3].

1.2 Problem Statement:

According to the Schlumberger Oilfield Glossary, sweep efficiency is defined as a measure of the effectiveness of an enhanced oil recovery process that depends on the volume of the reservoir contacted by the injected fluid. The volumetric sweep efficiency is an overall result that depends on the injection pattern selected, off-pattern wells, fractures in the reservoir, position of gas-oil and oil/water contacts, reservoir thickness, permeability and areal and vertical heterogeneity, mobility ratio, density difference between the displacing and the displaced fluid, and flow rate [17]. Thus in order to obtain high oil recovery, a sweeping mechanism in this case gas is needed to sweep the reservoir in a piston-like manner. However the mobility of the injected mechanism still remains and issue whether to increase or decrease it. Hence a complete evaluation with proper methodology can help us determine maximum oil recovery.

1.3 Objectives of the study:

a) To identify the effects of foam on gas mobility
b) To understand the effects of gas mobility on sweep efficiency

1.4 The scope of the study:

The determination of whether sweep efficiency is dependent on the injected gas mobility which is crucial due to the fact it correlates directly to the factor of oil recovery. Taking into account the role of foam in the FAWAG process on stabilizing the mobility of gas is also a major concern. By having an in depth study on this area, an economical method which results in improved oil recovery can be concluded.

1.5 The Relevance of the project:

As a petroleum engineering undergraduate, further studies on Enhanced Oil Recovery methods are important as it plays a vital role in current oil recovery and also in the near future. Furthermore, by having this knowledge, application in future work space can be done or improved. This project also ensures that the author is aware over implemented or on-going projects i.e. the Snorre Field that uses a large scale demonstration of FAWAG for mobility control [4].

1.6 Project Feasibility:

Further studies on this topic can help improve the understanding on factors that affect sweep efficiency hence improving oil recovery which is vital for the future of the Petroleum Industry. Based from the information gathered from journals and also SPE papers, the project has been able to be implemented in a full scale demonstration i.e. the Snorre Field [4].

Table 1: Foam Field Trials in the North Sea [4]

Year	Field	Problem Identification	Injection Procedure	Operator	Reference
1994	Oseberg	Coning	SAG	Norsk Hydro	Aarra et. al. 1996
1994	Beryl	Cusping	SAG/co-inj	Mobil	Zhdanov et. al., 1996
1996	Snorre	Gas chann.	SAG/co-inj.	Saga	Svorstøl et. al., 1997
1996	Oseberg	Cusping	SAG	Norsk Hydro	Aarra & Skauge, 2000
1997/ 1998	Snorre CFB	Mob.Control FAWAG	SAG Co-inj	Saga	Blaker et. al., 1999
1998	Brage	Mob. Control	SAG	Norsk Hydro	Aarra & Skauge, 2000
1999/ 2001	Snorre WFB	Mob.control FAWAG	SAG	Saga/ Norsk Hydro	This paper

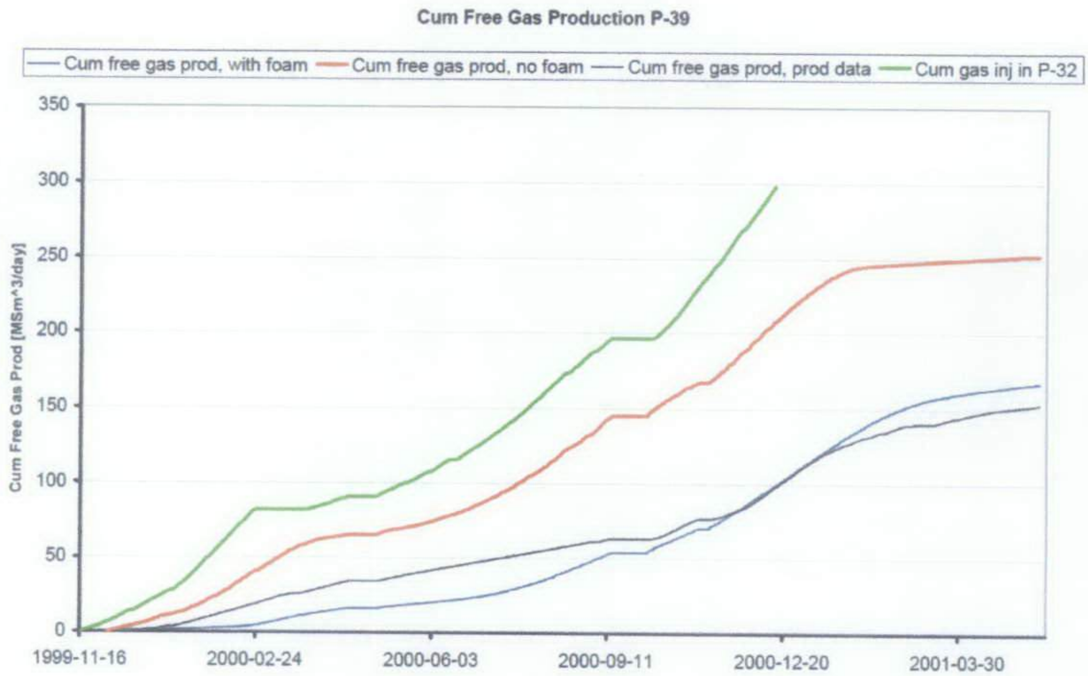

Figure 1: Comparing simulation results of free gas production, foam, and no-foam cases compared to historical production (P-39), and gas injection in P-32 [4]

Figure 1 compares simulated and historical cumulative free gas. The difference between injected and back produced gas indicate that large amount of gas have been stored in the reservoir. The no-foam simulation case include the gas stored by the WAG process, the difference between no-foam and foam case quantify the amount of gas diverted by foam injection (about 100MSm^3). [4]

CHAPTER 2

LITERATURE REVIEW

2.1 Enhanced Oil Recovery

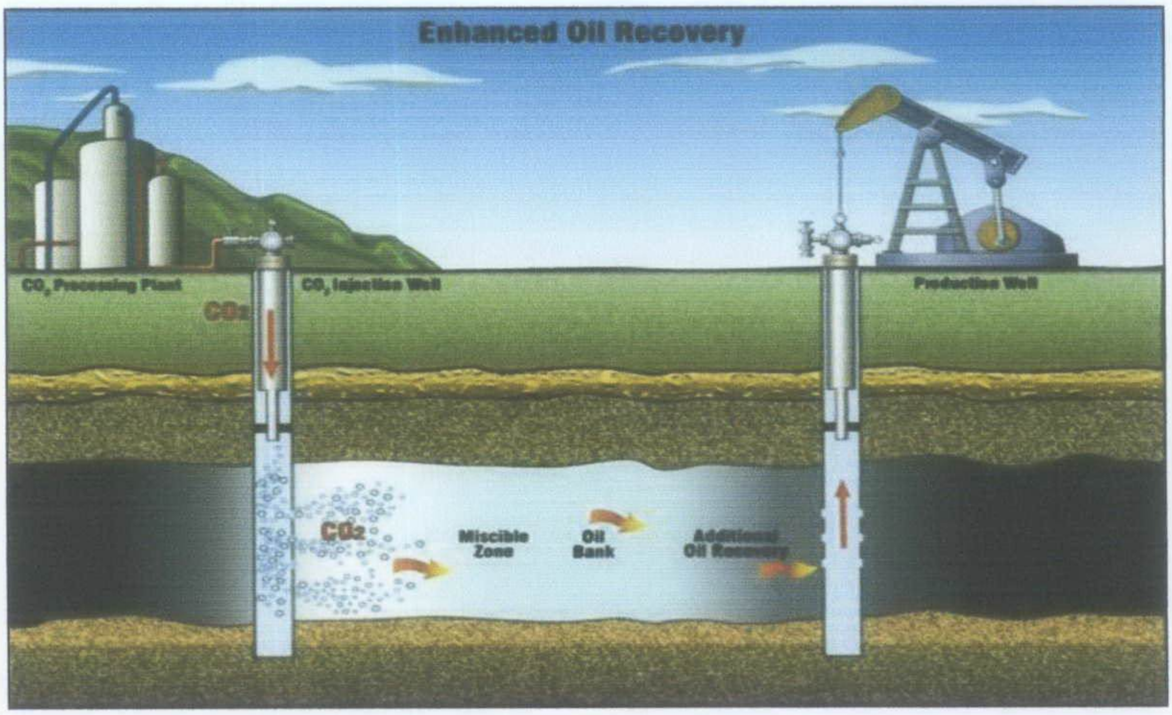

Figure 2: Enhanced Oil Recovery Using Carbon Dioxide [5]

Figure 2 is an example of an enhanced oil recovery method where the injection fluid is carbon dioxide (CO_2). Carbon dioxide is injected at the injection pump to maintain or restore pressure and oil is produced at the production pump. Enhanced oil recovery also known as tertiary recovery which is now used extensively used to increase the amount of oil extracted from an oil field. On average, primary and secondary recovery methods extract about 20% - 40% of the oil originally in place in the reservoir [1]. Meanwhile, enhanced oil recovery can achieve up to 30% - 60% [2].

2.2 Foam Assisted Water Alternating Gas (FAWAG)

The alternation of slugs of gas and water injection i.e. Water Alternating Gas (WAG) has been a common practice to obtain better mobility ratio and improve sweep efficiency [6]. This is because water injection decreases solvent mobility by decreasing the relative permeability of the reservoir to solvent [12]. Eventually, WAG can suffer from viscous instability and gravity overriding and therefore has not always been a successful method on controlling gas mobility. By foaming the gas and thus reducing its mobility results in a process called Foam Assisted Water Alternating Gas (FAWAG). This process is applied for gas shut-off and to improve sweep efficiency during gas injection [4]. Foam is generated by either dropping a soap stick (usually 1 in. diameter, 1 in. long) into the wellbore or by injecting foaming agents (surfactants) intermittently (or continuously) from the annulus [14].

The application of FAWAG for gas shut off is when the gas oil ratio of the wells is so high that it is uneconomical to continue production. In such cases, foam treatment i.e. FAWAG is used to reduce and impede the unwanted flow of gas. A classic example where such of treatment was successful was the Champion field in Brunei [8]. The Snorre field is an example of the application to improve sweep efficiency during gas injection. The field was having problem with early gas breakthrough and although the problem was delayed using water alternating gas process (WAG), it was proven that foam for mobility control i.e. FAWAG has the potential to improve the gas sweep efficiency in the Snorre WAG field according to the resulting lower gas oil it produces and higher oil recovery [4].

2.3 The Relationship between Gas Mobility and Sweep Efficiency

Sweep efficiency is the volume of formation that is in contact with the injected fluid. Sweep efficiency is expressed as follow [21]:

$$\text{Sweep Efficiency, Ev} = \frac{\text{Recovery Efficiency, R}}{\text{Displacement Efficiency, Ed}} \qquad \text{Equation 1: Sweep Efficiency}$$

$$\text{Displacement Efficiency} = 1 - \text{Recovery Efficiency} \qquad \text{Equation 2: Displacement Efficiency}$$

Ideal result is to have the injected fluid to cover total formation and push the oil to the production well in a piston-like manner [15]. The type of fluid that is injected also plays a role and in many field applications Carbon Dioxide (CO_2) is chosen as the medium. This is due to the fact that CO_2 possesses a unique ability to displace crude oil from reservoir rock. Although many gases have been tested for their crude-displacing efficiency, only CO_2 has the ability to reduce residual oil saturations to near zero and produce significant quantities of tertiary oil in models that have been previously waterflooded to the economic limit [7]

Since gas mobility can be altered, high or low mobility of gas can be achieved. By having high mobility gas, two inherent disadvantages arise: viscous instability and gravity override. The first is caused by the fact that the injected gas is more mobile than the reservoir oil, hence it tends to finger through the oil instead of sweeping it in a piston-like manner. Gravity override is caused by the density of the injected gas being less than that of the oil, thus the gas tends to rise over the oil and does not sweep the oil in reservoir uniformly. On the other hand, by decreasing gas mobility, viscous instability and gravity override can be counteracted to the addition of a mobility control agent i.e. foam.

2.3.1 True Foam Mobility Reduction Factor

Gas exists in foam surrounded by liquid lamellae. The efficiency of the foam process relies on this principle. The lamellae exert resistance on the flowing gas due to their contact with the pore walls. Some of the gas may be retained by immobile lamellae, which block some of the flow paths. The reduced gas flow paths in turn reduce gas relative permeability. Although, the actual gas viscosity is unchanged, the gas shows an apparent increase in gas viscosity because of its reduced flow rate [22]. The true foam mobility reduction factor (MRFTF) is defined as follows [23]:

$$\text{MRFTF: } \left[\frac{\Delta P_{\text{surfactant-gas}}}{\Delta P_{\text{brine-gas}}}\right]_{\text{at same rate}}$$

Equation 3: True Foam Mobility Reduction factor

The pressure drops are average values taken during steady-state flow of foam and gas brine-mixture.

2.4 Foam as a Mobility Control Agent in FAWAG Process

Foam is a mixture of surfactant, gas phase and liquid phase. The quality of the foam is defined as the percentage volume fraction of gas. Generally, the higher the quality of the foam the higher its viscosity [9]

Foam quality, fg (%) = $(V_g/V_{(g+w)})*100\ \%$

V_g = gas volume fraction

$V_{(g+w)}$ = total volume fraction

The ability of foams to lower the mobility of the injected fluid, under certain conditions, helps in reducing gravity override and channeling leading to improved sweep efficiency and oil recovery. Foam can improve the EOR in two ways [6]:

a. Stabilizing the displacement process by increasing the displacing fluid (gas) viscosity
b. Reducing the capillary forces via reducing the interfacial tension due to the presence of surfactant

Foams are used to check and impede this mobility, thus bringing the mobility ratio as close to 1 as possible. This would ensure a better sweep efficiency. Experiments were carried out on Indiana limestone cores to prove this [9]. It was shown after lab tests that gas mobility decreases with increasing foam quality until a critical foam quality, after which it increases [9]. Hence, it is very important for us remain below that critical foam quality because when gas mobility increases problems like early gas breakthrough would occur. This foam quality is determined by carrying out constant core-flooding experiments [9].

Also, tests show that when the concentration of surfactants is increased the gas mobility would decrease [9].

Figure below demonstrates gas mobility varies with foam quality 'fg'.

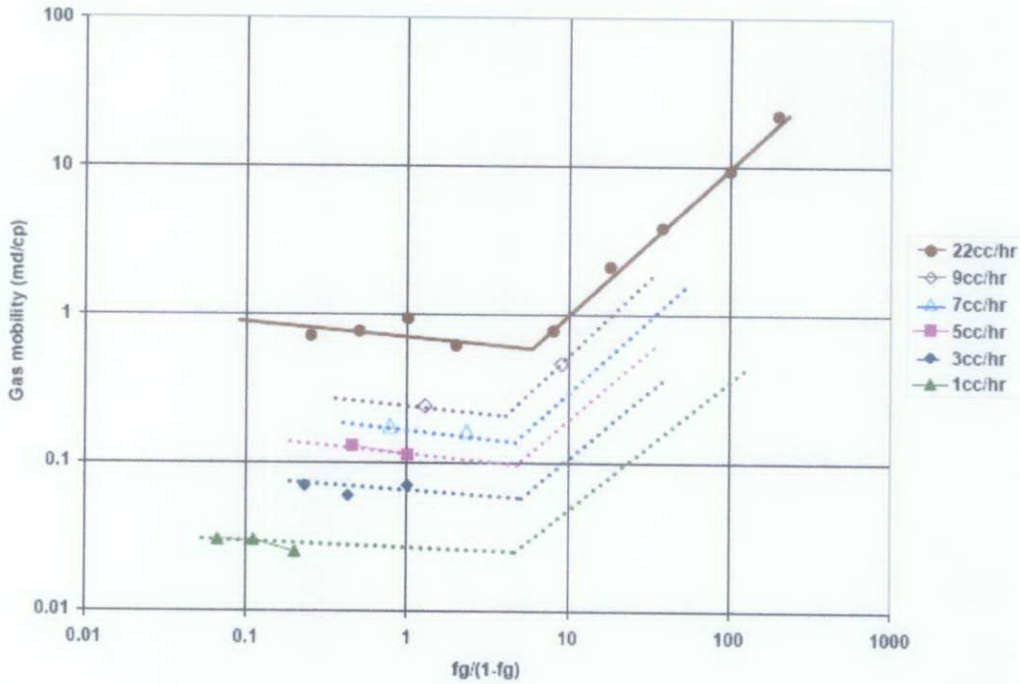

Figure 3: Shows determination of critical foam quality [9]

Looking at the above figure it appears that gas mobility decreases slightly as the foam quality increases till it reaches a critical foam quality value after which it increases.

This research aims to determine that critical foam quality and make sure that it is not exceeded as the purpose would be defeated. Increase in gas mobility would mean that it would not properly sweep the oil and a lot of it would be left behind.

2.4.1 Other usage of foam in field application:

a) Stimulant to increase gas production

Foam fracturing is extensively used to simulate gas production in cases where the permeability is really low [10]. In comparison to gelled water which was the traditional fracturing fluid, foams fare much better as it tends to recover the fluid more efficiently. The reason behind this is that the foams have a lesser pressure head when the well is opened for production and the hydrocarbons do not have to encounter much resistance and can be produced easily. Foam in general is more compressible than gelled water and this property also aids in higher recovery efficiency by having greater sweep efficiency and modifying the profile of the existing system [10]. The post clean up of foams is also much quicker as compared to gelled water which can take several days [10]. This means that you could start producing from the well much faster if you use foams as your fracturing fluid.

b) Reduce water cut

"Well A" where a surfactant based foamed Hcl (hydrochloric acid) was used [11]. This foam was used to plug the high permeable zone. This was done to prevent water production from the high permeable zone, thus reducing the water cut [13]. It was estimated that this permeable zone had already produced a cumulative of 70,000 barrels of water [11].The plugging of this zone meant that fluid (oil) from the lesser permeable zones faced lesser competition in their path to the well bore. As a result of this, although the rates were low, there a considerable drop in the water production and oil was the main fluid being produced.

c) Gas shut off

Sometimes the Gas Oil ratio of the wells is so high that it is uneconomical to continue production. In such cases, the foam treatment is used to reduce and impede the unwanted flow of gas [8]. A classic example where such a kind of foam treatment was successful was the Champion field in Brunei [8].

CHAPTER 3

METHODOLOGY

3.1 Project Flow:

This section consists of project analysis where it involves data and information gathering, decide the best method or some modification on the existence methods, some case study analysis and last but not least experimental results.

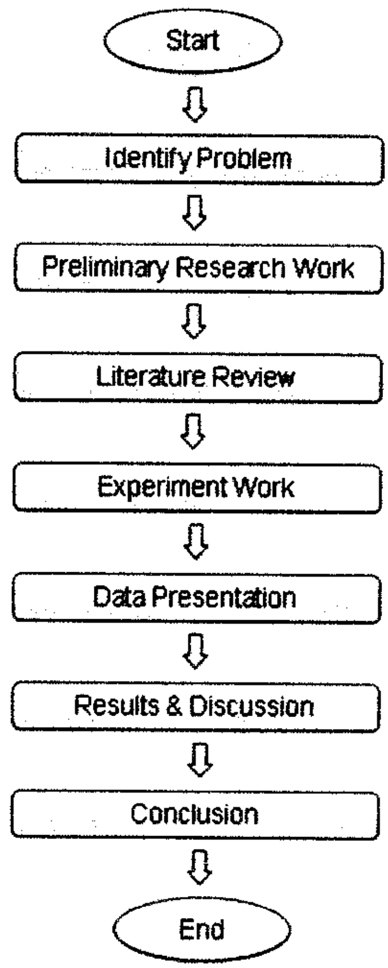

Figure 4: Project Flow Chart

3.2 Experimental Setup:

To determine whether lower gas mobility increases sweep efficiency, core flooding analysis is conducted. This experiment is done at block 15 laboratory in University Technology PETRONAS using the Steady State Gas Permeameter and Porosimeter and TEMCO RPS-800-10000 HTHP Relative Permeability Test System.

3.2.1 Core Flooding [18]

Core Flooding is a common test to determine rock permeability and how well various fluids including oil will flow through it. First, a cylindrical rock sample or core is cut from the oil reservoir. The core is placed in a rock core holder and the outer surface is pressurized to simulate the loads, or 3-axis stresses, that the core was under when it was removed. Of these loads or stresses, some are caused by the weight of the material above the core, which is known as the "overburdened" pressure. Loads on the rock will affect the core's permeability to fluids, so it is important to duplicate them during testing. A test fluid is then pumped through the core, flow rates and pressure drops across the core are measured. From this data, the resistance to flow is evaluated.

The experiment that I have planned is broken down into four parts.

a) First part – brine of 30,000ppm is pumped through the core holder to saturate the core
b) Second part – crude oil is pumped through the core holder to saturate the core
c) Third part – brine with the same concentration is flown through the core again to displaced the crude oil (water flooding)
d) Fourth part – Carbon dioxide (CO_2) is injected and alternately Sodium Dodecyl Sulfate (foam solution) is flown through the core

For each run, cores with similar properties are used and experiment conditions are made very close to reservoir conditions to evaluate the performance of EOR technique to be applied in the reservoir. The fourth part of the experiment the concentration of foam is altered by using different concentration in each run (0.5 wt%, 1.0 wt%, 2.0 wt%). To determine the results of each run, the accumulation of oil in the fluid collection is observed and calculated. Results obtained may not be the same as applied in a real reservoir but can be used as a correlation.

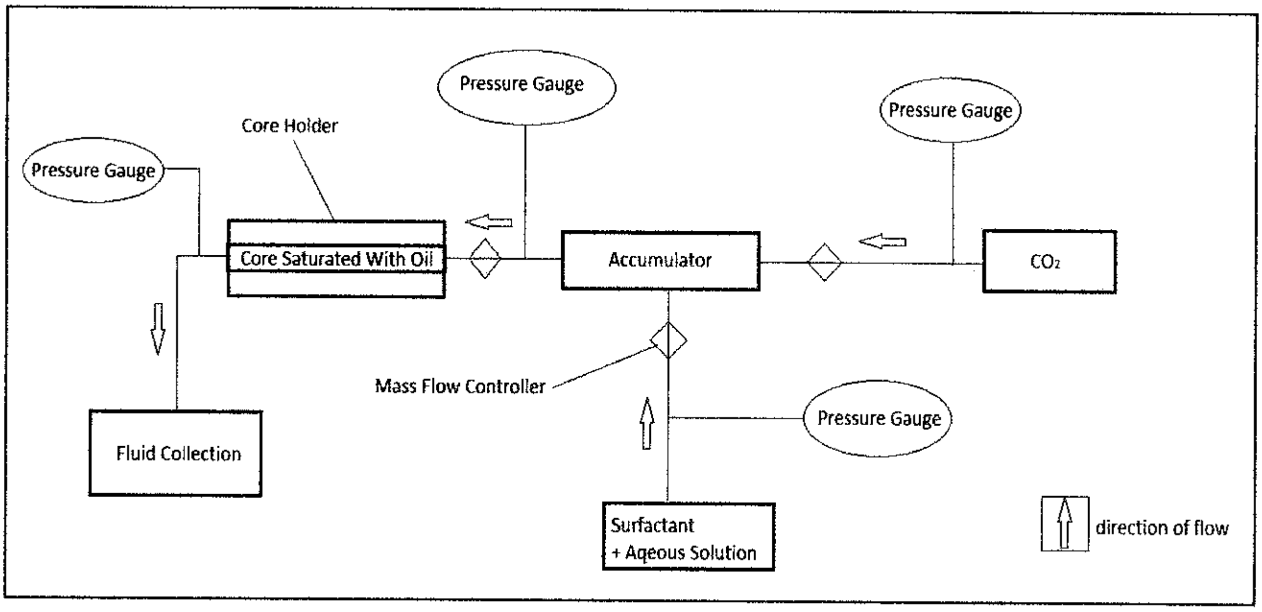

Figure 5: Core Flooding Schematic

Figure 5 shows a basic schematic of a core flood experiment setup with the following components:

a) Accumulator
b) Pressure gauges
c) Core holder
d) Fluid collection media
e) Foam generator
f) Carbon dioxide generator
g) Gas flow system with mass flow controller

3.3 Equipment Description

3.3.1 Poroperm machine

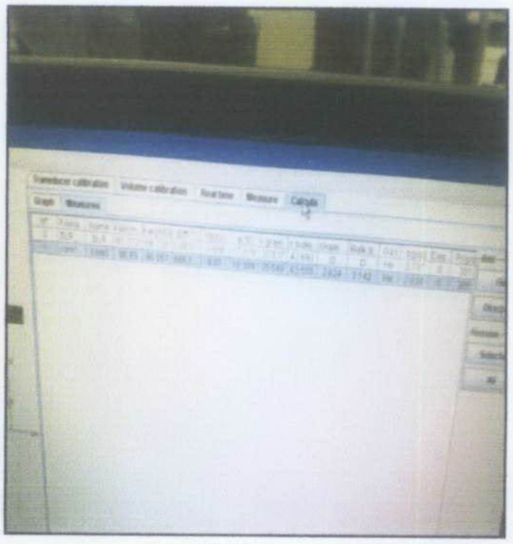

Figure 6: Steady State Gas Permeameter and Porosimeter (PoroPerm) Machine

The Poroperm machine is dedicated 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 core holder, a matrix cup and a data acquisition computer station to be operated in manual and automatic mode. An optional hydrostatic core holder can be used to perform measurement at overburden pressure

3.3.2 Relative Permeability Test (RPS)

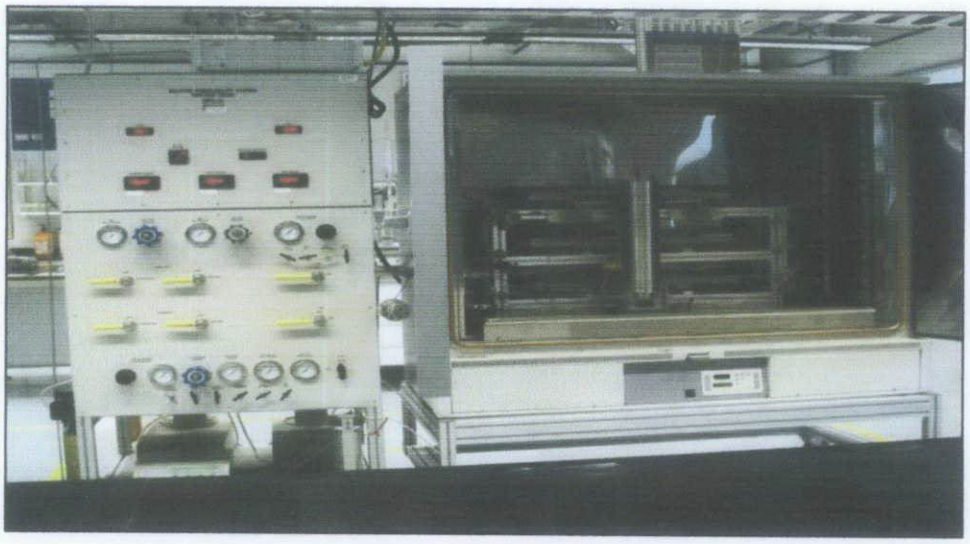

Figure 7: TEMCO RPS-800-10000 HTHP Relative Permeability Test System

The TEMCO RPS-800-10000 HTHP Relative Permeability Test System can be used for permeability and relative permeability flow 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, tertiary water flooding, permeability and relative permeability. Brine, oil or other fluids can be injected into and through the core sample. In this experiment, three different concentrations (0.5 wt%, 1.0 wt% & 2.0 wt%) of foam is used.

Four different fluids will be injected to the core holder which is crude oil, brine, foam (SDS) and CO_2. These fluids will each be stored in a medium called accumulator. Ideally we would need four accumulators for the experiment to run smoothly but since the RPS machine has only three, we need to replace the accumulator which contains foam with CO_2 for alternating injection.

3.4 Chemical Description

3.4.1 Surfactant

The surfactant that I will be using as an injection fluid that will be mix with water to create foam is Sodium Dodecyl Sulfate. Sodium Dodecyl Sulfate (SDS or NaDS), sodium laurilsulfate or sodium lauryl sulfate (SLS) ($C_{12}H_{25}SO_4Na$) is an anionic surfactant used in many cleaning and hygiene products [19]. This anionic detergent is popularly used for routine protein elecetrophoresis and cell lysis methods. The formulation is a mixture of several different alkyl sulfate chain lengths (C10 to C18) [20].

Table 2: Properties of SDS (values for pure C_{12})

Molecular Weight	288.5 g
Detergent Class	Ionic (anionic)
Aggregation Number	62
Micelle Molecular Weight	18000 g
Critical Micelle Concentration (CMC)	6 to 8 mM (0.1728 to 0.2304 %, w/v)
Cloud Point	>100 °C
Dialyzable	No

Specifications for Sodium Dodecyl Sulfate

a) Visual: white powder, free of foreign material
b) Solubility: 10% (aq, w/v) solution must be clear, colorless to slightly yellow
c) Chain length: C12 > 60%; C14: 20 to 35%; C16 < 10%; C10 and C18 < 1% each

Figure 8: SDS preparation

3.4.2 Crude Oil

The crude oil that is used in this experiment was collected from the Dulang field (date drawn: 7/9/2009) in Malaysia and was provided in the laboratory for experimental use. From the API value given in the table below, this oil is categorized as 'light oil' or easily to flow in room temperature.

Table 3: Characteristics of Crude Oil

Characteristics	Value
Specific Gravity of Oil at 60 °F	0.83976
API	37.8
Viscosity (initial)	0.82 cp
Density	0.8256 g/cm^3
Pressure at bubble point	1550 psi
Oil Formation Volume Factor	1.279 rbbl/STB

3.4.3 Brine

The brine that is used is just regular salt which is Sodium Chloride (NaCl). Sodium Chloride is easily obtained and is used to duplicate the reservoir fluids.

Figure 9: Different concentrations of SDS, brine and crude oil in their containers

3.5 Experimental Work

Table 4: Chemicals and Apparatus Preparation

Chemical	Quantity
Crude Oil	1000cc
Brine, 30000ppm	3000cc
Surfactant (Sodium Dodecyl Sulphate)	1000cc
Carbon Dioxide (CO_2)	1000cc

Apparatus	Quantity
Core plugs	2
Poroperm Machine	1
Relative Permeability System	1
Beaker	6
Measuring Cylinder	6

To calculate the weight percent (wt%) for foam and parts per million for brine the equation is as follows:

$$\text{Wt\%, ppm} = \frac{\text{Mass (gram)}}{\text{Volume (ml)}} \times 100$$

For each solution, 1000 ml (1 liter) volume of distilled water is used.

3.6 Experimental Procedures

PoroPerm Machine

Before proceeding with the experiment, we need to know the properties of the core. This is known by using the POROPERM machine. The steps are as follows:

a) Two clean core plugs are obtained and labeled.
b) Length, diameter, and weight of the cores are measured and recorded. Measurements are taken three times and averaged out.
c) Using the POROPERM device, the core plug is to be put in the core holder vertically in the machine and secured, confining pressure is applied up to 1000psi.
d) The software in the computer will automatically display the characteristics of the core and display it on graphs.
e) Core results are recorded.
f) Cores are then saturated in desiccators which contains 30000ppm of brine for at least a day. It is better to saturate the core longer times to ensure that it is fully saturated.

Relative Permeability System (RPS) Machine

Before running the machine, thorough cleaning is done to ensure that the machine is free from foreign fluids from previous experimental run. Hence, unreliable data can be avoided. The steps are as follows:

a) All of the tubing are cleaned using a degreaser and distilled water and dried using a high pressured air gun to make sure they are free from any foreign fluid or solids from previous experimental runs.

b) Crude oil is poured into an external pump and sealed completely. The air vent is pressured (40-50 psig) to pump the crude oil into the accumulator A. This process is repeated for brine (30000ppm) and surfactant (SDS) into accumulator B and C respectively.

c) Core holder equipment is made ready by fixing the core plug inside the latex tube about 1inch deep on one side.

d) Core holder is locked tightly at core holder closure end by using C-wrench

e) CO_2 will be injected in accumulator B later on after surfactant has been injected to the core. The injection of surfactant and CO_2 is done alternately.

f) Door of RPS machine is closed and secured.

g) Temperature of the machine is set 60 °C.

h) Using the RPS software, the steps are as follows:

   I. Brine is injected until permeability reading stabilizes. This is to determine the initial or absolute permeability

   II. After the core is fully saturated with brine, crude oil is injected next. This step gives us the S_o (saturation of oil in core) and by this S_{wir} (irreducible water saturation) is also calculated. Oil is injected to the core holder to displace brine and saturate the core with oil. This is done until there is no brine observed coming out of the outlet tube. Thus ensures that the core is saturated with oil.

   III. Brine is again injected to the core holder to determine the volume recovered by primary recovery or to calculate S_{oir} (irreducible oil saturation).

   IV. Brine in accumulator B is replaced with CO_2.

   V. Slugs of 4PV of surfactant, brine and CO_2 are injected alternatively twice in series. At first, CO_2 is injected followed by 4PV of surfactant solution.

   VI. Sample volume is noted manually by collecting sample at the outlet using a measuring cylinder.

3.7 Gantt Chart of the project flow

Table 5: Gantt Chart of Project

No.	Detail/Week	1	2	3	4	5	6	7		8	9	10	11	12	13	14
1	Discussion on Project Progress															
2	Commencement of Project															
3	Progress Report Submission															
4	Pre-EDX seminar								MID SEMESTER BREAK							
5	Project Work Continues															
6	Submission of Final Report															
7	Evaluation															

Suggested Milestone

Process

CHAPTER 4

RESULTS & DISCUSSIONS

4.1 Calculations

4.1.1 Core

The table 6 below shows the measurements and properties of a core plug using the POROPERM machine.

Figure 10: Core plug properties

4.1.2 Foam and Brine

Table 6: Concentration of SDS and Brine

Substance	Concentration
Sodium Dodecyl Sulfate (SDS)	0.5 wt%
	1.0 wt%
	2.0 wt%
Brine (NaCl)	30000ppm

The formula:

$$\text{Wt\%, ppm} = \frac{\text{Mass (gram)}}{\text{Volume (ml)}} \times 100$$;constant volume: 1000 ml (1 liter) distilled water

In case of 1.0 wt%:

$$\text{Weight percent, wt\%} = \frac{10 \text{ gram}}{1000 \text{ ml}} \times 100\ \%$$
$$= 1.0 \text{ wt\%}$$

For 30000ppm,

$$\text{Parts per million, ppm} = \frac{30 \text{ gram}}{1 \text{ liter}} \times 100$$
$$= 30000 \text{ grams/liter}$$
$$= 30000 \text{ ppm}$$

4.2 Core Flooding Results

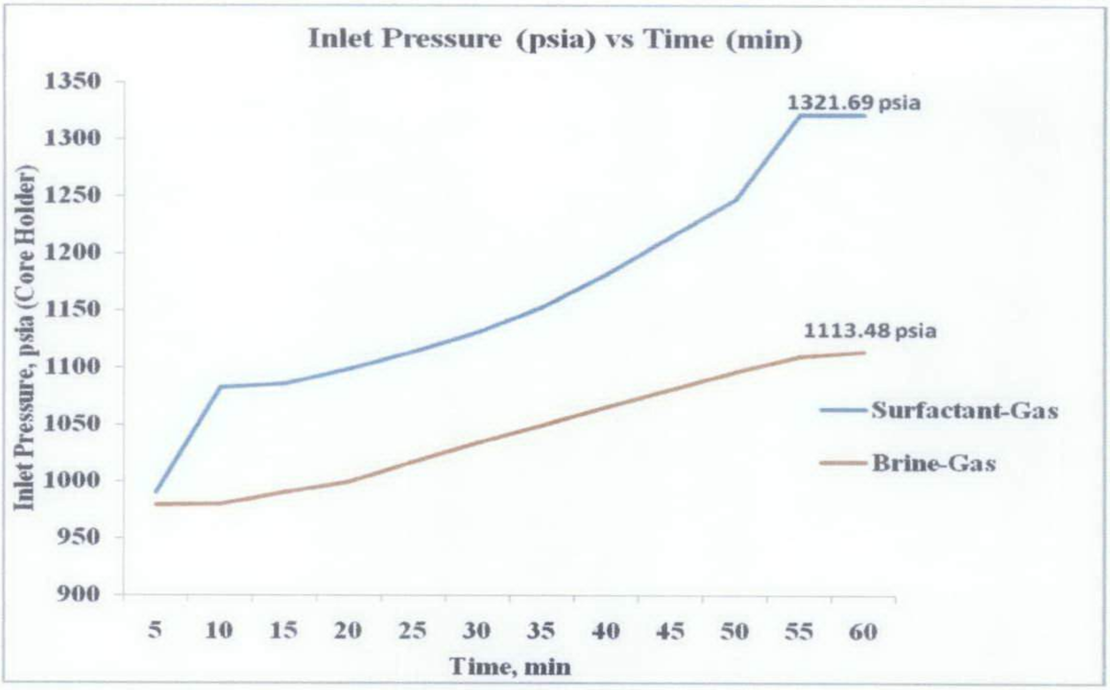

Figure 11: Graph of Inlet Pressure (psia) vs. Time (min) with 1 wt% Foam Concentration

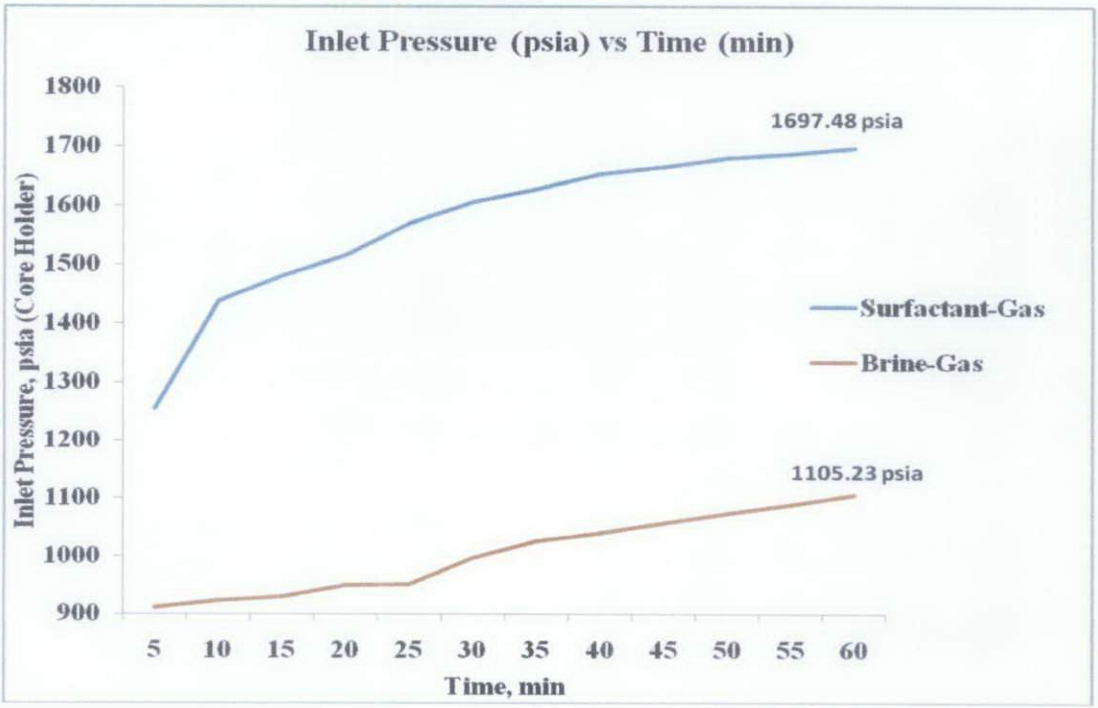

Figure 12: Graph of Inlet Pressure (psia) vs. Time (min) with 2 wt% Foam Concentration

Table 7: MRFTF Procedure

a) $\Delta P_{surfactant\text{-}gas}$

Foam Concentration, wt%	P_{inlet}, psia	P_{outlet}, psia	ΔP, psia
1	1321.69	1053.95	267.74
2	1697.48	1070.45	627.03

b) $\Delta P_{brine\text{-}gas}$

Foam Concentration, wt%	P_{inlet}, psia	P_{outlet}, psia	ΔP, psia
1	1113.48	1045.06	68.42
2	1105.23	1055.85	49.38

c) MRTF

Foam Concentration, wt%	$\Delta P_{surfactant\text{-}gas}$, psia	$\Delta P_{brine\text{-}gas}$, psia	MRFTF
1	267.74	68.42	3.91
2	627.03	49.38	12.70

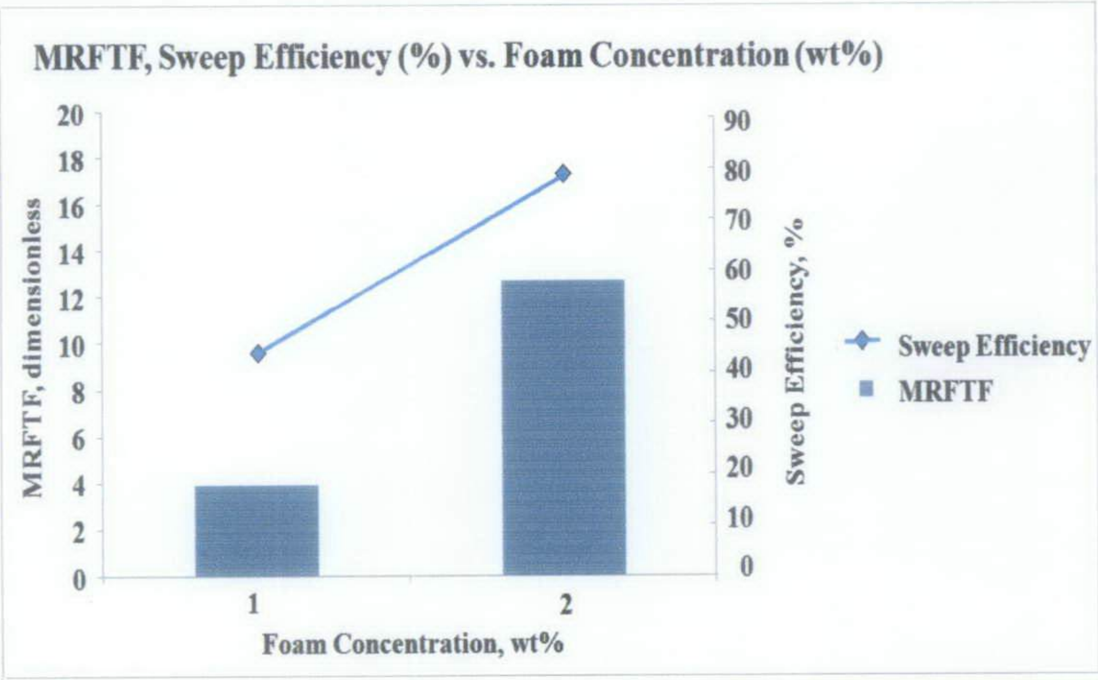

Figure 13: True Foam Mobility Reduction Factor (MRFTF), Sweep Efficiency (%), vs Foam Concentration (wt%)

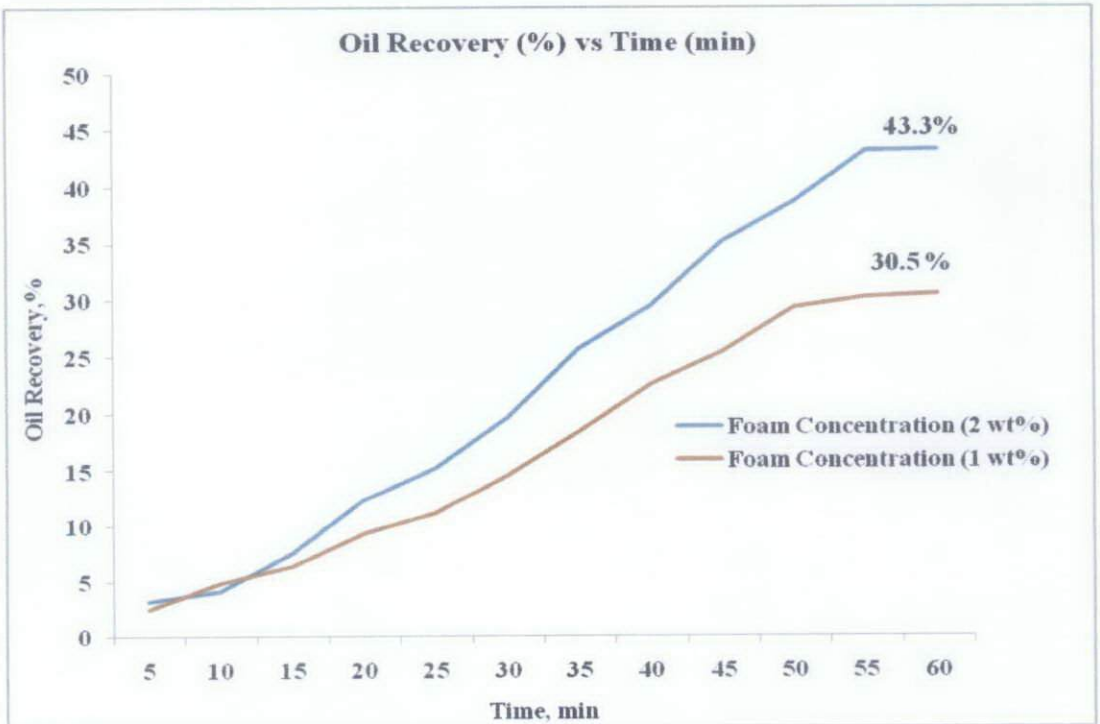

Figure 14: Oil Recovery (%) vs Time (min) and Foam Concentration

4.3 Discussion

As we can see from figure 11 and 12, it shows inlet pressure in different time interval for 1 and 2 wt% of foam concentration. Foam with 2 wt% of concentration gives higher inlet pressure readings. This is due to the increase of total fluid viscosity compared to the 1 wt% of foam concentration. Table 7 shows the steps in finding MRFTF. The pressure drops are average values taken during steady-state flow of foam and gas brine-mixture.

Figure 13 shows with increasing foam concentration the MRF increases. Furthermore, better sweep efficiency is achieved with higher foam concentration. An increase in MRF depicts an increase in apparent gas viscosity. Hence, reducing the mobility of gas injected. Figure 14 shows that different concentration of foam effects the amount of oil recovered. For 1 wt% of foam concentration, the oil that is recovered is 30.5 %, for 2 wt% of foam concentration the oil recovered is 43.3 %. A trend can be seen whereas increasing foam concentration will produce higher oil recovery.

From the results obtained, it proves that by reducing gas mobility, using foam as the mobility control agent, better sweep efficiency can be achieved. This is supported by the increase in oil recovery (30.5 to 43.3%) with increasing foam concentration. The relation between concentration of foam, gas mobility and sweep efficiency is illustrated below.

$$\text{Concentration of foam} \propto \text{Sweep efficiency} \propto \frac{1}{\text{Gas mobility}}$$

CHAPTER 5

CONCLUSIONS & RECOMMENDATIONS

5.1 Conclusion

From the results obtained it shows that by decreasing the gas mobility, which is done by increasing the concentration of foam, higher oil recovery is achieved. Thus, greater sweep efficiency is achieved. This is proven by the amount of oil accumulated at the end of each run. Based on the results that I have obtained, I was able to conclude that:

a) Increasing foam concentration, true foam mobility reduction factor will be higher due to higher total fluid viscosity thus restrict the movement of gas
b) Lower gas mobility permits the gas to sweep the pay zone entirely like a piston-like manner thus increase sweep efficiency
c) In achieving higher sweep efficiency, higher percentage of oil will be recovered thus increasing oil recovery of the reservoir

5.2 Recommendations

Further studies and experiment should be conducted to obtain the value for optimum foam concentration (critical foam value). Critical foam value would give us the optimum amount of foam concentration needed to recover oil optimally. Hence, increasing oil recovery factor for EOR.

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