COMPARISON OF FAWAG AND SWAG AS AN EFFECTIVE ENHANCED OIL RECOVERY METHOD

By

Tariq Ali Chandio

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Project Supervisor:

Saleem Qadir Tunio

Universiti Teknologi Petronas

Bandar Seri Iskandar

31750 Tronoh

Perak Darul Ridzuan

CERTIFICATE OF APPROVAL

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Project Supervisor

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH,PERAK

CERTIFICATE OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project and I hereby state that work submitted is solely my own except the one specified in references. I also take the entire responsibility that the work submitted is not taken from any unspecified sources or persons work.

Tariq Ali Chandio

ABSTRACT

At present petroleum engineering has become economic based field hence all efforts are being made to make sure that we squeeze out the last drop of oil from the reservoir [3]. Reservoirs start to deplete with time hence secondary recovery methods are applied. When such methods are also failed, Enhanced Oil Recovery (EOR) techniques remain the only solution for the production of well hence with EOR techniques 30-60 % of oil can be recovered. In EOR techniques we inject gas and/or water to provide energy (driving force) to the reservoir to produce. Currently Simultaneous Water Alternating Gas (SWAG) along with other techniques tends to improve oil recovery by improving reservoir fluids mobility and providing driving force [2]. Foam can also be added in water alternating gas technique to improve the sweeping mechanism and cut off the gas production and we term such method as Foam Assisted Water-Alternating Gas (FAWAG). In this study, a comparison has been made between FAWAG & SWAG in order to come up with the effective method of EOR, having better oil recovery. Core flooding is to be carried out for the evaluation of both techniques. Hence from previous experiences it has been predicted that SWAG tends to address all recovery related problems economically, where as foam has been seen to address the problems by assisting other Enhanced Oil Recovery Techniques and proved that foam assistance has given better recovery.

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

The present era has seen great importance towards energy reserves and towards different steps involved in utilizing those reserves economically and extract the source to its maximum recovery. In oil industry maximum oil recovery has remained a challenging job and different methods are being applied for recovery to extreme extent. Secondary and tertiary methods are being applied for further recovery after the recovery has started depleting by primary mechanisms. Enhanced Oil Recovery (EOR) has become a field of interest and of prime importance in present era. Enhanced Oil Recovery is a generic term for techniques to increase the amount of crude oil that can be extracted from an oil field. Using EOR, 30-60 %, or more, of the reservoir's original oil can be extracted compared with 20-40% using primary and secondary recovery. The water and gas might be injected alternatively, water alternating gas (WAG) or sometimes depending on the conditions both can be injected simultaneously as in simultaneous water alternating gas process (SWAG) basically to improve the sweeping efficiency of the well. Foam assisted water alternating gas (FAWAG) process uses foam for improving the sweep efficiency during gas injection, reduces the GOR and maximizes the production rate in the producer well [1]. Foam can only be used with other EOR techniques to solve the problems faced by the well in those current injection techniques such as overriding caused by thief zone or gravity override.

1.2 Problem Statement

Mostly enhanced oil recovery methods are used to improve driving mechanisms that improves reservoir energy and support reservoir pressure. Hence at most the basic injection of gas or water does the job but gas injection alone may result in early breakthrough and water can be used along with gas to increase sweep efficiency as WAG or SWAG processes [2] but still there are problems in basic designing and placement of the injector wells for SWAG. Mobility of the injected mechanism remains a issue hence a proper selection of foam addition can end such issue as new process is under trials named as FAWAG process. Hence a complete evaluation and comparative studies with proper plan can give us maximum recovery.

1.3 Objectives of the study

- To deeply study the EOR processes for proper understanding.
- Evaluate SWAG and FAWAG as efficient EOR process.
- Designing a proper model for efficient EOR method for efficient recovery, by comparing SWAG and FAWAG process.

1.4 Scope of the study

Evaluation of SWAG as individual and also FAWAG process for the addressing all the reservoir problems faced during EOR process and the detailed development of model which gives a proper recovery and indicates WAG process with better mobility and sweep efficiency is of major concern. Such development and evaluation can be of greater importance in reservoir Enhanced Oil Recovery process in present era when whole world is thinking of processes which are very economical and results in better recovery.

1.5 The Relevance of the project

This project is basically related to reservoir studies but being a petroleum engineering student, there is a need to have a detailed knowledge over on-going EOR projects having greater importance in present era of oil industry. SWAG and FAWAG has greater importance in all EOR methods as they tend to improve the drawbacks of basic EOR techniques.

1.6 Project Feasibility

The project will be having greater impact on understanding the best model of both FAWAG and SWAG. It will also explain in brief the impacts of the model designed and the factors that help up to improve the recovery in such techniques. Hence selection of proper EOR technique will surely influence any of the projects in petroleum industry.

CHAPTER 2

LITERATURE REVIEW

2.1 Enhanced Oil Recovery (EOR)

The natural drive mechanisms tend to be passive and the reservoir doesn't produce to its desired limit hence secondary methods are applied and if they fail we go for other options to get the maximum recovery with all the possible means.

The tertiary technique for the maximum hydrocarbon recovery during which sophisticated techniques are used that alter the original properties of the oil, is called Enhanced Oil Recovery (EOR)[3]. It not only restore's formation pressure but also improves oil displacement or fluid flow in the reservoir. The challenge of EOR is that the remaining oil often is located in regions of the reservoir that are difficult to access and the oil is held in the pores by capillary pressure. The goal of EOR program is to develop technologies that enable recovery of this remaining oil. During primary recovery, the natural pressure of the reservoir drives oil into the wellbore and artificial lift techniques (such as pumps) bring the oil to the surface. Only about 10 percent of a reservoir's original-oil-in-place (OOIP) is typically produced during primary recovery. By use of EOR methods,(30-60 %) or more of the reservoir's original oil can be extracted. Most EOR involves the injection of gases or chemicals or thermal enhancement. The injection processes can occur as flooding or as slugs (i.e., batches of fluids injected in phases) or as a combination of both. The combination processes typically include water as a flooding agent or as a slug for one of the phases in an effort to control costs.

Now, these days use of SWAG (Simultaneous Water Alternating Gas) to assist the fluid flow solves the fluid mobility problems and to improve the sweeping mechanism FAWAG (Foam Assisted WAG) are being used. Figure 1 below shows basic mechanism of EOR mechanism, where has is being injected at one end which improves the production at other end.

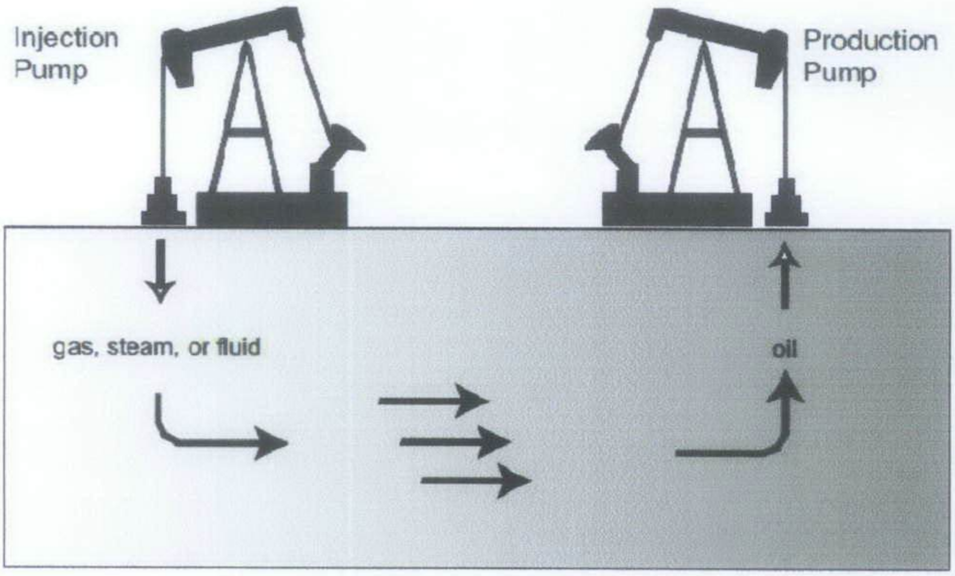


Figure 1 showing enhanced oil recovery mechanism

There are various techniques around the world for better oil recovery most common and currently used techniques are:

- Chemical injection
- Gas injection
- Steam injection
- Water alternating gas (WAG)
- Simultaneous water alternating gas (SWAG)
- Foam assisted water alternating gas (FAWAG)

Among all the above mentioned techniques we will deeply discuss SWAG and FAWAG techniques in detail to better grasp the idea before doing experimental work.

2.2 Simultaneous Water Alternating Gas (SWAG)

Simultaneous Water Alternating Gas (SWAG) is an enhanced oil recovery process in which gas is mixed with water and the mixture is then injected as two phase mixture in the well to get better oil recovery as in Water Alternating Gas process (WAG), water and gas injection alternatively are the best solution to cope with the problems such as early breakthrough which occur only when gas is injected individually due to unfavorable oil-gas mobility ratio. Hence simultaneous injection of gas and water would be of greater importance to improve the sweeping efficiency by improving the displacement front [2].Figure (2) shows a water/gas driven recovery mechanism showing a water/CO_2 injection.

SWAG combines the effects (benefits) of microscopic sweep efficiency obtained from miscible gas injection with better economics and frontal stability obtained from water flooding[17]. Water and gas can be injected alternatively in slugs or simultaneously. The experience of using SWAG is less but the experiments in different fields have suggested that use of SWAG as EOR process can be very crucial as it has been seen that less well injectivity and decrease in associated problems have occurred. SWAG has a Simplified injection volume system with fewer wells and reduced gas re-compression pressure required. Full fluid injection volume could be maintained by combining produced gas and produced water supplemented by seawater to the required total injection volume [13]. Usually greater recovery has been witnessed in the examined fields (e.g Siri Field on the Danish Continental Shelf) but there have been few drawbacks such as high monitoring is required in SWAG operations.

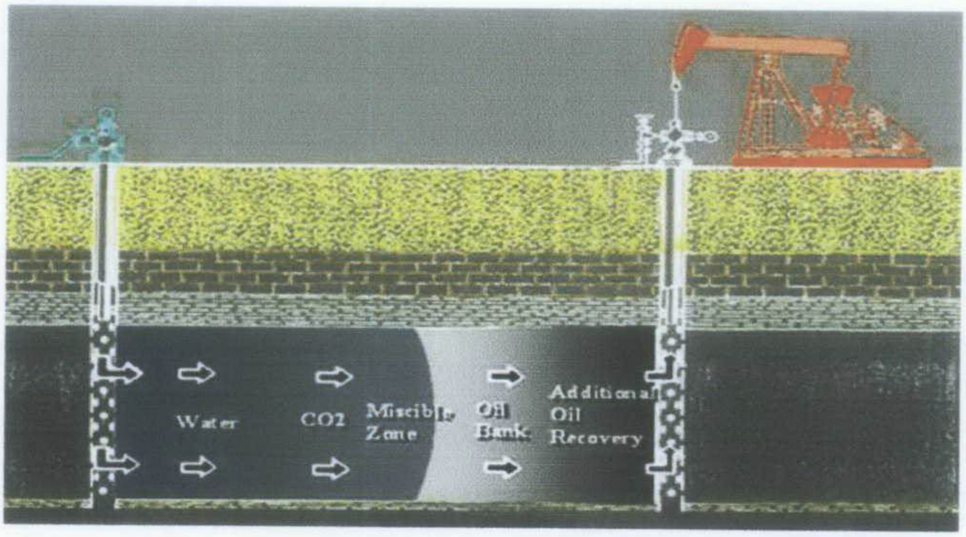


Figure 2 showing water/gas driven recovery

2.2.1 Major contributing factors

The main force that improves the recovery factor in SWAG comes from:

- Improved sweep efficiency
- Oil swelling
- Residual oil saturation (decrease/increase)

2.2.1.1 Improved sweep efficiency

Sweep efficiency is the measure of the volume of reservoir contacted by gas. In ideal cases sweep efficiency tends to contact whole reservoir but some problems arise to prevent this (i.e. Heterogeneities in the reservoir, density differences between gas and oil, fingering effect of gas through oil and water) are among few of the problems that affect the sweeping tendency [7].

There are various different techniques to improve sweep efficiency when any of the above problems exists. If formations are heterogeneous and few layers are of lower permeability while others are of higher permeability then in such a case all the injected fluids flow through less-resistant (highly permeable) zones bypassing the lower permeability zones. The new process [8] slugging of water is done based on the theory of "salting out" in which a non-electrolyte is added to water to reduce the solubility of electrolytic substances. In this new process, following a concentrated brine preflush, one or more slugs of a water soluble alcohol (such as ethanol) are injected into a reservoir. The mixing of alcohol with brine will cause salt precipitation. Alcohol and concentrated brine prefer to flow through water flooded zones because of the high relative permeability to these fluids. The formation of solid precipitate can partially or completely block the high-permeability zones and divert subsequent fluid flow into lower permeability zones where oil saturations are greater. A larger volume of the reservoir is thus contacted by the injected fluid, improving the overall volumetric sweep efficiency and the oil recovery. The experimental results show that the new selective plugging process can recover an additional 15% of original oil in place (OOIP) and there may be various methods which will help to improve sweep efficiency problems depending on situation faced.

2.2.1.2 Oil swelling

Swelling of crude oil due to solvent dissolution is a well-known phenomenon. Oil swelling has two benefits [9] to oil recovery, first oil swelling can mobile some of the residual oil so that it can be recovered. Second, oil swelling also increases oil saturation and consequently the relative permeability of oil. Hence oil swelling, in Enhanced Oil Recovery (EOR), forces the residual oil to move and mobilizes it which directly improves certain amount of recovery.

2.2.1.3 Residual oil saturation

During the displacing process of the crude oil system from the porous media by water or gas injection there will be some remaining oil left that is quantitatively characterized by a saturation value that is larger than critical oil saturation. This saturation value is called "residual oil saturation" [10]. Reduction in oil saturation occurs as reservoirs are depleted during primary and secondary recovery techniques [11]. However even the most effective secondary recovery programs still may not reduce oil saturation to the unrecoverable oil saturation point of the reservoir. In order to continue to reduce residual oil saturation and recover oil at economic rates a program must be put in place that:

- Increases the mobility of the displacement medium by increasing the viscosity of the water or decreasing the viscosity of the oil.
- Reduces interfacial tension between the oil and water.

2.2.2 Simultaneous Water Alternating Gas (SWAG) selection criteria

SWAG can be implemented as EOR process in many cases but major criteria again would be reservoir conditions and problems associated in recovery decline. Hence proper evaluation of alternative should be carried out. SWAG is acceptable if following situation prevail. [13]

a) If some small amount of gas is being produced and there is no gas infrastructure in vicinity and gas volume is not enough alone to be injected as EOR technique and further routine gas flaring is unacceptable in the area then reinjection is required.

b) Reservoir simulation studies suggest that an EOR to be carried out with combined gas and water injection as compare to pure water injection, to address the reservoir recovery problems.

c) Reservoir may require continuous water injection from multi injector wells to maintain its pressure.

Hence considering all the above conditions Simultaneous Water Alternating Gas (SWAG) mode of injection fulfils all these requirements, representing a safe, economic and environment-friendly development.

2.2.3 SWAG injectivity

Injectivity index (II)[13] is the direct measure of injector performance. It can be explained by simple relation mentioned below:

$$II = Qt \; / \Delta P \qquad (1)$$

Where

Q_t is the combined flow rate of gas and water (measure in Reservoir volumes).

ΔP is the pressure difference b/w bottom hole flowing pressure and formation pressure.

Hence eq: (1) describes the basic relation between injected fuid and the pressure variations resulted by injectivity hence Injectivity Index can be explained as the flow conductance of the fluid from injector well through the formation.

2.2.4 Errors in recovery prediction

Usually we have less field recovery [17] than predicted by simulator it is because of many reasons and approach. Less experimental details to allow the testing of ability of numerical simulations to predict the behavior of these displacements. Difference in theory and practical approach is because of uncertain reservoir heterogeneities and gravity along with inadequate physical description of SWAG displacement process in reservoir simulators.

2.3 Foam Assisted Water Alternating Gas (FAWAG)

Foam injections in water alternating gas (WAG) process has given tremendous improvement in recovery by improving sweep efficiency during gas injection and gas shut-off. Even less GOR was seen in most of the process. Foam has increased mobility control of gas flow and has come up with new method for improvement of well flow.

Foam is well known as a selective blocking agent and has shown promise for the diversion of steam under conditions of poor reservoir conformance. The hydrocarbon as in many other tertiary recovery schemes is less viscous and less dense than the fluids in the reservoir. Therefore, it is likely that a significant portion of the reservoir is bypassed due to gravity segregation and viscous fingering. One way to minimize such problems is the injection of foam [4]. Usually the foam injection has given better results and in most of applications oil rate increased by 1.5-5 times, while the water cut was seem to be decreased by 20 %, (for example from 80% to 60%)[12].

FAWAG is usually introduced in reservoirs with WAG already in use. In WAG water displaces the lower part of the oil bearing sands and gas fills the upper part. Though WAG is considered an oil-recovery enhancement technique but usually injected gas tends to rise to top of the reservoir relatively quickly and its presence can be detected from the oil produced from the upper zone. Hence FAWAG can be intended to create a foam barrier that "impedes" the upward passage of the gas, forcing it spread laterally and in the process contact previously unswept parts. Hence to achieve that barrier water and surfactant are injected simultaneously over several days, followed by gas injection. Foam is created in the area near wellbore vicinity at first making it difficult to inject gas injectivity gradually increases as gas finds paths unimpeded by the foam [18].

2.3.1 Problems solved by foam assisted EOR process

In a Enhanced Oil Recovery injection process using CO_2, Steam, N etc), the foam tends to improve oil recovery by solving following problems:

- Injectant overriding problem
- Thief zone in the upper part of the pay zone
- Thief zone not located in the uppermost interval.

In all three cases, an unfavorable mobility ratio between displacing agent and oil, and density contrast aggravate the problem, or influence the nature of the problem.

2.3.2 Performance evaluation of foam for EOR

Foams are believed to be used as mobility control and conformance improver in EOR processes. Hence a proper evaluation of the foaming agent is important for the success of proposed foam assisted EOR technique. Foam performance depends on many factors from its structural study (i.e. molecular weight, mole % of surfactant, hydrophobe carbon no, chemical structure etc)[14] but usually chemical structure parameters are not enough to evaluate its performance hence a correlation is required to relate Mobility Reduction Factor (MRF), foam stability, critical micelle concentration and cloud point. Hence there are many considerations which should be done depending on what sort of foam quality to be used based on what the problem is and what quality of foam will help in overcoming that problem.

As per research by Farooq ali and Selby in 1986, foam was confirmed to be as a mobility control and blocking agent, by addressing the problems like gravity segregation and channeling which tend to effect the sweeping efficiency. Hence they concluded foam to be non-Newtonian compressible fluids. Beside foams quality the forth texture and size of bubbles play[15] a decisive role in its performance. Hence in many experiments oil recovery has been found depending on foam qualities too. An "offending well" is defined as production well which experiences a pre-mature breakthrough of the injectant. This usually means that there is channeling of the injectant towards that production well either due to a thief zone or due to override of the injectant. [16]

2.3.3 Classes of foam used in EOR process

Different classes of foam used in EOR process are:

- In-depth mobility control foam (MCF)
- Blocking/diverting foam - BDF (also known as injection profile improvement foam)
- Gas Oil Ratio (GOR) control foam

In the field, foam can either be placed around either an injection well or a production well. The mode of foam placement would depend upon what sort of the problem in the well.

CHAPTER 3

METHODOLOGY

My approach in this project is basically divided in three major stages which are literature review, the experimental work of FAWAG and SWAG hence once results are achieved a detailed evaluation is to be done and results are to be discussed. The flow of my project would be as follows

3.1 Project Flow

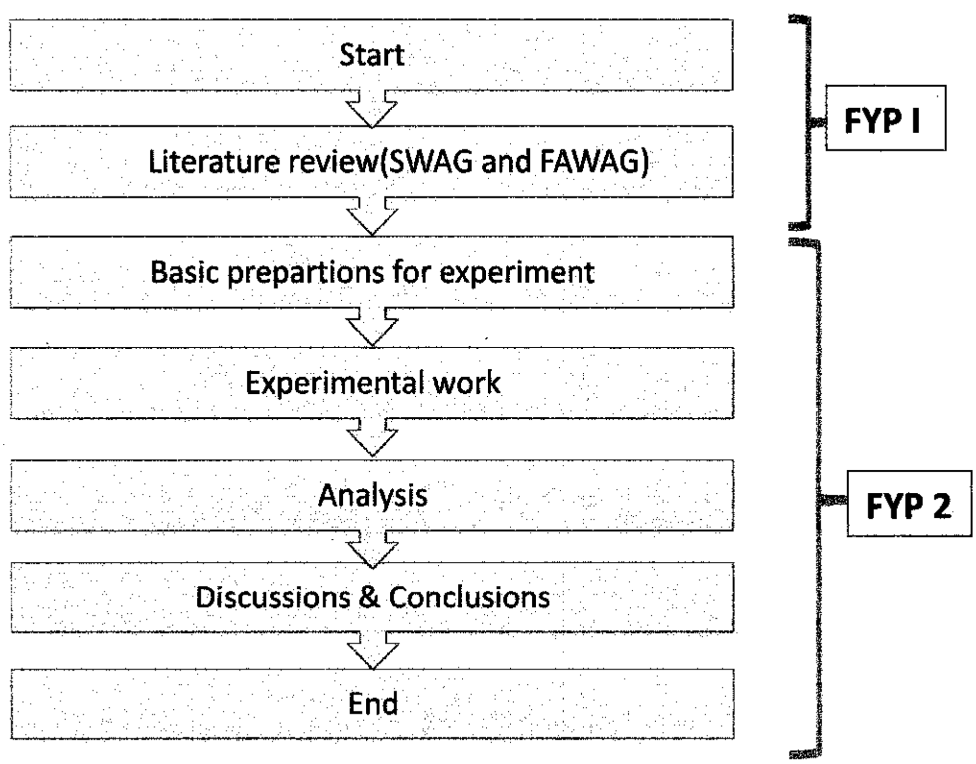


Figure 3 Project Flow

3.2 Experimental Setup

To determine which EOR techniques are best, tests are conducted to see how easily various fluids can flow through the reservoir rock. I only plan to go through one lab experiment of core flooding for each EOR technique (i.e. FAWAG and SWAG).

3.2.1 Rock Core flooding

Core Flooding is a common test to determine rock permeability, and how would the 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, and the flow rates, pressure drops across the core are measured. From this data, the resistance to flow is evaluated.

Usually in core flooding experiment the conditions are made very close to reservoir conditions to evaluate the performance of EOR technique to be applied in reservoir. Hence core flooding results may not be 100 percent correct but they give inside out and are reliable enough than other experiment. Usually one run can take 1 week hence it is quite obvious that proper evaluation is needed to make sure that all sort of behaviors are noted down. I intend to work on RPS POROPERM 800-1000 machine which is available in Block 15 of our university. Hence below is the typical schematic of core flooding experiment.

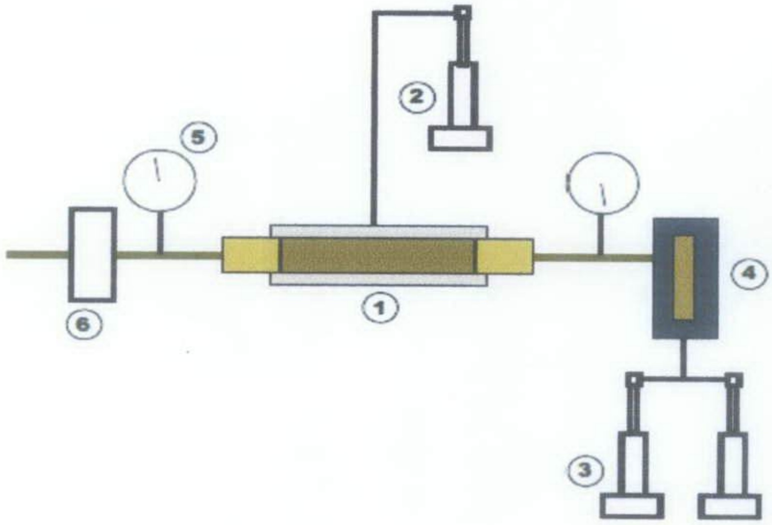


Figure 4 schematic of core flooding experiment setup

Figure 4 shows basic schematic of core flood experiment setup with following labeled components:

1) Core holder
2) Overburden pump
3) Flow pump
4) Accumulator
5) Pressure gauges or differential pressure gauges
6) Back pressure regulator.

The purpose of the system above is to recreate the conditions from which the rock sample was brought and then to pump fluids through the pump to evaluate the permeability and production rates. A pump running in "constant pressure mode" in our experiment constant design pressure would be used to duplicate the loads and stresses. The flow pump by running "constant flow model" is used to introduce fluid into the rock core holder and monitor the flow rates.

It takes several hours at high pressures and low flow rates for the newly introduced fluid to displace the oil from the rock sample. From the data provided by core flooding, we can predict the best way to recover the maximum amount of oil.

3.3 Equipment Description

Relative Permeability System (RPS):

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.

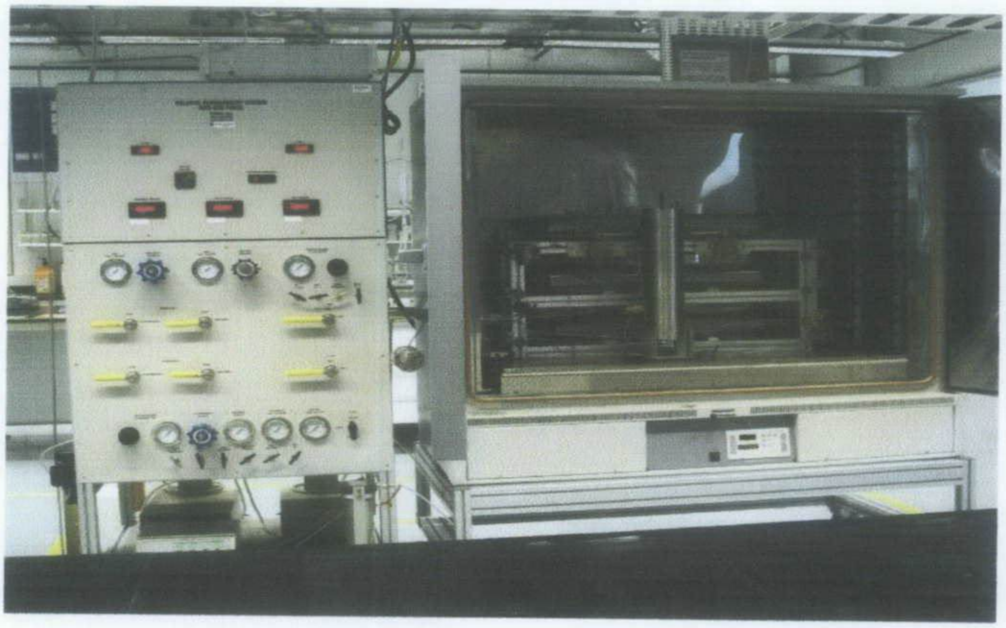


Figure 5 RPS 800-10000 machine in UTP

3.4 Chemical Info:

We will use Sodium Dodecyl Sulphate [19] (SDS or NaDS) ($C_{12}H_{25}SO_4Na$) as an injectant for foam production along with water in tertiary recovery. Sodium Dodecyl is commonly known as SDS. Thermo Scientific Sodium Dodecyl Sulfate (Lauryl) is standard-grade SDS detergent for use in protein polyacrylamide gel electrophoresis. This lauryl-grade sodium dodecyl sulfate (SDS) is a popular anionic detergent for routine protein electrophoresis and cell lysis methods. The formulation is a mixture of several different alkyl sulfate chain lengths (C10 to C18).

. Few of the basic properties of sodium dodecyl are given below:

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

- Molecular Weight: 288.5g
- Detergent Class: Ionic (anionic)
- Aggregation Number: 62
- Micelle Molecular Weight: 18,000g
- Critical Micelle Concentration (CMC): 6 to 8mM (0.1728 to 0.2304%, w/v)
- Cloud Point: >100°C
- Dialyzable: No

Specifications for Sodium Dodecyl Sulfate:

- Visual: White powder, free of foreign material.
- Solubility: 10% (aq, w/v) solution must be clear, colorless to slightly yellow.

Specifications for SDS, 20% Solution:

- Visual: Clear, colorless liquid, free of foreign material.
- pH: 5 to 8
- DNase, RNase and Protease: None

3.5 The experimental work

3.5.1 The Apparatus & Chemical Required:

The experiment apparatus and chemicals needed are:

Apparatus	Quantity
Core Plug – sandstone type	2
PoroPerm System Machine	1
Relative Permeability System Machine	1
Beaker	5
Measuring Cylinder	10
Chemical	Quantity
Light crude oil	1000 cc
Brine solution 30,000 ppm	3000 cc
Surfactant SDS (Sodium Dodecyl Sulphate)	1000 cc
CO_2	1000 cc

Table 1: Apparatus and chemicals preparation

3.5.2 POROPERM® MACHINE

In order to proceed with FAWAG and SWAG we need the core properties which are supposed to be studied by poroperm machine and the steps were repeated for both the cores the steps are as follows:

a) Get two blocks of cleaned core plug
b) Measure the diameter, length and weight of the core plug
c) Using the POROPERM® device, the core plugs are to be put in the core holder vertically in the machine, confining pressure is applied of up to 1000 psi.
d) The system in the computer would automatically display the graphs and characteristics of the core plug.
e) Record the porosity and permeability readings in the results section.

f) Saturate the core plug with distilled water in a manual pump sucker for at least 6 hours. In our experiment we have saturated the core for 2 days. It's better to saturate the cores for longer times.

3.6.2 Simultaneous Water Alternating Gas (SWAG):

a) All the tubings are cleaned by the air gun to make sure they are free from any foreign fluid or fluids from previous experimental runs.

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

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

d) Brine which was prepared earlier for 30,000 ppm is poured into the external pump and sealed completely, and then the air vent is pressured to pump the brine into the accumulator B.

e) Crude oil is then slowly poured into accumulator A which is again closed tightly and fixed to its place with half inch wrench.

g) CO_2 will be injected in the Accumulator C later on with the commencement of the experiment

g) In the computer interface software for RPS®, follow the steps below:

I. Inject brine solution until the permeability reading stabilizes. This step is done for determining the initial or absolute permeability.

II. After core has been saturated with brine we inject crude oil. 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 from accumulator A to displace the water from the core and saturate the core with crude the water is recovered at the outlet and amount is noted.

III. After this we inject Brine solution to determine the volume recovered by primary recovery or to calculate S_{oir} (irreducible oil saturation).

IV. Now SWAG technique as Enhanced Oil Recovery process is applied where by gas (CO2) from accumulator C and .brine solution from accumulator B is injected simultaneously to recover the remaining crude in the core.

V. Sample volume is noted manually by collecting sample in tester at outlet.

3.6.3 Foam Assisted Water Alternating Gas (FAWAG):

For FAWAG, surfactant mixture of 2 wt % of surfactant is added in 30,000 ppm brine for preparing a surfactant brine solution to be injected in cyclic pattern followed by gas slug to improve the recovery. The steps for the core flooding are as follows:

a) All the tubings are cleaned by the air gun to make sure they are free from any foreign fluid or fluids from previous experimental runs.

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

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

d) Brine which was prepared earlier for 30,000 ppm is poured into the external pump and sealed completely, and then the air vent is pressured to pump the brine into the accumulator B.

e) Crude oil is then slowly poured into accumulator A which is again closed tightly and fixed to its place with half inch wrench.

h) CO_2 will be injected in the Accumulator C later on with the commencement of the experiment.

i) Furthermore after getting Soir and Swir, the accumulator B having brine is filled with surfactant brine solution.

j) In the computer interface software for RPS®, follow the steps below:

I. Inject brine solution until the permeability reading stabilizes. This step is done for determining the initial or absolute permeability.

II. After core has been saturated with brine we inject crude oil. 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 from accumulator A to displace the water from the core and saturate the core with crude the water is recovered at the outlet and amount is noted.

III. After this we inject Brine solution to determine the volume recovered by primary recovery or to calculate S_{oir} (irreducible oil saturation).

IV. Hence now for application of FAWAG brine in accumulator B is replaced with brine solution containing surfactant concentration.

V. Now FAWAG technique is applied where slugs of 4PV of Surfactant /brine and gas are injected alternatively twice in series. At first we inject surfactant followed by 4PV of gas which is followed by 4PV of surfactant/brine solution and in the end 4PV of gas.

VI. Sample volume is noted manually by collecting sample in tester at outlet.

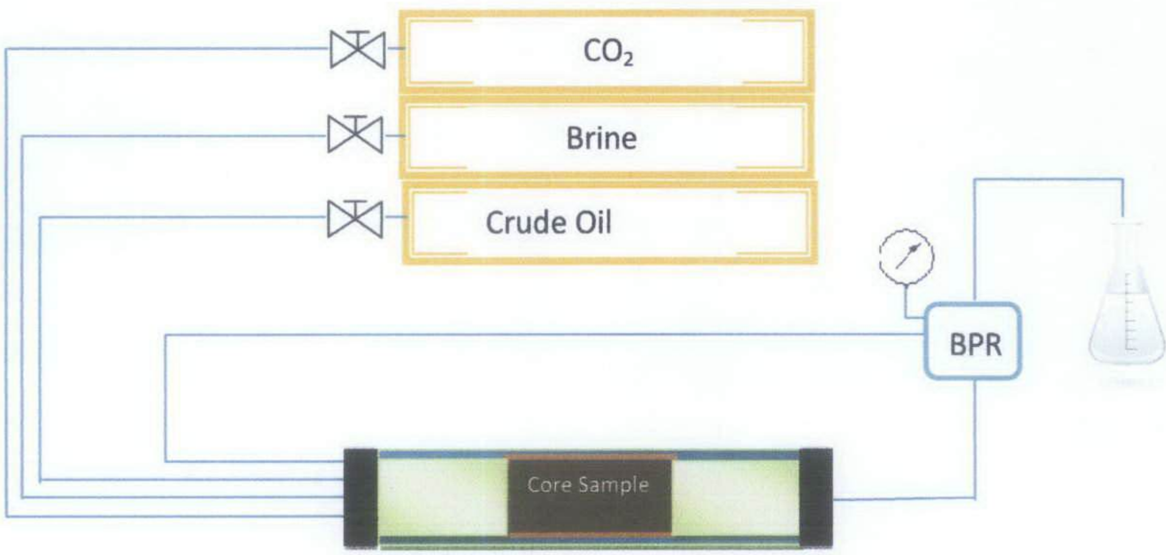


Figure 6 schematic of poreperm system

Hence the schematic in figure (6) shows the three acumulators containing the basic components CO_2, brine and crude with its vlaves at front which can be opened and closed manualy or by computer signal. Further the core from outlet end has a tubing which extends to the container for collecting sample and BPR (back pressure regulator) is connected to both the ends for maitining the pressure inside the core holder. Once the pumps are switched on they pump the distilled water inside the acumulators from one end which pushes the fluid in the acumulator towards the core on desired pressure and core is further saturated, by which the recovery of saturated fluids is achieved, which is to be noted manually.

Now, since the experiment is focusing on the tertiary recovery or EOR, we need to water flood the model first by saturating it with water. Then, brine is injected in at a sufficiently high rate, or 5ml/min to attain irreducible water saturation (S_{wir}).

At each end of the core holder would be pressure gauges for taking readings of P_{inlet} and P_{outlet} and BPR is used to maintain the pressure drop. In our experiment inlet pressure was set to be 1000 psi while outlet pressure was 800 psi with an overburden pressure of 1500 psi. Whole experiment was done at constant conditions of 65°C.

3.7 The Crude Oil Characteristics

The crude oil sample used in this experiment was collected from a field in Malaysia and was provided to me in UTP's lab. The properties of the crude oil applied are as given in table (2) below:

Characteristics	Value
API No	37°
Viscosity(initial) , μ_{oi}	0.82 cp
Pressure at bubble point, P_b	1550 psi
Density, ρ	0.8256 g/cm^3
Oil Formation Volume Factor, B_{oi}	1.279 rbbl/STB
Specific gravity of Oil at 60° F	0.83976

Table 2: crude oil properties

3.5 Gantt Chart of the project flow

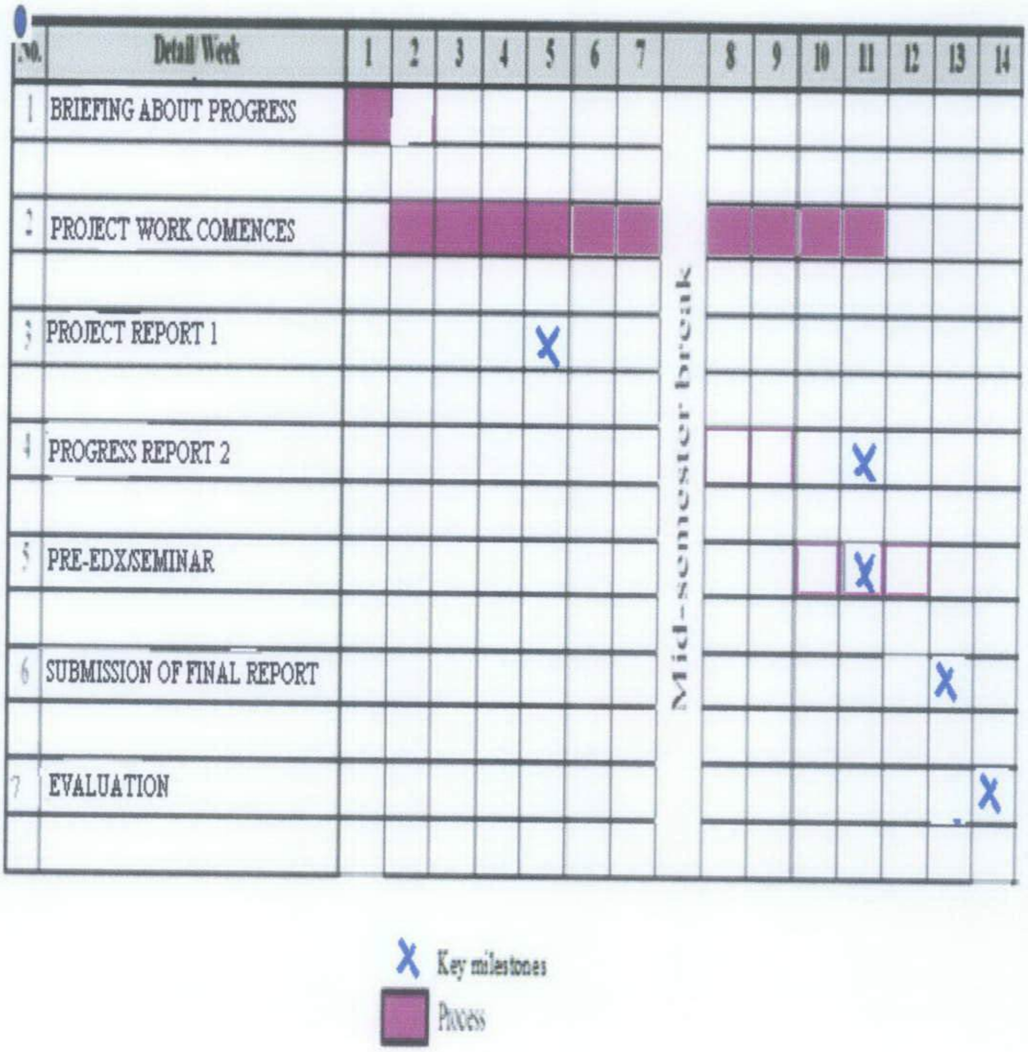


Figure 7 Gant chart of project flow

CHAPTER 4

RESULTS & DISCUSSIONS

4.1 Core calculations:

The table (3) given below shows the properties and calculation for two core plugs used in the experiment the

Core plug 1	Core plug 2
Name: T-2 Length: (77.7+77.8+77.6)/3 = 77.7mm Diameter: (37.8+37.9+37.7)/3 = 37.8mm Weight:(187.452+188.454+186.450)/3 = 187.834gm	Name: BR-7 Length: (75.27+76.19+75.05)/3 = 75.17mm Diameter: (37.62+37.79+37.72 = 37.71mm Weight:(:(176.5+176.484+177.176.489)/3 = 176.491gm
PoroPerm System Computer Calculation Results	
Vp (cc) = 15.439 K_{air} (mD) = 38.176 Φ (%) = 17.688 V bulk (cc) = 87.288	Vp (cc) = 16.633 K_{air} (mD) = 194.4 Φ (%) = 19.811 V bulk (cc) = 83.955

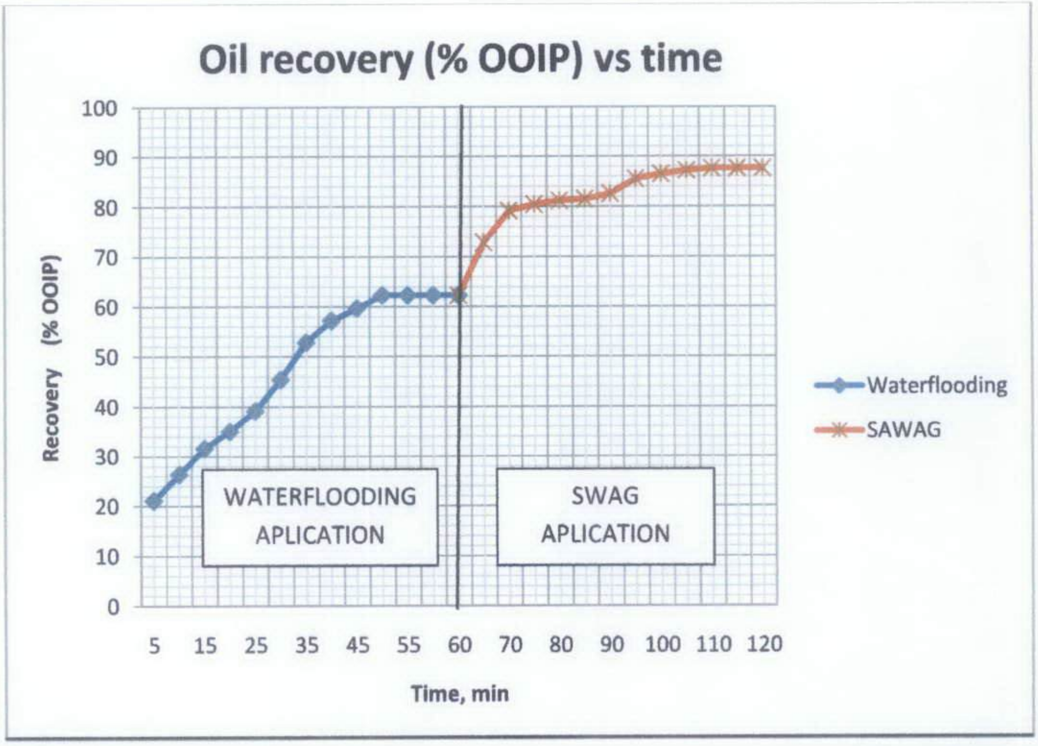
Table 3: Core plug properties measures by poroperm

4.2 Simultaneous water alternating gas (SWAG):

The SWAG was applied by simultaneous injection of gas and water below is the recovery by SWAG in % OOIP. The first column shows the recovery time in minutes while the 2nd column shows the recovery in terms of % OOIP recovered by secondary recovery or water flooding. The third column is recovery of Oil after applying SWAG which is additional to recovery by core flooding. The recovery by was significant with breakthrough recovery till 57.2 % and ultimately recovery by water flooding was 62.3 %. After SWAG`s application the recovery improved by 35 % of OOIP which tends show that SWAG has been successful in application.

Time (min) /Process	Recovery after brine injection/displacing oil (in % of OOIP)	Recovery after SWAG application (in % of OOIP)
5	21.11	72.86
10	26.4	79.19
15	31.6	80.46
20	35.05	81.2
25	39.17	81.52
30	45.4	82.6
35	52.8	85.53
40	57.2	86.48
45	59.66	87.22
50	62.3	87.64
55	62.3	87.64
60	62.3	87.64

Table 4: Showing oil recovery (in %) of OOIP



Graph 1: showing Oil recovery by SAWG (% of OOIP) vs time.

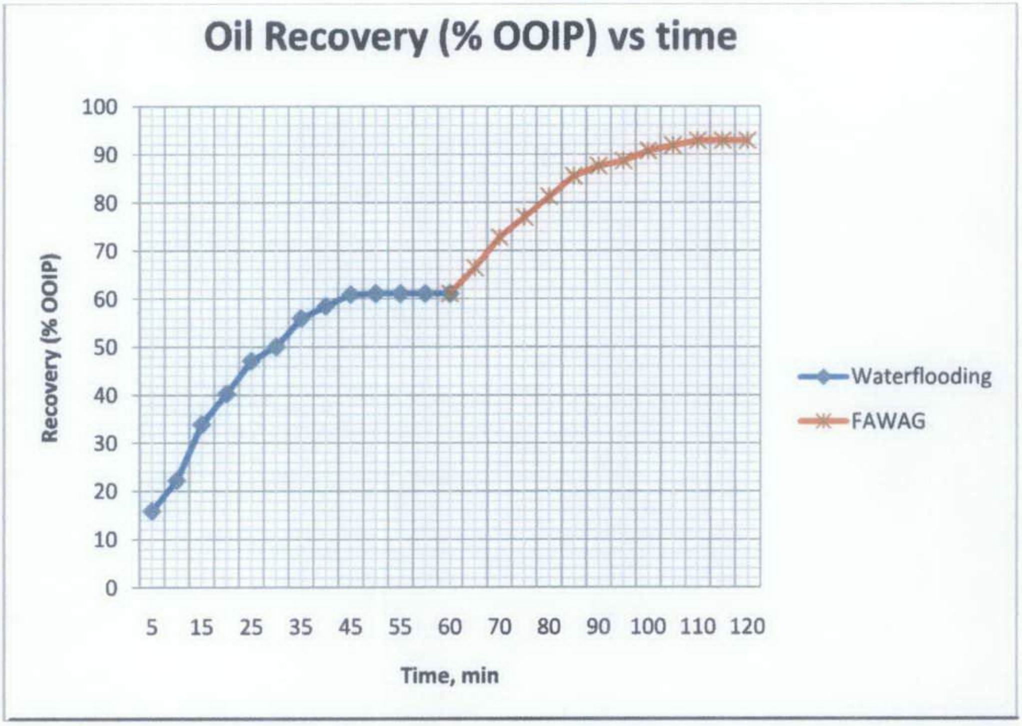
The graph above shows the recovery by both the phases. For 1st 60 minutes water flooding results of % OOIP against time are shown which extends to 62 %, while after SWAG application the recovery tends to improve significantly which becomes as much as 87% till next 60 minutes. The water breakthrough started almost at 57.2 % in water flooding and gas/brine mixture tended to breakthrough at 79% and the final recovery was seen to be 87 %

4.3 Foam assisted water alternating gas (FAWAG):

The table (5) below shows the recovery by water flooding for first 60 minutes, while the recovery by FAWAG in second 60 minutes. Recovery by water flooding was seen to be as much as 61.12 % of OOIP while recovery after FAWAG application extended to 92.9% of OOIP.

Time (min) /Process	Recovery after brine injection/displacing oil (in % of OOIP)	Recovery after FAWAG application (in % of OOIP)
5	15.9	66.426
10	22.25	72.78
15	33.9	77.02
20	40.26	81.26
25	47.14	85.5
30	50.1	87.62
35	55.94	88.67
40	58.48	90.8
45	60.9	91.85
50	61.12	92.9
55	61.12	92.9
60	61.12	92.9

Table 5: Oil recovery in percentage for FAWAG

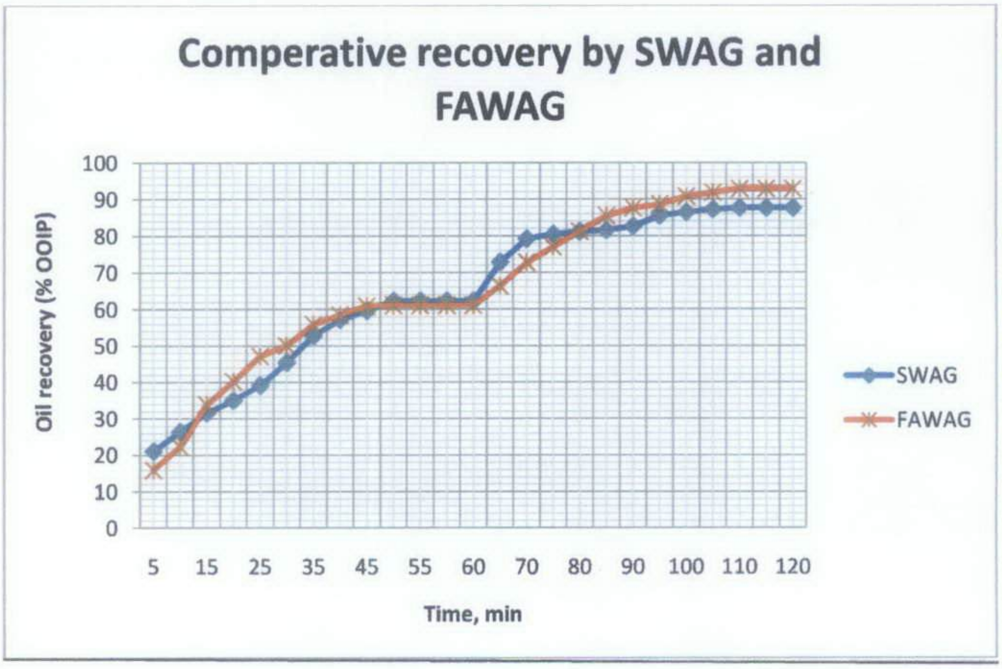


Graph 2: Oil recovered (% of OOIP) by FAWAG vs time (mins)

Graph (2) represents the results obtained from water flooding for 60 minutes where the breakthrough was seen at 58.48% while the application of FAWAG in next 60 minutes has extended the recovery significantly to 92.9 % where by foam was seen recovered with crude throughout the FAWAG application.

4.4 Comparison of SWAG and FAWAG results:

Hence its clear from the results that SWAG and FAWAG are one of the great techniques in terms of recovery. But FAWAG tends to address all the problems in detail and the recovery by FAWAG was 92 % which was higher than SWAG that was 87 %. Though if we consider the core impacts the core used in FAWAG had slightly less permeability than core used in SWAG. Furthermore the recovery by FAWAG was in three phases brine, foam and crude, but the brine and foam where still having traces of crude as emulsion or two phase hence if allowed to settle the recovery with FAWAG would have been bit more.



Graph 3: Comparative oil recovery by SWAG and FAWAG

CHAPTER 5

CONCLUSIONS & RECOMENDATIONS

5.1 Conclusions:

By thorough research and finally applying it practically, it has been seen that recovery by SWAG and FAWAG was tremendously above expectations. FAWAG gave us the maximum recovery and slight considerations and settling phases in recovery would have further maximized the recovery.

SWAG is efficiently improves the sweep efficiency by improving displacement front which tends to maximize the recovery. With simpler injection and requirement of fewer injection wells and reduction in gas recompression pressure makes it superior over other enhanced oil recovery technique.

FAWAG on the other had been most optimized recovery technique by decreasing GOR and increasing gas mobility control. It also solves gravity segregation and tends to control injectant viscous fingering problems.

Hence by all the considerations and my experimental results I have concluded FAWAG as the better of the two processes which tends to improve recovery more than SWAG.

5.2 Recommendations:

For future work for SWAG technique the experiments can be done for different injectant volumes in terms of slugs. For FAWAG different composition of surfactant be tested to see at what concentrations surfactant tends to produce more recovery. For field application of FAWAG proper economical considerations and designing a proper EOR model with respect of associated reservoir problems would be optimal.

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