BEHAVIOUR OF FOAM ON OIL PRODUCTIVITY DURING FAWAG PROCESS

By

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Final Report (FYP2)

Dissertation submitted to the Petroleum & Geoscience Engineering Programme'

In partial fulfillment of the requirements

for the degree

Bachelor of Engineering (Hons)

(Petroleum Engineering)

Project Supervisor:

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CERTIFICATE OF APPROVAL

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CERTIFICATION OF ORIGINALITY

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

MOHAMAD HALIM B JAILANI

Acknowledgement

In the name of Allah, the Most Gracious, the Most Merciful. Praise to Him the Almighty that in his will and given strength, I managed to complete final year project subject which include final year project 1 and II. The main objective of final year project is to create a critical thinking, creativity and innovation of UTP final year student in conducting a research project to enhance the oil productivity in oil and gas industry.

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Abstract

In the field of the petroleum engineering, economic has played more roles whereby many methods used to ultimately squeeze oil from the reservoir. FAWAG is one of Enhanced Oil Recovery (EOR) technique which can increase oil recovery at 30-60% by mobility control to improve sweep efficiency.Foaming injected gas is a useful and promising technique for achieving mobility control in porous media. In the presence of foam, gas and liquid flow behaviour is determined by bubble size and foam texture. Besides, in order to relate the foam behaviour to enhance the oil productivity requires a thorough knowledge of the physical aspects involved in foam flow through porous media. Film stability is strong function of surfactant concentration and type. This work studies foam flow behaviour at a variety of surfactant concentration using IFT and coreflooding experiments. Thus, the foam behaviour examined spans from weak to strong. Foam has been applied at the Snorre, North Sea Brent-type sandstone reservoir. The Snorre FAWAG is the world's largest application of foam in the oil industry.

The present project will focus on the rheology of foam which includes the foam generation, foam propagation and destruction. Several factors such as the viscosity, pressure drop, interfacial tension that affect the foam stability will be experimented at high pressure cell. The interfacial tension when oil react with surfactant examined using IFT 700 between different concentration (0.1%,0.2%0.3%0.5%1.0%, 2.0wt%) of SDS (Sodium Dodecyl Sulphate) followed by coreflooding experiment to measure the oil recovery.Beginning with the background of study, objective and problem statements, the research will be deeply understood with good literature review. Through experiment set up would produce result that shows the foam behaviour in terms of stability on oil productivity during FAWAG process. Conclude with overall find outs from the research and come out with recommendation to improve the understanding on foam behaviour. As the concentration of surfactant increases, the oil recovery increases.

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Nomenclature

S_{wir}= irreducible water saturation.

P_{inlet}= pressure at the inlet, psi

P_{outlet}= pressure at the outlet, psi.

k = absolute permeability, m^2

∇P= magnitude of pressure gradient *(Pa/m)*

K_{rg} = gas relative permeability

μ_g = gas viscosity *(cp)*

Chapter 1

INTRODUCTION

1.1 Background of Study

FAWAG process refers to foam assisted water alternating gas which is originally an enhanced oil recovery process whereby water and gas injection plus assisted with foam are alternately injected to the reservoir. This process takes period of time to provide a better sweep efficiency during gas flooding and to decrease the mobility of drive gas or steam.Foam has been applied at the Snorre, North Sea Brent-type sandstone reservoir, for different purposes. First initiated as a gas shut-off production well treatment, thereafter as two-scale gas mobility control processes.Foam, a coarse or fine dispersion of a gas in a liquid has been one of important subject in multiplicity of petroleum processes. As reviewed by Schramm[1], occurrence of foams in petroleum processes such as in oil-water separation, oil flotation and fractionation caused problems by reducing process efficiency and operation controllability.The rationale for foam application in such processes is derived from basic properties of a stable-foam dispersion propagating in porous media. In other words, two aspects have been chosen that relates the foam's behaviour on oil productivity during FAWAG process. These two aspects will be analyzed through experimental set up in order to investigate the stability of foam. The two aspects are foam texture and rheology during foam flow in porous media and factor that affect the foam stability. 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] Laurier L Schramm and Fred Wassmuth: 'Foam: Basic Principles,' Foams: Fundamentals &Applications in the Petroleum Industry, ACS Advances in Chemistry Series 242, American Chemical Society, Washington, DC (1994).

1.2 Problem Statement

1.2.1 <u>Problem Identification</u>

Normally, enhanced oil recovery technique is used to improve the driving force to maximize the oil recovery. In mid-1996 a foam treatment was performed on production well P18 located in the Central Fault Block of the Snorre Field. The P18 well had suffered high GOR due to premature gas breakthrough. It is difficult to control the foam behaviour to achieve desired purpose. Full understanding of the mechanism governing foam behaviour remains a challenge, pursued in many experimental and modeling studies. Some start by visualizing at the microscopic level the mechanisms of foam generation, transport and destruction. However, some of models are not adequate for investigating real field conditions, which need to be simulated by core-flood experiments. Although, the availability of a large body of experimental database, the existing theoretical foam models still cannot give a complete prediction of foam phenomena.

1.2.2 <u>Significant of the project</u>

Foams are gaining importance in the petroleum industry in a number of roles, notably as mobility control and blocking agents in enhanced oil recovery operations. Furthered study regarding foam's behaviour need to be carried out and in what aspects these behaviour affect the oil productivity during FAWAG process. What is the effect of foam flows in porous media? What is the major mechanism of foam flow? The foundation for foam application in such processes is derived from basic properties of a stable-foam dispersion circulating in porous media. The mechanism of foam generation through the process of 'breaking and reforming' takes the pore geometry as important characteristic.

1.3 Objective and the scope of study

The ultimate purpose of this project is to study the behaviour of foam in terms of stability at different concentration of SDS (Sodium Dodecyl Sulfate) and relate the result that affect the stability of foam during FAWAG processespecially the aspect that foams reacted. The aspect is foam texture, interfacial tension, pressure drop. In order to complete the study, following scope is expected to be achieved:

i. To study the foam flow in porous media that will focus on the foam texture and rheology, foam generation, foam propagation.
ii. To relate the aspects on foam stability and study the factors that affects the foam's stability at different concentrations of sodium dodecyl sulfate.
iii. To conduct the experimental set up which use IFT 700 and RPS core flooding to test the stability of foam in porous media.
iv. To measure the effectiveness experimental set up on the stability of foam.

1.4 The Relevancy of the Project

This project is relevance to all reservoir engineers since foam have been applied in enhanced oil recovery by gas or steam injection. In enhanced oil recovery (EOR) gases such as steam, carbon dioxide, enriched hydrocarbons, and nitrogen are injected into oil reservoirs to improve recovery. These gases are usually less viscous than water, and oil and the often channel selectively through high permeability zones or rise to the top of the reservoir by gravity segregation. Therefore, foaming the gas might overcome the mobility problem of gas-drive fluids and improve the contact with the oil because foam encounters large flow resistance in porous media.[2] The experience with foam in North Sea involves foam for mobility control and production well treatment[3]. Since foam is applied for gas shut-off and improves sweep efficiency during gas injection. Table 1 gives a summary of the test performed on different field and identify the problem before run the injection procedure. The production well treatments have varying degree of success, reducing the production GOR for weeks. The best GOR (gas oil ratio) reduction has been observed in

[2]Hoefner et al.1994; Aarra et al.1996;Patzek 1996.

[3]Hanssen, J. E., Holt, T., and Surguchev, L.M., 'Foam Processes: An Assessment of Their Potential in North Sea Reservoirs Based on a Critical Evaluation of Current Field Experience',SPE/DOE 27768, presented at the SPE/DOE Ninth Symposium on IOR, Tulsa; Oklahoma. 361,1994.

a gas coning situation[4]. The FAWAG (Foam Assisted Water-Alternating Gas) tests on Snorre has been a full scale field demonstration of the use of foam to improve gas sweep efficiency during WAG injection, partly funded by the European Commission's Thermie program.

Table 1: Foam field trials in the North Sea. [5]

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

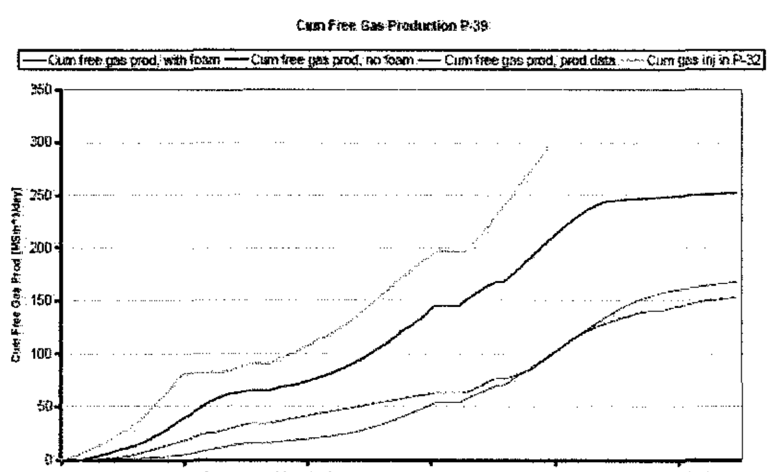

Figure 1: Results of free gas production, foam, and no-foam cases compared to historical production. [5]

[4]Aarra, M. G. and Skauge, A., Sognesand. S., and Stenhaug, M. 'A Foam Pilot Test Aimed at Reducing Gas Inflow in a Production Well at the Oseberg Field', Petroleum Geoscience, vol. 2, 125-132, 1996
[5]Skauge A., Aarra G.M., Surguchev L., Martinsen A. H., Rasmussen L.:"Foam-Assisted WAG: Experience from the Snorre Field.". SPE 75157-MS (2002).

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 includes the gas stored by the WAG process, the difference between no-foam and foam case quantifies the amount of gas diverted by foam injection (about 100 MSm□). The expenses for FAWAG on Western Fault Block (WFB) were 1Mllion USD, and additional oil recovery value was~ 25-40Million USD at current oil prices. [5]

Micromodels have proved to be useful in visualizing foam phenomena in porous media. Regardless of their up scaling limits regarding their dimensions, they provide an insight into foam in 'generated' and 'destroyed', the mechanism that dominates bubble size distribution and rheology properties. Microscopic observations offer valid insights that can be extrapolated to foam coreflood studies.Radke and Ransohoff[6] used visual observation to identify foam generation in glass bead packs. They showed that the importance of pore geometry on the mechanism of foam generation.

1.5. Feasibility of the Project within the Scope and Time frame.

This research is feasible to be conducted through experimental set up which consists of different concentration of SDS (Sodium Dodecyl Sulphate) in order to investigate the factor that may affect the stability of foam which focused on interfacial tension and pressure drop. This experimental set up isavailable in Petroleum Engineering Department of UTP block 15 which covers IFT 700 machine and RPS coreflooding machine. The scope of study will be mainly on microscopic and macroscopic of foam mechanisms which include how the foam is generated and destroyed, water saturation, surfactant concentration,and capillary pressure.

[6]RADKE, C.J. and RANSOHOFF, T.C., Mechanism of Foam Generation in Glass Bead Packs, SPE 15441, 61st Annual Tech Conf and Exh.New Orleans, Louisiana, 1986

Chapter 2

Literature Review

2.1Enhanced Oil Recovery (EOR) with surfactant

Enhanced Oil Recovery refers to generic term for technique for increasing the amount of crude oil that can be extracted from an oilfield. By applying enhanced oil recovery, 30-60% or more, of the reservoir's original oil can be extracted compared with 20-40% using primary and secondary recovery.

Enhanced oil recovery is also called improved oil recovery or tertiary recovery (as opposed to primary and secondary recovery). The challenge for EOR is that the remaining oil in the reservoir is difficult to access and the oil is held in the pores by capillary pressure. The ultimate objective of EOR programme is to develop technologies or techniques that enable recovery of the remaining oil. During the primary recovery, the crude oil is driven from the rock in to the production well by natural reservoir pressure. Throughout the secondary oil recovery phase water in injected into the reservoir. At the end of the secondary oil recovery phase capillary and viscous forces keep the residual crude trapped in the reservoir rock. If the capillary number is modified by adding additional substances to the waterflood one refers to tertiary oil recovery (EOR). The capillary number can be enlarged in the most efficient way by reducing the interfacial tension to ultra-low values. This is achieved by adding surfactant system adapted to the injection water, the nature of the crude oil and the reservoir conditions. At ultra-low IFT values microemulsions containing water and oil are formed in the reservoir. Due to the ultra-low IFT, trapped oil in the rock pores are deformed by the flood pressure. Most EOR involves the injection of gases or chemicals or thermal enhancement. 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) and foam assisted water alternating gas (FAWAG).

2.2Foam Assisted Water Alternating Gas (FAWAG)

Foam injection in water alternating gas (WAG) process has given tremendous improvement in recovery by improving sweep efficiency during gas injection and gas shut-off. In most of FAWAG application, it may reduce the GOR since higher GOR due to the premature gas breakthrough. Besides, 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.In EOR, gases such as steam, carbon dioxide, enriched hydrocarbons, and nitrogen are injected into oil reservoirs to improve recovery. These gases are usually less viscous than water and oil and they often channel selectively through high permeability zones or rise to the top of the reservoir by gravity segregation. As a result, sweep efficiency decreases and the amount of oil left behind increases. Again, foaming the gas might overcome the mobility problem of gas-drive fluids and improve the contact with the oil because foam encounters large flow resistance in porous media.[7] Usually, the foam injection has given better results and in most of applications oil rate increases by 1.5-5 times, while the water cut was seem to be decreased by 20% (for example from 80% to 60%).[8]

FAWAG is usually introduced in reservoirs with WAG already in use. In WAG water displaces the lower part of the oil bearing sand and gas fills the upper part. Through 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 unsweep parts. Hence to achieve that barrier water and surfactant are injected simultaneously over several days, followed by gas injection.

[7]Osman G. A., Anthony R.K.:"Surfactant concentration and end effects on foam flow in porous media", SUPRI TR-120 report,October 2000.

[8]Alex T. Turta and Ashok, "Field foam applications in Enhanced Oil Projects: sce=reening and Design Aspects" SPE paper #: 48895, presented at 1998 international SPE Conference in China,2-6 Nov 1998.

Foamis created in the area near wellbore vicinity at first making it difficult to inject gas injectivity gradually increases as gas find paths unimpeded by the foam.[9]

2.3 Foam Generation

Understanding foam generation in porous media requires the study of the mechanism of lamellae generation. Lamellae is called when gas flow in form of bubbles separated by thin films. Lamellae exhibits more resistance produced not only by viscous shear stress in thin films between the pore walls and the gas liquid interface, but also by the forces required to push lamellae through constricted pore throats. Investigators, based on visual observation, have identified several possible generation mechanisms of which are 'snap-off', 'lamella-division', and 'leave-behind'.[10]

a) **Snap-off.**

Lens/ lamellae generated by snap-off mechanism have been observed in most of microscopic studies of foam. Based on Chamers and Radke[11], 3 kinds of snap off which are 'pre-neck', 'neck snap-off', and 'rectilinear snap-off'. 'Pre-neck' snap-off occurred when only surfactant solution was injected into a micromodel following a foam flood experiment. Besides, once a gas bubbles blocks a given pore throat, a resulting liquid pressure gradient drives the accumulation of the liquid just upstream of the throat to pinch-off a smaller bubble from the initial one[12]. These phenomenon refer to 'neck snap-off' or on other term called 'roof snap-off'. Other kind of snap-off is 'rectilinear snap-off' occurs when the capillary pressure gradient resulting from invasion and further expansion of gas through a

[9]Foam-assisted injection trials could spread to other North Sea fields using energywebsite retrieved on 1st march,2010 from http://www.pennenergy.com/index/petroleum/display/185489/articles/offshore/volume-63/issue-8/technology/foam-assisted-injection-trials-could-spread-to-other-northsea- fields.html

[10]Nguyen P. Q., Alexandrov V. A., Zitha L. P., Currie K. P.: "Experimental and Modeling Studies on Foam in Porous Media: A Review", SPE 58799-MS (2000).

[11] Chambers, K. T., and Radke, C. J.: ' Micromodel Foam Flow Study', report, prepared for U.S Department of Energy, University of California, Chemical Engineering Department (Oct 1990)

[12]Ranshhoff, T. C. and Radke, C. J. : 'Laminar Flow of a Wetting Liquid along the Corners of a Predominantly Gas-Occupied Noncircular Pore,' J Colloid InterfacSci (1998)

given pore throat in drainage displacement and attached pore body drives liquid to flow back into the pore throat for snap-off.

b) **Lamella-division**

Mast[13] first identified another kind of lamellae generation called lamellae-division in an etched glass micromodel study. The frequency of lamella division is dependent on many parameters, of which the number of brunch points and bubbles sizes was found dominant. Availability of division sites in turn depends on occupancy of trapped bubbles (or stationary lamellae) or presence of a third phases such as oil droplets. Shirley[14]observed an extreme case of lamella division occurring only in those areas where one pore crossed another: a long bubble moving in one pore was probably broken up into two new ones as result of colliding with another moving bubble in intersecting pores.

c) **Leave- behind**

Lamellae can also be created parallel to the flow direction as snap-off and lamella-division may be considered the controlling mechanisms of gas viscosity, since increased gas viscosity arises primarily from pushing lamellae through constrictions. The leave-behind mechanism contributes principally to a further reduction of gas permeability by giving rise to blocked flow paths to gas. Ranshohoff and Radke[15] found a five-fold decrease of gas permeability by flow-parallel lamellae against several hundred-fold reduction in gas mobility by flow-perpendicular ones.

2.4Foam propagation

After generation in porous media, lamellae will either block flow paths as trapped bubbles or flow for a certain distance before rupture. The trapped gas may reduce the

[13] Mast, R. F.; 'Microscopic Behaviour of Foam in Porous Media', paper SPE3997 presented at the 1972 SPE Annual Technical Conference and Exhibition, San Antonio, Texas, Oct 8-11.

[14] Arthur I. Shirley: 'Foam Formation in Porous Media: A microscopic Visual Study' surfactant- based Mobility Control: Progress in Miscible-Flood Enhanced Oil Recovery, Duane H. Smith, ACS Symposium Series 373 (1988).

[15] Falls, A. H. Musters, J. J., and Ratuloski, J.: 'The Apparent Viscosity of Foams in Homogeneous Beadpacks' SPE Reservoir Eng (1989).

fraction of flowing path. Mast and Owete indicated independently that flow became temporarily blocked because of the phase distribution.

2.5 Foam Destruction

The rate of lamellae destruction has an important role to play in controlling gas mobility. Generated lamellae can be destroyed in four ways:

i. Capillary suction coalescence.
ii. Gas diffusion.
iii. Liquid evaporation and condensation.
iv. Influence of additional phases.

2.6Stability of Foam

Foam stability is governed by interfacial properties, which reflect the importance of the foaming agent in minimizing input energy during interface deformation. The concept of 'foam stability' is rather relative in kinetic sense due to the fact that foam is not stable thermodynamically. For example, when two bubbles approach to one another or collide, the liquid film formed between them undergoes the thinning process in which the film is either finally ruptured or reaches a metastable super-thin film, as described visually by Wasan and Malhotra.[16]

2.7 Factors that affect the foam stability

a) **Effect of liquid oil viscosity**

In any fluid liquid flow process, the liquid viscosity offers resistance to flow and has a direct bearing on the rate of liquid drainage. Besides, the rate of film thinning will decrease as the liquid viscosity increases and in the extreme case of very high viscosity such as solidified films of latex foam, the resistance to flow can make the foam very stable. It happens when higher oil viscosity will offer higher resistance to the movement of

[16]Wasan, D. T. and Malhotra, A. K.: 'Thin Liquid Surfactant Film Drainage Phenomena-A Review,' AIChe Symposium Series.

gas bubbles in the liquid oil phase, thus making the foamy oil system more stable.

b) **Effect of solid particles**

Ward and Levart[17] indicated that very small bubbles may be present in a thermodynamically stable form in the presence of a rough surface. This surface may be either that of the boundary or that of particles suspended in the solution. Microbubbles (2 to $5\mu m$) formed in this way are stable, requiring a further reduction in pressure to make them grow, which reduces the possibility of growth by coalescence.

c) **Effect of interfacial tension**

Interfacial tension (IFT) is a measurement of the cohesive (excess) energy present at an interface arising from the imbalance of forces between molecules at an interface (oil/ surfactant). An ultra-low interfacial may improving of displacing fluid by better sweep efficiency and increase in foam stability. There are factor that affect the interfacial tension reading such as effect of temperature, salinity and shearing.

d) **Effect of porous media**

Smith[18] pointed that even though Gibb's stability theory indicates that bubbles larger than 200 micron size are to grow unstably, Ward et al.[19] concluded through their experimental and theoretical study that microbubble could be stable under the constraint of a closed volume and at some temperature and pressure. Their analysis indicated that it is possible to generate micro-sized bubbles in a porous medium. That is because these bubbles are much smaller than the average pore throat size; they are not restricted to flowing only as a continuous phase, but may move with or through the oil, and probably faster than it, through a common pore space.

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[17] WARD, C.A. and LEVART, E., Conditions for Stability of Bubble Nuclei in Solid Surfaces Contacting a Liquid-gas Solution; Journal of Applied Physics, vol 56, no 2, pp 491-500,1984.

[18] SMITH, G. E., Fluid Flow and Sand Production in Heavy Oil Reservoirs Under Solution Gas Drive; SPE Production Engineering, pp 169-80, May 1988.

[19] WARD, C.C., TIKUISIS, P. and VENTER,R.D.; Stability Analysis in a Close Volume of Liquid of Liquid-Gas Solution; Journal of Applied Physics, Vol 53, No 9, pp-6076-6084,1982.

Yortsos and Parlar[20] stated that bubble growth is controlled by the pore wall curvature and geometry which may stabilize otherwise unstable gas bubbles. This is what differentiates foamy oil bubbles in porous medium from bubbles in a bulk vessel. Li[21] also reported that the coarsening process which occurs in phase transition process in the bulk that not happen in multiple bubble growth process in his glass micromodel experiments. The main reason is that in porous media, the concentration at the interface is not related to the bubble volume size, but only to the particular pore curvature. This is contrast to the case of phase transition in the bulk, where the solute concentration at the interface, directly related to its size, makes it possible for the large bubbles to grow at the expense of the smaller ones, because the bubble size and radius of curvature are directly proportional to each other.

This theory is of less relevance to porous media, where cluster size and capillary characteristics are only indirectly coupled. In porous media the competition between growing clusters is controlled by porous medium capillary characteristics and by mass transfer, the solubility dependence on radius being insignificant.

The relationship between stability and mobility reduction factor observed by Maini and Ma[22] suggests that the same types of surface forces control the rheological properties of foam in a porous medium and the foam stability characteristics outside the porous medium. They observed that in all cases investigated, the optimum surfactant concentrations for maximizing foam stability and for maximizing the mobility reduction factor was identical.

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[20] YORTSOS, Y. C. and PARLAR, M. Phase Change in Binary Systems in Porous Media: Application to Solution Gas Drive; paper SPE 19697 presented at the 64th Annual Technical Conference and Exhibition of SPE of AIME, San Antonio, TX, October 8-11, 1989.

[21] LI, X. Bubble Growth During Pressure Depletion in Porous Media; Ph. D. Dissertation, University of Southern California, Los Angeles; CA,p 158. May 1993.

[22] MAINI,B.B. and MA, V. ; Relationship Between Foam Stability Measured in Static Tests and Flow Behaviour of Foams in Porous Media; paper SPE 13073 presented at the 59th Annual Technical Conference and Exhibition of SPE AIM, Houston, TX, September 16-19, 1984.

Chapter 3

Methodology

3.1 Research Methodology

The flowchart shows the flow of methods or systematically processes start from the beginning of FYP1 until the compilation process on FYP2. Each process refers to the main objectives that affect the stability of foam.

Figure 2: Flowchart of research methodology

3.2 Gantt Chart and Key Milestone

Table 2: Table of Gantt chart and key milestone for FYP1 and FYP2.

	FYP1				FYP2			
Activities	2	3	4	5	6	7	8	9
Research on foam behaviour, rheology and properties.								
Study the effect different concentration of SDS react with oil								
Gathering relevant data for experiment with consists of different concentration of SDS.								
Understanding the experiment procedure, apparatus set up for IFT 700 and RPS coreflooding.								
Research Documentation.								
Milestone								
Completion of foam rheology and mechanism.								
Completion of experiment procedure and tools.								
Completion of experiment design and results.								
Project completion								

3.3 Experimental Setup

To determine the stability of foam in terms of different SDS concentration, interfacial tension between the SDS and oil need to be experimented. Plus, proceed with coreflooding experiment to show which optimum concentration will extract or give better sweep efficiency to oil productivity. This project require different concentration of Sodium Dodecyl Sulfate (SDS), IFT 700 machine,Poroperm machine,TEMCO RPS-800-1000 HTHP coreflooding machine, plug core which is high in permeability, DMA 35N density meter.

3.3.1 Rock core flooding

Core flooding is a common test to determine rock permeability, and shows how well various fluids, including oil, will flow through it.[23] First, a cylindrical rock sample or core

[23] Teledyne Isco, Inc., Ssyringe Pump Application Note AN3, "Core Analysis"- (http://www.isco.com/WebProductFiles/Applications/105/Application Notes/Core%20Analysis.pdf)

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 and pressure drops across the core are measured. From this data, the resistance to flow is evaluated.

Usually, the core flooding experiment will be made very close to reservoir condition in order to evaluate the performance of EOR technique to be applied in the reservoir. Even though the pressure and temperature is the same as in the reservoir condition, it doesn't mean that it give 100% correct result as it is in the real reservoir condition but at least it shows the clear picture what will happen in the reservoir. Usually, one run of experiment takes around one week includes the preparation period where as all the connecting pipe need to be cleaned up. Besides, each run core sample needs to be washed and diluted with brine. Hence, below is the typical schematic of coreflooding experiment.

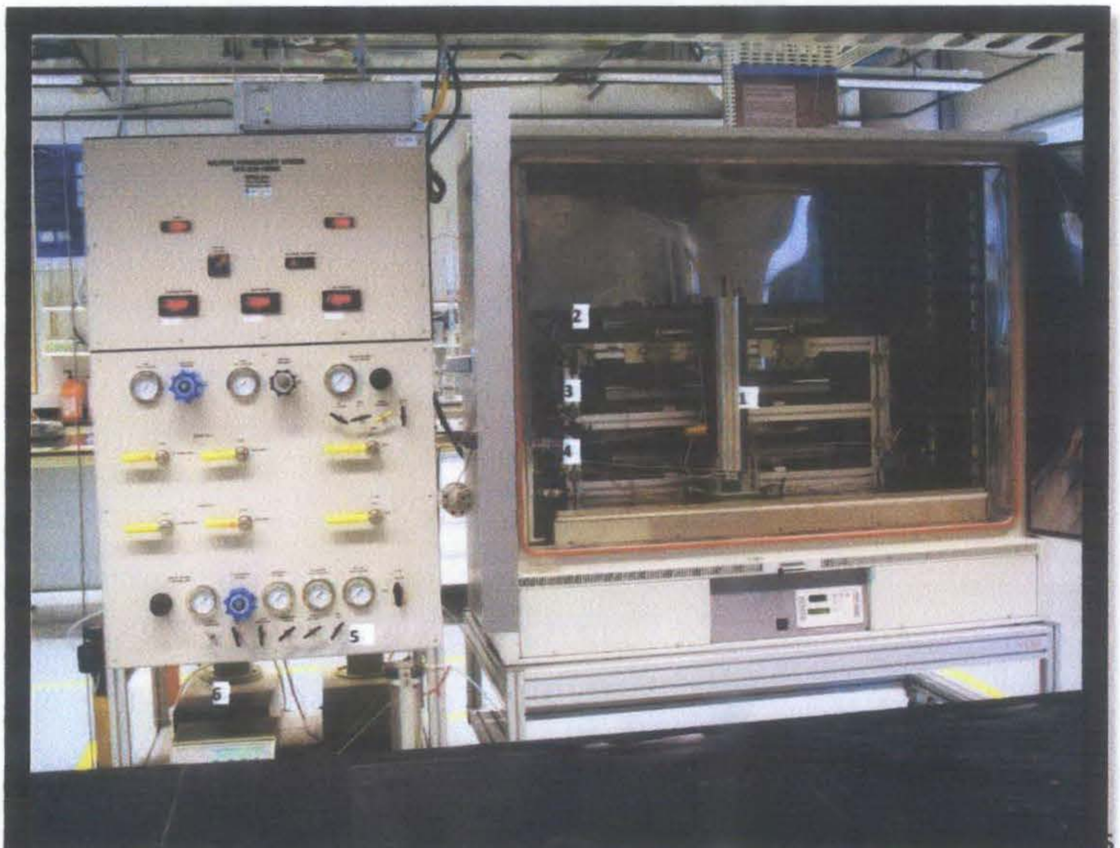


Figure 3: TEMCO RPS-800-1000 HTHP core flooding machine

Figure 3 shows TEMCO RPS-800-1000 HTHP core flood machine with following labeled component:

1) Core holder.
2) Sodium Dodecyl Sulfate container.
3) Brine accumulator.
4) Crude oil accumulator.
5) Pressure gauges or differential pressure gauge.
6) Flow pump.

The purpose of the system above is to create the conditions from which the rock sample was brought and then to pump fluids through the pump to evaluate the oil productivity by measure the oil produce during injection of Sodium Dodecyl Sulfate followed by CO_2 injection.

3.3.2 Chemical info

We will use Sodium Dodecyl Sulfate (SDS or NaDS) ($C_{12}H_{25}SO_4Na$) as surfactant for foam production along with water in tertiary recovery. Sodium Dodecyl Sulfate is well known as SDS in short. Sodium dodecyl sulfate is an anionic surfactant used in many cleaning and hygiene products. SDS is highly effective surfactant and is used in any task requiring the removal of oily stains and residues. Sodium dodecyl sulfate is used since it is easy to be getting in the market plus the price is quite cheap.Few of the basic properties of sodium dodecyl sulfate are given below:

Properties of SDS (value 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

Specification for Sodium Dodecyl Sulfate:

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

For successfully aim the objective, different concentration of sodium dodecyl sulfate is mixed up to get concentration of 0.1wt%, 0.2wt%, 0.3wt%, 0.5wt%. 1.0wt%, 1.5 wt% and 2.0wt%.

$$\textit{weight percent} = \frac{\textit{mass (gram)}}{\textit{volume (ml)}} x100 \quad (1)$$

Equation 1: Equation to calculate the weight percent of SDS

Using the mathematical formulation above, different concentration of sodium dodecyl sulfate is set up. In addition help of magnetic stirring machine, the process become faster and efficient rather than stir using spoon.

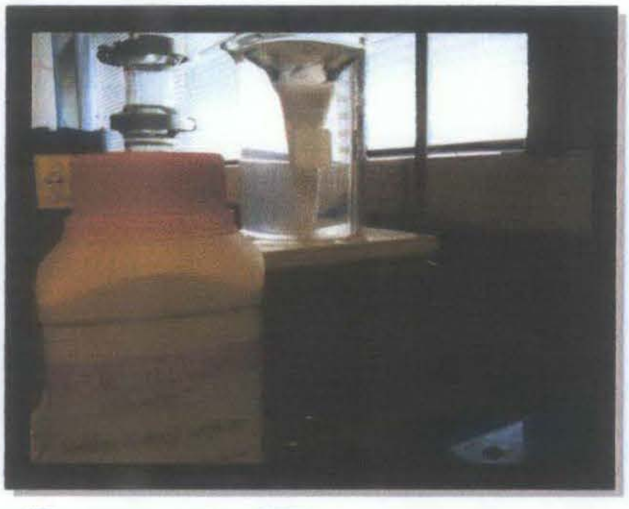


Figure 4: The procedure to create different concentration of SDS

All different concentration of sodium dodecyl sulfate is stored in 2 liters bottle which is stored in the given shelf wardrobe.

3.3.3Equipment Description

1) **DMA 35N Density meter.**

The DMA 35N density meter is used to measure density of different concentration of SDS at 0.1wt%, 0.2wt%, 0.3wt%, 0.5wt%. 1.0wt%, 1.5 wt% and 2.0wt%.The density meter is small, compact, lightweight design and easily cleaned. Each runs of SDS used, the density container need to be flushed and clean by distilled water.All the density measurement will be recorded as result.

Figure 5: DMA 23N Density Meter

2) **IFT 700**

IFT is an apparatus allows for determination at reservoir conditions of interfacial tension between sodium dodecyl sulfate and crude oil using pendent drop method as well as the contact angle between SDS and oil. For each SDS concentration, cell need to be clean so that not effecting the interfacial tension reading.

Figure 6: VINCI IFT 700

3) **Poroperm machine**

The VINCI Poroperm i used to measure the core porosity, permeability, grain size at room condition. Before the core measured using the poroperm, the length, diameter and the weight is measured first.

Figure 7: VINCI Poroperm

3.4 The Experimental Work

3.4.1 The apparatus & chemical required:

The experiment apparatus and chemicals needed are:

Apparatus

- Core plug-sandstone type-1ea
- VINCI Poroperm System machine-1ea
- TEMCO RPS coreflooding machine-1ea
- Graduated cylinder-5ea
- VINCI IFT 700-1ea
- DMA 35N Density Meter-1ea

Chemical

- Light Crude oil-1000cc
- Brine crude Oil (30 000ppm)-3000cc
- Surfactant SDS (Sodium Dodecyl Sulfate)-1000cc
- CO_2-1000cc

Figure 8: List of apparatus and chemical needed.

3.4.2 VINCI Poroperm Machine

In order to proceed with coreflooding experiment, we need to measure the core properties which in terms of porosity, permeability, weight, volume of grain and bulk volume. These properties need to be measured and key in the software during coreflooding experiment. These are steps to use measure the core properties:

1) Get a core which is sandstone core. The core should be clean and not damage. Each core being labeled for easy identification.
2) Measure the diameter, length using the vernier caliper. Take 3 readings and calculate the average. Repeat the same process to measure the weight of each core using the digital scale.
3) Using the Poroperm machine, the core plugs are to be put inside the core holder vertically in the machine and the confining pressure is set higher than the inlet pressure. The inlet pressure is set up to 1000psi and the confining pressure is set up to 1200 psi.
4) Pressurized the helium inlet and let Helium flow through the core holder to measure the core properties.

5) The system will measure the core properties in a 20 minutes time depends on the core characteristics. The better the core characteristics, the shorter the time taken for the system to measure the core properties. The system will be automatically display the graphs and the results table of the core properties.
6) Record the result of core properties in the result sections.
7) After running with poroperm machine, the core need to be saturated with brine which is 30,000ppm and vacuumed in a beaker at least 6 hours to make sure all the air bubbles release out and the core is fully saturated with the brine. In our experiment, the time taken for both of the core fully saturated with the brine is almost one day.

3.4.3 VINCI IFT 700

1) The IFT 700 is designed to determine interfacial tension and contact angle, but also to observe heat and mass transfer phenomena. The main component of IFT-700 in this experimental set-up is a see-through windowed high-pressure cell. The maximum operating pressure and temperature of this pressure cell are equal to 10,000 psig and 200°C, respectively. Pendant rise is chosen due to lower density value of crude oil compared to bulk volume at the respected condition and also due to the many sample use in this project. The equilibrium pressure inside the pressure cell is measured by using a digital pressure gauge.
2) A microscope camera is used to capture the digital images of the pendant oil rise inside the pressure cell at different times. The high pressure cell is positioned horizontally between the light source and the microscope camera. The data will be processed by the software of Vinci Technologies (OPMAN IFT 700) to get the data and IFT measurement.
3) Firstly, switch on the equipment and the computer. Then, inject 0.1wt% of Sodium Dodecyl Sulfate in bulk cell. Once, it is fully injected, close the valve and inject the oil to remaining inlet. There are two inlet for measuring the interfacial tension of SDS when react with oil.
4) The cell is heated at 60°C and pressurized up to 1000psi. The pressure and temperature is monitored through the digital meter sensor. Switched the camera

on so that, it can focus on the needle inside the cell. The image can be clearly seen in the monitor screen on the computer.

5) Control the pressure manually using the pressure control unit until small droplets of oil come out from the needle. Then, open the program software and make calibration for the oil droplet.
6) Optimize the contact angle so that it will give better measurement of interfacial tension. Run measurement for 20 seconds and result table will be displayed on the monitor screen. Sort the angle from the biggest to the lowest, and the biggest contact angle will give the best result for interfacial tension.
7) Clean the bulk cell and repeat the procedure for different concentration of sodium dodecyl sulfate.

3.4.4 Foam Assisted Water Alternating Gas (FAWAG):

For FAWAG, surfactant mixture of 2wt% is added injected with 30,000 ppm brine for preparing a surfactant brine solution and to be injected in cyclic pattern followed by surfactant and CO_2 to improve recovery. The steps of coreflooding are follows:

1) All the tubing are cleaned with degreaser and distilled water followed by air gun to make they are free from any foreign fluid or fluids from previous experimental runs.
2) Core holder equipment is made ready by fixing the core plug inside the latex about 1 inch deep on one side. The core is placed inside the accumulator A, the brine in accumulator B, crude oil at accumulator C and surfactant at the accumulator D.
3) Core holder is locked tightly at core holder closure end by using C-wrench.
4) Brine that was prepared earlier at 30,000 ppm is poured in accumulator B and pressured using air vent pumped into the accumulator A which core is placed. A beaker is place outside where the outlet tube is heading to. The purpose to place the beaker is to fill the remaining waste brine.
5) Next, crude oil in accumulator C is injected into accumulator A until brine is flow out into the beaker. Make sure there is no bubble inside the tube so that the core is fully saturated with oil.

6) Once there is no bubble flows in the tube, the core injected back by brine in accumulator B to until brine flows out which create a reservoir to run tertiary recovery which is chemical flooding.
7) Surfactant in accumulator D is injected into the core followed by CO_2 injection to create foam.
8) In the computer interface software for RPS, follow the steps below:
   I. Inject brine solution until the permeability reading is stabilizes. This step is done for determining the initial or absolute permeability.
   II. After the core has been saturated with brine, we inject the crude oil. This step given us the So (saturation of oil in core) and by this S_{wir} (irreducible water saturation) is also calculated. Oil is injected from the accumulator C to displace brine from the core and saturate the core with crude oil. The amount of brine at the outlet 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). Hence, for application of FAWAG brine in accumulator B is replaced with surfactant concentration which is sodium dodecyl sulfate.
   IV. Now FAWAG technique is applied where slugs of 4PV of surfactant/ brine and CO_2 gas injected alternatively twice in series. At first we inject surfactant followed by 4PV of CO_2 gas which is followed by 4PV of surfactant solution.
   V. Sample volume is noted manually by collecting sample in tester at the outlet measuring cylinder.

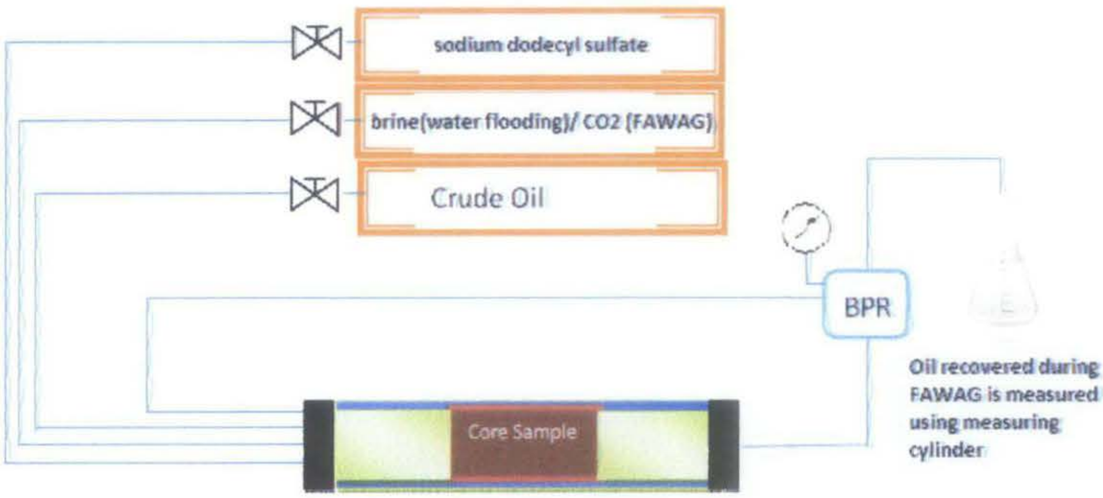


Figure 9: schematic of RPS coreflooding system.

Hence, from figure 9 shows the three accumulators containing the basic components which are crude oil, sodium dodecyl sulfate and for brine is only used during water flooding and replaced by CO_2 gas which will be used during FAWAG process. The flow of accumulator is controlled using valves and can be control manually instead for pressure pump which is automatically controlled. Further the core from outlet end has tubing which extends to the container for collecting sample and BPR (back pressure regulator) is connected to both the ends for maintaining the pressure inside the core holder. Once the pumps are switched on, the distilled water will be pumped inside the accumulator from one end which pushes the fluid in the accumulator towards the core on desired pressure and core is further saturated, by which the recovery of saturated fluids is achieved. Since the purpose of the experiment is focusing on the tertiary recovery or EOR, we need to water flood the model first by saturating it with water. Then, 30000 ppm brine is injected in at a sufficiently high rate (5ml/min) to attain irreducible water saturation (S_{wir}). At each end of the core holder would be pressure gauges for taking reading the P_{inlet}, P_{outlet} and BPR which are used to maintain the pressure drop. In the experiment, inlet pressure was set to be 1000psi while the outlet pressure was 800psi with an overburden pressure of 1500psi. Whole experiment was done in the oven at constant temperature of 60°C.

3.4.5 The crude oil characteristics.

The crude oil which is used in the experiment was collected from Dulang field in Malaysia and was provided in UTP lab. The properties of the crude oil applied are given in table below.

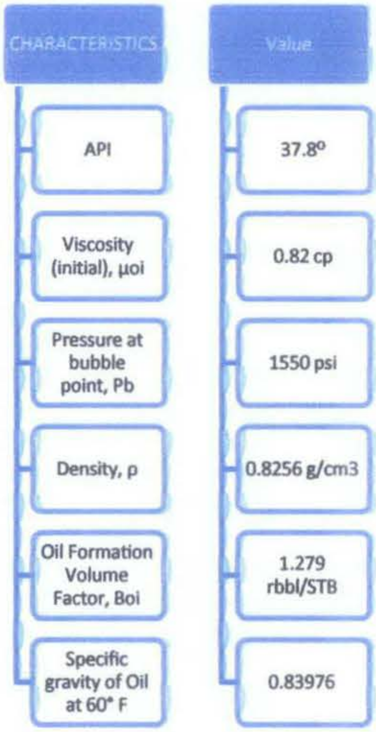


Figure 10: crude oil characteristics.

Chapter 4

Result and Discussion

4.1 Core calculations:

The table given below shows the properties and calculation for a core plug used in the experiment.

Table 3: Table of core sample plug properties

Properties	Core Plug 1 (B1-5R/12/8/09)
Length	38.563mm
Diameter	37.923mm
weight	93.293
Vp (cc)	8.01
Kair (mD)	96.89
Φ (%)	18.39
V bulk (cc)	43.56
V grain (cc)	35.55
Grain density (g/cc)	2.62
Bulk density (g/cc)	2.14

4.2 IFT 700 Results:

The IFT 700 experiment is tested using different concentration of sodium dodecyl sulfate which are 0.1wt%, 0.2wt%, 0.3wt%, 0.5wt%, 1.0wt% and 2.0wt%. The IFT test will be conducted using core plug 1 with permeability of 96.89mD. The manipulated factor is the concentration of surfactant and the crude oil is remaining the same in each run. The result shows:

Table 4: Compilation result of 0.1wt%, 0.2wt%, 0.3wt%, 0.5wt%, 1.0wt% and 2.0wt% SDS with crude oil using core plug 1 with permeability of 96.89mD.

SDS concentration	interfacial tension
0.1	3.18
0.2	2.75
0.3	2.21
0.5	2.15
1	2.06
2	2.04

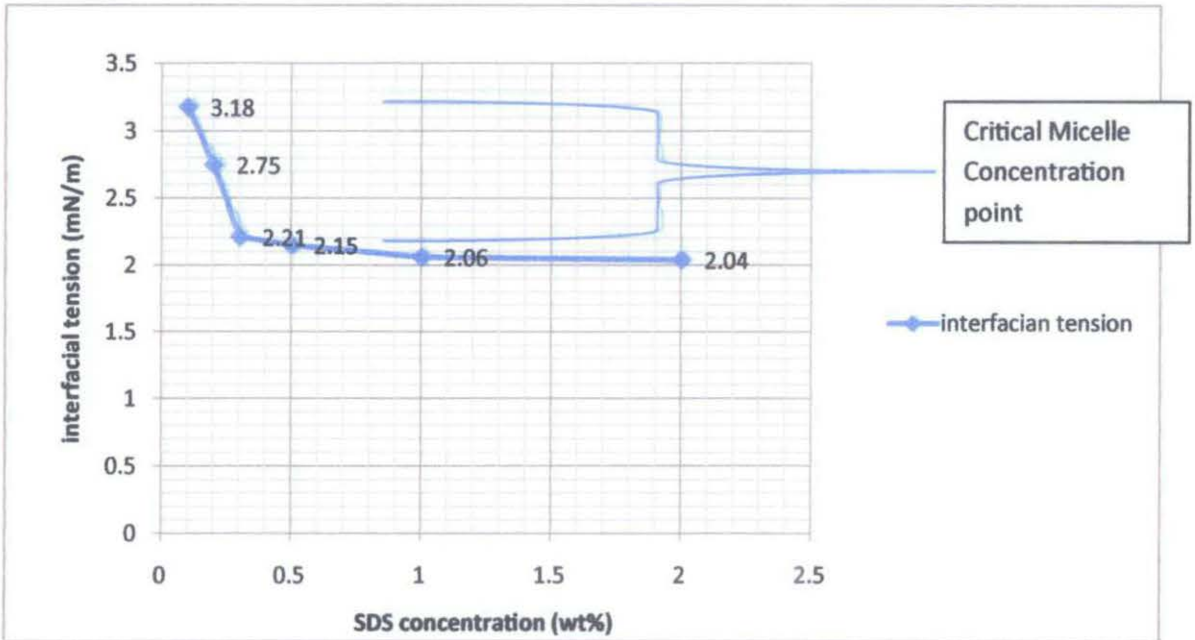


Figure 11: Graph of compilation result interfacial tension vs. contact angle between 0.1wt%, 0.2wt%, 0.3wt%, 0.5wt%, 1.0wt% and 2.0wt% SDS with crude oil.

IFT test result conducted using VINCI IFT 700with different concentration of sodium dodecyl sulfate. Each run of sodium dodecyl sulfate takes around half a day includes preparation period to clean the cell. From figure 11, it shows that as SDS concentration is increasing from 0.1wt% to 2.0wt%, the interfacial tension decreasing from 3.18mN/m to 2.04mN/m. Based on the CMC (Critical Micelle Concentration) of sodium dodecyl sulfate is around 0.1728 to 0.2304%, the interfacial tension from 0.1 to 0.3wt% SDS is drastically decreased in high slope as the concentration of surfactant increase. Moreover, from 0.3 to 2.0wt%, the interfacial tensions nearly the same. At low concentration surfactant will favor arrangement on the surface. As the surface become crowded with surfactant more molecules will arrange into micelles. At some concentration, the surface becomes completely loaded with surfactant and any further additions must arrange as micelles. This concentration is called the Critical Micelle Concentration (CMC).[24] Therefore, as the concentration from 0.3 to 2.0wt% nearly the same since surface become fully loaded, no further change in surface tension. Interfacial tension decrease since the presence of these molecules on the surface disrupts the cohesive energy at the surface and thus lowers the surface tension. For each run, the biggest contact angle is choose for better precision interfacial tension result because the bigger the contact between the crude oil and the sodium dodecyl sulfate, the higher of outer layer of oil covers in touch with surfactant. Foam plays a major role as mobility control agent in enhanced oil recovery and lowering the interfacial tension is needed in order to improving the sweep efficiency of displacing fluid. Not only is to make the lower interfacial tension of surfactant as the main purpose, the stability of foam also very important to control the gas mobility.

[24] Critical Micelle Concentration: http://www.attension.com/critical-micelle-concentration.aspx

4.3 Coreflooding Results:

Coreflooding test has been conducted using core which is higher in permeability.2 runs were conducted using TEMCO RPS 800-1000 HTHP machine. The results show:

RUN 1

Coreflooding test uses core plug 1 with a surfactant concentration of 2.0wt%

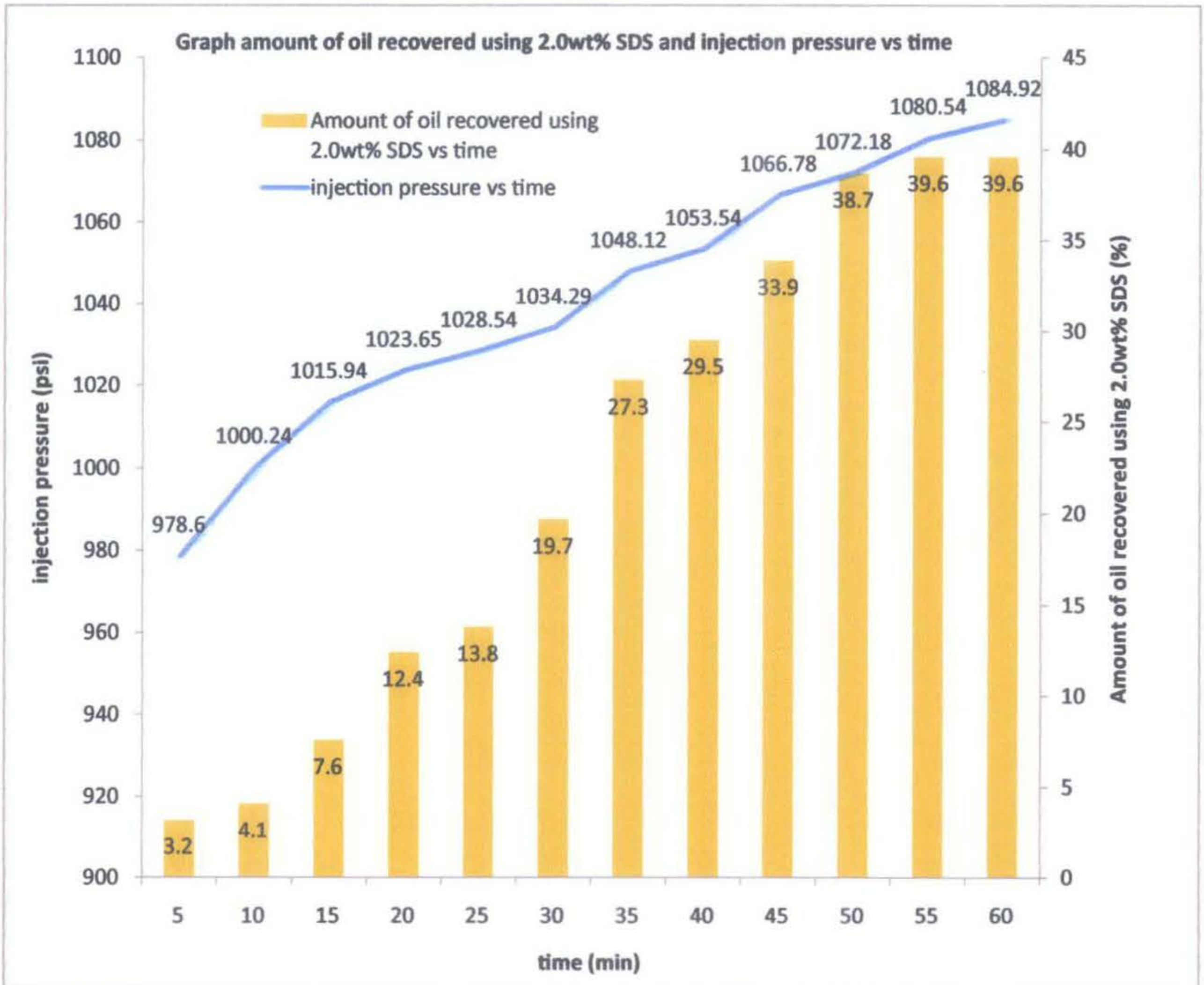


Figure 12: Graph Amount of Oil Recovered using 2.0wt% SDS and injection pressure vs. time

Figure 12 shows that amount of oil recovered in terms of percent using 2.0wt% of sodium dodecyl sulfate and injection pressure while running the coreflooding experiment. The maximum oil recovery achieved at 40% and the maximum injection pressure shows 1085 psi. The injection pressure increase with time since the pore in the core holder being plugged by precipitation from sodium dodecyl sulfate.

RUN 2

Coreflooding test uses core plug 1 with a surfactant concentration of 1.0wt%

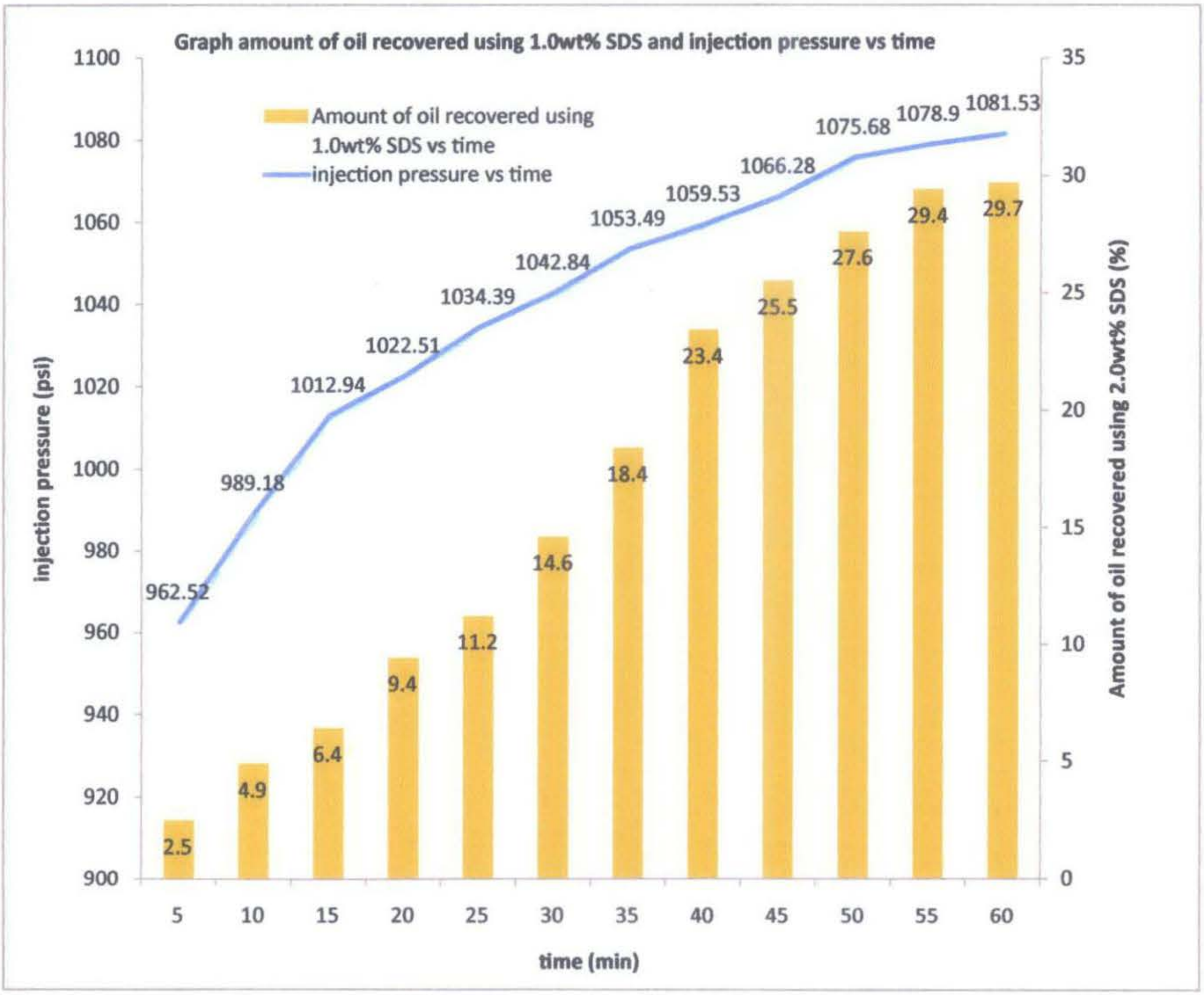
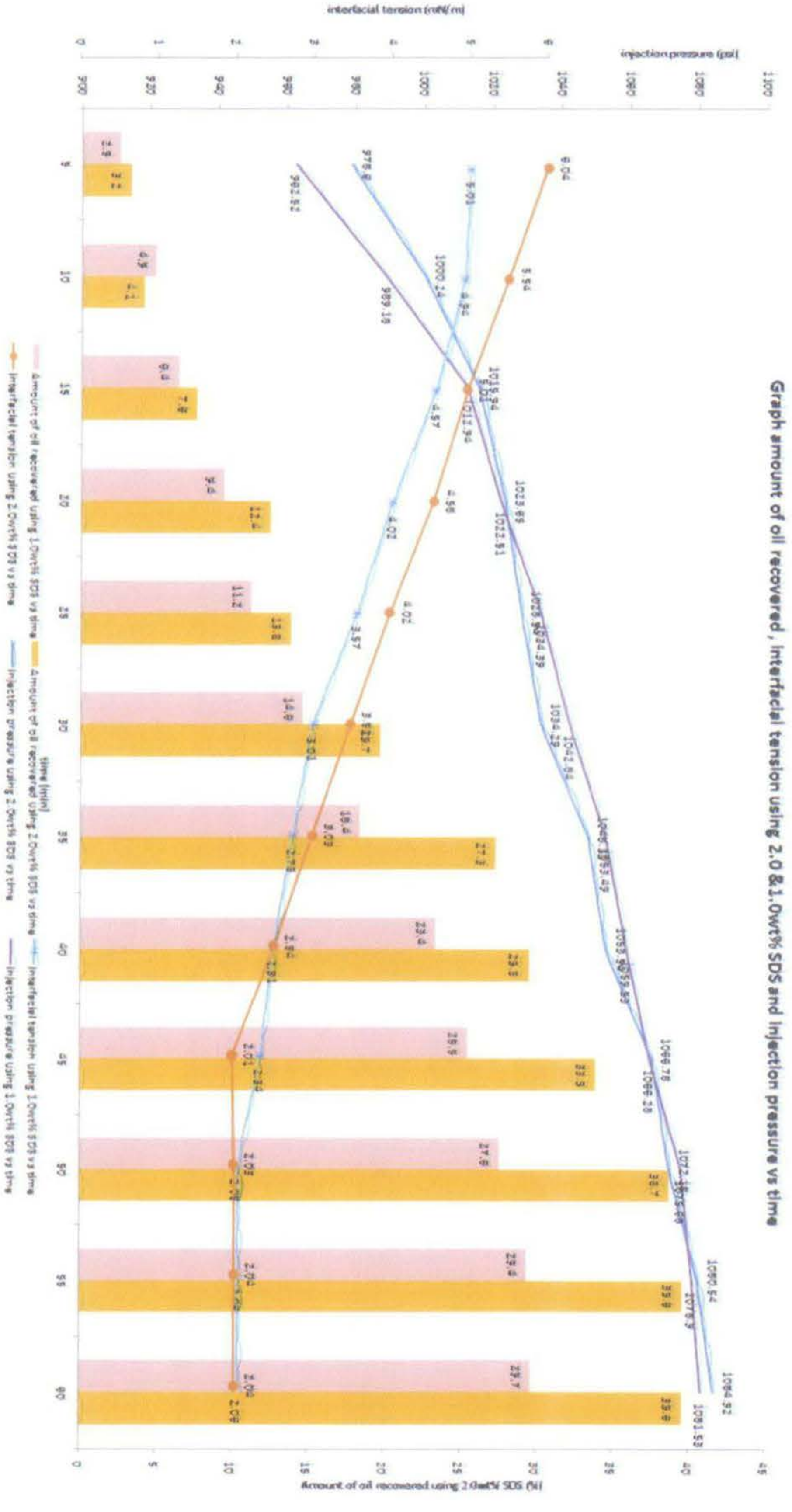


Figure 13: Graph Amount of Oil Recovered using 1.0wt% SDS and injection pressure vs. time

Figure 13 shows the amount of oil recovered in terms of percent using 1.0wt% of sodium dodecyl sulfate and injection pressure while running the coreflooding experiment. The maximum oil recovery achieved at 30% and the maximum injection pressure shows 1082psi.

4.4 Comparisons of different Surfactant concentration on the effectiveness of FAWAG process based on results:



As can been seen in figure 14 shows the comparison for 2 different concentration of sodium dodecyl sulfate which affect the percentage amount of oil recovered with respect to time. As for Run 1 with 2.0 wt% sodium dodecyl sulfate recovered amount of oil at 40%, Run 2 with 1.0wt% sodium dodecyl sulfate recovered amount of oil at 30%.It shows that as the concentration of sodium dodecyl sulfate in increase, the percentage amount of oil recovered is increasing. The stability of foam increasing as the concentration of surfactant increase and the more stable foam created may recovered more displace oil and give better sweep efficiency by mobility control. Besides, the injectivity pressure is directly proportional as time passes from 5 to 60 minutes. The injectivity increase since there is blockage in the pore space in the core by the precipitation of surfactant used which is sodium dodecyl sulfate. As the injectivity pressure increase, the confining pressure and outlet pressure will be increase to control pressure inside the core from being fluctuate and damage the core. Instead to interfacial tension result, as the time passes, the result of interfacial tension decrease from 5.01 to 2.06mN/m as 1.0wt% SDS injected to the core. As for 2.0wt% SDS, the interfacial drop from 6.04 to 2.04mN/m.

4.5 Discussion

There are few issues while running the coreflooding experiment. The first main problem is due the low temperature of carbon dioxide gas, the back pressure gauge become freeze and blocks the fluid flow out to graduated cylinder measurement. Therefore, hairdryer need to be used as external heater to heat the back pressure gauge. Moreover, the overburden pressure has to make sure above the inlet pressure to avoid the core from being damage and temperature of the oven need to maintain at 60°C to avoid any affect to experimental result. Safety glasses, lab coat and gloves need to be worn to avoid any accident happen and apparatus manual need to be read before running the experiment.

Chapter 5

Conclusions and Recommendation

4.1 Conclusion

From this project, we can analyze the foam behaviour whichenhances the oil productivity during FAWAG process. Foam stability in porous media is governed by several global factors such as pressure drop, interfacial tension, concentration. As the concentration is higher, the stable the surfactant will be and lowering the interfacial tension which will give better efficiency in sweeping the residual out to the surface. The application of foam during FAWAG process brings a lot of benefits such as the expenses for FAWAG on Western Fault Block (WFB) was 1Million USD, and additional oil recovery value was~ 25-40Million USD at current oil prices. [5]

4.2 Recommendation

Further studies can be made in order to further improve the oil recovery during FAWAG process by fully understanding the foam behaviour, pursued in many experimental and modeling studies. Moreover, simulation using more technologies software like eclipse 300, CMG need to be conducted to give better overview on how behaviour of foam react to the better oil productivity during FAWAG process.

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