بسم الله الرحمن الرحيم

Sudan university of science and technology

College of petroleum and mining engineering

Department of petroleum engineering

Project Title:

Design of 3D visualization flooding model and experimental recovery test of the alkaline flooding for Al fula crude oil- Sudan

تصميم نموذج غمر مرئي ثلاثي الأبعاد واختبار استخلاص تجريبي للغمر بالقلويات لخام الفولا النفطي-السودان

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February 2022

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This project is accepted by petroleum engineering and technology department of petroleum engineering

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Date: /2/2022

الإستهلال

بِسۡمِ ٱللَّهِ ٱلرَّحۡمَٰنِ ٱلرَّحِيمِ

ٱقۡرَأۡ بِٱسۡمِ رَبِّكَ ٱلَّذِى خَلَقَ ﴿١﴾ خَلَقَ ٱلۡإِنسَٰنَ
مِنۡ عَلَقٍ ﴿٢﴾ ٱقۡرَأۡ وَرَبُّكَ ٱلۡأَكۡرَمُ ﴿٣﴾ ٱلَّذِى عَلَّمَ
بِٱلۡقَلَمِ ﴿٤﴾ عَلَّمَ ٱلۡإِنسَٰنَ مَا لَمۡ يَعۡلَمۡ ﴿٥﴾

صدق الله العظيم

Dedication

To express our thanks to all those who were contributed in many ways to the success of this study and made it an unforgettable for us.

To our god (**Allah**) who is always there when we are in need. Thank you for guiding us and giving us strength in our everyday life. Thank you for making all of these happened.

To our lovely parents who have been our constant source of inspiration. Without their love and support this research would not have been possible.

To our advisor **Dr. Elradi Abass**, we would like to sincerely thank you for your unlimited support, guidance, and patience through this study.

To our friends who encourages us every step of the way.

Acknowledgement

Life taught us lessons and one of them is that every beginning has an end. We acknowledge the efforts of all teachers that gave their knowledge to us in particular our supervisor **Dr. Elradi Abass**, without your help this moment could not be happened.

A special thanks to the engineer **M Faroug** who supported and guided us on several steps during the journey of our project. Our great thanks and respects also extended to everyone who encourages or gives us a help in this research.

Abstract

Core flood experiment is actually one of the methods that used to simulate the reservoir system, measure its properties, and predict the production performance. Core flood 3D visualization model has added the characterization of simulating the process of oil recovery through visual way better than the conventional core flood models.

A designing of core flood 3D visualization model has been made in this research. Fula oil field is located in west Kordofan, and has an acidity heavy crude oil, our experiments have proven that applying Alkaline flooding method could achieve effective production goals, so as a screening method it is possible to apply Alkaline flooding method to enhance the oil recovery.

Alkaline flooding with Fula crude oil has been experienced by the designed core flood model, the results have shown that the model succeeded to conduct the experiment through visual way. A water flood test has been run by injecting water with flow rate of 20 ml per minute for 125 minutes, the result has shown that water flooding has recovered 15.2 ml.

Alkali agent (Na2Co3) with concentration of 1% has been injected, continuously into the core flood model with the same flow rate for 250 minutes, the result has shown that Na2Co3 has recovered 97.5 ml of the crude oil. Alkali agent (NaOH) with concentration of 1% has been injected in the core flood for 200 minutes, the result has shown that NaOH has recovered 168.25 ml of the crude oil. The total recovery of alkaline flooding process was 280.95 ml.

Keywords: Alkaline flooding, Chemical EOR, Core flood.

التجريد

تعد تجربة غمر العينات إحدى الطرق المستخدمة لتمثيل نظام المكمن وقياس خواص ه،

والتنبؤ بأدائية الانتاج .أضافت أجهزة غمر العينات المرئية خاصية جديدة، وهي تم ثيل عملية استخلاص النفط من خلال الرؤية الموضحة لما يحدث. تم تصميم جهاز م رئي لغمرالعينة في هذا البحث.

يقع حقل الفولة في غرب كردفان، ويمتاز بخام نفطي ثقيل ذو حمضية عالية، حسب ا لتجارب المعروفة ان الغمر بالطريقة القلوية يمكن ان يستخدم لتحسين انتاج الخام ال حمضي.

تم اجراء تجربة الغمر بالقلويات مع خام الفولة في الجهاز المصمم، النتائج أظهرت قدرة الجهاز على إجراء التجربة بطريقة مرئية.

في البداية، تم إجراء عملية الغمر بالماء للعينة وذلك بضخ ماء بمعدل تدفق 20 مل ل لدقيقة لمدة 125 دقيقة، النتائج أظهرت قدرة عملية الغمر بالماء على إنتاج 15.2مل من النفط الموجود في العينة. تم ضخ المادة القلوية (كربونات الصوديوم) بتركيز1% في الجهاز بنفس معدل التدفق للعملية السابقة ولمدة 250 دقيقة، النتائج أظهرت أن ا لمادة القلوية قد استخلصت 33.94 مل من النفط الخام.

تم ضخ المادة القلوية(هيدروكسيد الصوديوم) بتركيز 1% في الجهاز ولمدة 200 دقيقة، النتائج أظهرت مقدرتها علي استخلاص 58.58 مل من النفط الخام. استطاع الجهاز في العملية كاملة علي استخلاص 280.95مل من النفط الموجود(4 لتر).

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NOMENCLATURE

EOR	Enhanced oil Recovery
IOR	Improved Oil Recovery
AS	Alkaline Surfactant
AP	Alkaline Polymer
SP	Surfactant Polymer
ASP	Alkaline Surfactant Polymer
1D,2D,3D	1,2,3 Dimension
IFT	Interfacial Tension
FTIR	Fourier transform infrared
OOIP	Original Oil in Place
NMR	Nuclear Magnetic Resonance
TV	Total Volume
PV	Pore Volume
ϴ	Porosity
OR	Oil Recovery
OP	Oil Production

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Chapter One

Introduction

1.1 General Introduction

Oil recovery can be defined into three main phases: primary, secondary and tertiary. Primary recovery is recovery by natural drive energy initially available in the reservoir. It does not require injection of any external fluids or heat as a driving energy. The natural energy sources include rock and fluid expansion, solution gas, water influx, gas cap, and gravity drainage.

Secondary recovery is recovery by injection of external fluids, such as water and/or gas, mainly for the purpose of pressure maintenance and volumetric sweep efficiency. Tertiary recovery or EOR refers to the recovery after secondary recovery. It is characterized by injection of special fluids such as chemicals, miscible gases, and/or the injection of thermal energy.

1.2 Enhanced Oil Recovery

The extraction of residual oil after the primary and secondary phases of production is known as tertiary or enhanced oil recovery. At this point, modern and technically advanced procedures are used to either adjust the properties of reservoir fluids or the features of reservoir rock, with the goal of achieving recovery efficiencies that are higher than those attained by traditional recovery methods (primary and secondary recovery stages).

Tertiary recovery allows for the recovery of extra 5% to 15% of the reservoir's oil. To improve oil production, tertiary oil recovery reduces the viscosity of the oil. Enhanced oil recovery is oil recovery by injection of gases or chemicals and/or thermal energy into the reservoir. It is not restricted to a particular phase, as defined previously, in the producing life of the reservoir. Another term, improved oil recovery (IOR), is also used in the petroleum industry. The terms EOR and IOR have been used loosely and interchangeably at times.

Some feel that the two terms are synonymous; others feel that IOR covers just about anything, including infill drilling and reservoir characterization. Workable definitions of EOR and IOR are necessary not just for improved communication, but also to recoverable reserves booking, government incentives, taxation, and regulatory authorities when looking at fiscal issues contract negotiations.

1.3 Chemical EOR

Chemical EOR is the optimization of injection water by adding a chemical substance. There are three types of chemical EOR, the well-known chemical EOR methods are polymer, surfactant, and alkaline flooding.

Different modes of chemical flood injections were devised, studied, and applied for EOR processes. This includes the binary mix of alkaline-surfactant (AS), mix of alkaline-polymer (AP), mix of surfactant-polymer (SP), and the mix of alkaline-surfactant-polymer (ASP).

1.4 Alkaline Flooding

The alkaline flooding method relies on a chemical reaction between chemicals such as sodium carbonate and sodium hydroxide (most common alkali agents) and organic acids (saponifiable components) in crude oil to produce in situ surfactants (soaps) that can lower interfacial tension. The addition of the alkali increases pH and lowers the surfactant adsorption so that very low surfactant concentrations can be used to reduce cost.

1.5 core flood experiment

A laboratory test in which a fluid or combination of fluids is injected into a sample of rock. Objectives include measurement of permeability, relative permeability, saturation change, formation damage caused by the fluid injection, or interactions between the fluid and the rock. The core material often comes from an oil reservoir, but some tests use outcrop rock.

The fluid in place at the start of the test is typically either a simulated formation brine, oil (either crude oil or refined oil), or a combination of brine and oil. Injected fluids may include crude oil, simulated reservoir brine, refined fluids, drilling mud filtrate, acids, foam or other chemicals used in the oil field.(Baldygin, Nobes et al. 2014)

1.6 Problem Statement

The laboratory experiments of CEOR are conducted by flood 1D model and it has a lack of visual performance of the flood process inside the model. The main work of this research is to perform self-designed physical simulation flood model as 3D visualization model, which is capable to simulate a visual view of the process of injecting chemicals into the reservoir.

Generally, Sudanese Oil Fields have proven oil reserve more than 5 billion barrels; however, oil production is facing low production rates reach 54 thousand barrel per day, and high water cut reaches 80% in some fields (site, 2022). Our experiments have indicated that the possibility of applying alkaline flooding could result a better recovery for Sudanese acidity crude oil, Fula oil field as an example for conducting our experiments.

1.7 Objectives of the Study

The objectives of this research are:

1. To design a 3D core flood visualization model.
2. To test the ability of the model to conduct the experiment in visual way.
3. To measure the properties of the selected core through the designed model.
4. To conduct an experimental test for using alkaline flooding to enhance the recovery of Fula oil through the model.

Chapter Two

Literature Review

2.1 History of Core Flood and Alkaline Flooding

2.1.1 History of Alkaline flooding

Johnson 1975 defined four mechanisms of enhanced oil recovery by alkaline flooding: (1) "Emulsification and Entrainment" in which the crude oil is emulsified in-situ and entrained by the flowing aqueous alkali, (2) "Wettability Reversal (Oil-Wet to Water-Wet)" in which oil production increases due to favourable changes in permeabilities accompanying the change in wettability, (3) "Wettability Reversal (Water-Wet to Oil-Wet)" in which low residual oil saturation is attained through low interfacial tension and viscous water-in-oil emulsions working together to produce high viscous/ capillary number, and (4) "Emulsification and Entrapment" in which sweep efficiency is improved by the action of emulsified oil droplets ~locking the smaller pore throats. Castor, et al. proposed a fifth mechanism, "Emulsification and Coalescence," in which unstable water-in-oil emulsions form spontaneously in the alkaline solution, then break to create local regions of high oil saturation, hence, increased permeability to oil.(Johnson 1976)

jeff Rudin and Darsh T. Wasan (1993) show that alkaline flooding process involves injecting alkaline agents into the reservoir to produce more oil than is produced through conventional waterflooding. The interaction of the alkali in the flood water with the naturally occurring acids in the reservoir oil results in in-situ formation of soaps, which are partially responsible for decreasing IFT and improving oil recovery. Ionic strength is believed to be the governing mechanism for the minimum in 1FT when alkali concentration is increased. An increase in pH produces surface-active soaps, which decrease the IFT. Most investigation use a single alkaline chemical that buffers at a specific pH (i.e., Naoh, NaHC03, Na2C03, Na4Si04, etc.).(Jeff and Wasan 1993)

Abhijit Samanta, Keka Ojha, and Ajay Mandal in 2011 showed that Alkaline flooding is a method of enhanced oil recovery, in which alkali reacts with acidic components in the crude oil to form surface-active substances. In the present study, the interaction between alkali and crude oil was studied by measuring their physicochemical properties. A Fourier transform infrared (FTIR) spectrum of the crude oil reveals the presence of carboxylic acid groups leading to in situ formation of surfactants, which in turn decreases the interfacial tension between oil and water and other petrophysical properties responsible for better oil recovery. The effectiveness of alkali on enhanced oil recovery was tested with three sets of flooding experiments performed in the sand-pack systems. Substantial additional recoveries (more than 15% of original oil in place) over conventional water flooding were obtained in the present investigation.(Samanta, Ojha et al. 2011)

2.1.2 history of core flood

Nelson 1984 conducted a laboratory flooding experiments in (1) 2 x 2 x 10-inch or 2 x 2 x 44-inch Berea cores having about 600 md permeability to brine and about 21 percent porosity, (2) 2 x 2 x ll-inch Berea cores of the same initial permeability and porosity but fired to reduce their residual oil saturation to water flooding, and (3) 2-inch diameter by l2-inch, 4-5 Darcy, sand packs of still lower residual oil saturation to water flooding. The unfired Berea cores were run horizontally; the fired Berea cores and the sand packs were run vertically. Flow rate, controlled by Ruska pump, was one foot per day (single phase frontal velocity). Cosurfactant-enhanced alkaline floods with two crude oils, identified as Oil G and Oil S, are reported. Both are stock tank oils of acid number about unity and are from Gulf Coast reservoirs. Temperatures of the experiments, 168 and 155°F, correspond to the respective reservoir temperatures of the two crudes. All of the Activity Maps and all of the floods, unless specified otherwise, are for Oil G. The alkali in most of the floods was sodium "metasilicate" (Na20 to Si02 weight ratio of unity) used in a concentration of 1.55 percent by weight. The cosurfactant was either the alcohol methosulfates, a product of Shell Chemical Company, or olefin sulfonates made from Shell Chemical olefins.

The alcohol methosulfate was used at 0.12 percent active concentration; the olefin sulfonates were used at 0.30 and 0.41 percent active concentration. Sodium chloride was added to adjust salinity as required. Unless specified otherwise, the floods were continuous and were run without polymer for mobility control. All began at waterflood residual oil saturation. The waterflood brine contained sodium chloride in deionized water at the concentration required to match the sodium ion concentration in the alkaline slug. The results have shown that lowest interfacial tensions between a crude oil and alkali frequently occur at very low concentrations of alkali.(Nelson, Lawson et al. 1984)

H.H. Pei, G.C. zhang , J.J.Ge , China university of petroleum 2012 In this study, a comparative study of alkaline studying and alkaline/surfactant flooding was conducted for zhuanxgi heavy oil with viscosity of 325 mPa s and 55 C. the results of core flooding test have shown that, the tertiary recovery of alkaline flooding with concentration 0.4_1 % can reach 22-31 % OOIP, However the tertiary oil recovery of alkaline/surfactant flooding are lower than those of alkaline-oily flooding.(Pei, Zhang et al. 2012)

Aleksey Baldygin, David S. Nobes, and Sushanta K. Mitra in 2014 focuses on finding ways to improve traditional core flooding experimental set-up which has been used by the reservoir engineers over the past decades. The new proposed set-up can be used in contemporary studies related to enhanced oil recovery. This set-up has a possibility of using different flooding agents, e.g., surfactant, polymer, emulsion, oil and water. It also on the oil recovery efficiency.(Baldygin, Nobes et al. 2014)

2.2 Theoretical Background about alkaline flooding:

2.2.1 Introduction of EOR

The processes of oil recovery are majorly in three stages namely: primary, secondary and tertiary (EOR) stage. After the application of primary and secondary oil recovery techniques, two-third of the original oil in place (OOIP) remains in the reservoir. This is either because the oil is trapped by capillary forces (residual oil) or bypassed in some other way. The bypassed oil arises due to reservoir heterogeneities or because of unfavourable mobility ratio between the aqueous and oleic phase.

On the other hand, the residual oil is made up of discrete ganglia that are produced when a finger-like protrusion of the oleic mass forms a narrow neck by the combined effects of local pressure gradient and interfacial tension (IFT) To enhance the overall oil displacement efficiency, numerous EOR methods have been devised and utilized. During oil recovery, the overall oil displacement efficiency is a combination of macroscopic (volumetric sweep) and microscopic (pore scale) displacement efficiency.

Macroscopic displacement efficiency is a measure of the effectiveness of the injected fluids in contacting the oil zone volumetrically with respect to the total reservoir volume while microscopic displacement efficiency is the efficiency related to the ability of the displacing fluid(s) to mobilize oil trapped at the pore scale when it contacts the oil. Summarily, any mechanism that can increase oil recovery efficiency at either the micro or macro-scale or both is beneficial for EOR. The devised and utilized EOR methods are majorly categorized into thermal and non-thermal EOR methods.

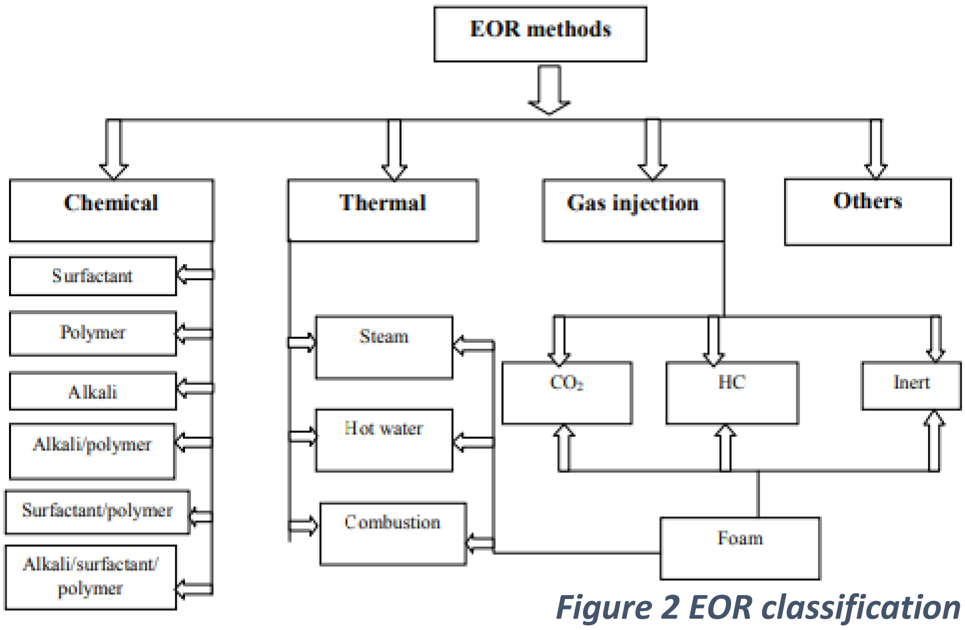

Figure 2 EOR classification

2.2.2 Chemical EOR

Chemical EOR methods increase oil recovery by increasing the effectiveness of water injected into the reservoir to displace the oil. Dependent on the type of chemical EOR process, chemicals injected with the water slug alter the fluid–fluid and/or fluid–rock interaction in the reservoir. This includes lowering of the IFT between the imbibing fluid and oil or an increment in the viscosity of the injectant for improving mobility and conformance control. Besides, the injected chemicals result in wettability alteration of the rock to increase oil permeability. The well-known traditional chemical EOR methods are polymer flooding, surfactant and alkaline flooding.

Chemical flooding can be classified as 4 modes:

1.AS.(Alkaline-surfactant flooding)

2.SP.(Surfactant-Polymer)

3.AP.(Alkaline-Polymer)

4.ASP. (Alkaline-Surfactant-Polymer)

Field projects of chemical EOR

Chemical EOR project has been implemented in various fields across the world. China has the largest field application of chemical EOR with a reported incremental 300,000 bbl/day of oil. Other countries with high implementation of chemical EOR are USA and Canada. Polymer flooding and ASP flooding have been the most widely used chemicals for field application and most of the oilfields have been sandstone formations.

2.2.3 Polymer flooding

Polymer flooding consists of injecting polymer-augmented water into a subterranean oil formation in order to improve the sweep efficiency in the reservoir. The increased viscosity of the water causes a better mobility control between the injected water and the hydrocarbons within the reservoir.

Polymer flooding is often implemented in two cases:

1) When the mobility ratio during a waterflood is not favourable, continuous polymer injection
2) Even with a favourable mobility ratio, if the reservoir has some degree of heterogeneity, polymer injection can help to reduce the water mobility in the high-permeability layers supporting the displacement of oil from the low-permeability layers

2.2.4 Surfactant flooding

Surfactant flooding is a proven EOR technique used for mobilizing residual oil trapped in the reservoir. The aim of surfactant injection into reservoir for improving oil recovery factor is to alter the fluid/fluid interaction by reducing IFT between the oil and brine, and fluid/rock properties via wettability alteration of the porous medium.

Mechanism of surfactant flooding

Surfactant flooding improves pore-scale displacement efficiency through the mechanism of interfacial tension reduction, or wettability alteration, or a combination of both mechanisms.

2.2.5 Alkaline flooding

Alkali flooding is an EOR technique that utilizes an alkali (a basic compound, ionic salt of an alkali metal or alkaline earth metal) to improve oil recovery factor. The method is distinct from other EOR methods on the basis that the chemicals that aid the oil recovery are generated in situ during the EOR process by saponification reaction. Saponification reaction is defined as the reaction between an organic acid and caustic alkali to form soap indicated by the reaction.

Figure below illustrates the chemical model for the alkali–oil chemistry in reservoir rock. The organic acid is obtained from the acidic component of the crude oil. The generated soap acts as an in-situ surfactant to lower IFT and emulsify the crude oil, thereby, improving oil recovery. Along with the aforementioned low IFT and emulsification processes, different mechanisms have been postulated to be responsible for higher oil recovery by alkali flooding.

HA + OH (3) − ↔ A− + H2O **Equation 1 Alkali reaction**

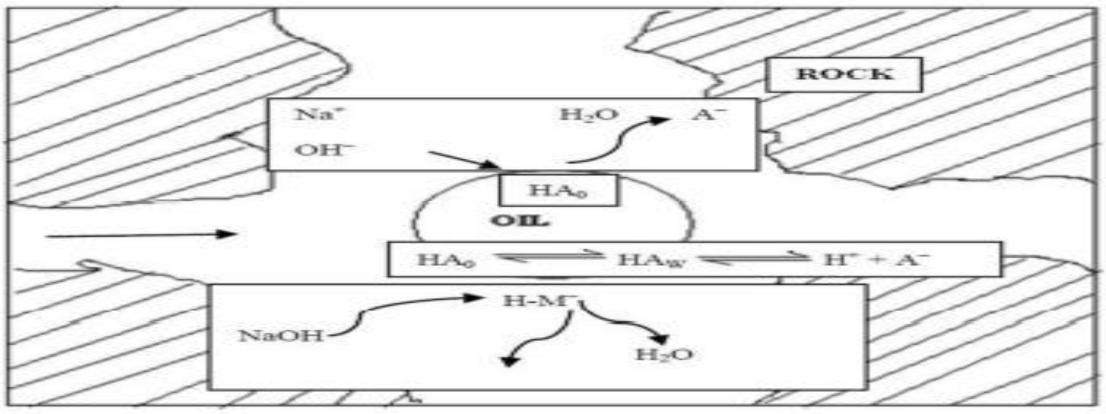

Figure 3 the chemical model for the alkali–oil chemistry

Figure 5 Oil before reaction with alkali

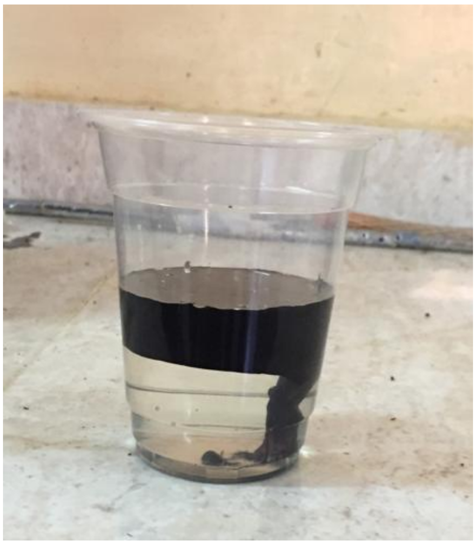

Figure 4 Oil after reaction with alkali

Other mechanisms posited for EOR by alkali flooding. includes: oil-phase swelling, wettability alteration, and disruption of rigid films. The existence of divergent mechanisms is due to the dissimilar chemical character of the crude oil and the reservoir rock under distinct environments such as temperature, salinity, pH, and hardness concentration. The different crude oil in different reservoirs exhibit widely disparate behaviours when they come in contact with alkali.

Depending on the mineralogy of the rock, the alkali interacts with the rock in numerous ways such as surface exchange and hydrolysis, congruent and incongruent dis solution reactions, and insoluble salt formation by reaction with hardness ions in the fluid and those exchanges from rock surface. Several alkalis have been screened for application in alkali flooding. These include sodium metaborate ($NaBO_2$), sodium carbonate (Na_2CO_3), sodium hydroxide (NaOH), and sodium bicarbonate ($NaHCO_3$).

The selection of alkali to be used is dependent on the type of formation, clay and mineral content, and the presence of divalent cations. NaOH are less preferred because at elevated temperature, they interact strongly with the sandstone surface, thus, causing increased porosity and consequently sandstone weight loss. Moreover, caustic consumption resulting from the dissolution of the caustic alkali in silicate minerals pose detrimental factor during field application. Na_2CO_3 is the most preferred alkali due to its low-cost and better transport properties in porous media. Nonetheless, the presence of calcium and other divalent cations cause precipitation of alkalis such as Na_2CO_3 unless soft brine is used.

$NaBO_2$ have better tolerance for divalent ions and have been suggested as replacement for Na_2CO_3. Meanwhile, $NaHCO_3$ is preferred in reservoirs containing clay minerals. Finally, due to precipitation of alkali in carbonate reservoirs due to the presence of anhydrite ($CaSO_4$) and gypsum ($CaSO_4.2H_2O$), sandstone reservoirs are the preferred formation for alkali flooding.(Gbadamosi, Junin et al. 2019)

2.2 Introduction to core flood

A laboratory test in which a fluid or combination of fluids is injected into a sample of rock. Objectives include measurement of permeability, relative permeability, saturation change, formation damage caused by the fluid injection, or interactions between the fluid and the rock. The core material often comes from an oil reservoir, but some tests use outcrop rock. The fluid in place at the start of the test is typically either a simulated formation brine, oil (either crude oil or refined oil), or a combination of brine and oil. Injected fluids may include crude oil, simulated reservoir brine, refined fluids, drilling mud filtrate, acids, foam or other chemicals used in the oil field.

Depending on the purpose of the test, conditions may be either ambient temperature and low confining pressure or high temperature and pressure of a subject reservoir. Pressures and flow rates at both ends of the core are measured, and the core can also be investigated using other measurements such as nuclear magnetic resonance (NMR) during the test. A core flood is typically used to determine the optimum development option for an oil reservoir and often helps evaluate the effect of injecting fluids specially designed to improve or enhance oil recovery.

2.2.2 The need of core flood

1. A tool in understanding basic formation damage phenomena e.g. permeability reduction.
2. For use in predicting well injectivity and productivity performance.
3. Determine the optimum development option for an oil reservoir
4. Determine rock permeability, and how well various fluids, including oil, will flow through it.

2.2.3 Types of core flood Models

i. 1D core flood model

Figure 6 1D core flood model: used for linear flow.

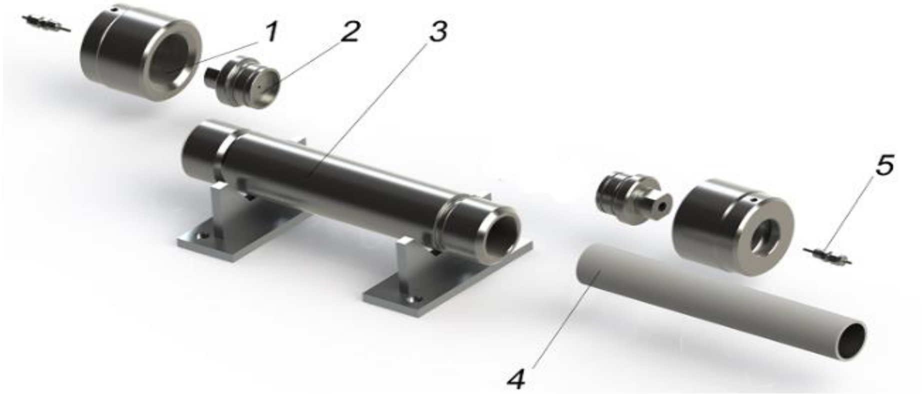

Figure 7 1D core flood components

ii. The 2D core flood model: (represent the radial flow)

There are three types of 2D core flood models:

Figure 9 plane square model

Figure 8 Triangle model

Figure 10 Side square model

iii. The 3D core Flood model.

Figure 11 3D Model Core Floods

Traditional core flood systems

The traditional core flooding system, has three main components: the upstream, the core block, and the downstream. The upstream supplies relevant fluids (saturation and flooding agents) to the core block using syringe pumps and piston accumulators (PA).

The core block contains the porous media and often simulates the reservoir conditions which could include overburden pressure and thermal jacket to maintain reservoir temperature. The downstream collects the effluent from the core block by using fraction collectors17 or two-/three-phase separators. the analysis of such data often leads to the estimation of the efficiency of tested oil recovery method.

Every system component is connected to a data acquisition module through which the user can communicate, which is referred here as a control module. Such experimental techniques work well for single phase fluids (such as water or oil) and certain restricted two-phase systems (oil and water mixture as effluent from the production wells). Primitive methods lack a realistic representation of the field environment, as the sample is taken and tested in a special way, therefore the flow is far from the real reservoir flow.

New Core Flooding System

A new core flooding apparatus has been designed and constructed by considering the potential challenges related to the traditional core flooding system, pointed out above.

Modern methods focused on representing the annular flow instead of the linear one, in order to obtain more accurate and more realistic results to try to represent the reservoir conditions and the field environment in a clearer and closer to reality.

2.2.4 Most technology of core flooding model:

Primitive one-dimensional methods for core tests have been developed into more advanced methods in some laboratories and international universities, where some techniques have appeared that depend on radial flow instead of linear flow, which does not represent the reality of the reservoir and gives inaccurate results because the flow in the reservoir is radial and not linear, Two-dimensional techniques appeared, but they are murky and do not show the process from visualization point. The most modern model is the three-dimensional model, which represents the reservoir and field environment with all its details in a clear and visual way, which is therefore more accurate and explains the process closer to reality. But it is very modern and rare and appeared in some modern Chinese laboratories and universitiess.(Baldygin, Nobes et al. 2014)

Chapter Three

Methodology

3.1 Design 3D physical visualization model:

A core flood model defined as a model which is used in petroleum laboratory to measure the fluid and rock properties as well as predicting well injectivity and productivity performance.

3.1.1 Determining the dimensions of model.

The dimensions were designed as follow:

The length was 50 cm, the thickness was 15 cm and

the height was 30 cm.

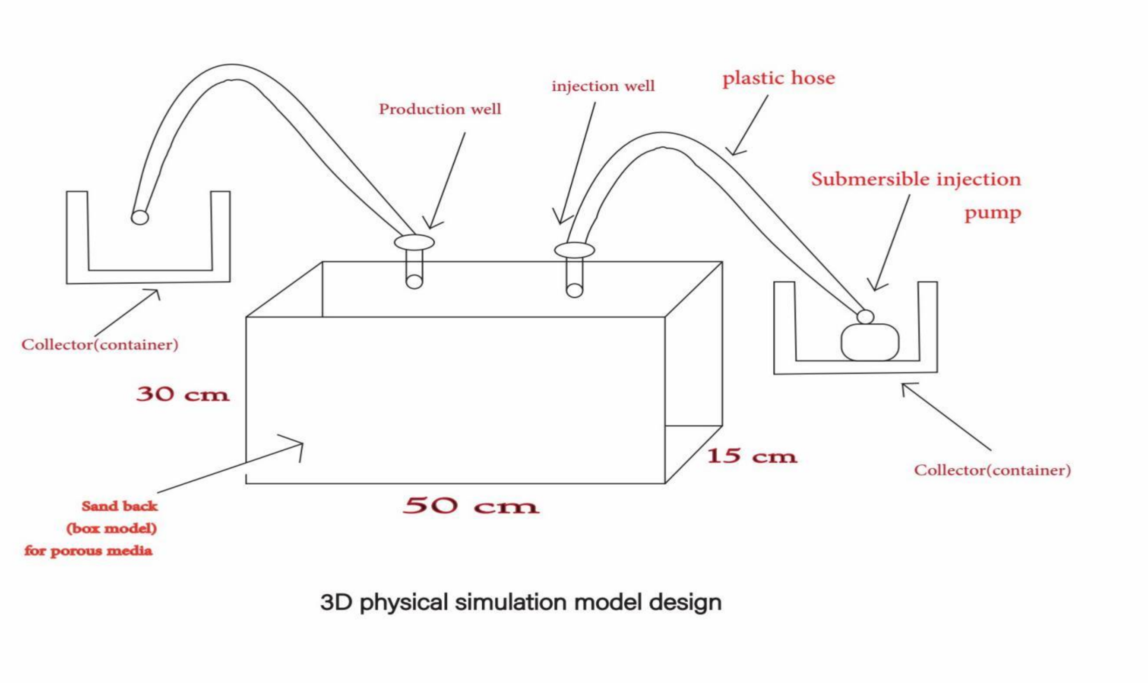

Figure 12 3D physical simulation model

3.1.2 Preparing and gathering the required materials

Table 1 (Table of materials)

Materials	Specifications	Figure number
The model:	A model was made from fibber-glass with thickness of 4 mm.	No: 13
The submersible pump:	Submersible pump was used to inject the fluid with flow rate of 20 cc per min	No: 14
The formation:	Sand gravel pack was used as a core sample with porosity of 0.154 And permeability	No: 15,16
The wells:	Steel perforated pipes were used as injection and production wells.	No: 17,18
Filter:	Filter is used as a gravel pack to prevent the wells from sand plugging and production.	No: 20
Plastic hose:	2 plastic hose the production plastic hose length is 60 cm and the production is 90 cm	No: 19,23
Containers (collectors):	2 measured containers one used for production and injection fluids	No: 24,25
Alkaline material:	NaOH & Na2Co3	No: 26,27
Crude oil:	5L Fula field Crude oil, High acidity crude oil	No: 29,30
Valves:	3 valves 2 control valves and a choke valve	No: 28
Graduated Cylinder:	Used for flow rate calculation	No: 34
Volumetric flask:	Used for mixing the solutions with water	No: 33
XYLEN GPC:	Used for cleaning	No: 32

Sensitive scale:	Used for calculating the weight of Alkaline materials	No: 31

Figure 13 The model

Figure 14 The Submersible pump

Figure 16 The formation

Figure 15 Formation

Figure 17 injection well

Figure 18 Production well

Figure 19 Filter

Figure 21 Production plastic hose

Figure 20 Injection plastic hose

Figure 22 Production container

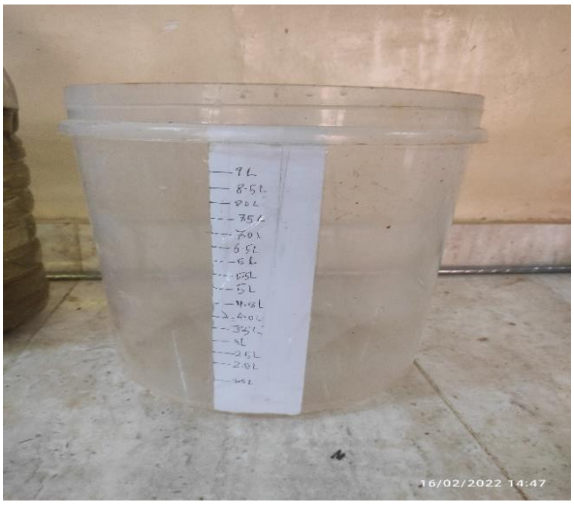

Figure 23 injection fluid container

Figure 24 Na2Co3

Figure 25 Alkaline material

Figure 26 Graduated Cylinder

Figure 27 valves in the injection plastic hose

Figure 28 pouring the crude after heating

Figure 30 Fula crude oil

Figure 32 Sensitive scale

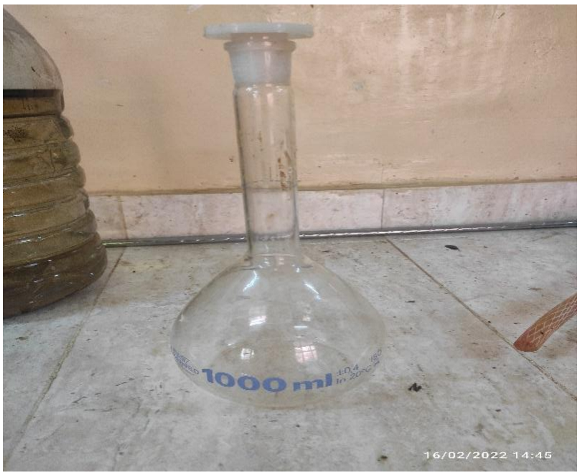

Figure 31 Volumetric flask

Figure 29 XYLEN GPC

Figure 33 Final model

3.2 Running the lab experiment

3.2.1 Core cleaning:

The sand was cleaned by pure water, and then dried. After drying the sand dimensions, weight, permeability, and porosity were measured.

3.2.2 Brine saturation

The core samples were saturated with formation water. After saturation was achieved, weight method was applied to measure porosity, then core was dried from water.

Calculation of porosity

$$\boldsymbol{\theta = \frac{PV\ weigh}{TV\ weigh}}$$ *Equation 2 porosity measurement*

Θ Represents Porosity of the core (%).

PV Represents Weigh of pore volume (gram).

TV Represents Weigh of total volume (gram).

3.2.3 Crude oil saturation

The core was saturated with crude oil and water with certain percent.

Figure 34 Oil Saturation

3.2.4 A water flood test

The saturated core sample was placed in the model, identical flooding conditions i.e. a temperature of 25 C, gravity stable displacement, and a nominal flooding rate of 20 CC per Min.

The core flood was a continuous injection of formation water to remaining oil saturation, remaining oil saturation after water flooding was considered to be obtained when water cut values were high and stable over the time, the produced oil was collected from the production well and the oil recovery was determined as the percentage of original oil in place (percentage of OOIP).

3.2.4 Alkaline CEOR Test

After water flood test, the core flood was continuously injected with alkali agent (Na2Co3) with concentration of 10 grams per litre, pump rate of 20 CC per Min, and pore volume of 3.5 litres, then followed by 1.5 litres water for driving, next alkali agent (NaOH) with concentration of 10 grams per litre and volume of 2.5 litres was injected, then followed by 1.5 litres water. Finally, the efficiency of alkaline flood was measured.(Shaddel, Hemmati et al. 2014)

Water cut and oil production measurement:

Wt and OP are measurement from the production when it reaches 500 ml.

Oil recovery calculation:

$$\boldsymbol{OR = \frac{Op * V\ Inj}{100}}$$

Equation 3 Oil Recovery

OR Represents oil recovery (ml).

OP Represents average of oil production (%).

V Inj Represents volume of injected fluid (ml).

Chapter Four

Results and discussion

4.1 Result and Discussion

This result of study is based on the high acidity of Fula crude oil, by using a laboratory experiment to test the efficiency of applying alkaline CEOR method.

4.1 Result of experiment

4.1.1 Core properties

The porosity of sand gravel pack is 0.1542

4.1.2 Water flooding test

Table 2 Water flooding test

Pore volume (ml)	**Time (minute)**	**Oil production %**	**Water cut**
0-500	25	2	98
1000	50	1	99
1500	75	0.04	99.9
2000	100	0	100
2500	125	0	100

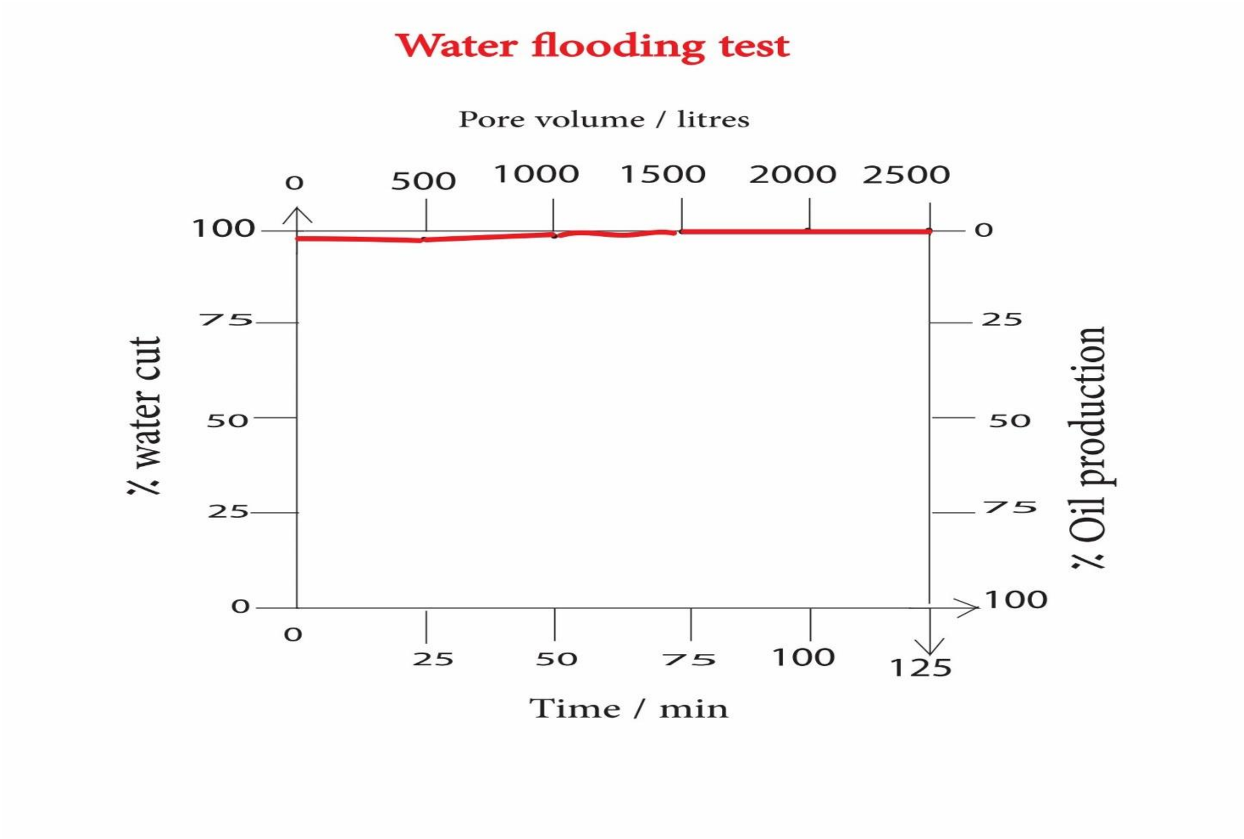

Figure 35 Water flood result

Average of oil production as a percentage is 0.605%.

Recovered oil is 15.2 ml.

4.1.3 Alkaline flooding

Na2Co3 of (1%), 3.5liters +1.5liters of water

Table 3 Alkali (Na2Co3) results

Pore volume (ml)	Time min	Oil production %	Water cut %
0-500	150	0	100
1000	175	1	99
1500	200	1.2	98.7
2000	225	1.5	98.5
2500	250	2.4	97.6
3000	275	2.4	97.6
3500	300	2.6	97.4
4000	325	2.7	97.3
4500	350	2.7	97.3
5000	375	3	97

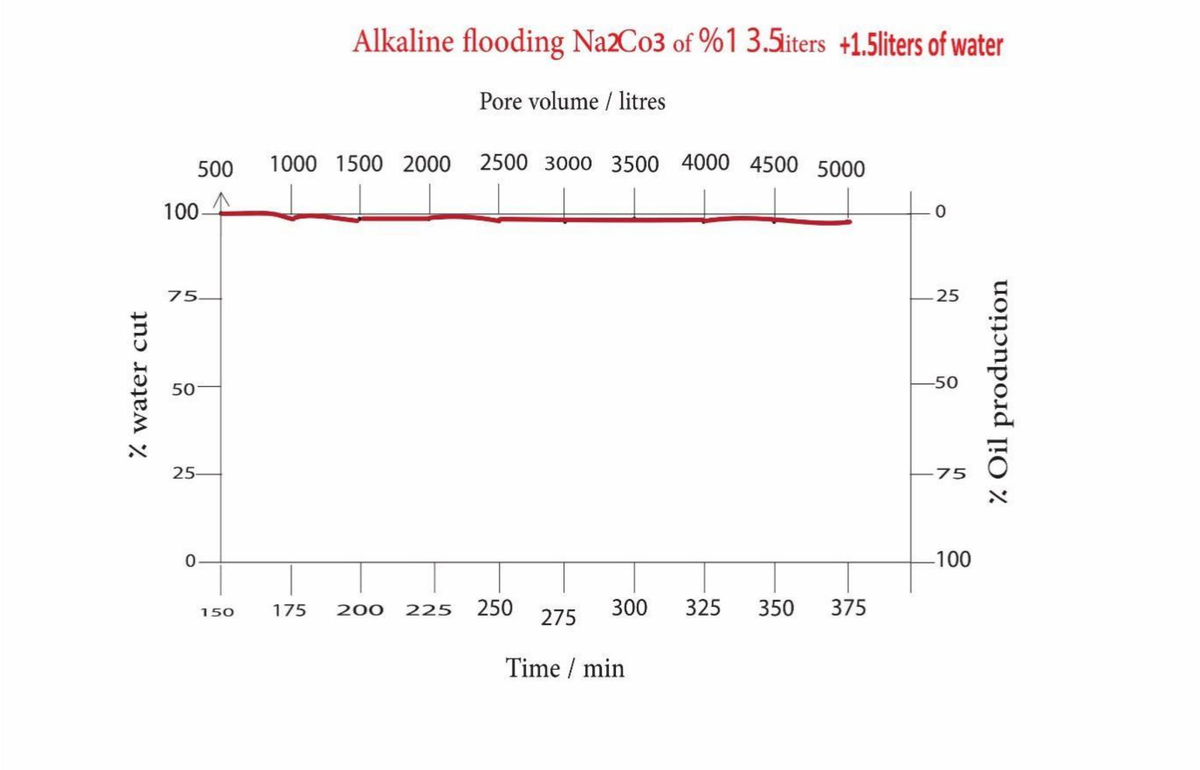

Figure 36 Na2Co3 result

Average of oil production as a percentage is 1.95%.

Recovered oil is 97.5 ml.

4.1.4 Alkaline flooding

1 % NaOH ,2.5 litres+1.5litres of water

Table 4 Alkali (NaOH) results

Pore volume litres	Time min	Oil production %	Water
500	400	3	97
1000	425	3.1	96.8
1500	450	3.6	96.4
2000	475	3.6	96.4
2500	500	4.25	95.75
3000	525	4.7	95.3
3500	550	5.6	94.4
4000	575	5.8	94.2

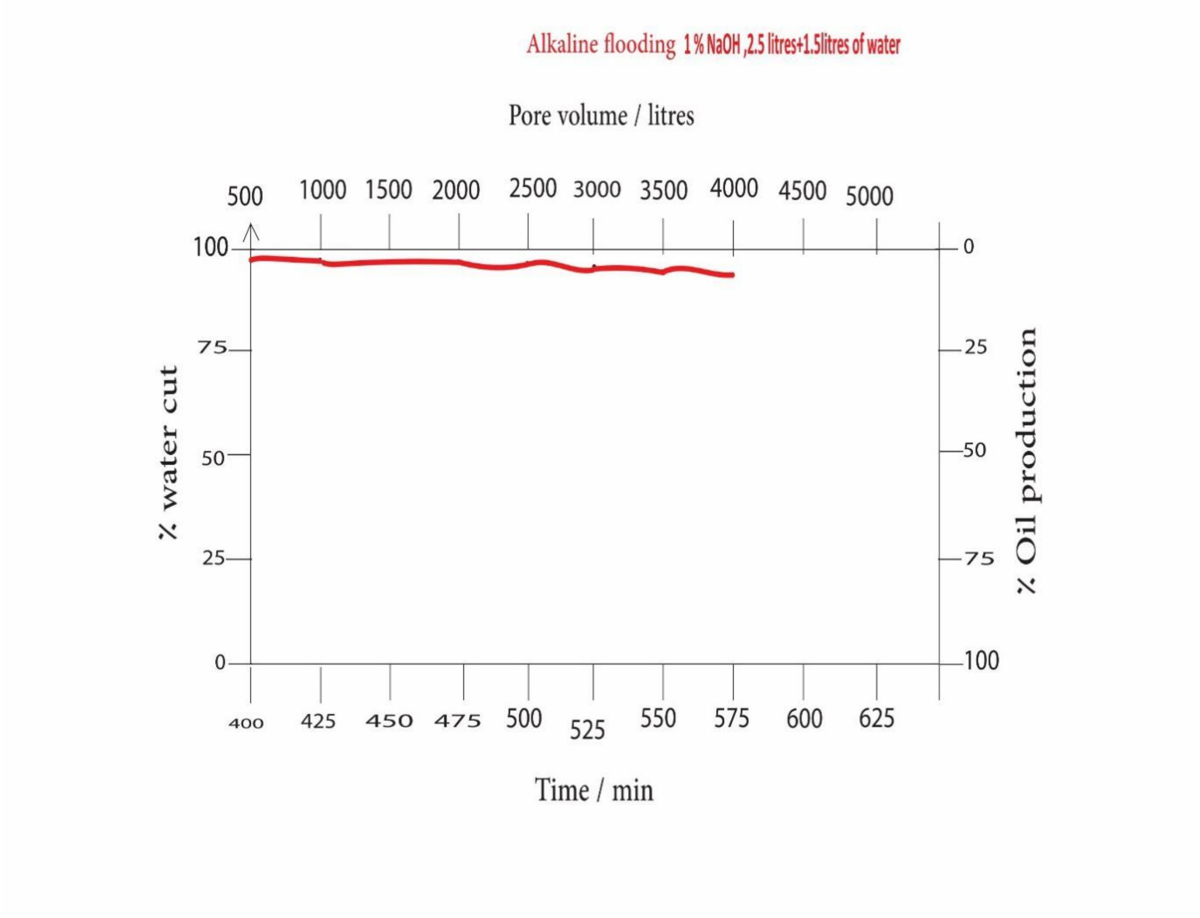

Figure 37 NaOH result

Average of oil production as a percentage is 4.206%.

Recovered oil is 168.25 ml.

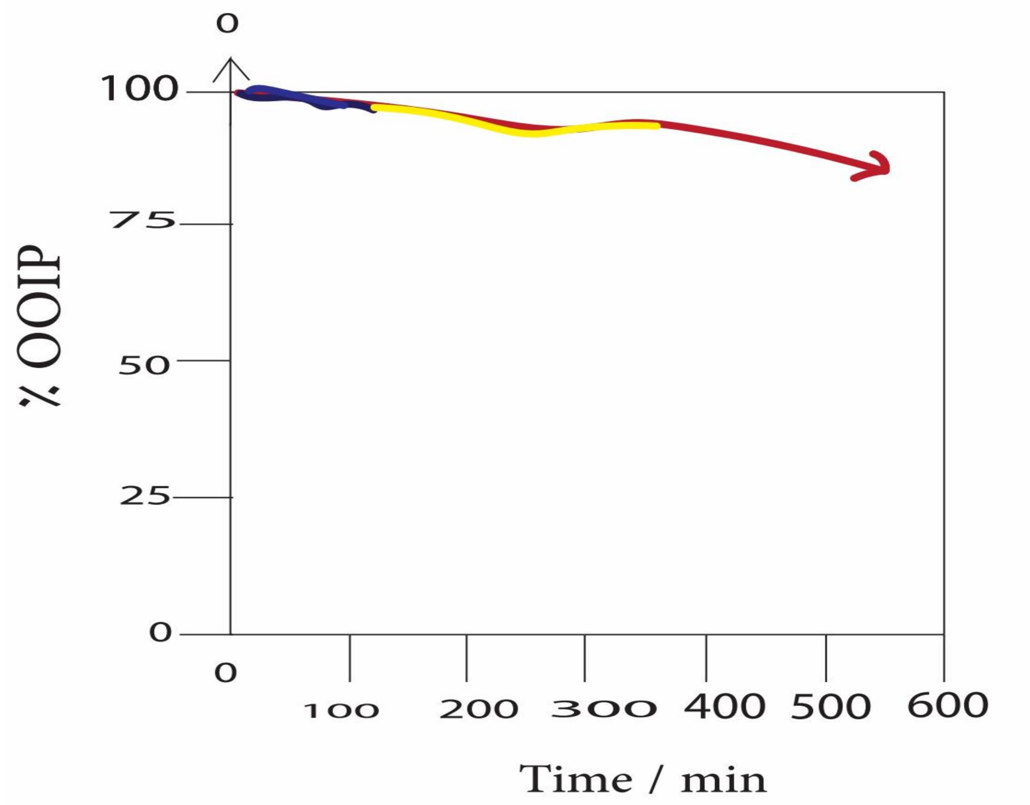

Figure 38 Total recovery of oil

Total recovery of alkaline flooding is 280.95 ml (7.02%) from 4 liters (OOIP).

4.2 Discussion:

The model has succeeded in recovering 280.95 ml of the oil in the core (4 litres), the process took 9 hours and 20 minutes.

The low recovery was justified as the model has not have a hoven to heat the oil to that temperature of the reservoir, so the temperature was low, and the viscosity was high. According to that reason the oil is not recovered as high quantities.

Chapter Five

Conclusions and Recommendations

5.1 Conclusions:

1. The model was designed to test the performance of alkaline flooding in enhancing the recovery of Fula oil.
2. A water flooding test was conducted by injecting water for 125 minutes which results in recovering 15.2 ml from the crude oil.
3. Alkali agent ($Na2Co3$) with concentration of 1% was injected for 250 minutes, and the test has recovered 97.5 ml from original oil in place.
4. Alkali agent (NaOH) with concentration of 1% was injected for 200 minutes, the test has recovered 168.25 ml from OOIP, and has better results than the previous alkali.
5. The test has recovered 7.02% (280.95 ml) from the OOIP (4 litres).
6. The model has an effective result in showing the alkaline performance via 3D visualization method.
7. The model is capable to test all types of chemical EOR methods.

5.2 Recommendations:

5.2.1 The core flood model

1. Recommended to replace the fiber glass with thickness of 4 mm to a glass with thickness of 6 mm.
2. Recommended to use oven to heat the oil in the model.
3. Recommended to add pressure gauge to the model.
4. Recommended to reduce the thickness of the model from 15 cm to 10 cm.
5. 3D physical visualization model on EOR experiments can achieve more sensible visual about oil recovery performance, and we recommended more applications condition.

5.2.2 Fula crude oil:

1. Alkaline flooding for Fula crude oil production has an effective influence and we recommend that more researches should be done on this field.

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