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Sudan University of Science and Technology

College of Petroleum Engineering & Technology

Petroleum Engineering Department

EXPERIMENTAL STUDY OF OIL RECOVERY BY LOW SALINITY WATER FLOODING

دراسة معملية لإستخلاص الزيت بواسطة الغمر بالماء منخفض الملوحة

This dissertation is submitted as a partial requirement of B.Sc. degree (honor) in petroleum engineering

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الآيـــــة

قــال تـعـالـى :-

بسم الله الرحمن الرحيم

{وقــل ربــي زدني علمـــاً}

صدق الله العظيم

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DEDICATION

For the man who drinks from empty cup to give me a drop of love & respect ,,, for the man who teach me the way of life , happiness and his finger print in my life determine my way ,, for the man who want to see me the best one in the world so not just my project is for you but all my steps in the right way is because of you ,,,

♥♥My Father♥♥

For the woman who give me support & love without for price , the woman love my success more than her life ,,, the woman who is ready to accept any pain to make me happy & not feel pain for my angle in the life for the meaning of love & smile of life ,,, for the woman who her prays is cause of my success & her love is antidote of ALLAH blessing you ,,,

♥♥My Mother♥♥

For those who teach me the meaning of responsibility & wisdom, those their smiles make me forget the black dots in my life, for the source of light & nice,,,

♥♥My Sister , Brothers♥♥

For the angels who lift me off my feel when my wings have trouble remembering how to fly , those who preceded me , still among me and they flow me ,,,

♥♥My Friends ♥♥

`

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<u>Dr. AlradiAbass</u>

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<u>Central Petroleum Laboratories</u>

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Abstract

Several laboratory indicated that oil recovery in water flooding is dependent on the salinity of the injected water, that low salinity water injectioncan improve oil recovery.

Low salinity brine is a promising method for improving oil recovery in sandstone reservoirs. Several mechanisms have known to be responsible for improving recovery by low salinity water flooding.

This project presents laboratory results and analysis of core flood studies of lab oil (iso bar-l) for understanding how low salinity brine affects in the final recovery.

An experiment was done in tertiary recovery mode. In an experimental procedure high salinity brine injected firstly to reach a high water cut value and all oil produced almost depleted, then injection of low salinity brine.

Oil recovery by high salinity water injection equals 3.5 cc at water cut 95% and by low salinity water injection equals 0.8 cc at water cut 85% .The results showed that oil recovery increasing when we injected low salinity after injected high salinity brine.

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التجريد

عدة تجارب تشير إلي أن استخلاص النفط بواسطة الغمر المائي يعتمد علي ملوحة الماء المحقون وأن الماء منخفض الملوحة يحسن استخلاص النفط .

حقن الماء منخفض الملوحة يعتبر من الطرق الواعدة لتحسين استخلاص النفط في المكامن الرملية. هذا المشروع يقدم نتائج معملية وتحليل غمر العينة لزيت تم تصنيعه في المعمل (iso bar-l) لدراسة تأثير الماء منخفض الملوحة في النفط المستخلص .

أولا تم حقن الماء عالي الملوحة للعينه و مراقبة الزيت المستخلص الى ان تنخفض نسبة استخلاصه ، عندها ترتفع نسبة الماء المصاحبة (water cut)و منثم تم حقن الماء منخفض الملوحة في نفس الظروف .

وجد ان الزيت المستخلص بواسطة الماء عالي الملوحة يساوي3.5ملم مكعب عند water cut 95% وعند استخدام الماء منخفض الملوحة يساوي 0.8ملم مكعب عند85% water cut لنفس الظروف مما يبرهن علي ان كمية من النفط استخلصت بفاعلية الماء منخفض الملوحة.

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Abbreviations

LSWI	**Low Salinity Water Injection**
PPM	**Part Per Million**
PH	**Potential of Hydrogen**
TDS	**Total Dissolved Solids**
LSW	**low Salinity Water**
HSW	**High Salinity Water**
PV	**Pore Volume**

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Chapter 1

1.1 INTRODUCTION

Water flooding is one of the most used enhanced oil recovery technique. Until recently it has been viewed exclusively as a physical process for maintaining pressure and sweeping oil to producing wells unless scaling or souring potential was present.

Tertiary or enhance oil recovery refers to processes in the porous medium that recover not produced oil by the conventional primary the sweep efficiency in the reservoir by use of injectants that can reduce the remaining oil saturation below the level achieved by conventional injection methods.

The success of any EOR technique is the ability to release significant volumes of oil, after secondary recovery scheme, rapidly and at low cost. Most of the reduced condition waterfloods in the literature have suggested that the oil produced by low salinity waterflooding would not develop into an oil bank but would be produced as a long drainage process at high fractional flow of water. Low salinity water injection (LSWI) is gaining popularity as an improved oil recovery technique in both secondary and tertiary injection modes.

The LSWI effect on oil recovery from carbonate is not well addressed compared to sandstone rocks due to the previous thoughts of relating wettability alteration by low salinity water to the presence of clay, which is not the case in carbonate rocks. Nevertheless, the effect of LSWI on oil recovery from carbonate rocks was investigated at laboratory scale using both spontaneous imbibition and coreflooding studies.

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1.2 Case Study

The area of Heglig suffer from problem of low productivity of oil. This problem refer to the technique of waterflooding because they use high salinity water injection .

We will use low salinity water injection to increase the oil recovery . This water usually called " smart water" , it is define as enhanced oil recovery fluid with an optimal ionic composition and salinity ,which can act as a wettability modifier in carbonate reservoir.
Injection brines were simulated formation brine for high salinity water floods (salinity 15,000 ppm to >200,000 ppm), and low salinity brine (<5000 ppm) for the low salinity core floods.

1.3 Objectives

1- To investigate the additional oil recovery by low salinity injection compared to high salinity injection.

2-To achieve the laboratories procedures of flooding.

3- To investigate effects of operational parameters for the Low salinity water injection .

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Chapter 2

Theoretical Background & Literature Review

1.4 Literature review

A lot of works on low salinity injection have been published in the literature. We group them under experimental and modeling works. While a lot of experimental works have been published few modeling works be found,relatively.

Valdya and Fogler (1992) concluded that the release of fine is due to both low-salinity and high PH. They reported a change in permeability at a PH higher than 9.A significant reduction of permeability was reported at a PH higher than 11 which indicate a severe damage caused by high salinity water.

Yildiz and Morrow (1996) conducted core floods using Berea sandstone, Murray crude oil and either sodium basedbrine composed of 4 % Nalco , 0.5 % $CaCl_2$ or calcium-based brine composed of 2 % $CaCl_2$.

Recovery was higher with the calcium brine when the connate and injected brines were Identical. The highest recovery was achieved by initially saturating the core with calcium brine, injecting Na brine until residual oil saturation was achieved, then injecting calcium brine.

Tang and Morrow (1997) investigated the effects of connate and injection brine salinity, aging time and temperature on water flooding and imbibition with 3 different crude oils and 3 different brines.

They concluded that in water floods with constant connate brine salinity and variable injected brine salinity, diluting injected brine 100 times produced *5 % incremental oil recovery. In water floods with variable connate brine salinity and constant injected brine salinity, decreasing connate brine salinity dramatically improved recovery—about 40 % incremental oil recovery was achieved by diluted the connate brine 100 times.

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Tang and Morrow (1999) reported fine migration during Low Salinity water floods on Brea sandstones cores. They concluded that fine removal form rock surfaces resulted in exposure of underlying surfaces and that resulted in alteration of the system wettability to more water wet system. High salinity water floods has no effect on clays and the system maintain its wettability condition.

Webb et al. (2003) observed a reduction in residual oilsaturation in the near wellbore region by injecting lowsalinitybrine. Three different brines were injected into aplastic formation from a producing well. Saturation wasmeasured after each injection using a pulsed neutroncapture log. A base line Soar was established with a syntheticnative brine (250,000 ppm). Synthetic sea water(120,000 ppm), injected second, did not reduce oil saturationfurther. Low-salinity brine (3,000 ppm), injected last, reduced Soar significantly in two sand intervals and slightlyin another.

Sharma and Falco (2005)investigated the impact of connate and injection brinesalinity and crude oil on oil recovery, residual saturationsand wettability using Berea cores, 3 different oils and NaClbrine in various concentrations. In their imbibition experiments,decreasing connate water salinity increasedrecovery and significantly affected relative permeability.
The salinity of the displacing brine had no significantimpact. Drainage experiment's recovery and relative permeability were insensitive to salinity. During waterfloodingof crude oil, oil recovery increased with decreasing connatebrine salinity. However, during waterflooding of mineraloil, recovery was insensitive to connate brine salinity.

Zhang et al. (2007) reported increased recovery in thetertiary mode by reducing reservoir brine salinity 20 times.
Two consolidated reservoir sandstone cores were used. X-ray diffraction indicated that each of the cores were rich in chert and kaolinite. Two different crudes and a mineral oil were used. Almost 70 % incremental oil recovery wasachieved in the secondary mode. Both the high and lowsalinitysecondary floods were conducted in the same core.Tertiary recovery was also quite large; 25 % incrementalrecovery in the best case**.**

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Pu et al. (2008) observed low-salinity tertiary recovery from an almost clay-free core for the first time. They injected coalbed methane (CBM) water into 3 sandstone reservoir cores composed of quartz, feldspar, dolomite, and anhydrite cements but which had very little clay.

The CBMwater's salinity was about 1,316 ppm TDS. Cores were first waterflooded with high salinity formation brine (38,651 ppm). When oil production due to high salinity brine ceased CBM water was injected. In all cases CBM water liberated additional oil. In each core, the benefit of tertiary low-salinity flooding became less dramatic after each flood and restoration.
A core was acidized to remove dolomite crystals and subsequently its recovery became insensitive to low-salinity flooding.

Ashraf et.al (2010) studied the low salinity effect at different wetting conditions by using different oil with different wetting conditions with the Berea sandstone and connate brine**.**

1.5 Theoretical Background

1.6 Introduction

Extensive laboratory studies have now indicated that oil recovery in water flooding is dependent on the chemistry of the injected water.

In this work, core flood experiments were performed to investigate the effect of injected water and crude oil chemistry on the oil recovery to further understand the low salinity waterflooding process .

The general mechanism of oil recovery is movement of hydrocarbons to production wells due to a pressure difference between the reservoir and the production wells. The recovery of oil may be subdivided into three major categories those are primary, secondary and tertiary recovery which known as Enhanced oil Recovery.

Primary methods that use natural reservoir energy (gas cap drive, solution gas drive, water drive, liquid and rock expansion drive and combination drive) and secondary pressure maintenance methods (water, gas and combination of water and gas injection) leave behind more than half of the original oil in place.

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1.7 About Enhance Oil Recovery

The terms primary oil recovery, secondary oil recovery, and tertiary (enhanced) oil recovery are traditionally used to describe hydrocarbons recovered according to the method of production or the time at which they are obtained.

1.7.1.1 Primary oil recovery

Primary oil recovery describes the production of hydrocarbons under the natural driving mechanisms present in the reservoir without supplementary help from injected fluids such as gas or water. In most cases, the natural driving mechanism is a relatively inefficient process and results in a low overall oil recovery. The lack of sufficient natural drive in most reservoirs has led to the practice of supplementing the natural reservoir energy by introducing some form of artificial drive, the most basic method being the injection of gas or water.

1.7.1.2 Secondary oil recovery

Secondary oil recovery refers to the additional recovery that results from the conventional methods of water injection and immiscible gas injection. Usually, the selected secondary recovery process follows theprimary recovery but it can also be conducted concurrently with the primary recovery. Waterflooding is perhaps the most common method of secondary recovery. However, before undertaking a secondary recovery project, it should be clearly proven that the natural recovery processes are insufficient; otherwise there is a risk that the substantial capital investment required for a secondary recovery project may be wasted.

1.7.1.3 Tertiary oil recovery

Tertiary (enhanced) oil recovery is that additional recovery over and above what could be recovered by primary and secondary recovery methods. Various methods of enhanced oil recovery (EOR) are essentiallydesigned to recover oil, commonly described as residual oil, left in the reservoir after both primary and secondary recovery methods have been exploited to their respective economic limits .

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1.7.2 Low Salinity Effect in Sandstones Reservoir :

Chemical and physical properties vary between rock types (e.g. sandstones and carbonates), and the related effect of LSW has not yet been fully determined.

The wettability modification implied that adsorbed crude oil components at the rock surface were partially reversed due to the decrease in salinity, hence shifting surface preference towards water-wet conditions. Results confirmed that wettability alterations improved oil recovery.

In the sandstone reservoir, successful low salinity injections have been observed consistent with laboratory results.

Injection brines were simulated formation brine for high salinity waterfloods (salinity 15,000 ppm to >200,000 ppm), and low salinity brine (more than 5000 ppm) for the low salinity corefloods.

1.7.3 Wettability effects and its alteration

It is believed that enhanced oil recovery in low salinity waterflooding is related to wettability change. Furthermore there is direct evidencethat wettability altered to more water-wet during low salinity waterflooding. Accordingly, initial and final wettabilities are key indices which have been evaluated. However, results are controversial.

The type and level of salinity water injection is important to create wettability of a reservoir. In presence of plagioclase mineral, higher salinity water cause PH below 7 which in turn create mixed-wet condition which is favourable condition for low salinity waterflooding. On the other hand, in moderate low salinity water injection this mineral causes pH>7 which create unfavourable water-wet state.

The desired final wettability is also matter of debate. Some researchers reported that low salinity waterflooding change the wettability into neutral state rather than water-wet state.

Ashraf et al pointed out same results, but they also reported that highest Sor reduction took place in resulted water-wet condition.

It is argued that although residual saturation in low salinity flooded water-wet condition is higher than that mixed-wet condition, but higher oil relative permeability leads to net preference of final water-wet condition than the final mixed-wet condition.

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It is clear that change in wettability correspond to change in relative permeabilities curve which in turn results in change in fluid flow in porous media. Experiment by Webb et al showed due to low salinity water injection ,the relative permeabilities curves have similar motilities with the previous ones, but are shifted in saturation, benefitted the low salinity waterflooding resulted in incremental dry oil recovery.

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Chapter 3

Experimental Apparatus & Procedure

1.8 Experimental material

1.8.1 Crude oil:

The condition and characteristics of oil used in this experimental shows in table below

Table 3.1: The Properties of Oil Used in Experiment

Oil name	Viscosity(cp)	The degree
Iso bar-l	1.565	—

1.8.2 Brines:

Salinity was varied by changing the concentration of total dissolved solid of synthetic brine in proportion ,the brines were used during water flood experiments .Synthetic injection brines 40000(mg/l) as the high salinity brine, with 763(mg/l) TDS or distilled water as low salinity brine .

Table 3.2: The Synthetic Brine Properties

Salinity Type	Total Salinity(mg/l)
HSW	40000
LSW	763

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1.8.3 Geological Description of Sample:

The rock type is sandstone in a brown color and the grain size is coarse to medium grains .The degree of sorting is well sorted and the cement of grains is well (consolidated) by siliceous cement. The rock have a secondary minerals which is kaolin.

1.9 Experimental Apparatus

The experimental contain (-) main components : dean and stark extraction system, digital hilum porosometer, digital gas permeameter , saturator pump, device to measure differential pressure, core holder, Pharmacia pump and data recording devices.

1.9.1 Description of the main component of the apparatus :

1.9.1.1 Core holder:

The core holder is used for routine and special core analysis, the design is recommended for the testing of unconsolidated samples at high pressure and high temperature applications, while the injection cell is stain less steel cylinder ,water and oil that have been carefully weighed.

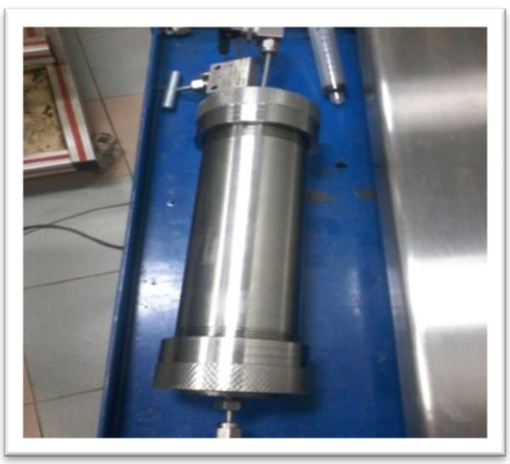

Figure 3.1 : Core Holder

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1.9.1.2 Pharmacia pump

The High Precision Pump P-500 is the ideal solvent delivery system for general liquid chromatography and other applications where precise and constant flow at pressures from 0–4 MPa (600 psi) is required. The design features of the P-500 create a dependable laboratory instrument for use with the high performance chromatography media for FPLC , and also provide complete compatibility with standard separation methods. Excellent chemical resistance allows the pump to be used with corrosive liquids and organic solvents. The Pump P-500 is a valuable contribution to any chromatographic application and is an integral part of the FPLC System. The characteristic of this Pump are :

- Flow rate range 1-499 ml/h, increment 1 ml/h.
- Pharmacia part # 19-4301-01
- Max pressure 5.0 Mpa (750psi)
- Old piston design
- The maximum flow rate for the pump is 500 cc/h.

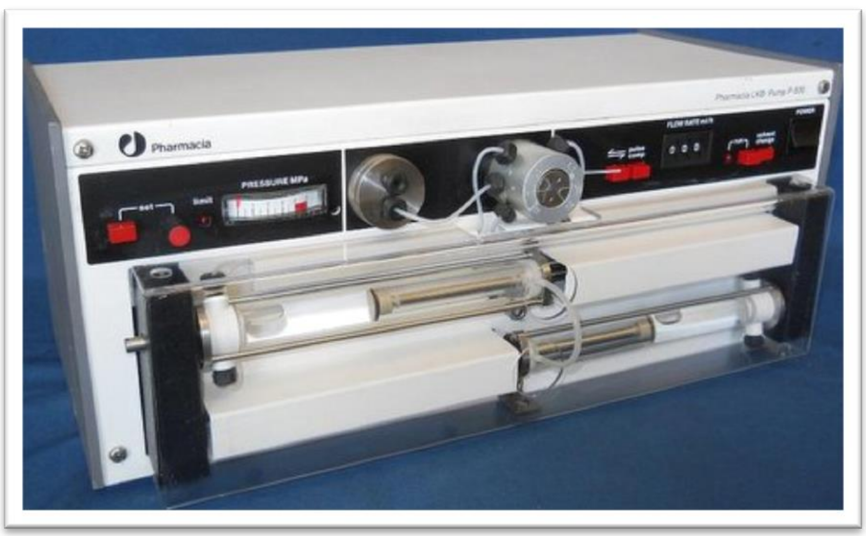

Figure 3. 1: The Pharmacia pump p-500

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1.9.1.3 Vacuum air device

It mainly contains a vacuum pump which was affixed to evacuate the core that sited in core chamber for the purpose of water saturation

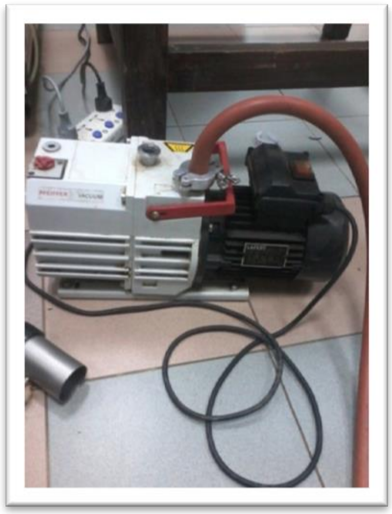

Figure 2.3 : Vacuum Pump

1.9.1.4 Nitrogen cylinder

A gas cylinder or tank is pressure vessel used to store gases at above atmospheric pressure .high gas pressure nitrogen cylinder is used in injection processes to maintain a high gas pressure support for Pharmacia pump, it can be used to vacuum the intermediate container by depressurize the water from it, and also it can be used in testing the connectivity of pipes.

1.9.1.5 Saturator pump:

Sample was loaded into hydrostatic coreholders and miscibly solvent cleaned with cycles of toluene and methanol, prior to saturation with simulated water .

It consists of:

- Core holder
- Vacuum pump
- Maximator

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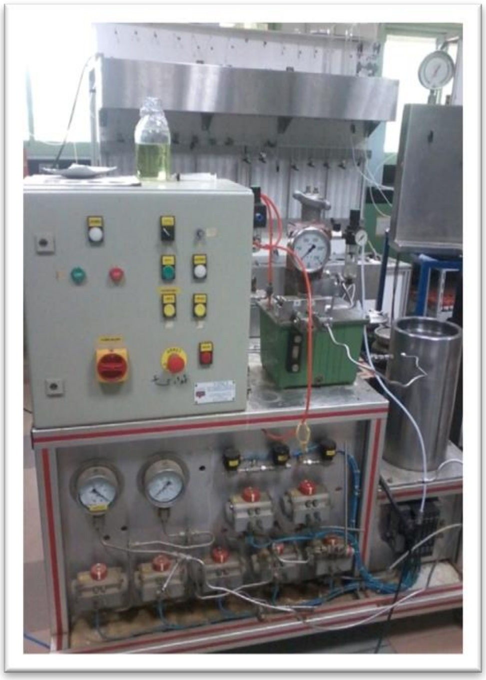

Figure 3. 3 : Saturator Pump

1.9.1.6 Pressure drop (Δp):

Used to measure absolute permeability set the device in certain pressure and open one of three valve, open pump in flow rate after period of time then record pressure drop recycle this process in many flow rate in different period of time then record the pressure drops. Joint with Pharmacia pump.

Figure 3.4 : Device to Calculate Pressure drop

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1.9.1.7 Distiller:

In this device use temperature effect until reaches the boiling point the isolate water from impurities or salts ,the water vapor condensate when it touch with cool surface. after that will be receive distill water

Distilled water is water that has many of its impurities removed through distillation. Distillation involves boiling the water and then condensing the steam into a clean container.

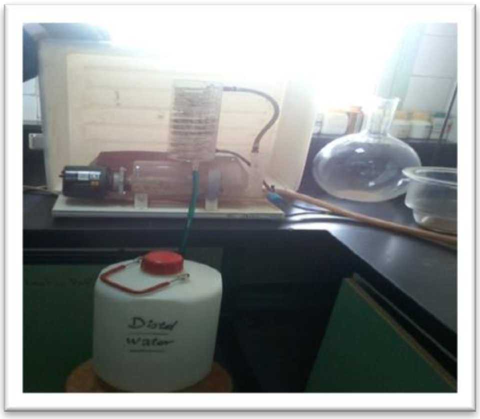

Figure 3.5 : Distiller

1.9.1.8 Ture weight:

Weigh the salt after ture the device to ensure additional weight cause error in weight.

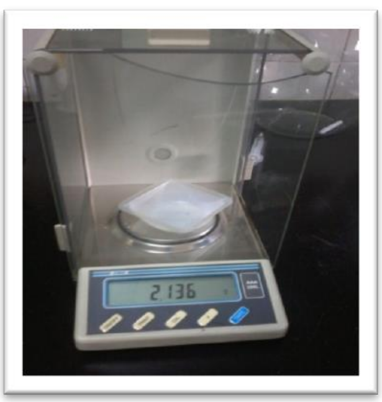

Figure 3.6 : Ture Weight

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1.9.1.9 Stairer

In this device put the brine in staring adding the distill water about 75% of total volume of water ,run the starrier after some minutes put remaining of distill water ,continue the mixing period of time until ensure all salt dissolve in water .

Figure 3.7 : Stairer

1.9.1.10 Degasser

After stairing put the the low or high salinity brine in degasser by using vacuum pump for period of times appears bubble of gases absorbed this bubble of air vacuum pump.

Figure 3.8 : Degaser

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1.10Experimental procedures:

Prepare core and measure the weight:

The core is put in cutting machine to slapping it .Plugging the core by Syderic after showering it , Put core in trealming to become like cylindrical form and finally The core is Put in methanol to clean brines Put core in furnace to drying it.

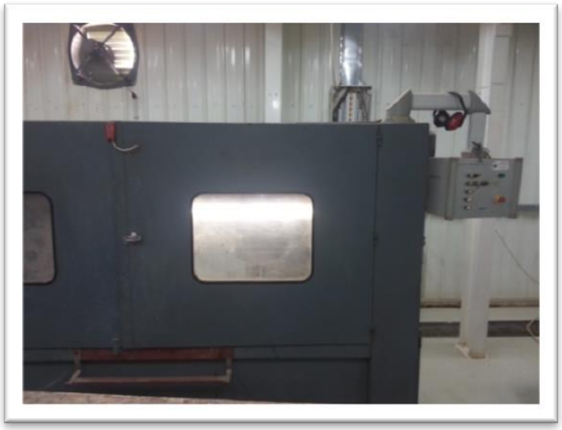

Figure 3.9 : Slabbing Machine

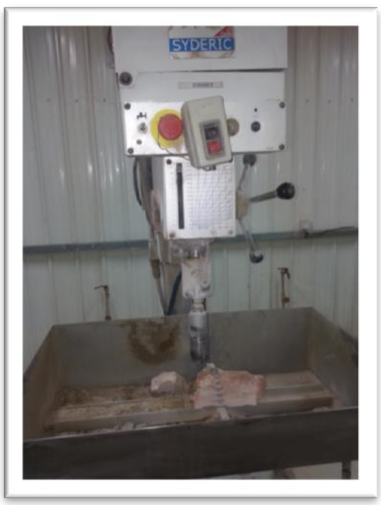

Figure 3.10 : Plugging Machine

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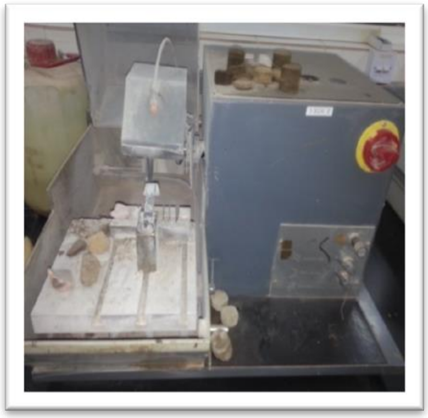

Figure 3.11 : Trimming Machine

1.10.1.1 Porosity :

The device is used for porosity called Digital Hillume Porosmeter, calculates bulk and grain volume using confining pressure about 100 psi in internal room.

This device using Boyles Law :

$$(p1 \times v1) = (p2 \times v2) \qquad (3\text{-}1)$$

$$\Phi = \left({}^{vp}/_{vb} \right) \times 100 \qquad (3\text{-}2)$$

Where;

Φ≡ porosity

Vp ≡ pore volume

Vb ≡ bulk volume

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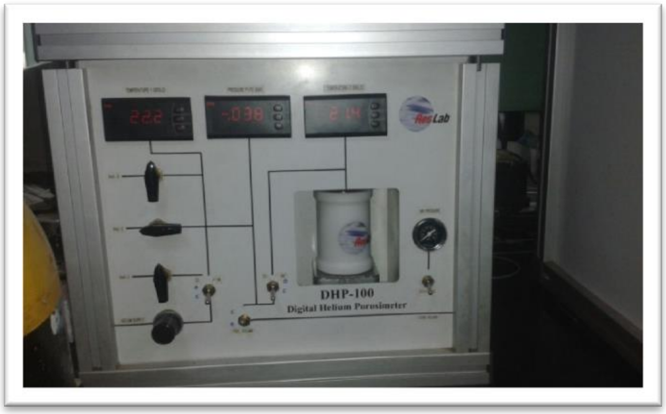

Figure 3.12: Digital Helium Porosimeter

1.10.1.2 Permeability :

The device is used to calculate permeability (K) called digital Gas Permeameter using Nitrogen Gas, At Temperature = 17.62ºF ,Pressure = 750psi . Put sample into core holder at confined pressure 400psi , entair data (length, Diameter) in software to calculate (K) by Darcy equation.

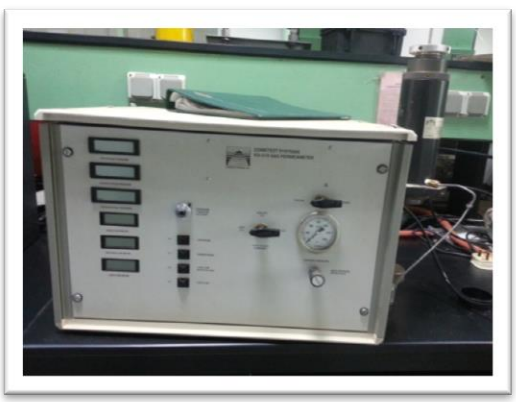

Figure 3.13: Gas Permeameter

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$$K = \left(\frac{Q \times \mu \times L}{A \times \Delta P}\right) \qquad (3\text{-}3)$$

$$A = \left(\frac{\pi}{4}\right) \times D^2 \qquad (3\text{-}4)$$

Where:

K ≡ permeability (md)

Q ≡ flow rate (cc/h)

μ ≡ viscosity (cp)

L≡ length of sample (cm)

D ≡ diameter of sample (cm)

Δp ≡ pressure drop (psi)

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1.10.1.3 The experiment operation steps of core :

The experimental work carries out one type of injection cell, show as figure (1-1) the experimental apparatus for core holder, which consists of one run for core.

The experimental operation to observe the displacement mechanism of low salinity concerning tertiary recovery can be conducted in this way:

The following steps were undertaken to saturate the core with water:

- Using air device, a vacuum pump was affixed to the outflow valve and a vacuum gauge was affixed to the inlet valve, all other valves were closed. The core was evacuated for about 1 hours, then the vacuum pump was turned off and the core pressure was observed to check for leaks.
- The vacuum was sustained again for one hour the core inflow was connected to container holding brine that simulates the reservoir water. The inflow valve was opened the brine was sucked into the core. The inflow was shut when no more water formation would access the core.
- After the core samples were saturated with water formation equilibrated at room temperature actual crude oil is injected into the core at low constant rate, to maintain oil saturation.

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- Establishing initial water saturation (Swi) by displacement with crude oil at 5 cc/h. for 5 to 8 time of pore volume (PV). The initial water in the core will be referred to as connate water. Initial water saturation valves are calculated by extraction of volume or weight.

1.10.1.4 Prepare water we can be used to saturate core:

Table 3.3: Concentrations of Ions in Water

Na^{+}	66.7
Ca^{+2}	12.
Mg^{+2}	2.43
SO_4^{-2}	19.21
Cl^{-}	10.64
HCO_3^{-1}	183.06

Concentration of salt = 0.33g/l

1.10.1.5 Preparing low and high salinity water:

Using destiller to isolate brine from the water ,Tare truy weight (for lsw 0.547and for HSW 2.136) and Put volume of distiller water (1 liter). Concentration for LSW (0.763g/l and for HSW 40g/l) Put NaCl , Run the stairer and add distill water and brine. During mixed of distillated water and NaCl put 75% of water .after short period of time then put remaing of distiller water to ensure all brines mix with water. After that do degassing for air in the water by degaser and vaccum pump.

1.10.1.6 High salinity and low salinity injection:

Waterfloods were then performed on the samples by injecting brine at constant flow rate (5cc/h) at elevated temperature and with nominal back pressure on the plug samples, to ensure no gas production from the oil.

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Measuring the results of residual oil saturation and oil recovery after high salinity water flooding followed by observation of additional oil recovery after low salinity water flooding in the same line of the experiment condition then we can observe if more oil recovery can be achieved from the low salinity one.

For tertiary low salinity water flooding, high salinity brine was firstly injected.

The pressure and oil production were continuously measured, the brine was injected until no further oil production or sharp change in pressure was observed, at which time low salinity water injection commenced from the low oil saturation achieved after high salinity brine injection.

The time required for any flooding process (high and low salinity water) about 24 hours.

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Chapter 4

Results and discussion

1.11 Calculate the effective porosity:

The effective porosity is linked to the concept of pore fluid displacement rather than to the percentage of the volume occupied by the pore spaces, it is calculated by Boyles Law

$$porosity = \frac{pore\ volume}{bulk\ volume} \qquad (4\text{-}1)$$

$$\Phi = \left(\frac{Vp}{Vb}\right) \times 100\% \qquad (4\text{-}2)$$

$$Vb = \left(\frac{\pi}{4}\right) \times D\text{^}2 \times L \qquad (4\text{-}3)$$

Boyles Low:

$$(p1 \times v1) = (p2 \times v2) \qquad (4\text{-}4)$$

$$V2 = \frac{P1 \times V1}{P2} \qquad (4\text{-}5)$$

$$V2 = V1 + Vc - Vd - Vg \qquad (4\text{-}6)$$

$$\frac{P1 \times V1}{P2} = V1 + Vc - Vd - Vg \qquad (4\text{-}7)$$

Where:

Vg ≡ grain volume (cc).

Vc ≡ cup volume (cc).

Vd ≡ disk volume (cc).

$$Vp = Vb - Vg \qquad (4\text{-}8)$$

$$Vp = 45.95 - 35.5 = 10.45\ cc \qquad (4\text{-}9)$$

$$\Phi = \left(\frac{10.45}{45.95}\right) \times 100\% = 22.74\% \qquad (4\text{-}10)$$

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Table 4.1 : Results of Porosity

SN	Corrected	WEIGHT	BULK VOLUME	G.V	GRAIN VOLUME	PORE VOLUME	POROSITY	GRAIN DENSITY
	WEIGHT	(g)	(cc)	Corrected	(cc)	(cc)	(%)	(g/cc)
2s	87.70	87.70	45.95	35.50	35.50	10.45	22.74	2.62

1.12 Calculate the effective permeability:

The effective permeability is the ability to preferentially flow or transmit a particular fluid when other immiscible fluids are present in the reservoir it is calculated by Darcy Law.

From Darcy equation;

$K=(Q\times\mu\times L)/(A\times\Delta P)$

$A=(\pi/4))\times D^2$

D = 3.7858

L = 3.859

Q =334.3401 (cc/h)

Δp = 2.687

μ ≡ viscosity of N_2 (0.00018 poise)

K = 168.1726md

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Table 4.2 : Result of Permeability

ID	Length(cm)	Diam(cm)	Pconf	Patm	dP	Rate	Perm(md)
Sample	3.859	3.7858	400	750	2.6873	334.3401	168.1726

1.13 Calculate absolute permeability:

To calculate The absolute permeability, we injected same water to measure the core permeability, we used three values of flow rate to find differential pressure for any one from this values of flow rates and pressures using Darcy equation.

L= 3.859

Porosity =22.74%

D = 3.7858

Brine water viscosity = 0.92 cp

Table 4.3: Calculations of Absolute Permeability

Q(cc/h)	Δp(psi)	K(md)
10	0.5	25.762
20	1.25	20.609
40	3	17.175

1.14 Calculate initial water saturation:

Initial water saturation was acquired by constant pressure oil flood. Values were found to be matched to those corresponding to the height of the sample above the oil water contact.

Samples were then loaded into hydrostatic core holders, prior to taking the samples to the conditions of the test. The sample was then shut in for a period of time (ageing).

Saturate oil for the core .

Injected water using certain flow rate, then injected oil in same conditions to displace the water from sample, volume of water produced equals to the volume of oil is founded in the core.

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Increasing the flow rates until occurs stabilization for the water volume, then read it and we calculated initial water saturation from following equation:

$$SWi = \frac{TPV-(water\ volume-dead\ volume)}{TPV} \times 100\% \qquad (4\text{-}11)$$

Dead volume = 0.5900cc

Reference volume = 10cc

Produce volume of water = 7cc

Total pore volume=10.45cc

$$SWi = \frac{10.45-(7-0.5900)}{10.45} \times 100\% = 38.7\% \qquad (4\text{-}12)$$

Then , **Calculate Initial oil saturation (Soi**) :

$$Soi = 100 - Swi \qquad (4\text{-}13)$$

Soi=100 – 38.7 = 61.3 % (4-14)

Table 4.4 : Rock Properties of Core Plug

Core ID	Length (cm)	Diameter (cm)	Porosity (%)	Permeability (md)	Swi%
Student	3.859	3.7858	22.74	168.1726	38.7

1.15 Calculate Recovery factor:

The recovery factor increased when we injected low salinity water, compared with the injection of high salinity water, it is calculated form the following equation:

$$RF = \frac{Vo-\Delta V}{TPV} \qquad (4\text{-}15)$$

Where:

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Vo ≡ oil volume (cc).

ΔV ≡ oil volume – oil produced.

TPV ≡ total pore volume

For High salinity water:

$$RF = \frac{6.41-(6.41-3.5)}{10.45} = 0.33 \qquad (4\text{-}16)$$

For low salinity water:

$$RF = \frac{6.41-(6.41-0.8)}{10.45} = 0.0766 \qquad (4\text{-}17)$$

$$cumulative\ oil\ recovery = oil\ recovery\ for\ high\ salinity + oil\ recovery\ for\ low\ salinity$$

cumulative oil recovery= 3.5 +0.8= 4.3 cc

Table 4.5: Comparison between Oil Recovery by High and Low Salinity Water Injection

Salinity Type	Total salinity(mg/l)	Oil recovery(cc)	Recovery Factor	Water cut(%)
HSW	40000	3.5	0.335	95
LSW	763	0.8	0.0766	85

Oil recovery by high salinity water injection at water cut(95%), then injected low salinity water at water cut(85%) . decreasing in water cut value that means oil recovery increased by low salinity water injection.

1.16 Calculate times of injected volume:

$$Times\ of\ injected\ volume = \frac{Q \times t}{TPV} \qquad (4\text{-}18)$$

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Where:

Q≡ flow rate (cc/h).

t≡ time (h).

TPV≡ total pore volume (cc).

Times of injected volume at pore volume (10.45)= $\frac{5\times24}{10.45}$=11.48 times

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Chapter 5

Conclusion and Recommendations

1.17 Conclusion

The experiment by low salinity approve that the effect of low salinity flooding when applied to the residual oil after high salinity water flood can induce more additional oil that would be recovered .

Wettability is an important parameter which influence on the oil recovery to agreater extent, The highest reduction in Sor by law salinity water injection occurred at water wet conditions.

1.18Recommendation

1- More run to approve low salinity mechanism as it can induce more oil recovery.

2- Study the effect of more low salinity water concentration.

3- Can be used in horizontal core holder to investigate low salinity effect

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