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College of Petroleum Engineering & Technology

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

Evaluation of Wettability Alteration as Mechanism to Induce Oil recovery by using Greenzyme (biochemical agent)

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October 2018

الآيـة

وَقُلِ اعْمَلُوا فَسَيَرَى اللَّهُ عَمَلَكُمْ وَرَسُولُهُ وَالْمُؤْمِنُونَ وَسَتُرَدُّون
◌َإِلَى عَالِمِ الْغَيْب ◌ِوَالشَّهَادَةِ فَيُنَبِّئُكُم بِمَاكُنتُمْ تَعْمَلُونَ

صدق الله العظيم

سورة التوبة

الاية 105

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,,,

♥♥Our Family♥♥

……

♥♥My Friends ♥♥

……

AKNOWLEDGEMENT

First of all our greatly thankful to ALLAH to finish this work, Really it is not easy for us to do this work in this form without the kind, experienced and confident guidance of our supervisor Dr. AlradiAbass We cannot find satisfactory words to express our gratefulness to him for his encouragement, patience and valuable supervision. We would like to extend our deep respect and great fullness to the teaching staff in Sudan University Science &Technology, especially in college of Petroleum Engineering & Technology.

We would to record our sincerest thanks and appreciations to all staff members of petroleum engineering in Central Petroleum Laboratories Especially, Engineers Haitham Gadalmoula Fadlelsayed and Mohammad Mirghani Mohammad.

Abstract

Several laboratory experiments indicated that interfacial tension reduction between oil and water or oil and solid surface by chemical and biochemical flooding can improve oil recovery.

Enzymes flooding are promising method for improving oil recovery in sandstone reservoirs with much less safety and environmental hazards and low cost on addition to its availability and ease of composition.

This research presents laboratory results and analysis of core flood to evaluate how Greenzyme affect wettability. The experiment was done in tertiary recovery mode and the results show an obvious improvement in oil recovery due to change in wettability applied to core samples A,B and D. the recovery factor increased from 41.32 to 56.47, 39.41 to 46.75 and 43.57 to 53.13 percentages respectively.

التجريد

العديد من الدراسات تشير الى أن تقليل التوتر السطحي بين النفط والماء أو النفط والسطح الصلب من خلال الغمر الكيميائي والبيوكيميائي من شأنه أن يحسن من عملية استخلاص النفط.

يعد الغمر بالإنزيم احدى الطرق الواعده في عمليات تحسين استخلاص النفط من مكامن الصخور الرملية مع ماتتميز به من قلة التكلفه والوفره وسهولة التحضير وكذلك قلة المخاطر البيئيه.

هذا البحث يتناول عرض وتحليل نتائج معمليه لعملية غمرعينة لباب صخري بمادة قرينزايم لتقييم تأثيرها على خاصية التبلل.

تم إجراء هذا الإختبار ضمن طرق الإستخلاص المحسن للنفط والتي تنطوي تحت الطور الثالث من أطوار إستخلاص النفط وكانت النتائج ايجابيه حيث أظهرت النتائج تزايداً ملحوظا لمعامل الإستخلاص لكل من العينات (أ' ب' د) وكانت النتائج زيلدة معامل الإستخلاص من(41.32) إلى(56.47) ومن(39.41) إلى (46.75) و(43.57)إلى (53.13) في المئه على التوالي.

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INTRODUCTION

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INTRODUCTION

1-1 Wettability:

Wettability is a major factor controlling the location, flow and distribution of fluids in a reservoir rock. The wettability of a core affects almost all types of core analyses. In addition wettability changes relative permeability graph shape (i.e. oil wet, water wet or intermediate) each scenario has separate drawing shape.

Wettability of a reservoir-rock fluid system is the ability of one fluid in the presence of another fluid to spread on rock surface. It plays an important role in oil and gas production as it does not only determine the initial fluid distribution, but also controls flow process in the porous media. The wetness degree of solids by liquids is usually measured by the contact angle that a liquid-liquid interface makes with a solid.

A fluid drop on a plane solid surface can take various shapes. The respective shape (either flat or shaped like a pearl) depends on the wettability of the considered solid. **Figure 1.1** illustrates thatwater is the wetting phase in case of air and water, whereas air is the wetting fluid when air and mercury are present.

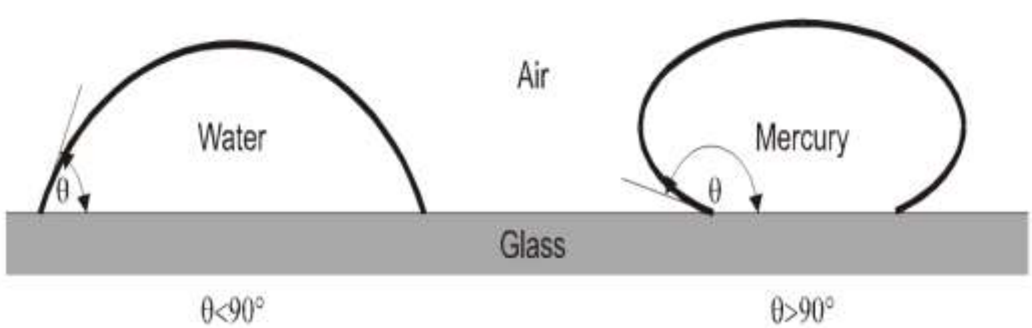

Figure 1.1: Comparison of wetting to non-wetting fluid

1.2Wettability Measurement:

Many methods have been used to measure wettability, describes the three quantitative methods in use today contact angle, Amott method which is used in this study, and the U.S. Bureau of Mines (USBM) method

1.2.1Contact angle method:

The contact angle is used to measure wettability. The fluid is called wetting fluid, if the contact angle is less than 90°. However if the contact angle is larger than 90°, then the fluid is referred to as non-wetting. The contact angle is defined as a consequence of the static equilibrium between a drop of liquid and a plane of a solid surface (Young1984).The drop of a liquid will take a certain shape due to the interfacial tension acting on it figure 1-2 illustrates (σ_{12}) as interfacial tension between fluids (1 and 2) and (σ_{s1}), (σ_{s2}) are the interfacial tensions between solid and fluids.

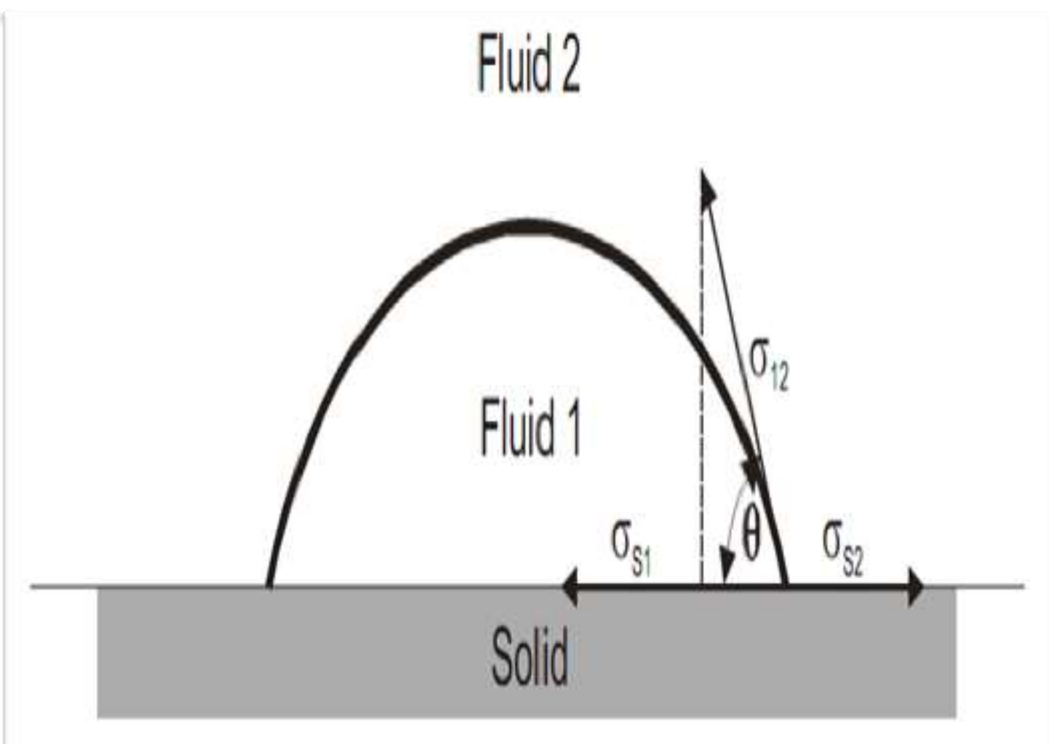

Figure 1.2: contact angle method (by Young 1984)

$$\cos\theta = \frac{\sigma_{s\,2} - \sigma_{s\,1}}{\sigma_{1\,2}} \qquad (1\text{-}1)$$

$$\sigma_{s\,1} + \sigma_{1\,2}\cos\theta = \sigma_{s\,2} \qquad (1\text{-}2)$$

Interfacial tensions, $\sigma_{s\,1}\sigma_{s\,2}$, and θ, are regarded as temperature-dependent. At room temperature the interfacial tension between water and air is 0.073 [N/m] and between oil and water about [0.03 N/m].

1.2.2 Amott Harvey index

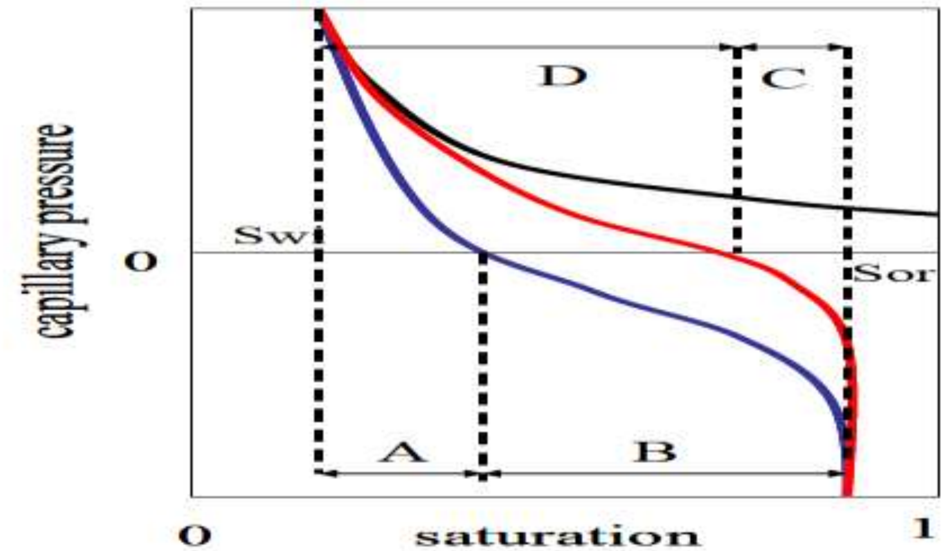

Figure 1.3Calculation of Amott wettability index

The Amott water index I_w is defined as the ratio of volume (or saturation) of oil displaced during spontaneous imbibition's to the volume of oil produced during the total imbibition's.

The Amott oil index I_O is the ratio of water produced during spontaneous (negative) drainage to the total drainage. With notation in **figure 1.3:**

$$\mathbf{Iw} = \frac{A}{A+B} \qquad 1.3$$

$$\mathbf{Io} = \frac{C}{C+D} \qquad 1.4$$

And the Amott index I_{Amott} is the difference between the above two indexes:

$$I_{Amott} = I_w - I_O \qquad 1.5$$

1.3 Problem statement:

Oil is attached to a solid or sand mixture producing high flow resistance that clogs the operation. High viscosity crude oil at Bantiu 3B reservoir at Bamboo field is an oil-wet where thermal EOR is not optimum way to enhance oil recovery. Instead of that chemical and biochemical solutions might induce oil recovery. There is no study confirms that Greenzyme (biochemical) agent can affect wettability and consequently on oil recovery. This study is going to approve that Greenzyme can apply wettability alteration mechanism at mentioned reservoir.

1.4 Study Objectives:

- Main objective:

  To evaluate the extent of Using Greenzyme (biochemical) agent to enhance oil recovery.

- Sub objectives:

1. To evaluate how wettability affected by Greenzyme flooding.
2. To measure the wettability of core sample by using Amott method.
3. To compare wettability results before and after Greenzyme flood.

CHAPTER TWO

Literature review and Theoretical background

Chapter TWO

Literature review and Theoretical background

2.1 Literature review:

Li JiaHua(2002) conducted analysis of single well stimulation done for Shengli oilfield china using Greenzyme. 25 wells were selected; results show that daily fluid production increase from 6bpd -13.6 bpd, viscosity drops from 19.2 Mpa.s to 16.9 Mpa.s, the water content was kept below 60% as a result significant improvement of fluid mobility obtained.

John L Gray(2007) conducted analysis of EEOR using Greenzyme, the treatment included acidizing the well before injecting the Greenzyme, the results also showed that the enzyme fluid can be effective for higher API gravity oil (i.e. 34 API gravity).

HamidrezaNasiri(2009) conducted a laboratory experiment study on use different types of enzymes to improve water flood Performance ,the aim of the study is to determine the effect of Greenzyme on wettability by flooding the cores with different types of enzymes and measuring the Contact Angle, Interfacial Tension and crude oil Viscosity the result of contact angle measurement indicates more water wet behavior using enzymes especially Greenzyme, IFT between oil and brine solution containing Greenzyme has the lowest value.

William K.Ott(2011) applied EEOR treatment in well by injection of concentrated water- soluble enzyme made from proteins released from selected microbes in oil zones which results in an improvement in oil production tests indicates that it is more effective in high water cut well

Liu He (2011) studied the Biological enzyme EOR for low permeability reservoirs, laboratory experiment was conducted by applying 4 types of biological enzymes solution with different concentrations ranging from 0.4% to 5%. The result shows that biological enzymes can effectively release oil from low permeability rocks

2.2 Theoretical background:

The reaction between Greenzyme and injection water/brine results in soaps production (Saponification) at the contact between oil-water phases.IFT reductions happen due to in-situ production of surfactant. As well as more trapped oil produced from residual oil saturation (S_{or}) in addition to wettability change from oil wet to water wet.

2.3 Classification of oil recovery:

According to method or time, oil recovery is classified into three major branches:

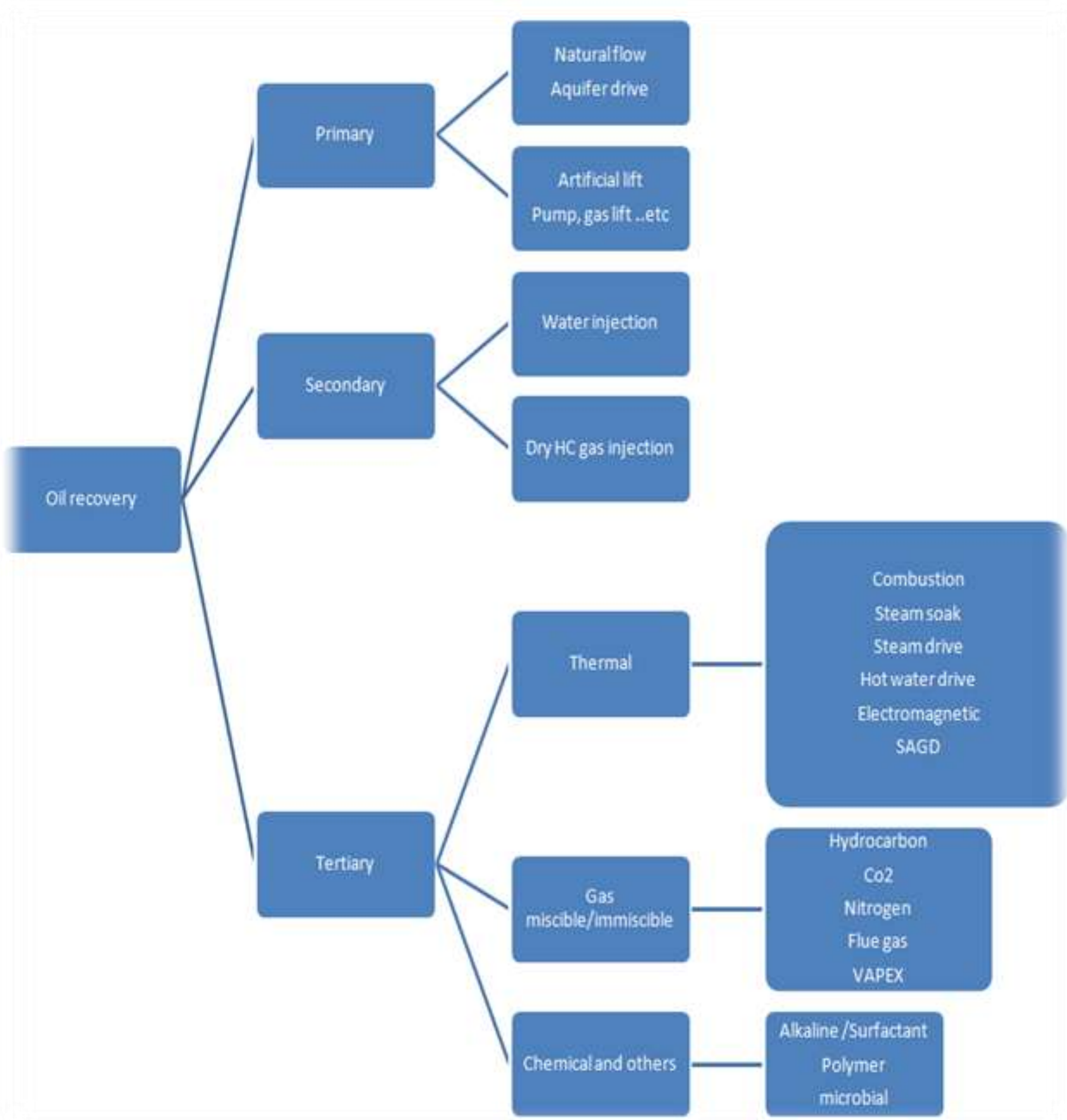

Figure 2.1 Classification of oil recovery

2.4 Chemical and biochemical EOR:

Chemical EOR is the process of injecting of chemical materials (usually add to water) or called (water base) into the reservoir in order to control the mobility ratio (M) by increasing of water viscosity , Reduce the IFT ,Make soaps between interfaces of the fluids and or wettability alteration.

2.4.1 Greenzyme biochemical agent:

Greenzyme is one of biochemical EOR tools which are derived from naturally existed non-pathogenic microbes with some chemical stabilizers which are considered biological in nature and friendly to environment. It is concentrated solution of catalytic enzymes which is very effective in cleaning up high toxic and contaminated solids and sediments.

2.4.1.1Greenzyme physical properties:

This table below shows Greenzyme physically shapes

Table 2.1Greenzyme physical properties:

Greenzyme	
Color	brown (tawny) semitransparent
Composition	Polymeric biological enzyme stabilizer and water.
PH	5-7 (sometimes slightly acidic).
Density	1g/cm^3
solubility	Completely soluble in water, compatible with sewage with any salinity and insoluble in oil.
Boiling point	100℃.
T℃	To 220℃.
Safety	Biologically and will not corrode Or pollute facilities and surrounding environment

Figure 2.2 Greenzyme appearances.

2.4.1.2 Interaction mechanism of Greenzyme:

Greenzyme is a polymeric biological enzyme and as water soluble Product, it can efficiently release hydrocarbon on the surfaces of solid particles in reservoir. It can adhere to rock surface for a long time to change the property of rock into hydrophilic biological surface, reduce wetting angle and interfacial tension of rock particles thereby reducing the flowing resistance of crude oil in Pores but also making oil drops become smaller and more easily exude through Pores.

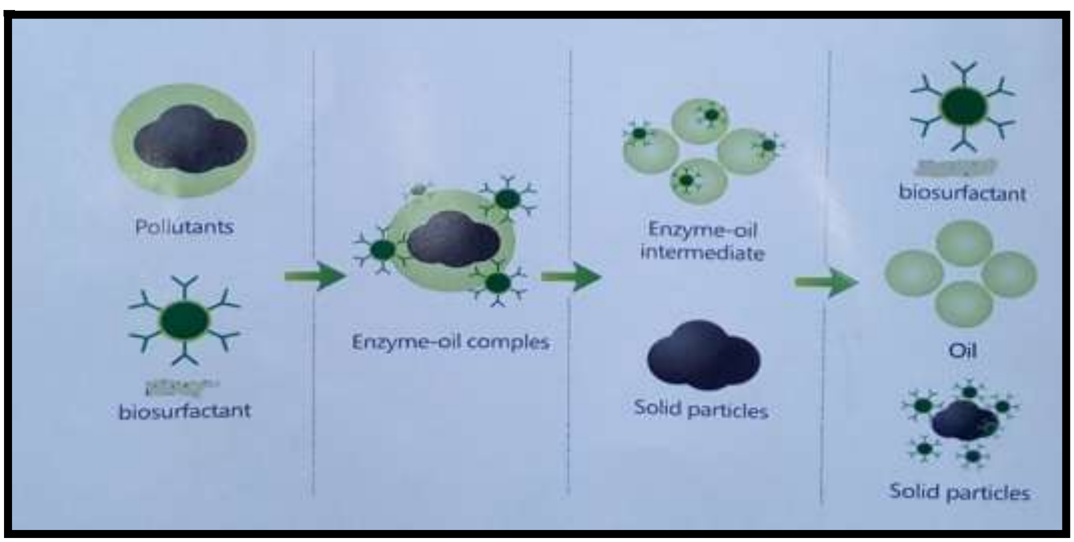

Figure 2.3 Schematic diagrams for interaction mechanism of Greenzyme.

- **Greenzyme** is a concentrated solution of catalytic enzymes which is very effective in cleaning up high toxic and contaminated solids and sediments.
- **Greenzyme** is derived from naturally existed non-pathogenic microbes with some chemical stabilizers which are considered biological in nature and friendly to environment. Does not produce any CO2 or CH4.
- Major examples of environmental clean ups are: Tank bottoms, Storage tanks, Sludge bottoms, Ground water, Surface water, Oilfield mud pits, Platforms, Mining sites.
- The main function of Greenzyme is to release hydrocarbon oil from the oily solids.
- Hydrocarbon content in solids is normally less than 1% after Greenzyme treatment, only 5% to 10% of Apollo Greenzyme mixed with 95% to 90% of water is effective for most applications to release hydrocarbon oil from contaminated solids.
- Can be recycled again and again as long as the percentage of Apollo Greenzyme is not very low.

Do not degrade under 270 degree C.

CHAPTER THREE

Methodology

Chapter THREE

Methodology

3.1 Experimental material:

3.1.1 Crude oil:

The characteristics of oil used in this experiment are shown in below table:

Table 3.1: The Properties of Oil Used in Experiment

Oil name	Viscosity (cp) at 70	API Gravity @ 60 °F (15.6 °C)
Crude oil of Bamboo	**1237**	**17.6**

- **Preparation of crude oil:**

Crude oil from field goes through separating funnel at lab under same reservoir temperature provided by special oven to separate the water from crude oil as shown in figure 3.2.

Figure 3.1separating funnel in the oven

3.1.2 Brines:

Salinity adjusted by changing the concentration of total dissolved salt of synthetic brine in proportion, Synthetic brines contain 300 -1000ppm TDS or distilled water brine. Concentration of salt was 0.5 g/l.

Table 3.2: Concentrations of Ions of Water:

Salinity Type	Total Salinity(ppm)
S_w	300 – 1000

3.2 main components of the apparatus:

3.2.1Stirrer evacuation pump and filter:

In this device put the distill water in stirrer and adding the concentration of salt of reservoir condition ,run the starrier after that ,continue the mixing period of time until ensure all salt dissolve in water then filter brine and degassed .

Figure 3.2: Stirrer and evacuation pump

3.2.2 Core holders:

Figure 3.3 shows core holders which are used for Enhanced oil recovery and designed to test unconsolidated samples at high pressure and temperature applications, the injection cell is made of stainless steel cylinder.

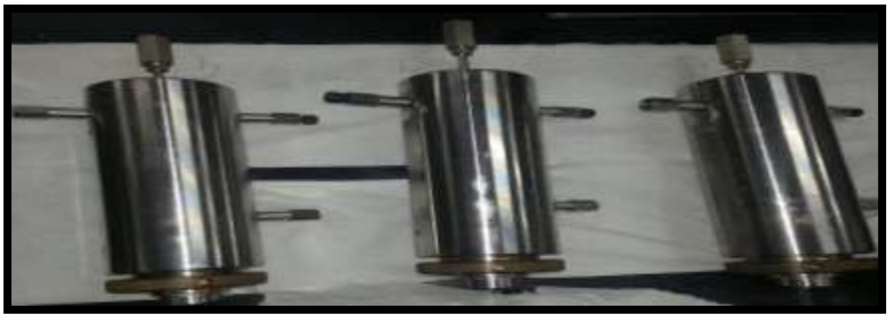

Figure 3.3 aging cell core holders

3.2.3Saturator Machine:

Samples which were loaded into the cell are connected to saturator machine as shown in figure 3.4, prior to be saturated with simulated formation water (brine).

It consists of:

- Cell of samples
- Vacuum pump
- Maxi meter

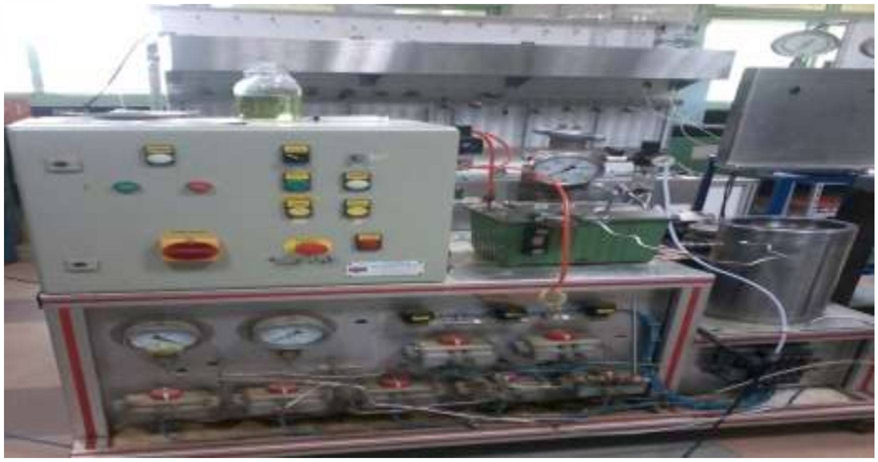

Figure 3.4: Saturator machine

3.2.4 Preparing Greenzyme and brine:

Referring to SPE EOR studies for Greenzyme with Brine Flooding, the optimum concentration of Greenzyme is 0.6 of brine figure 3.5 shows a sample of prepared Greenzyme with brine.

Figure 3.5 Greenzyme with Brine

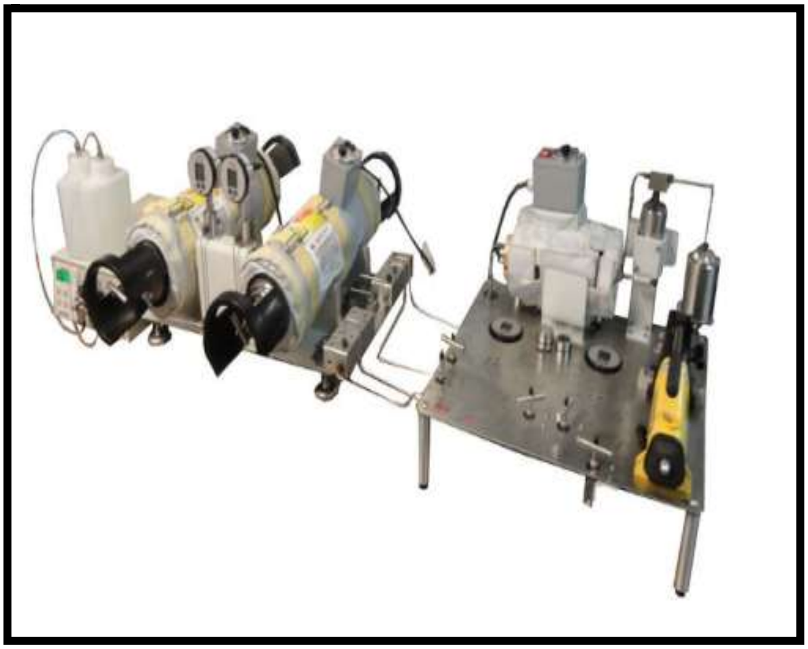

Figure3.6 core Aging system

3.2.5 Core Aging Test Procedures:

- **Aging System Features:**

shows core aging system that has following features:

- Maximum confining and pore pressure
- 10, 000 psi.
- Working temperature: up to 150°C.
- Core length: up to 3 inch.
- Core diameter: 1 or 1 ½ inch.

  Figure 3.6 aging system
- Flow rate: up to 10 ml/min.
- Wetted material: stainless steel.
- N2 requirement: 2,000 psi.
- Power supply: 220VAC, 50Hz.

- **Lab Procedure**

i. System Preparation:

a. Water and oil accumulators were cleaned using distal water/methanol kerosene and soap. Toluene or other light solvent can be used in case of using heavy crude oil.

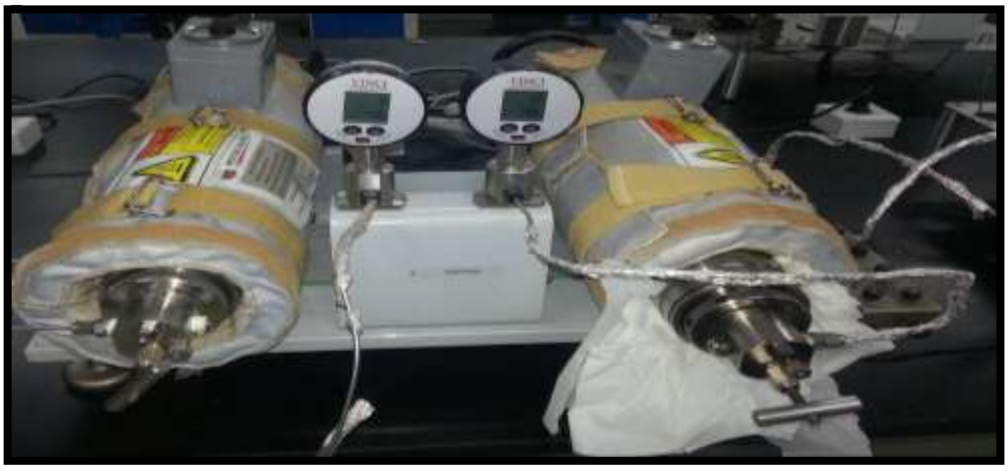

Figure 3.7 EOR accumulators

b. Parts of aging core holder system were cleaned i.e. tube lines, core holder, pushers, etc.

c. Both accumulators were filled one with simulated formation water and the other with crude oil.

d. Heat jackets placed to cover the accumulators, and heat was adjusted to desired temperature as shown in figure 3.7

ii. Loading Sample in the Core Holder:

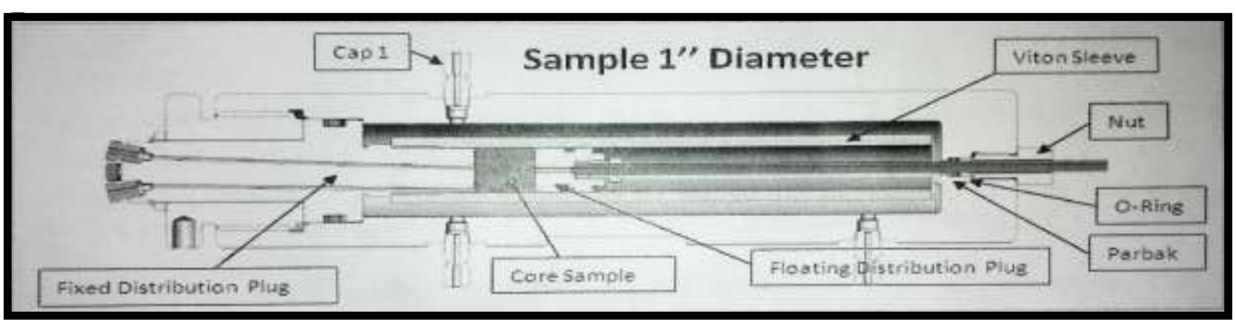

Figure 3.8 Schematic of Aging Core Holder

a. Viton sleeve (figure 3.8) was mounted around fixed distribution plug.
b. The core sample into a rubber sleeve was placed in contact with the fixed distribution plug (figure 3.8).
c. Core holder was connected with the confining system as shown in Figure 3.9

iii. Initiate the Aging Conditions:

a. Air was purged from confining pressure system through the core holder.
b. Confining pressure of 20~50 psi applied and water injected to re-saturate the core sample and remove the air from the flooding system.
c. The net confining pressure was calculated to be equal to Overburden Pressure minus Pore Pressure and squeezing water volume been recorded.
d. Desired temperature been applied to the core holder until stabilization.
e. System back pressurized by dry air (N_2).
f. Water was pumped at initial back pressure of atmospheric pressure.
g. System was pressurized to the desired value with respect to the minimum difference between the confining pressure and the pore pressure is 500psi then system checked for leakage during stability period.

➢ **Experiment Procedures:**

a. Oil injected to saturate the core.

d. The incremental of produced water recorded with different designed flow rates until stability of reading. Then initial water saturation (S_{wi}) was calculated with outlet dead volume extracted.

e. Finally, the core containing crude oil and connate water saturation submerged in Greenzyme-Brine solution for five weeks at reservoir temperature (provided by oven shown in figure 3.10) and pressure.

Figure 3.9 EOR Core holder

Figure 3.10 Oven to set reservoir temperature

3.3 Wettability calculations:

Water production and outlet dead volume were obtained from the experiment. Prior to achieve wettability evaluation using Amott Harvey index the following volumes were calculated:

- Initial oil volume (v_{oi}):

  By applying the following equation:

  $$\mathbf{voi = water\ productiion - dead\ volume} \quad 3.1$$

- Initial water saturation (s_{wi}):

$$\mathbf{swi = \frac{pore\ volume - voi}{pore\ volume} \times 100} \quad 3.2$$

- Incremental of oil after spontaneous period from experiment. Figure 3.11 .Then,
- Recovery factor after spontaneous period is:

  $$\mathbf{Rf = \frac{incremental\ of\ oil\ after\ spontaneous\ period}{voi} \times 100} \quad 3.3$$

- Incremental of oil after forced period from experiment. Then,
- Final recovery factor is given by equation 3.4:

$$\mathbf{Rf = \frac{oil\ \ increment\ sp\ period + oil\ increment\ forced\ period}{voi} \times 100} \quad 3.4$$

- Amott water index:

$$\mathbf{wi = \frac{oil\ increment\ sp\ period}{oil\ increment\ sp\ \ period + oil\ increment\ forced\ period}} \quad 3.5$$

From Amott water index core wetness can be estimated as if w_i is zero then the core is considered strongly oil wet whereas if w_i belongs to 1 it is said to be strongly water wet otherwise wettability differs between water wet when close to 1 or oil wet when approaching zero.

Figure 3.11Cumulative oil after spontaneous period

CHAPTER FOUR

Results and discussion

Chapter Four

Results and discussion

4.1 Core properties:

The below table shows the effective porosity, effective permeability and Fluid Saturations for four samples collected from one interval:

Table 4.1: Tabulated data:

SAMPLE No.	DEPTH (m)	NITROGEN PERMEABILITY mD		HELIUM POROSITY %	RESIDUAL SATURATION % PV		GRAIN DENSITY gm/cm³
		HORIZONTAL	KL		OIL	WATER	
A	1465.54	806.26	769.20	24.06	49.03	19.91	2.66
B	1474.51	271.49	252.67	28.84	36.36	0.00	2.66
C	1483.03	698.49	666.01	23.21	39.48	14.09	2.67
D	1489.50	222.34	211	26.59	18.11	36.59	2.66

4.2 reservoir properties:

The below table shows reservoir characteristic data from bamboo field

Table 4.2: Reservoir Condition

Bamboo West Data		
Interval, mkb	1455 - 1490	
Reservoir	Bentiu-3B	
Pressure, psi	1600	
Temperature, ℃	73	
Salinity, ppm	300 to 1000	fresh water
Viscosity at 70℃	1237	

4.3 Initial water saturation for core samples:

Tables 4.3, 4.4, 4.5 and 4.6 show experimental results of squeezed pore volume, outlet dead volume and water production prior to calculate initial water saturation as final result.

Table 4.3: initial water saturation for sample A

Depth ,ft	**1465.54**
Sat. porosity at room condition, %	22.3
Permeability, md	806.2
Temperature, C	73.0
Pore Pressure/ Back pressure, psi	14.7
Overburden/Confining Pressure, psi	400.0
Squeeze Volume @ 400 psi , cc	0.80
Squeezed pore volume, cc	11.4
Water production reading in tubes, cc	8.9
Outlet dead volume, cc	1.59
Incremental of water after oil flooding, cc	7.26
Initial water saturation Swi, % PV	36.1

Table 4.4: initial water saturation for sample B

Depth ,ft	**1474.51**
Sat. Pore volume, cc	17.0
Sat. porosity at room condition, %	28.5
Permeability, md	271.5
Temperature, C	73.0
Pore Pressure/ Back pressure, psi	14.7
Overburden/Confining Pressure, psi	400.0
Squeeze Volume @ 400 psi , cc	0.80
Squeezed pore volume, cc	16.2
Water production reading in tubes, cc	12.5
Outlet dead volume, cc	1.59
Incremental of water after oil flooding, cc	10.91
Initial water saturation Swi, % PV	32.8

Table 4.5: initial water saturation for sample C

Depth	**1483.3**
Sat. porosity at room condition, %	22.6
Permeability, md	698.5
Temperature, C	73.0
Pore Pressure/ Back pressure, psi	14.7
Overburden/Confining Pressure, psi	400.0
Squeeze Volume @ 400 psi , cc	0.50
Squeezed pore volume, cc	10.2
Water production reading in tubes, cc	10.5
Outlet dead volume, cc	1.59
Incremental of water after oil flooding, cc	8.91
Initial water saturation Swi, % PV	12.6

Table 4.6: initial water saturation for sample D

Depth	**1489.5**
Sat. Pore volume, cc	13.6
Sat. porosity at room condition, %	25.9
Permeability, md	222.3
Temperature, C	73.0
Pore Pressure/ Back pressure, psi	14.7
Overburden/Confining Pressure, psi	400.0
Squeeze Volume @ 400 psi , cc	0.30
Squeezed pore volume, cc	13.3
Water production reading in tubes, cc	11.0
Outlet dead volume, cc	1.59
Incremental of water after oil flooding, cc	9.41
Initial water saturation Swi, % PV	29.2

4.4 **Cumulative oil results after Greenzyme floodafter spontaneous period:**

Tables 4.7, 4.8, 4.9 and 4.10 showweekly records of cumulative oil results for Greenzyme/Brine flooded core samples A, B and D and Brine flooded sample C**:**

Table 4.7 Cum. Oil for sample A

Brine + Greenzyme Sample number : A	
Time/Weeks	**Cum.Oil/cc**
0	0.00
1	2.30
2	2.70
3	2.90
4	3.00
5	3.00

Table 4.8 Cum. Oil for sample B

Brine + Greenzyme Sample number : B	
Time/Weeks	**Cum.Oil/cc**
0	**0.00**
1	**2.70**
2	**3.50**
3	**3.90**
4	**4.20**
5	**4.30**

Table 4.9 Cum. Oil for sample C

Brine Sample number : C	
Time/Weeks	**Cum.Oil/cc**
0	**0.00**
1	**1.40**
2	**1.90**
3	**2.20**
4	**2.45**
5	**2.50**

Table 4.10 Cum. Oil for sample D

Brine + Greenzyme Sample number : D	
Time/Weeks	**Cum.Oil/cc**
0	**0.00**
1	**2.75**
2	**3.50**
3	**3.80**
4	**4.00**
5	**4.10**

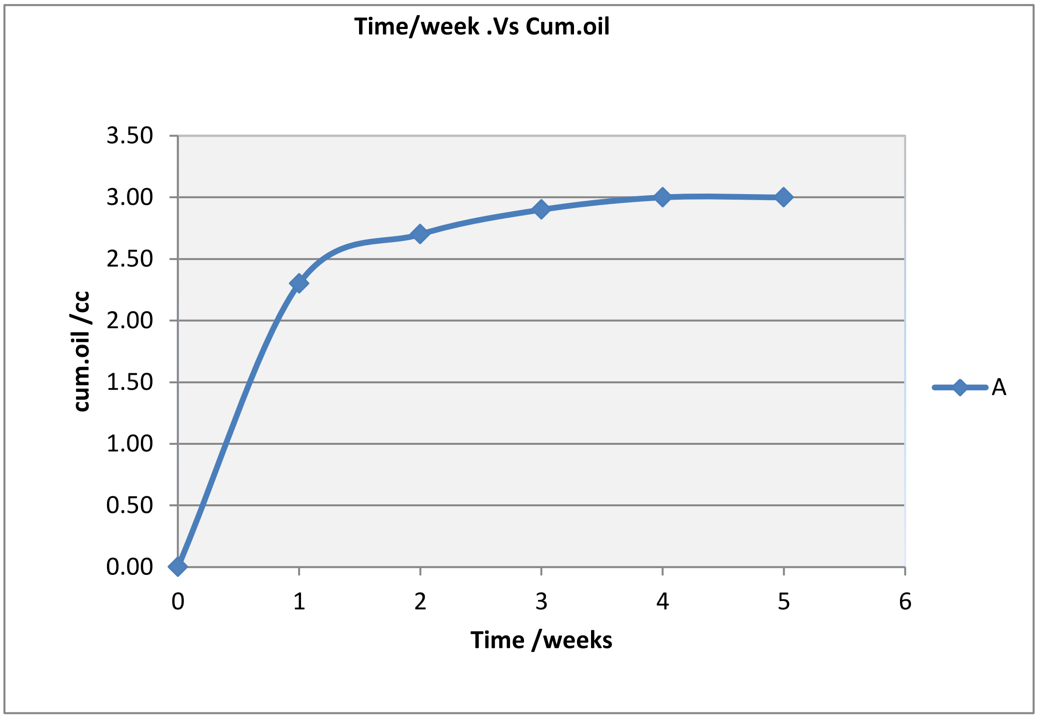

Figure 4.1 cum. Oil vs time/ weeks for (A)

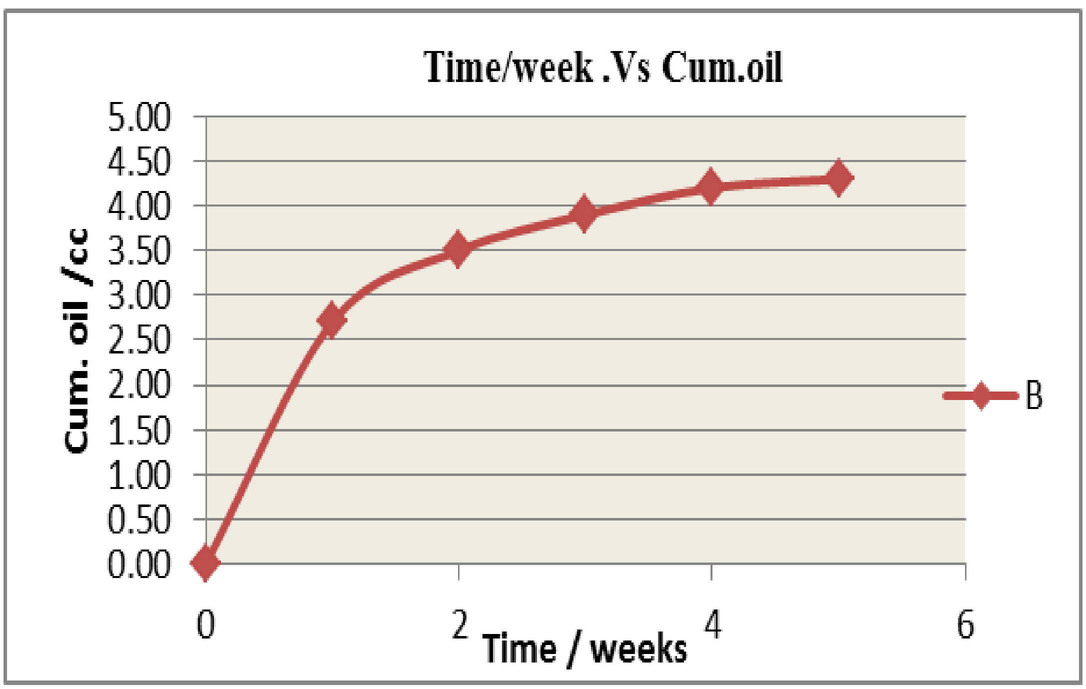

Figure 4.2 cum. Oil vs time/ weeks for (B)

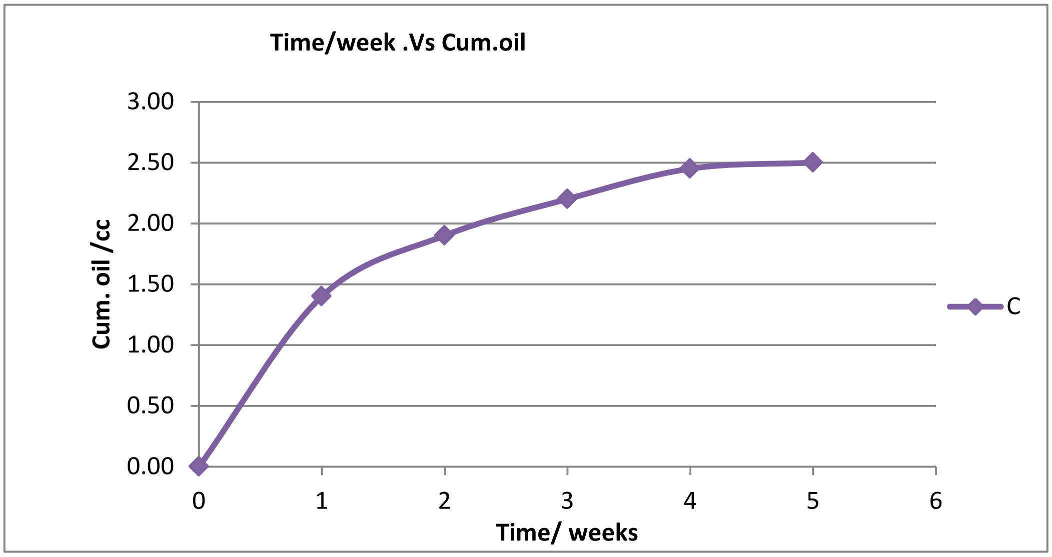

Figure 4.3 cum. Oil vs time/ weeks for (C)

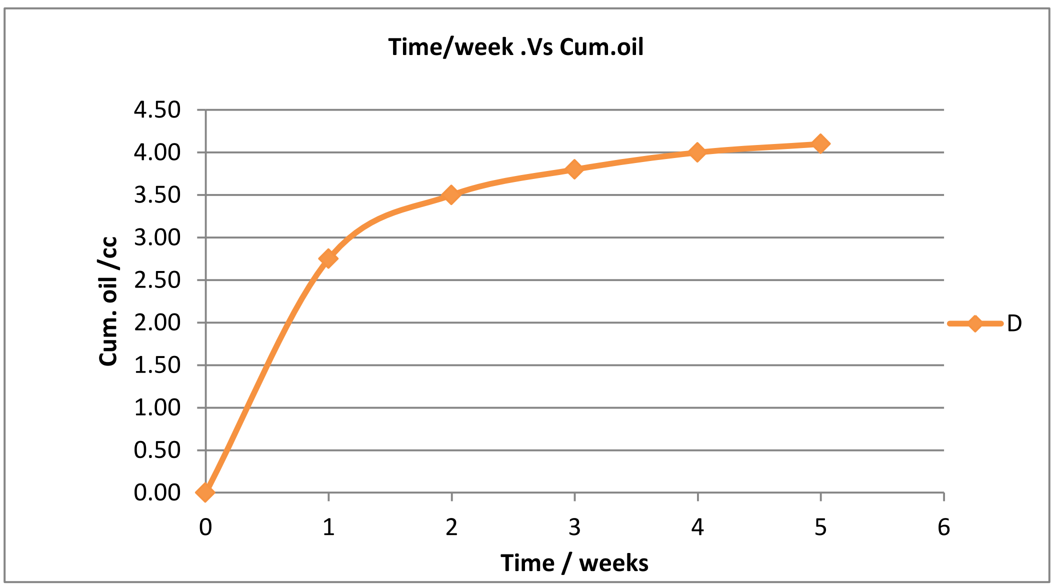

Figure 4.4 cum. Oil vs time/ weeks for (D)

- Figures 4.1, 4.2, 4.3 and 4.4 illustrate weekly records of cumulative oil results for Greenzyme/Brine flooded core samples A, B and D and Brine flooded sample C:-

Table 4.11 recovery factor for sample A

Brine + Greenzyme Sample number : A		
Time/Weeks	**Cum.Oil/cc**	**RF**
0	0.00	0.00
1	2.30	31.68
2	2.70	37.19
3	2.90	39.94
4	3.00	41.32
5	3.00	41.32

Table 4.12 recovery factor for sample B

Brine + Greenzyme Sample number : B		
Time/Weeks	**Cum.Oil/cc**	**RF**
0	0.00	0.00
1	2.70	24.75
2	3.50	32.08
3	3.90	35.75
4	4.20	38.50
5	4.30	39.41

Table 4.13 recovery factor for sample C

Brine Sample number : C		
Time/Weeks	**Cum.Oil/cc**	**RF**
0	0.00	0.00
1	1.40	15.71
2	1.90	21.32
3	2.20	24.69
4	2.45	27.50
5	2.50	28.06

Table 4.14 recovery factor for sample

Brine + Greenzyme Sample number : D		
Time/Weeks	**Cum.Oil/cc**	**RF**
0	0.00	0.00
1	2.75	29.22
2	3.50	37.19
3	3.80	40.38
4	4.00	42.51
5	4.10	43.57

The above tables 4.11, 4.12, 4.13 and 4.14show calculated recovery factor for weekly record of cumulative oil for core samples.

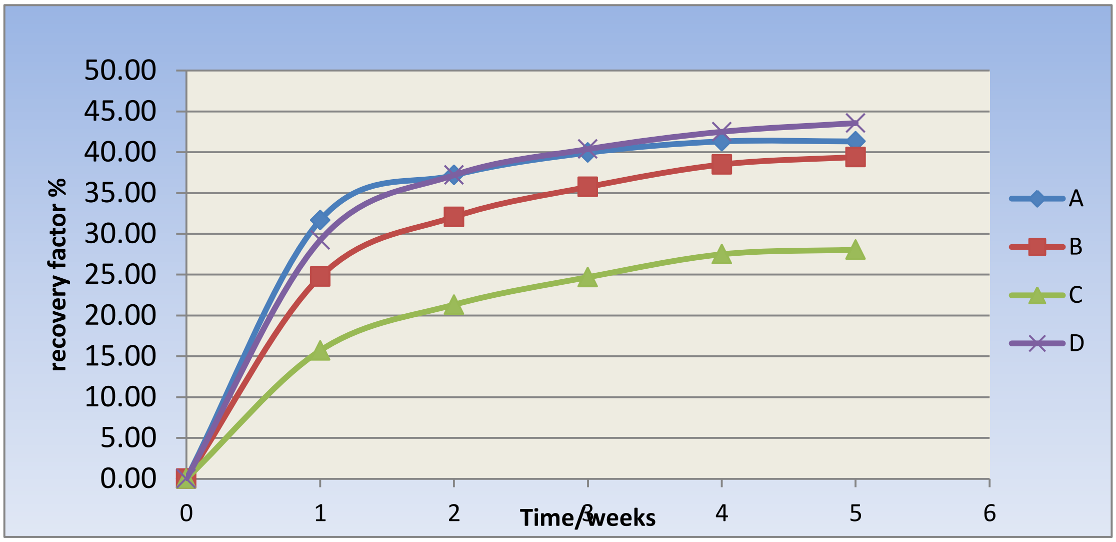

Figure 4.5 recovery factorsvs time

Figure 4.5 shows an increase in recovery after spontaneous period forGreenZyme/Brine flooded samples A, B and D higher than sample C which was flooded by Brine only.

4.5Amott water index Final results:

Table 4.15 Amott water index for sample A

Sample… A	
incremental of oil after Spontaneous period, cc	3.00
RF after Spontaneous period, %	41.32
incremental of oil after forced period, cc	1.10
final RF , %	56.47
Amott water index	0.73

As shown in table 4.15 Amott water index for sample A was 0.73 which indicates strongly water wet condition.

Table 4.16 Amott water index for sample B

Sample…B	
incremental of oil after Spontaneous period, cc	4.30
RF after Spontaneous period, %	39.41
incremental of oil after forced period, cc	1.00
final RF , %	46.75
Wettability index of water	0.80

As shown in table 4.16 Amott water index for sample B was 0.80 which indicates strongly water wet condition.

Table 4.17 Amott water index for sample C

Sample…C	
incremental of oil after Spontaneous period, cc	2.5
RF after Spontaneous period, %	28.06
incremental of oil after forced period, cc	1.20
final RF , %	41.5
Wettability index of water	0.67

As shown in table 4.17 Amott water index for sample C was 0.67 which indicates water wet condition.

Table 4.18 Amott water index for sample D

Sample…D	
incremental of oil after Spontaneous period, cc	4.10
RF after Spontaneous period, %	43.57
incremental of oil after forced period, cc	0.90
final RF , %	53.13
Amott water index	0.82

As shown in table 4.18 Amott water index for sample D was 0.82 which indicates strongly water wet condition.

CHAPTER FIVE

Conclusion and recommendations

Chapter Five

Conclusion and recommendations

5.1 Conclusion:

Experiment results show that:

(1) Greenzyme can change the wettability for sandstone slice from weakly oil-wet to strongly water-wet in a short time, increase relative permeability to oil phase, decrease the relative permeability to water phase, so reduce water cut of produced liquid; whereas biological enzyme slowly changes the wettability for limestone slice.

(2) For water-wet reservoir, when oil phase is displaced by water phase (imbibitions process), biological enzyme can increase driving force, while for oil-wet reservoir, biological enzyme can decrease resistance force (drainage process), which will result in remarkably increasing of actuation, aggregation and movement of residual oil in porous media

(3) Greenzyme can decrease in situ of adhesion for oil phase, and make easy extract the residual oil on the surface of rock, so improve oil recovery

5.2 Recommendation

- This research recommends applying Amott Harvey wettability index, Amott oil index should be determined through drainage exterminate.

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