CHAPTER 1

INTRODUCTION

1.1 Background

Alkaline flooding is one of Enhance Oil Recovery method that cause pH increased in injection water by present of cheap alkali like sodium hydroxide and appear to be the simplest one among all chemical flooding process that can be used to save cost (J, B, & Leung, 2008,p 1-7). This project is emphasizing more on cause for recovery improvement in low acid number crude oil by using strong and weak alkali. In order to do that, all the parameters and cause of each process contribute in this study such as alkali concentration, salinity of the alkali solution and reservoir condition are determined earlier in compatibility test.

Besides that, comparison study of mechanisms occur to achieve incremental oil recovery like emulsification and wettabilty alteration in low acid number crude oil are determined at the end of this project. Finally, this project is feasible in term of period conducting it because the scope of work and objective has been narrow down to make sure it can be finished in given time frame.

Although previous works has conducted detail and comprehensive study on this topic but there are some improvement need to be done in order to get the accurate result and correlation. First, the type of alkali used in previous project only one which is sodium hydroxide and for this project, I will used one strong alkali and one weak alkali to get better understanding on the relative permeability changes. Second, the formation of alcohol claimed by previous work is not proven scientifically because there is no composition analysis of effluent after core flooding but for this project, Gas chromatographic test is introduced to analyze the composition whether alcohol formation is present or not in lowering IFT. Third, previous work do not put more emphasize on the emulsion retention test and the effect on IFT so, this project will put focus on oil-in-water emulsion in reservoir condition which is in reservoir temperature and it's dynamic IFT. Lastly, previous work did not prform study on wettability alteration after alkaline flooding so, this project will examine the wettability changes with respect to contact angle and end-point relative permeability.

1.2 Problem statement

The minimum acid numbers ranging from 0.5 to 1.5 mg KOH per gm of oil have been suggested as condition to improve recovery (Cooke, Williams, Kolodzie, 1974, p 1374). Majority of works suggest that application of alkaline flooding is very limited due to low carboxylic acid content in crude oil to react with alkaline in producing in-situ surfactant. Hence the recovery of residual oil is lower compared to high acid number crude oil due to Interfacial tension (IFT) cannot be lowered due to lack of surfactant produced during reaction. However there is actually no direct correlation has been observed between acid number (AN) of the crude and IFT also the magnitude of enhanced oil recovery. Increased production did not correlate with AN or IFT beyond these threshold values (Ehrlich, Wygal, 1977, p 270). This project is significant to prove there is effect in macrospic and microspic displacement efficiency even in low acid number crude oil because both the IFT and contact angle experiment indicate that the acid structures or type present in the crude may be more important than its concentration(Hoeiland, Barth, Blokhus, & Skauge, 2001,p91-103).

1.3 Objectives

1. To examine changes of end-point fluid relative permeability changes using strong and weak alkali in low acid number crude oil.
2. To examine emulsion retention of oil-in-water emulsion for low and high acid number crude oil and relation with dynamic interfacial tension.
3. To investigate wettability alteration of alkaline flooding in low acid number crude oil with respect to contact angle.

1.4 Scope of study

1. Relative permeability end point and oil saturation
2. Emulsion retention of oil-in-water emulsion
3. Dynamic Interfacial tension of oil and water
4. Wettability alteration of reservoir rock with respect to contact angle changes using sessile drop and relative permeability end point.
5. Gas chromatographic test to trace the alcohol of effluent after core flooding.

1.5 Project significant

Due to low acid number in crude oil, it is hard to create in-situ surfactant for lowering the interfacial tension but it is important to prove this alkaline flooding in low acid number crude oil is successful due to this method is lower cost for enhance oil recovery (EOR) compare to the other methods. This research and laboratory conducted to contribute in the study on alkaline flooding for Dulang crude oil.

CHAPTER 2

LITERATURE REVIEW AND THEORY

2.1 Theory

Alkaline flooding is another method by which oil displacement efficiency can be improved. The benefits of this process have been known for a long time and were first observed by Squires (1917) and by others later on (Carcoana, 1992,p 160). The alkaline flooding method relies on a chemical reaction between chemicals such as sodium carbonate and sodium hydroxide which most common alkali agents and organic acids in crude oil to produce in situ surfactants (soaps) that can lower interfacial tension (IFT) (James J. Sheng, 2011, p 389). The most important element is whether the crude oil has the carboxylic acid or not to react with the alkali in formation of in-situ surfactant (Hoeiland, Barth, Blokhus, & Skauge, 2001,p 91-103).

2.2 Recovery Mechanism

The mechanisms involve in this method play important role in contributing the Enhance Oil Recovery. Expert has found the combination of mechanism that assists in displacement efficiency such as **emulsification and entrainment** (Johnson Jr, 1976, p85) and **emulsification and entrapment** (Jennings Jr, Johnson Jr, McAuliffe, 1974, p 1344) that affect interfacial tension (IFT). In this project, the focus is more on the retention of emulsion. If the emulsion is stable enough, like oil-in-water emulsification oil once dispersed as fine droplets remains in the aqueous emulsion phase and can be recovered(Larson, Davis, Scriven,1980, p246).The retention of this emulsion depends on the concentration of the reservoir formed alkali-oil surfactant at the interface (Guo, Liu, Li, Wu, & Alfred, 2005,p213-218). The last mechanism is **wettability alteration** of the pore walls by chemical agents can improve oil recovery when the original wettability condition is unfavorable. surfactant and caustic flooding alter wettability by changing the distribution of the fluid phase in the pore space and influence relative permeabilities, imbibition, drainage behaviour,and capillary pressure by presumably of contact made with rock surface by interface between aqueous and oleic phases (Larson, Davis, Scriven,1980, p244).The ability of acids to adsorb onto mineral surfaces and thereby alter the wetting properties of the surface (Thomas et al.,1993). In this project the focus in wettabilty changes is contact angle measurement on silicate surfaces that show higher acid number (AN) result in water-wet surface and higher base number result in oil-wet surface (Hoeiland, Barth, Blokhus, & Skauge, 2001,p91-103).

2.3 Type of alkali used

In the past, sodium hydroxide, sodium carbonate used most often. The dissociation of an alkali results in high pH. For example, NaOH dissociates to yield OH^-:

$NaOH — Na^+ + OH^-$

Sodium carbonate dissociates as

$Na_2CO_3 — 2Na^+ + CO_3^{2-}$

Followed by the hydrolysis reaction

$CO_3^{2-} + H_2O — HCO_3^- + OH^-$

(James J. Sheng, 2011, p 389-390).

Although some expert said that sodium orthosilicate has higher residual oil recovery than sodium hydroxide for continuous flooding in same concentration and 0.5 PV slug (C & Krumrine, 1979,p3) but the mechanisms through which sodium orthosilicate produced higher recovery than sodium hydroxide in those tests were not concluded. Reduction in IFT is similar for both chemicals. Previous work proved that emulsion retention is closely related to type of alkaline used in the solution. As for example, sodium orthosilicate will result in less emulsion problems like emulsion formation with higher shear viscosity than with corresponding sodium hydroxide systems (Mun Sik & Darsh T, 1980, pp. 255-258). This problem in emulsion can be minimized using optimum salinity of the alkaline solution which is in range of 0.5% - 1% sodium chloride or salinity. There must be other factors that play more important role so, it is still relevant to use sodium hydroxide as the alkali agent. The pH of the solutions varies with salt content. For instance, the pH of caustic solutions decreases from 13.2 to 12.5 when the salinity increases from 0 to 1% NaCl (James J. Sheng, 2011, p 389-390). By comparison, the pH of sodium carbonate solutions is less dependent on salinity (Labrid, 1991, p 123-155). It has been observed that the minimum IFT occurs over a narrow range of alkaline concentrations, typically 0.05 to 0.1 wt.% with a minimum IFT of 0.01 mN/m (Green and Willhite, 1998).I would like to emphasize on the optimum concentration of alkali and salinity in this project to achieve the objective by focus on type of alkali used in lowering the IFT.

2.4 Laboratory studies of alkaline flooding

From the past, many experts have done research on this method also known as caustic flooding to determine the relationship between crude oil properties particularly in acid number (AN) and Enhance Oil Recovery (EOR). The results of the linear regression analysis showed that the best correlation AN and Interfacial Tension (IFT) is with the log of the AN that result in all crudes with an AN greater than 0.5 proportionally increase with caustic coefficient that show IFT will be lowered if the value of coefficient is high (Jennings, Harley Y, 1975, p 202). After years, argument happened because the one expert showed the correlation the highest AN or the lowest IFT do not necessarily give the best recovery (Ehrlich, Wygal, 1977, p 270). However, it has been reported from the pilot testing on various field utilizing alkaline flooding, it was discovered that even in reservoirs with very low AN ; the performance of alkaline flooding somehow equals with reservoirs with higher AN (Mayer, Berg, Carmichael, Weinbrandt, 1980, p23). Recent finding claim that even if the AN of the oil was zero, IFT could be reduced by adding alkali in the water (James J. Sheng, 2011, p 402). This observation requires better understanding of the displacement mechanism by considering other factors that contributes in increase the recovery for low AN crude oil. All of the mechanisms can be determined using laboratory approach in order to investigate which mechanism affects most the EOR from the beginning of this method introduced. In comparison of the type of alkali used whether strong or weak in the experiment has showed that lower IFT were observed at low and high concentrations of sodium hydroxide which is strong alkali than with sodium silicate less strong alkali (Larrondo, Urness, Milosz, 1985, p 310). Recently, laboratory result shows that sodium carbonate reduces the extent of ion exchange and mineral dissolution in sandstones as a weaker alkali compared with sodium hydroxide because mineral dissolution increases with pH value (James J. Sheng, 2011, p 246).

During earlier experiment, most experts focus more on IFT measurement to study the effect in oil recovery. In fact, one of the important experiments is measuring the contact angle using sessile drop technique (Neuman and Good,1979,p31) to investigate the wettability alteration. Expert has proved that acid structures or types may be more important than its concentration in crude oil from the result of contact angle measurement (Hoeiland, Barth, Blokhus, & Skauge, 2001,p 91-103).

Besides that, two important laboratory studies before we can proceed to the next level is acid extraction experiment and acid number measurement. According to (Lijuan, Benxian, & Gongqun, 2008) the 2-methylidazole solution in ethanol was used to remove naphthenic acids from crude oil and the optimal duration is 10 minutes in room temperature. Acid number measurement for this experiment is according to ASTM D974 to measure of acidic constituents using a color change to indicate the inflection. The sample is dissolved into a solution of toluene, p-naphtholbenzne, and ethanol containing water. The solution is titrated with KOH in ethanol while the color is monitored. This test is used on new oils and oils that are not excessively dark. According to (Fan & Buckley, 2006) the solvent for most titrations is mixture of 50% tolune,49.4% alcohol, and 0.06% deionized distilled water. In addition,oil sample is titrated using alcohlic KOH.

2.5 Crude oil fraction and fluid properties

In many papers and journals, researchers put lot of efforts to investigate the fractions inside the crude oil itself to see the effect on lowering IFT (P.A, N, J.T, R.M, & T.F, 1979, pp. 103-113) and changes in contact angles (Hoeiland, Barth, Blokhus, & Skauge, 2001,p 91-103). The fractionation of crude oil used is the modified SARA-fractionation which the oil is precipitated with n-pentane. The deasphaltened fraction which contain approximately same amount of acids as the original crude is more eluted with hexane to get saturates toluene to get aromatics, and dichloromethane to get resin (Hoeiland, Barth, Boe, & Skauge, 2001,p 1-9). The other method is by 2 fractions which are benzene eluted and ether eluted fraction (P.A, N, J.T, R.M, & T.F, 1979, pp. 103-113). Many expert agreed that asphaltene will lead to increase of IFT and not comparable to surfactant in lowering the IFT. It is obvious that the ultralow IFT values of the crude are exceedingly narrow in pH range but in the other studies stated that the decrease in IFT with increasing pH in the alkaline pH range corresponds to the acid numbers and independent of acid concentration. From the experiment conducted, both the IFT and contact angles indicate that the acid structures or type may be more important than its concentration. The high content of phenolic compounds, alkyl acids, and cyclopentane acids has greatest impact on wettability but high acid number due to polyvalent acid give greatest impact on IFT (Hoeiland, Barth, Blokhus, & Skauge, 2001,p 91-103). Later investigation has proved that 2 of the low acid number crude oil exhibited the IFT that decrease continuously with increasing pH (Jill S & Tianguang, 2005, pp. 1-12). From the research and experiment, there is still potential of recovery increment for low acid number crude oil.

In term of interfacial rheological properties, more research conducted with respect to viscosity as it can lead to extend the studies in mobility ratio. The result from most journals has agreed that the decrease of oil viscosity will increase the oil recovery. As from (Jill S & Tianguang, 2005, pp. 1-12) stated that IFT decrease with lower viscosity. Besides, Laboratory studies on Saudi oil successfully proved that oil viscosity decrease with increasing temperature from 22̊ c to 60̊ c and give remarkable increase in mobility ratio (M.H & M.S, 1993, pp. 295-314). Further studies by (J & I, 1999, pp. 41-47) concluded that interfacial viscosity of non-newtonian flow behavior decrease drastically in the presence of alkaline solution especially sodium hydroxide. The concentration of alkaline is also important as proved by (J & I, 1999, pp. 41-47) the positive effect on decrease in interfacial viscosity with increase of sodium hydroxide concentration from 0.1 g/L until 1 g/L and at high concentration, the temperature effect is negligible. High acid is not the only precondition for efficient in lowering IFT due to not all the hydrolyzed organic precursor are active at surface.

As conclusion, further study on the cause for improved oil recovery in alkaline flooding of low acid number crude oil is significant in order to determine which cause contribute the most in oil recovery.

CHAPTER 3

METHODOLOGY / PROJECT WORK

3.1 Methodology

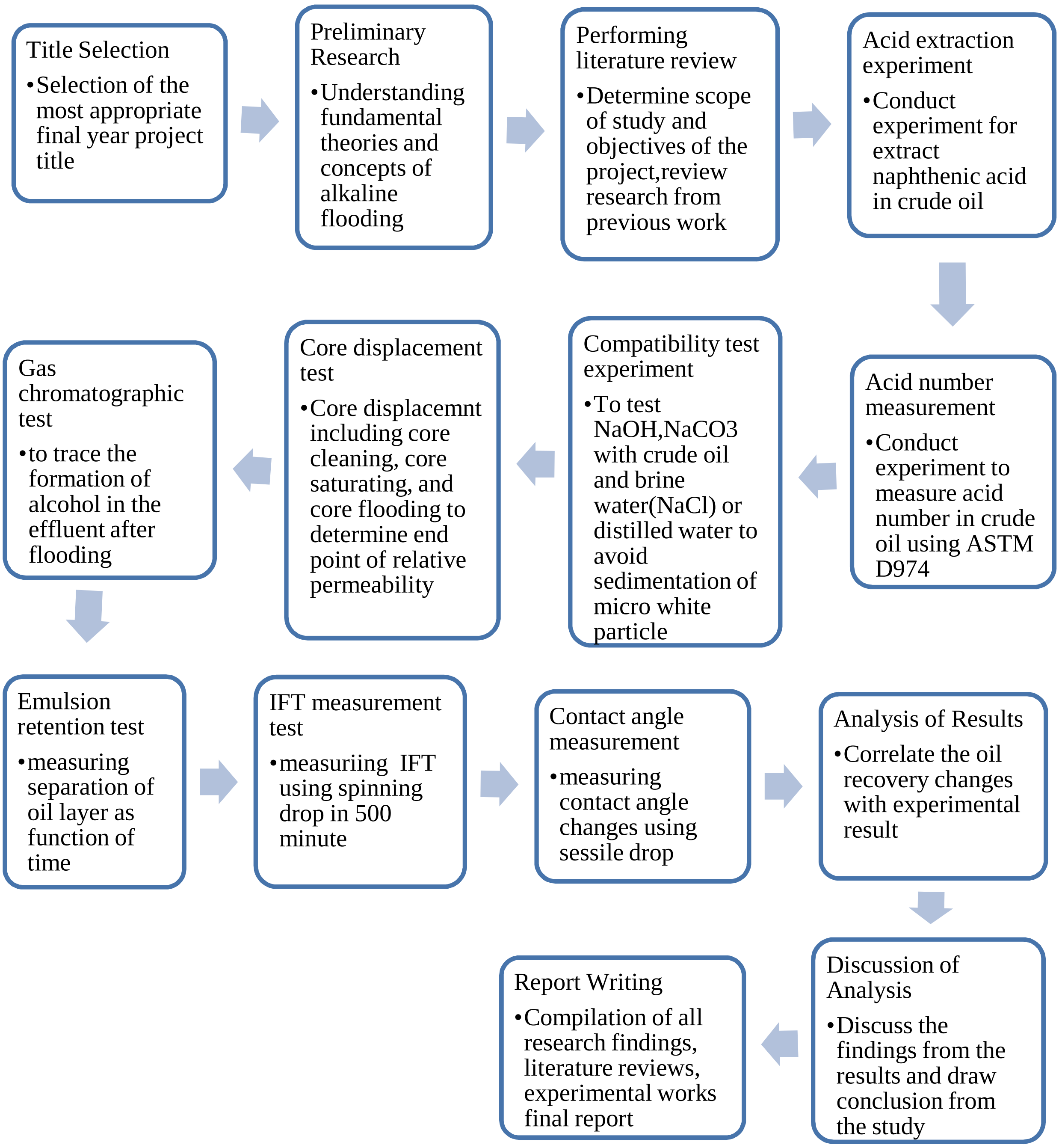


Figure 1: methodology of the project work

3.2 Gantt chart

No.	Activities /Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Selection of Project Topic														
2	Preliminary research work														
3	Literature review and understanding theory and concept														
4	Preliminary Report Submission														
5	Detail Studies On Laboratory Procedure														
6	Proposal Defence and Progress Evaluation														
7	Provision of chemical and material for experiment														
8	Acid extraction experiment														
9	Acid number measurement														
10	Compatibility test experiment														
11	Initial results Gathering														
12	Draft Interim Report Submission														
13	Submission of Interim Report														

Table 1: Gantt chart of the whole project in FYP 1

No.	Activities /Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Core displacement test/core flooding															
2	Gas chromatographic test															
3	Emulsion retention test															
4	IFT measurement test															
5	Contact angle measurement															
6	Analysis and discussion of result															
7	Submission of Progress Report															
8	Submission of Draft Report															
9	Submission of Dissertation (soft bound)															
10	Submission of Technical Paper															
11	Oral Presentation															
12	Submission of Project Dissertation (Hard Bound)															

Table 2: Gantt chart of the whole project in FYP 2

3.3 Research Methodology

This project begin with identify the problem statement which is the alkaline flooding in low acid number crude oil. Then, analysis of the problem take place where the possible route problem identified and possible alternative and method to overcome it determined using literature review and understanding fundamental theory and concept. After that, selection of the possible alternative and method selected after narrow down the scope of study. This process continues with planning the chemical and material needed to be used in experiments also project activity such as procedure for experiment.

3.4 Experimental Methodologies

In order to achieve all the objectives, series of experiments has been setup and divided into 2 types which are general experiments and objective oriented experiments.

3.4.1 General Experiments

It is mean to provide the chemical before the objective oriented experiments take place and as compatibility test of the optimum alkali solution or aqueous for flooding including salinity and concentration of alkali. The experiments are as follow:

3.4.1.1 Acid number determination

- Objective: To determine the acid number in crude oil and add carboxylic acid to crude oil to make the crude oil high acid content.
- Materials: Ethanol or Isopropanol, Potassium Hydroxide, p-naphtholbenzne Solution, Carboxylic acid like acetic acid, crude oil and pH meter.
- Apparatus: burette, graduated cylinder, weighing scale, retort stand, beaker 1 liter
- Procedure: Alkaline solution titration was prepared by weighing out 0.1 mole of KOH (= 2.805 g), dissolved it in ethanol to make the total volume equal to exactly 500 ml. This gave 0.1M KOH solution in ethanol. Then 500 ml solvent for crude oil is prepared consist of 250ml tolune,225ml ethanol, and 25ml deionized distilled water.3 to 4 drops of phenolphthalein solution were added and titrated with 0.1M KOH alcoholic solution. The color of the indicator changes from colorless to pink. Accurately 10g of sample is weighed and was added into 100 ml of the solvent in the beaker. The sample is swirled completely until dissolved by the solvent. Then it is titrated immediately with 0.1M KOH alcoholic solution at room temperature, using a 25 ml burette. The solution is swirled vigorously until the color of the indicator changes from colorless to pink as was with solvent and crude oil neutralization.

  *remark: The method described is a color titration method ASTM D974 in order to determine at which titration volume should be stopped, a pH meter was used to indicate that the solution has been neutralized due to the fact that crude oil is black to brown in color but it is visible in the solvent.

3.4.1.2 Acid extraction or removal

- Objective: To extract acid component (naphthenic acid) in crude oil and become low acid content.
- Materials: 2-Ethylimidazole, Ethanol, crude oil
- Apparatus: Beaker 1 liter, Magnetic stirrer, Thermometer, Separating funnel, retort stand, weighing scale
- Procedure: 1 litre of Ethanol was mixed with 200g of 2-Ethylimidazole powder to create the extraction solvents reagents. 500g of crude oil sample was weighted. Then 200g of the reagent mixture was mixed with the crude sample. This gave a ratio of reagent: oil to 0.4:1. During the extraction, the mixture was heated at a constant 37^{o}C and constantly stirred using magnetic stirrer. The process was conducted for 10 minutes. After the extraction, the mixture was put into a separating funnel for 30 minutes at room temperature to gravity-separate the reagent with the acid compounds extracted from the crude oil. At the top of the funnel will be mainly the de-acidified crude oil and in the bottom was mainly reagent with ionic liquid.

  *remark: The method described was extracted from (Lijuan, Benxian, & Gongqun, 2008) in the paper Removal of Naphthenic Acids from Beijing Crude Oil by Forming Ionic Liquids.

3.4.1.2 Compatibility test of alkali solution

- Objective : To find the optimum concentration and salinity aqueous solution using NaOH, NaCO3 with crude oil and brine water(NaCl) or distilled water to avoid precipitation of micro white particle
- Materials: Sodium Hydroxide, Sodium Carbonate, Sodium Chloride, Distilled water, crude oil
- Apparatus: Test tube, graduated cylinder, weighing scale
- Procedure:

  The mass of sodium hydroxide needed is calculated using the following formula:
  Mass = (volume x mass percentage) / (100 - mass percentage).

For example, to make a 1 percent solution using 60 mL of distilled water, this equation used to determine the amount of sodium hydroxide to be used:

Mass = 60 x 1 / (100 - 1) = 0.6 g

The calculated amount of sodium hydroxide is weighed on the scale. Distilled water of 60 mL is poured into the test tube, and add sodium hydroxide. The solution is mixed with the spoon or gently swirl the test tube until the salt dissolves completely. Then, the mass of sodium chloride is calculated using above formula for example 1 percent solution in 60 mL then add into test tube. About 40mL crude oil (de-acidified and acidic) is measure and added into test tube to make the solution 100 mL. The test tube is shacked and waits for several minute to see whether precipitation occurs or not. If the precipitation occurs, above step is repeated until there is no precipitation. This procedure also applied to sodium carbonate and is kept in oven at 70^{o}C.

*remark: solutions are made with mass percentage according to major papers rather than molarity of the solution.

3.4.2 Objective Oriented Experiments

It is mean to achieve the objectives that have been setup in this project. The experiments are as follow:

3.4.2.1 Objective 1 experiment (To examine changes of end-point fluid relative permeability changes using strong and weak alkali in low acid number crude oil)

- Experiment 1: Core displacement test including core cleaning, core saturating, and core flooding using relative permeability system test.
- Materials: Tolune, Brine water (Sodium Chloride), crude oil, alkaline solution (Sodium Hydroxide and Sodium Carbonate),
- Apparatus: Test tube, graduated cylinder, soxhlet extractor
- Machine : Relative Permeability System,CO_2 core cleaning,
- Procedure :

  <u>Core cleaning</u>

  The Soxhlet distillation extraction method is used to dissolve and extract oil and brine from rock core sample by using Toluene. The cleanliness of the sample was determined from the colour of the solvent that siphons periodically from the extractor which must be clear. The core samples are placed in the extractor and cleaned by refluxing solvent. The solvent is heated and vaporized in boiling flasks and cooled at the top by condenser. The cooled solvent liquid falls into the sample chamber. The cleaned solvent fills the chamber and soaked the core sample. Once cleaned and dried in oven, the porosity and permeability of the core samples were measured.

Core Saturating

The core sample will undergo two saturating stages, firstly with normal brine water as pre-flush. The core permeability to brine will be measured using a constant rate pump. Then it will be flooded again with crude oil until both samples are at the state of irreducible water saturation. Following this, the cores are aged for 10 hours in order to approach wetting equilibrium. This process is oil saturating process.

Core Flooding

After aging, brine of Sodium Chloride content was used to flood and displaced the oil. The process was conducted until a stable residual oil is established. Then, it followed by a continuous flooding of the alkaline solution in order to remove the residual oil. Displacements runs were conducted using 1 crude samples (de-acidified) with 2 type alkalis which are sodium hydroxide and sodium carbonate.

- Experiment 2: Gas chromatographic test to trace the alcohol in effluent after flooding using Gas chromatographic machine.
- Materials : Alkaline flooding effluent
- Apparatus: Test tube
- Machine : Gas chromatographic machine
- Procedure: The effluent will be collected at the end of each run to be used in the gas chromatographic analysis. The method for mixture of hydrocarbon and alcohol also the capillary column diameter must be determined in order to test the effluent. The result obtain will be interpreted according to its concentration and selected peak to trace the alcohol whether methanol or ethanol.

3.4.2.2 Objective 2 experiment (To examine emulsion retention of oil-in-water emulsion for low and high acid number crude oil and relation with dynamic interfacial tension)

- Experiment 3: Emulsion retention test of oil-in-water emulsion with alkaline solution by measuring separation of oil layer as function of time.
- Materials : Brine water(Sodium Chloride), crude oil, alkaline solution (Sodium Hydroxide and Sodium Carbonate),
- Apparatus: Test tube, graduated cylinder

  Procedure:

  The mass of sodium hydroxide needed is calculated using the following formula:

  Mass = (volume x mass percentage) / (100 - mass percentage).

  For example, to make a 1 percent solution using 60 mL of distilled water, this equation used to determine the amount of sodium hydroxide to be used:

  Mass = 60 x 1 / (100 - 1) = 0.6 g

  The calculated amount of sodium hydroxide is weighed on the scale. Distilled water of 60 mL is poured into the test tube, and adds sodium hydroxide. The solution is mixed with the spoon or gently swirl the test tube until the salt dissolves completely. Then, the mass of sodium chloride is calculated using above formula for example 1 percent solution in 60 mL then add into test tube. About 40mL crude oil (de-acidified and acidic) is measure and added into test tube to make the solution 100 mL. The test tube is shacked 50 times at room temperature then, it is put in oven at reservoir temperature which is 70^{o}C and waits for several minute. The emulsion is determined visually by measuring the oil separated from the emulsion at 70^{o}C in every 12 hours period and carried out in three days.

- Experiment 4: IFT measurement test using spinning drop method for given duration period to make correlation between dynamic IFT and retention of emulsion.
- Materials : crude oil, alkaline containing brine solution (Sodium Hydroxide and Sodium Carbonate)
- Apparatus: Test tube, syringes
- Machine : Spinning Drop Machine

- Procedure: Dynamic IFT between aqueous solution contain brine and alkaline with oil sample is measured at 70^oC with Reactivity index 1.3427 for aqueous solution contain brine and sodium hydroxide and 1.3422 for aqueous solution contain brine and sodium carbonate. The method used is spinning drop and run in 500 minutes for every run to get the dynamic IFT.

3.4.2.3 Objective 3 experiment (To investigate wettability alteration of alkaline flooding in low acid number crude oil with respect to contact angle)

- Experiment 5: Contact angle measurement of fluid phase at core slice using sessile drop.
- Materials : crude oil, alkaline containing brine solution (Sodium Hydroxide)
- Apparatus: Test tube, syringes
- Machine : IFT 700
- Procedure: Contact angle between alkaline containing brine solutions with oil sample is measured at 70^oC with 2000 Psia using sessile drop of IFT 700. The core is sliced in range not more than 0.1 cm for the preparation of surface in sessile drop. The changes of contact angle with time before and after alkaline flooding as in the experiment 1 are recorded.

Figure 2.1: Acid extraction experiment during mixing process

Figure 2.2: Acid extraction experiment during gravity separation

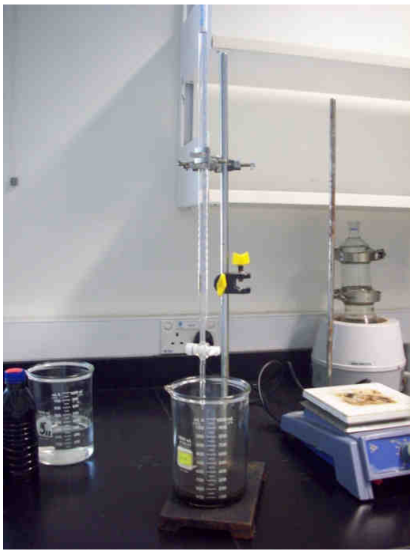


Figure 3.1: Acid number measurement during titration process

Figure 3.2: Acid number measurement during solvent preparation process

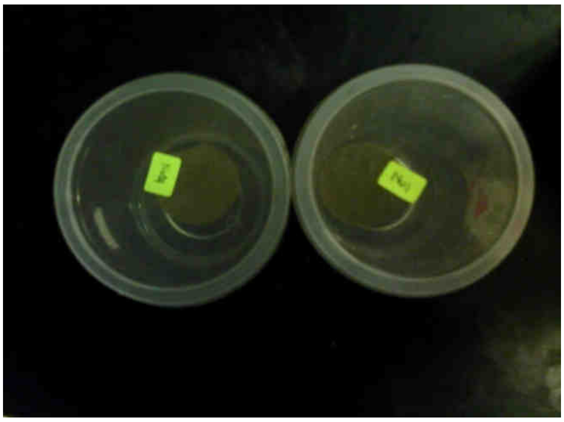


Figure 4: Core slice saturation in preparation for sessile drop

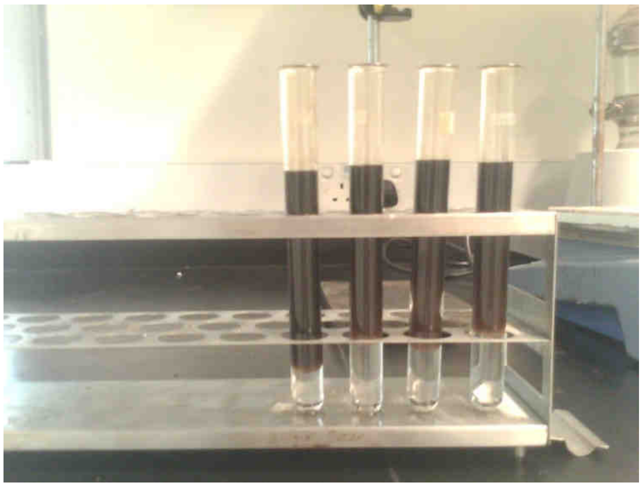


Figure 5: Compatibility test for acidic and de-acidified crude oil using different type of alkaline

Figure 6: Emulsion retention test

CHAPTER 4

RESULT AND DISCUSSION

4.1 Acid Number Measurement

The result for this experiment is divided into 3 which are the dulang crude oil, de-acidified crude oil (dulang), and acidic crude oil (dulang). The results of titration and pH value are shown in table 3. The formula to calculate the acid number by definition from the ASTM D974 and ASTM D3339 book in 2005 is using below formula:

Acid number (mgKOH / g) = 56.10 M (A-B)/W

A : Titration volume (ml) KOH solution required for titration of the sample

B : Blank level (0.1ml) KOH solution required for titration of the blank

M: Molarity (0.1)

W : Sample used (g)

From the result obtained, It can concluded that the AN for dulang can be considered as low because from the literature stated that the minimum acid should be around 1mg KOH/mg oil. This is good condition for me to examine the real low acid number crude oil in alkaline flooding. This result is already amended from the previous report due to the unavailability of references of ASTM book. The blank is performed by perform a blank titration on 100ml at titration solvent (which are toluene, ethanol, and distilled water) and 0.5ml at indicator solution, adding 0.1ml or less increment at the 0.1M KOH solution. This result might be different from previous work due to different titration solvent that used in this experiment. As for molarity the formula is as follow: Molarity = Grams/(Molecular Weight X Volume).

Crude oil	Crude oil weight (gram)	Volume of titration alcoholic KOH (ml)	pH value before titration	pH value after titration	Acid number mg KOH/mg oil
Dulang	10	2.0	5.8	7.3	1.066
De-acidified	10	0.25	6.7	7.5	0.084
Acidic	10	8.5	3.0	7.0	4.712

Table 3: Result from acid number measurement using ASTM D974

4.2 Acid Extraction

The result for this experiment shown as function of acid-removal rate as follow: **Acid-removal rate: (1-AN (de-acidified)/AN (dulang)) x 100%** according to (Lijuan, Benxian, & Gongqun, 2008) so the result is 92.16%. But the volume deacifed crude oil collected after gravity separation is about 500ml only instead of 560ml approximate to 500g so, the volume effeciency of the de-acidified crude oil is 89%.

From the result obtained, It can concluded that this acid removal process is successful because it can achieved more than **90% acid removal rate** and **89% of volume effeciency** of the de-acidified crude oil.

4.3 Compatibility Test

The result for this experiment is presented in table 4.1 until table 4.4 and categorised according to type of alkali. From the result obtained, it can be concluded that the most **suitable concentration** for alkaline and brine is **1% wt of Sodium Chloride and 1.5%wt of Sodium Hydroxide** and same goes to **Sodium Carbonate**. This is because according to literature review, the excessive alkaline and brine will result in white particle precipitation. Comprehensive study and comparison has been study from many journals and data from dulang field related to reservoir and fluid properties to short list the suitable range of alkaline concentration and salinity to be tested in this experiment.

For alkaline solution NaOH + NaCl

De-acidified crude oil

Trial 1	
wt% of NaCl	0.5
wt% of NaOH	1
Length of microemulsion after 1 day	5.0 cm
Observation	more stable emulsion more than 3 days
Trial 2	
wt% of NaCl	1
wt% of NaOH	1.5

Length of microemulsion after 1 day	6.0 cm
Observation	more stable emulsion more than 3 days
Trial 3	
wt% of NaCl	1.5
wt% of NaOH	2
Length of microemulsion after 1 day	6.3 cm
Observation	not stable emulsion only lasting in 2 days
Trial 4	
wt% of NaCl	2
wt% of NaOH	2.5
Length of microemulsion after 1 day	6.3 cm
Observation	not stable emulsion only lasting in 2 days

Table 4.1: Result from compatibility test for de-acidified crude oil in NaOH

Acidic Crude oil

Trial 1	
wt% of NaCl	0.5
wt% of NaOH	1
Length of microemulsion after 1 day	6.0 cm
Observation	more stable emulsion more than 3 days
Trial 2	
wt% of NaCl	1
wt% of NaOH	1.5
Length of microemulsion after 1 day	6.3 cm
Observation	more stable emulsion more than 3 days
Trial 3	
wt% of NaCl	1.5
wt% of NaOH	2
Length of microemulsion after 1 day	6.7 cm
Observation	moderately stable emulsion lasting in 3 days
Trial 4	
wt% of NaCl	2
wt% of NaOH	2.5
Length of microemulsion after 1 day	7.0 cm
Observation	moderately stable emulsion lasting in 3 days

Table 4.2: Result from compatibility test for acidic crude oil in NaOH

For alkaline solution NaCl + Na_2CO_3

De-acidified crude oil

Trial 1	
wt% of NaCl	0.5
wt% of Na_2CO_3	1

Length of microemulsion after 1 day	3.5 cm
Observation	not stable emulsion lasting after 1 day
Trial 2	
wt% of NaCl	1
wt% of Na_2CO_3	1.5
Length of microemulsion after 1 day	3.7 cm
Observation	not stable emulsion lasting after 1 day
Trial 3	
wt% of NaCl	1.5
wt% of Na_2CO_3	2
Length of microemulsion after 1 day	4.0 cm
Observation	not stable emulsion lasting after 1 day
Trial 4	
wt% of NaCl	2
wt% of Na_2CO_3	2.5
Length of microemulsion after 1 day	4.1 cm
Observation	not stable emulsion lasting after 1 day

Table 4.3: Result from compatibility test for de-acidified crude oil in Na_2CO_3

Acidic Crude oil

Trial 1	
wt% of NaCl	0.5
wt% of Na_2CO_3	1
Length of microemulsion after 1 day	7.1 cm
Observation	more stable emulsion more than 3 days
Trial 2	
wt% of NaCl	1
wt% of Na_2CO_3	1.5
Length of microemulsion after 1 day	7.6 cm
Observation	more stable emulsion more than 3 days
Trial 3	
wt% of NaCl	1.5
wt% of Na_2CO_3	2
Length of microemulsion after 1 day	8.0 cm
Observation	moderately stable emulsion lasting in 3 days
Trial 4	
wt% of NaCl	2
wt% of Na_2CO_3	2.5
Length of microemulsion after 1 day	8.3 cm
Observation	moderately stable emulsion lasting in 3 days

Table 4.4: Result from compatibility test for acidic crude oil in Na_2CO_3

4.4 Emulsion Retention test

The result for this experiment is presented in figure 7.1 until figure 7.7 for alkaline solution 1.5% NaOH and figure 8.1 until figure 8.6 for solution 1.5% Na_2CO_3. In figure 9 showed the percentage of oil separated from water. First, the pictures from the emulsion retention and there is formation of **winsor type III microemulsion** in this experiment as shown in pictures. From the pictures, it can be said that both acidic and de-acidified microemulsions in alkaline solution 1.5% NaOH + 1% NaCl and alkaline solution 1.5% Na_2CO_3 + 1% NaCl are stable and lasting more than 3 days except for de-acidified crude oil with Na_2CO_3. Therefore, it is suitable to be candidate for alkaline flooding even though the acid number in de-acidified crude oil can be considered very low. This finding is according to the latest finding even in zero value acid number claimed that IFT could be reduced by adding alkali in the water (James J. Sheng, 2011, p 402). The most important finding is the formation of microemulsion which mean a system of water, oil and an amphiphile which is a single optically isotropic and thermodynamically stable liquid solution (Danielsson, Lindman,1981, p391). In some respects, microemulsion can be considered as small-scale versions of emulsions droplet type in this experiment is dispersions of oil-in-water, with a size range in the order of 5−50 nm in drop radius. As for simple aqueous systems, microemulsion formation is dependent on surfactant type and structure. If the surfactant is ionic and contains a single hydrocarbon chain like sodium dodecylsulphate, microemulsions are only formed if a co-surfactant like a medium size aliphatic alcohol and/or electrolyte like 0.2 M NaCl are also present. With double chain ionics like Aerosol-OT and some non-ionic surfactants a co-surfactant is not necessary. As for this experiment, the in situ surfactant formed during shacking process that result in spontaneous formation of microemulsion. All of these are result from most fundamental properties of microemulsions, that is, an ultra-low IFT between the oil and water phases. As for this experiment, the ultra-low IFT is not achieved and yet formation of microemulsion still happened. This phenomenon is really contradict from many journals and can be considered as new finding in this project. Further studies must be done to investigate the other causes contribute in its formation.

The result is also presented in graph to get the comparison between all runs. From the graph, it can be concluded that microemulsion retention completely break mostly above 80 hours. There is no water separation from the emulsion in first 12 hours for acidic crude oil but not for de-acidified crude oil.

As conclusion, the sodium carbonate is suitable for acidic crude as it can form the longest period of microemulsion but for de-acidified crude oil the longest period is in sodium hydroxide solution. Besides, the retention of emulsion form using sodium hydroxide is better than sodium carbonate because it takes long time for oil to separate from water. The mechanism studied in this experiment is **emulsification** so, it is proved that this mechanism contribute in recovery mechanism as it can lower the IFT and form stable microemulsion. Data is attached at the appendix for detail references.

For crude oil in alkaline solution 1.5% NaOH + 1% NaCl

Figure 7.1:
1 De-acidified crude oil & 2. Acidic crude oil After 1 hour

Figure 7.2:
1 De-acidified crude oil & 2. Acidic crude oil Day 2

Figure 7.3:
1 De-acidified crude oil & 2. Acidic crude oil Day 3

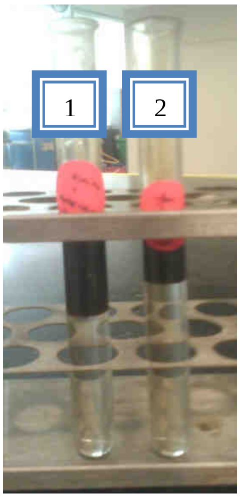


Figure7.4:
1 De-acidified crude oil & 2. Acidic crude oil Day 4

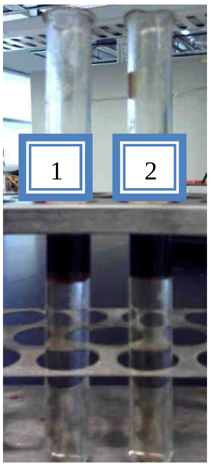


Figure 7.5:
1 De-acidified crude oil & 2. Acidic crude oil Day 5

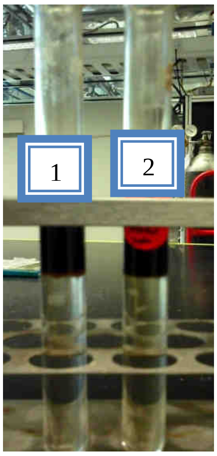


Figure 7.6:
1 De-acidified crude oil & 2. Acidic crude oil Day 6

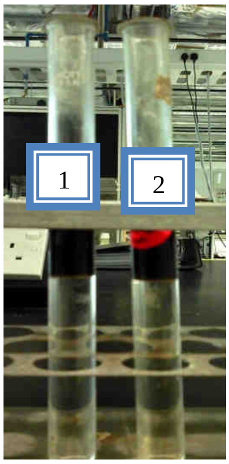


Figure 7.7:
1 De-acidified crude oil & 2. Acidic crude oil Day 7

For crude oil in alkaline solution 1.5% Na_2CO_3 + 1% NaCl

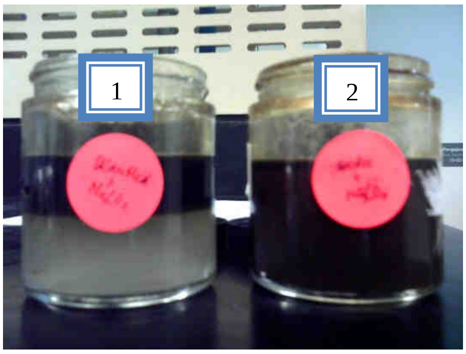


Figure 8.1:
1 De-acidified crude oil & 2. Acidic crude oil
After 1 hour

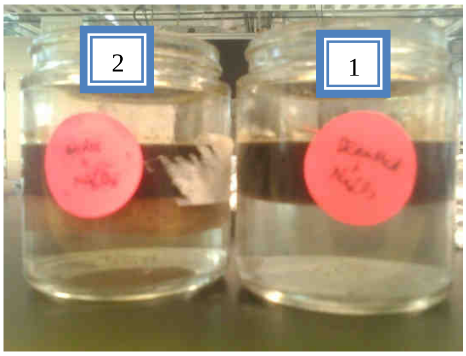


Figure 8.2:
1 De-acidified crude oil & 2. Acidic crude oil
Day 2

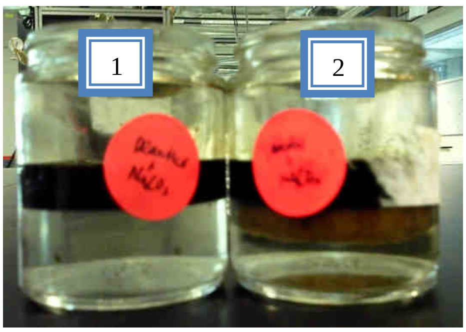


Figure 8.3:
1 De-acidified crude oil & 2. Acidic crude oil
Day 3

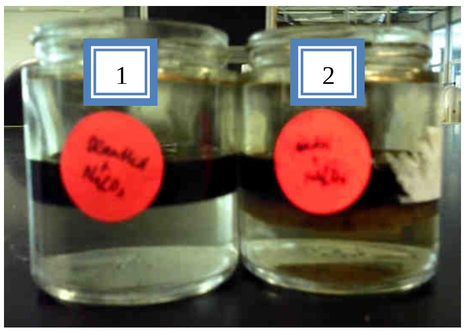


Figure 8.4:
1 De-acidified crude oil & 2. Acidic crude oil
Day 4

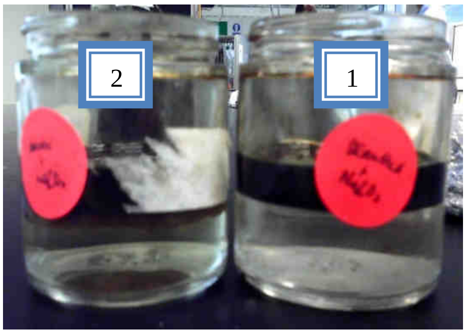


Figure 8.5:
1 De-acidified crude oil & 2. Acidic crude oil
Day 5

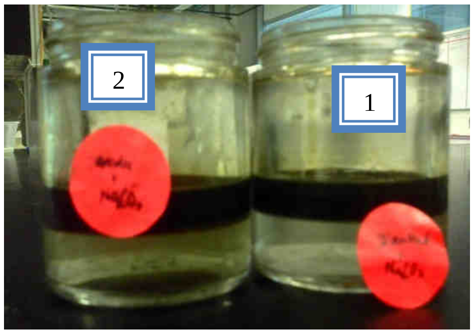


Figure 8.6:
1 De-acidified crude oil & 2. Acidic crude oil
Day 6

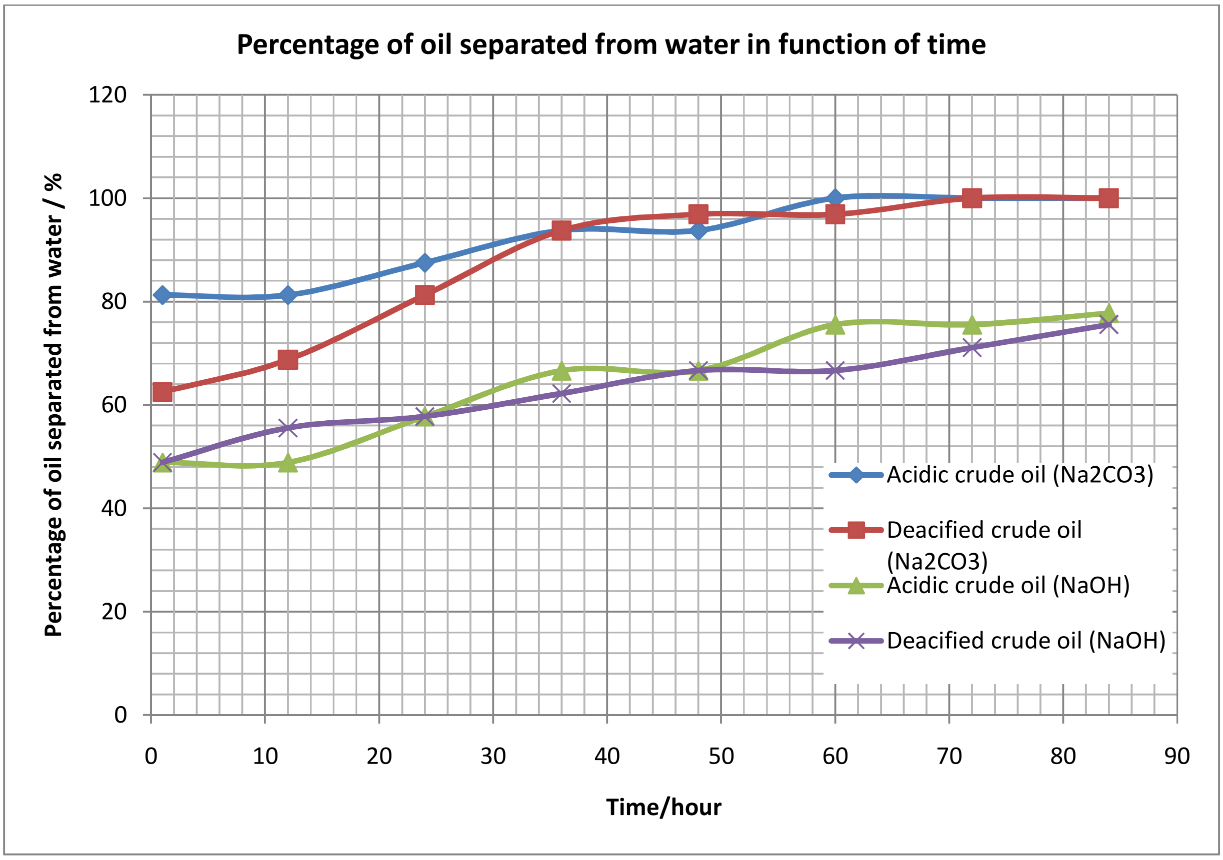


Figure 9: Emulsion retention test presented in graph in function of time and percentage of oil separate from water

4.5 Dynamic IFT test using spinning drop

The result is presented in graph to get the comparison between all runs. The graph is shown in figure 10.2. From the graph, it can be concluded that the **lowest** value of **IFT** for both de acidified crude oil and acidic crude oil is using aqueous solution with **sodium carbonate**. To calculate and compare the value, the rotational velocities must be set constant for all runs which are 4000 rpm. The formula to calculate IFT using spinning drop is as follow:

$$\gamma = \frac{1}{4} r^3 \Delta\rho\omega^2$$

γ: Interfacial tension
r: radius of the drop (for this case, oil droplet)
ρ: density of the fluid
ω: rotational velocities

At low rotational velocities, the fluid drop will take on an ellipsoidal shape, but when a velocity is sufficiently large, it will become cylindrical. The density different between aqueous solution and oil droplet is determined first before begin the run. Under this latter condition, the radius of the cylindrical drop is determined by the interfacial tension, the density difference between the drop and the surrounding fluid, and the rotational velocity of the drop. The higher temperature like 70^{o}C other than an ambient temperature is set and it necessary for controlling a proper viscosity of the aqueous solution and crude oil samples.

The mechanism tested in this experiment is **emulsification** so, it is proved that this mechanism assisted in alkaline flooding by lowering the IFT using Sodium Carbonate. This latest finding needs to be investigated on the other variables or parameters such as fraction of crude and type of acid exist which can contribute in lowering the IFT because it is very contradict with the emulsion retention test that result in no correlation between emulsion retention and dynamic IFT. Data for all runs and formula is provided at the appendix for further references and understanding.

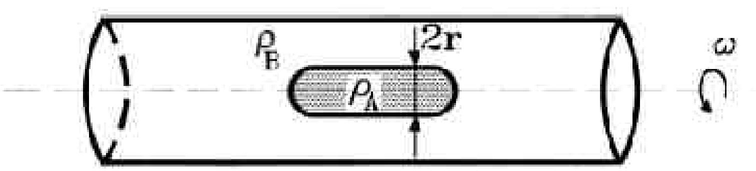


Figure 10.1: schematic of spinning drop method

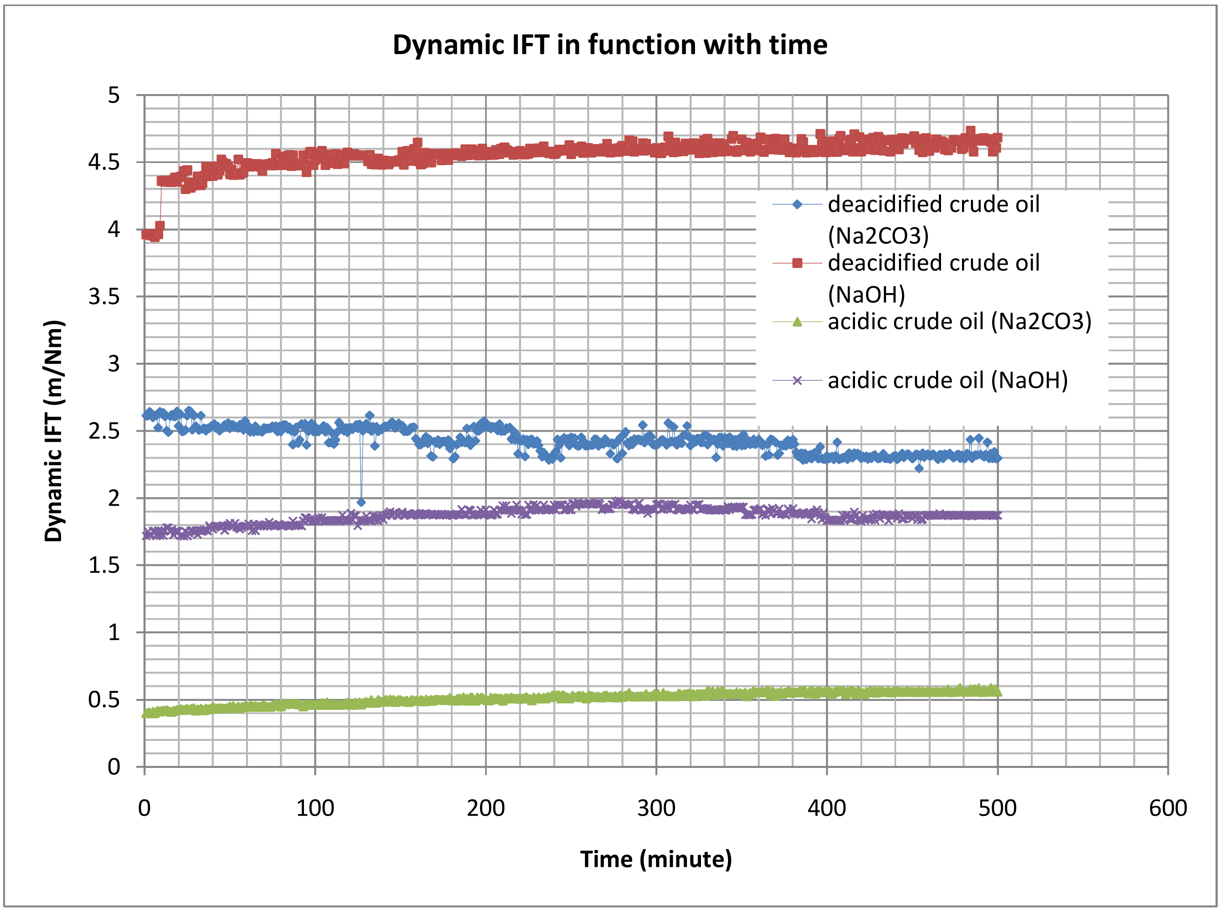


Figure 10.2: Dynamic IFT presented in graph in function of time

4.6 Core displacement/flooding experiment.

The result is presented in picture, table, and graph to get the comparison between 2 runs. The pictures are shown in figure 11.1 – 11.3 for alkaline solution 1.5% NaOH and figure 12.1-12.3 for alkaline solution 1.5% Na_2CO_3. Table 5 showed the result from core flooding for all runs. Figure 13 showed the recovery factor comparison for all runs and table 6 presented the volume oil and water displaced and recovery factor for all runs.

From the pictures, the volume of residual oil recovered is not consistent for example; there is no oil inside dedicated cylinder 4-6 and 17 in run 1 plus the effluent suddenly become clearer from 4-6. This is mainly because the alkaline solution taking different path inside core plug which is not contains oil. Hence, there is no reaction for in-situ surfactant formation and no residual oil recovery. For run 2, there is no residual oil recovered for the first 2 dedicated cylinders and starting 3-12 volume of oil is recovered. The volume of oil displaced after alkaline flooding for run 1 is 1.1 ml and run 2 is 0.82 that indicate the sodium hydroxide give higher recovery compare to sodium carbonate and this result is supported by many journals and previous work like (Larrondo, Urness, Milosz, 1985, p 310) state that largest volume oil was recovered by 0.3 wt% sodium hydroxide at all Pore Volume 1. Other than that, the pressure drop for run 1 is stable because might no precipitation inside core plug but for run 2 the pressure drop is not stable and give higher different value because of the precipitation might happened inside the core.

The result for end-point relative permeability and mobility ratio for all runs are as follow:

	Average end point k_{rw} (water flooding)	Average end point k_{rw} (alkaline flooding)	Average mobility ratio (water flooding)	Average mobility ratio (alkaline flooding)	Swc	Sor (water flooding)	Sor (alkaline flooding)
Run 1	0.108	0.083	0.423	0.293	0.397	0.252	0.186
Run 2	0.051	0.018	0.199	0.066	0.320	0.287	0.230

Table 5 : Result from core flooding experiment for all runs

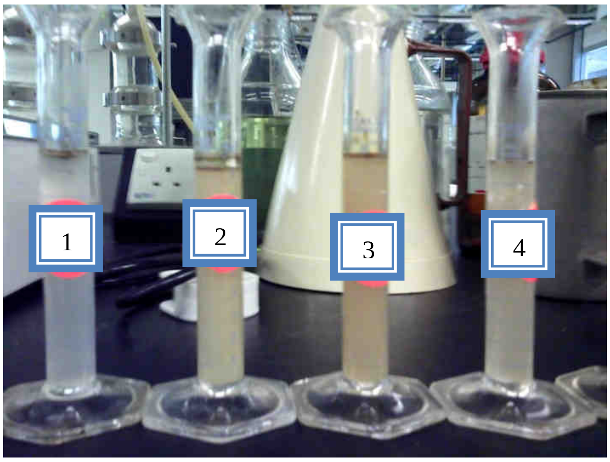
The reduction in **end-point relative permeability** of water after alkaline flooding show that core plug become more water wet and the reduction in **mobility ratio** (<1) showed the displacement is stable, a fairly sharp separates the mobile oil and water phases. These results also suggest that swelling of the oil phase as a result from emulsification of water might have aided in mobilization and production of oil.

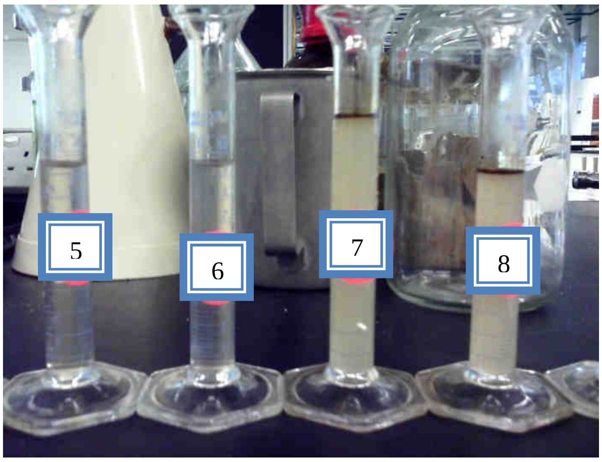
As conclusion, it can be said that sodium hydroxide or NaOH give higher recovery of residual oil in de-acidified crude oil compare to sodium carbonate or Na_2CO_3 as the recovery factor of residual oil for **run 1** is **69.21%** and **run 2** is **66.40%** which give the effective incremental of **11.03%** for NaOH **(Run 1)** and **8.23%** for Na_2CO_3 **(Run 2)** after alkaline flooding. The mechanism investigated indirectly in this experiment is wettability alteration as stated from journal (Larrondo, Urness, Milosz, 1985, p 310) the reduction in end-point relative permeability of water after alkaline flooding show that core plug become more water wet. The limitation of time and run is the main reason why further studies must be done in order to do comparison between acidic and de-acidified crude oil to perceive the major factor contribute in recovery mechanism whether emulsification by lowering the IFT or wettability changes in the core after alkaline flooding by setting dulang crude oil as control value in this experiment. All the related data for all runs is attached at appendix for further references.

Run 1 (alkaline solution 1.5% NaOH + 1% NaCl)

Figure 11.1
Effluent from Oil saturate

Figure 11.2
Effluent from Water flooding
(1% NaCl)





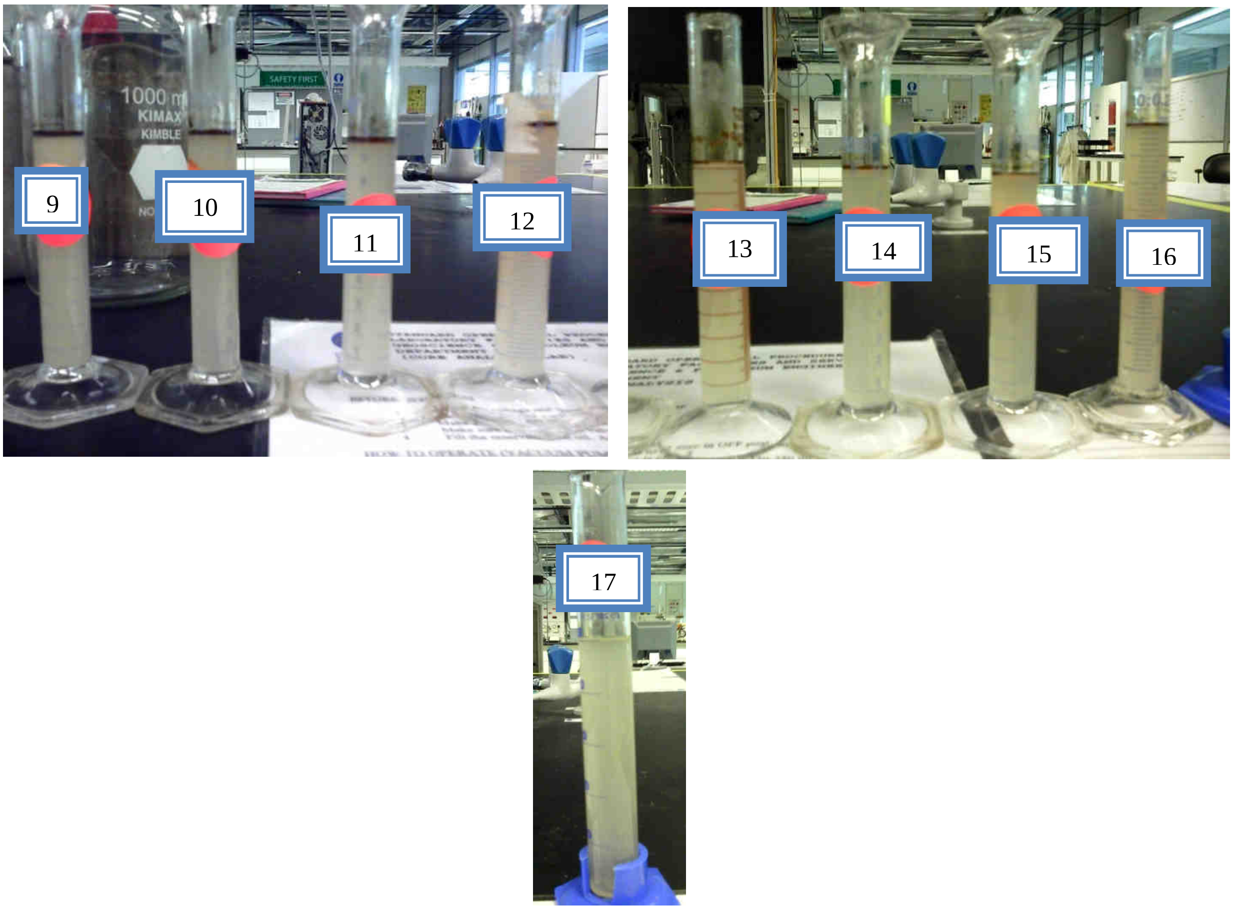


Figure 11.3 Effluent from Alkaline flooding in 1-17 dedicated cylinder

Run 2 (alkaline solution 1.5% Na_2CO_3 + 1% NaCl)

Figure 12.1
Effluent from Oil saturate

Figure 12.2
Effluent from Water flooding
(1% NaCl)

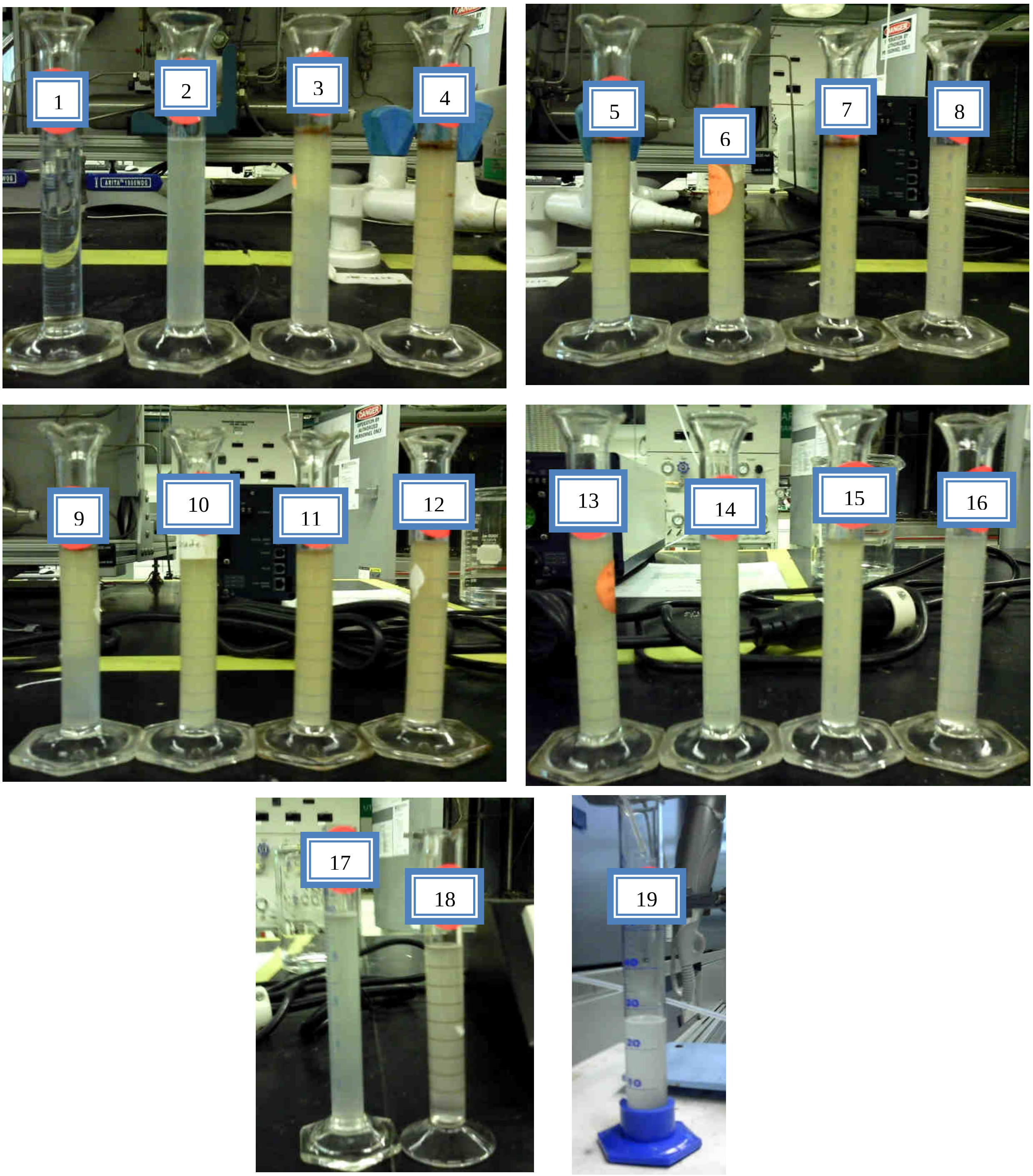


Figure 12.3 Effluent from Alkaline flooding in 1-17 dedicated cylinder

Recovery after flooding

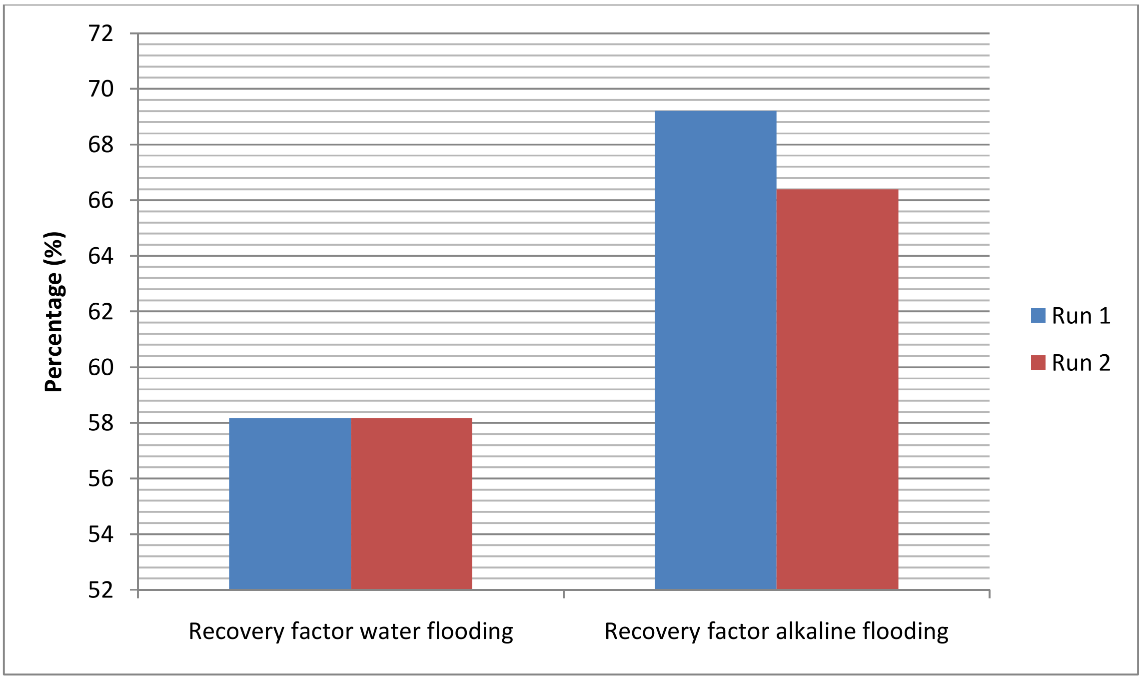


Figure 13: Recovery factor comparison for all runs

Run 1	
original oil in place/ml	9.97
Volume displaced oil after water flooding/ml	5.8
Volume displaced oil after alkaline flooding/ml	1.1
Recovery factor water flooding (%)	58.174
Recovery factor alkaline flooding (%)	**69.207**
Incremental recovery (%)	**11.033**

Run 2	
original oil in place/ml	9.97
Volume displaced oil after water flooding/ml	5.8
Volume displaced oil after alkaline flooding/ml	0.82
Recovery factor water flooding (%)	58.174
Recovery factor alkaline flooding (%)	**66.399**
Incremental recovery (%)	**8.225**

Table 6: Volume oil and water displaced and recovery factor for all runs

End-Points Relative Permeability Calculation

General Darcy Law equation in SI units,

$$q = \frac{kA}{\mu}\frac{dP}{dX}$$

Q = Fluid flow rate (cm3/s)

K = Absolute permeability (Darcy)

A = Core area (cm2)

μ = Viscosity (Cp)

dP = Pressure Difference, Pinlet – Poutlet (Atm)

dX = Core length between inlet to outlet point (cm)

Incorporate with relative permeability for water displacement in oil using relative permeability system. By considering all the conversion factor and unit applied in that system, the equation yield:

$$60\,\frac{\pi \times \frac{d^2}{4} \times \frac{\Delta P}{14.7} \times k k_{rw}}{1000\ \times TEF\ \times \mu \times l} = q$$

Rearranging the whole equation in terms of relative permeability to water,

$$\frac{1000\ \times TEF\ \times \frac{q}{60} \times \mu \times l}{\pi \times \frac{d^2}{4} \times \frac{\Delta P}{14.7} \times k} = k_{rw}$$

In the core displacement or flooding, once residual oil is established prior to water flooding or alkaline flooding, flow rate at the outlet is measured to ensure a near steady –state condition is achieved.

This is obtained once,

$$q_{injected fluid@inlet} = q_{produced fluid@outlet}$$

This is significant in ensuring the equation for relative permeability derived from Darcy Law valid, as it requires a steady-state, isothermal, incompressible, laminar flow.

Unit used in Relative Permeability System

TEF = Temperature Effect Factor, usually 1

q = flow rate (ml/min)

μ = viscosity (cp)

d = core length (cm)

l = core diameter (cm)

P = pressure (psig)

k = permeability (mD)

Calculation of mobility rations using the end-points:

$$M = \frac{krw/\mu_w}{kro/\mu_o}$$

k_{rw} = Relative Permeability of water

k_{ro} = Relative Permeability of oil (assume 1 as at residual water, only oil flow, thus relative permeability to oil is 1)

μ_w = Viscosity of water

μ_o = Viscosity of oil

This procedure is applied to all runs that calculate the end-points relative permeability and mobility ration of either water or alkaline flooding.

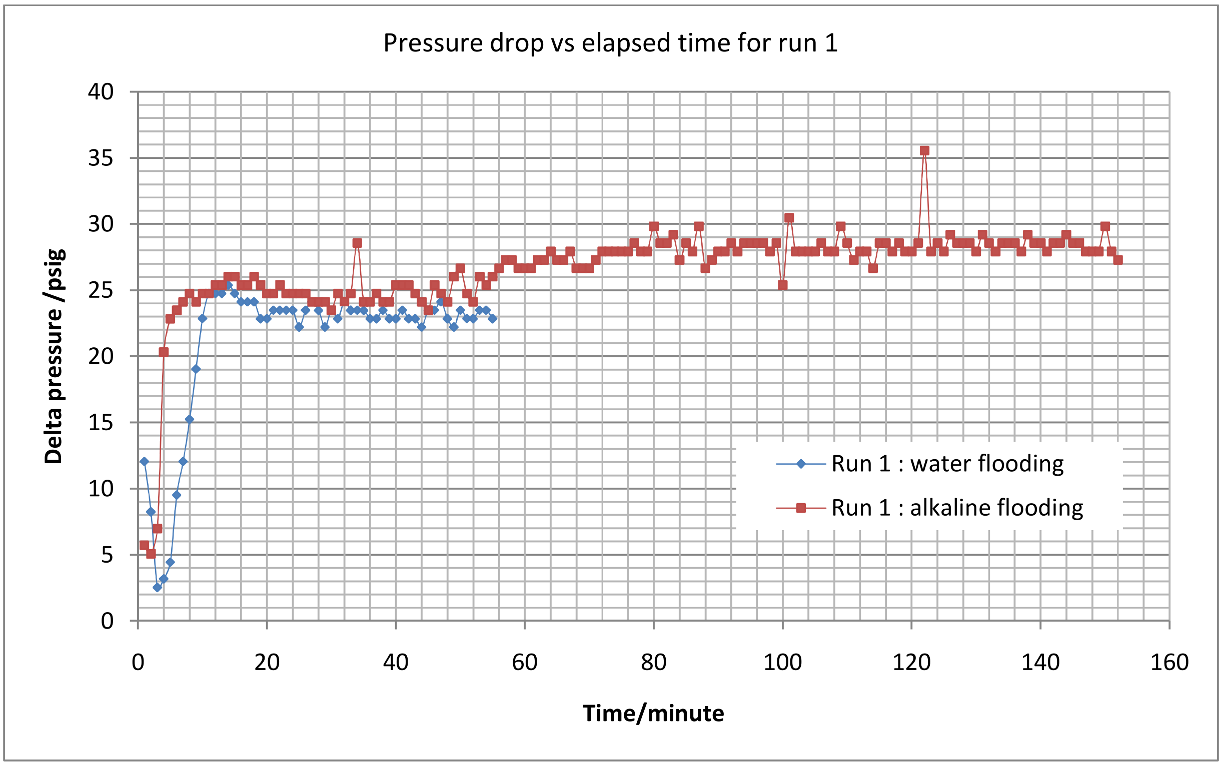


Figure 14.1: Pressure drop for for run 1

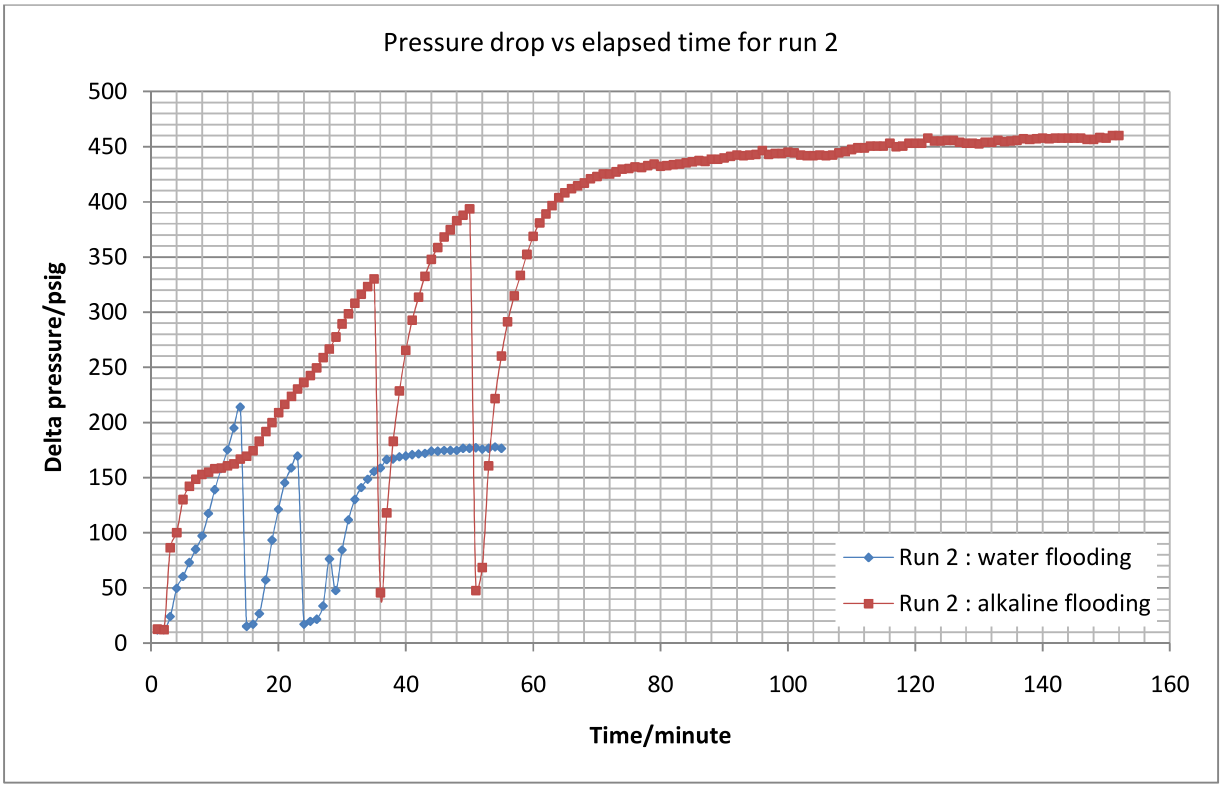


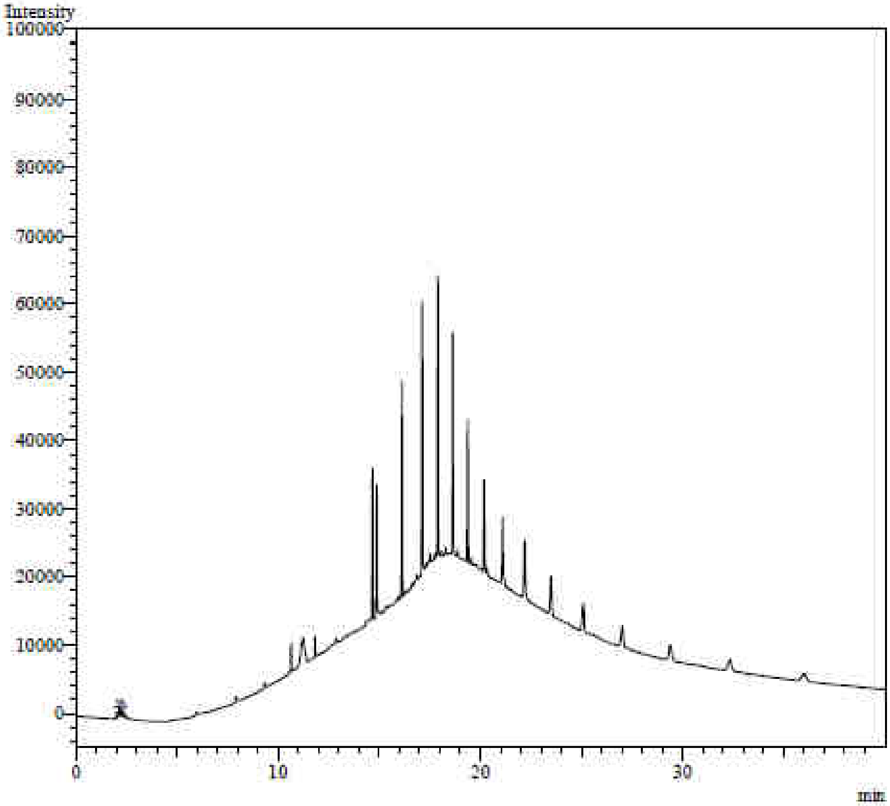
Figure 14.2: Pressure drop for for run 2

4.7 Gas chromatographic test

The result is presented in table and graph to get the comparison between 2 runs of effluent after alkaline flooding. The graphs are shown in figure 15.1 and 15.2 and table 7. From the result obtained in this test, it can be said that there is existence of alcohol in the effluent as claimed by the previous work but there must be further run of alkaline flooding using only dulang crude oi without extract the naphthenic acid also add carboxylic acid as control value in this experiment to compare the reading of concentration of alcohol. The table show that concentration 0.0110 for Run 1(NaOH) and 0.0842 for Run 2(Na_2CO_3). The reason behind this very low concentration of alcohol is due to not all ethanol react with 2-Ethylimidazole in removing naphthenic acid, hence ethanol still remain in crude oil in very small amount.

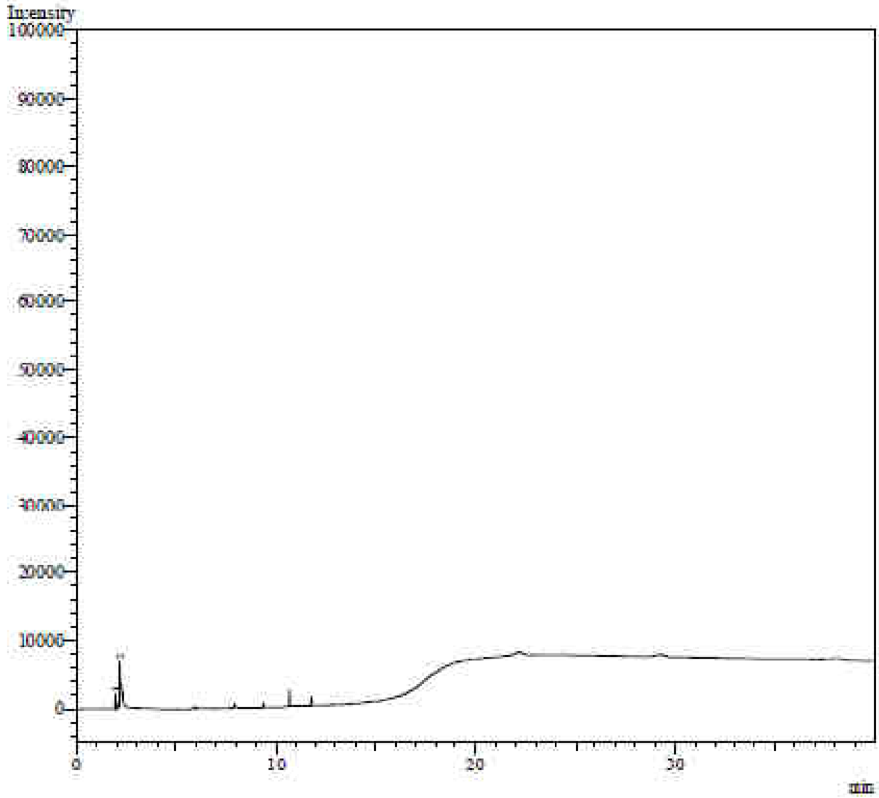
Previous work state that due to the presence of instable hydroxide ion dissolve in the alkaline solution, theoretically, it could react with the carbon chain in the crude oil (Alkanes) to formed alcohol components. Catalyst for this reaction could be the high temperature and pressure along with Ca/Mg/Fe/Al elements coming from the rock minerals. The possibility of the generation of alcohol is due to the fact that chemical industry produced alcohol based on if not the same phenomena, with almost similar condition with the temperature and pressure. But there must be some specific catalyst for this reaction like Ca/Mg/Fe/Al with high concentration not depends on the core alone itself because it might not enough in producing alcohol. The mechanism that indirectly studied in this experiment is emulsification with respect to lowering the IFT as stated in previous work by mixing dulang crude oil with butanol, n-Heptane, and oleic acid. When alcohol is mixed into the oil-water-alkaline system, the lowest IFT achieved was 0.14 Dynes/cm at butanol concentration of 5% wt.

To measure the concentration of alcohol, the ASTM method D5501 is used GC with 150-meter methyl silicone capillary column and sub ambient oven temperatures to separate the methanol and ethanol from the low-boiling hydrocarbons. While this approach is effective, the run times are in excess of 40 minutes and the method requires the use of a cryogenic coolant.



Peak#	Ret.Time	Area	Height	Conc.	Units	Name
1	2.030	2959.02	646.55	0.0000		
2	2.149	1751.88	1041.87	0.0110		ethanol
3	2.272	4013.45	910.31	0.0000		
4	2.380	1421.49	567.90	0.0000		
Total		10145.84		0.0110		

Figure 15.1: Gas chromatographic anslysis for effluent in run 1



Peak#	Ret.Time	Area	Height	Conc.	Units	Name
1	1.936	3828.89	2176.04	0.0000		
2	2.155	13443.07	5683.35	0.0842		ethanol
Total		17271.96		0.0842		

Figure 15.2: Gas chromatographic anslysis for effluent in run 2

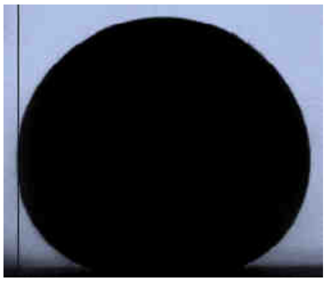
	Run 1	Run 2
Concentration of alcohol after alkaline flooding (ethanol)	0.0110	0.0842

Table 7 : Result from gas chromatographic test for effluent

4.8 Contact angle measurement using sessile drop

The result is presented in picture and table to get the comparison between 2 runs for sodium chloride alone and sodium hydroxide plus sodium chloride. The pictures are shown in figure 16.1 and figure 16.2 also table 8. From the result obtained in the experiment it showed that before alkaline flooding, the core is more oil wet because the angle is more than 45̊ and the core is more water wet after alkaline flooding due to the wettability alteration mechanism according to many journals which results in the contact angle reduced to 43.92 which is less than 45̊. This result is supported by many experts that advocated relative permeability end-point observation according to (Larrondo, Urness, Milosz, 1985, p 310) the reduction in end-point relative permeability of water after alkaline flooding show that core plug become more water wet. Due to limitation of time and machine, only 2 runs obtained from this experiment by sorting the most important runs only which is sodium chloride and sodium hydroxide because it give higher recovery of residual oil compare to sodium carbonate, in order to investigate the wettabilty changes mechanism in alkaline flooding. Further runs must be obtained in future research to get the clear comparison between types of alkali especially with respect to contact angle.

of crude oil
ig



angle of crude oil
flooding

Contact angle after water flooding (1% NaCl)	**48.99°**
Contact angle after alkaline flooding(1.5%NaOH+1%NaCl)	**43.92°**

oding

4.9 Macroscopic displacement efficiency

4.9.1 Reduction in End-point relative permeability

Relative permeability is dimensionless and normally measured relative to the base permeability. The base permeability can be either absolute permeability which is single phase flow or permeability of certain fluid at initial water saturation. In core flooding, 2 phases distribution result in characteristic wetting and non-wetting phase. The relative permeability can be summarized as ability of 1 phase fluid to flow when there is another 1 phase fluid occupied or saturated the core. End- point relative permeability for water Krw@Sor is determined from core flooding experiment at residual oil saturation when there is no more oil being displaced by water and alkaline flooding. For all runs, end-point relative permeability of water were reduced as much 23.15% for run 1 and 64.70% for run 2 from its original value after alkaline flooding. This observation corresponds to lower residual oil value for alkaline flooding compare to water flooding. Reduction in end-point relative permeability value indicated that the flow favours for displacement of oil as it reduced the by-passing of the displacing which is alkaline solution hence the core plug become more water wet.

4.9.2 Reduction in Mobility ratio

Mobility, k/μ, is defined as permeability of a porous material to a given phase divided by the viscosity of that phase. Mobility ratio, M, is defined as mobility of the displacing phase divided by the mobility of the displaced phase. When Mobility ratio less than 1, the displacement is stable, a fairly sharp separates the mobile oil and water phases, and the permeability to water stabilizes fairly quickly. In this case, alkaline is added in the brine water to increase the viscosity from 1.010 cp to 1.120 cp for sodium hydroxide and 1.070 for sodium carbonate. It is about 9.8% increment for sodium hydroxide and 5.6% increment for sodium carbonate. From experiment, the mobility of water as displacing fluid is reduce due to the end-point relative permeability of water decrease after alkaline flooding and viscosity for water increase after 1.5% wt alkaline is added. In the other hand, the mobility of displaced fluid is constant because end-point relative permeability of oil constant which is 1 by considering only oil flow at residual water and viscosity of oil is remain same due to only dulang de-acidified present in the core. The mobility ratio of run 1 and 2 after water flooding is lower than 1 indicated the stable displacement of oil inside the core without any formation of oil wormholes. In addition, the mobility ratio of run 1 and 2 were reduced after alkaline flooding as much 30% for run 1 and 66% for run 2 from its original value that lead to better and stable displacement and sweeping efficiency which associate a piston-like displacement to displaced the oil inside the core.

4.9.3 Wettability alteration with respect to contact angle

Wetting phase defined as phase occupied the smaller pore opening at small saturation and non-wetting phase occupied the central pore openings which contribute matrerially to fluid flow through the core. From the experiment, contact angle of crude oil after water flooding is 48.99° and after alkaline flooding is 43.92° for NaOH and it changes to be more water-wet even in small amount of degree. When the wettability is changed from oil-wet to water-wet, oil recovery increases owing to favourable changes in end-point relative permeability of water because residual oil in a water-wet porous medium is immobile. This indicates that the water prefers to adhere to the rock surfaces, leads to the mobilization of residual oil which initially occupies the rock surface. This mechanism can be observed in de-acidified dulang crude oil as it is not depend on the amount of acid present in crude oil during displacement.

4.10 Microscopic displacement efficiency

4.10.1 Emulsification by lowering interfacial tension

The emulsion occurred when the IFT is lowered by the formation of in-situ surfactant which origin from the reaction of alkali and carboxylic acid in the crude oil. From the experiment result, the formation of microemulsion winsor type III indicate that the IFT is ultralow but the IFT measurement using spinning drop method contradict proved the IFT is not achieving ultralow except for sodium carbonate in acidic crude oil which is below than 1. As for other runs which is de-acidified and acidic dulang crude oil with sodium hydroxide and de-acidified dulang crude oil with sodium carbonate proved that the IFT is lowered after alkaline was added in the water. This behaviour indicates that with low acid present, the surface activities between alkaline and solution is less thus leading to little bit higher IFT compared to oil with higher acid component where the IFT is greatly reduced. Thus this situation is proved by latest finding that stated even in zero value acid number claimed that IFT could be reduced by adding alkali in the water (James J. Sheng, 2011, p 402). When the dynamic IFT reached ultralow, emulsification occurred. Even when dynamic IFT went up, emulsified oil droplets did not easily coalesce. In alkaline flooding, emulsification is instant, and emulsions are very stable. From this emulsification point of view, the dynamic minimum IFT plays an important role in enhanced oil recovery. Once the residual oil droplets become mobile owing to the instantaneous minimum IFT, it coalesced to form a continuous oil bank. The emulsification mechanism in alkaline flooding is more favorable in high acid number crude oil compared to low acid number crude oil.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

As conclusion, alkaline flooding is successful even in de-acidified (Dulang) crude oil which can be consider as very low acid number because the recovery factor of residual oil for run 1 using sodium hydroxide as a alkali agent is 69.21% and run 2 using sodium carbonate is 66.40% which give the effective incremental of 11.03% for run 1 and 8.23% for run 2 after alkaline flooding which result in sodium hydroxide as the preferable type of alkali used in alkaline flooding of low acid number crude oil.

The objectives of this project are accomplished because reduction in end-point relative permeability value indicated better displacement efficiency of oil, hence the core plug become more water wet. Besides that, mobility ratio were reduced after alkaline flooding that lead to better and stable displacement and sweeping efficiency of residual oil. In addition, the formation of microemulsions between alkaline solution and crude oil are stable and lasting more than 3 days except for de-acidified crude oil with Na_2CO_3 show that it helps in increase the recovery in by mobilize the residual oil as it can lower the IFT and form stable microemulsion event though there is no correlation between lower IFT and stable microemulsion. Furthermore, when the contact angles before and after alkaline flooding was changes indicated the wettability was changed from oil-wet to water-wet, oil recovery increases owing to favourable changes in end-point relative permeability of water.

Finally, the mechanisms of alkaline flooding investigated in this project are emulsification and wettability alteration because this 2 mechanism are most obvious mechanism for this chemical injection in EOR.

5.2 Finding and Recommendation

After conducting all experiments, there some findings during general experiment those are different from the journal and previous experiment. First is about the acid number measurement, at first point it is very hard to determine the end point of titration since the solvent of crude oil is dark. To fix this problem, pH meter used to measure the exact end point before the phenolphthalein change from colorless to pink. Due to safety factor, this experiment conducted in fume hood to avoid any injury and hazardous. Second finding is about acid extraction experiment, during the gravity separation, the de-acidified oil is at the top position instead of at the bottom according to journal. This is because the density of crude oil is lighter than the reagent and ionic liquid.

As for objective oriented experiment and test, there are 2 major findings which are the formation of microemulsion and changes in contact angle of oil and water on rock surface. These findings need to be investigated further in order to find the cause for higher recovery of residual oil. The result from this project can be improved and expanded in big scale to examine the other factor contribute in the mechanism and to justify the objectives achieved. First, Core flooding must be conducted using core samples where the original wettability and reservoir fluida are still intact and at its initial state also more runs is required because it will gives better illustration of effectiveness of alkaline flooding of low acid number crude oil. Second, wide range of crude oil other than dulang with different properties and different concentration of alkali in measuring the IFT, contact angle, and recovery from flooding experiment so the findings and results from this experiment is applicable to various type of crude oil. Third, the alkaline consumption test must be conducted in order to investigate the absorption rate of alkali inside the core. Finally, the alcohol traced using gas chromatography machine in this experiment must be further studied by comparison of result using original dulang crude oil.

REFERENCES

1. Cooke, C.E. Jr., Williams, R. E., & Kolodzie, P.A.: “Oil Recovery by Alkaline Flooding”, *J. Pet. Tech.*, pp 1365-1374, Dec. 1974.
2. Ehrlich, R. and Wygal, R.J.: “Interrelation of Crude Oil and Rock Properties with the Recovery of Oil by Caustic Waterflooding”, *Soc. Pet. Eng. J.*, pp 263-270, Aug. 1977.
3. Jennings, Harley Y., Jr.: “A Study of Caustic Solution-Crude Oil Interfacial Tensions”, *Soc. Pet. Eng. J., Trans., AIME*, Vol. 259, pp 197-202, June 1975.
4. Mayer, E.H., Berg, R.L Carmichael, J.D., and Weinbrandt, R.M.: “Alkaline Injection for Enhanced Oil Recovery: A Status Report”, presented at the First SPE/DOE Symposium on Enhanced Oil Recovery, Tulsa, April 20-23, 1980, Paper SPE 8848.
5. Johnson Jr., C.E.: “Status of Caustic and Emulsion Methods,” *J. Pet. Tech.*, pp 85, Jan. 1976.
6. Jennings Jr., H.Y., Johnson Jr., C.E., & McAuliffe, C.D., “A Caustic Water flooding Process for Heavy Oils,” *J. Pet. Tech.*, pp 1344, Dec. 1974.
7. Larson, R.G., Davis, H.T., & Scriven, L.E.: “Elementary Mechanisms of Oil Recovery by Chemical Methods”, presented at the First SPE/DOE Symposium on Enhanced Oil Recovery, Tulsa, April 20-23, 1980, Paper SPE 8840.
8. Larrondo, L.E.,Urness, C.M., & Milosz G.M.,: “Laboratory Evaluation of Sodium Hydroxide,Sodium Orthosilicate,and Sodium Metasilicate as Alkaline Flooding Agents for a Western Canada Reservoir,” presented at the International Symposium on Oilfield and Geothermal Chemistry, Arizona, April 9-11, 1985, Paper SPE 13577.
9. James J. Sheng, P. D. (2011). Modern Chemical Enhanced Oil Recovery. In J. Sheng, *Theory and Practice* (p. 393). Burlington: Elsevier Incorporation.
10. Labrid, J., 1991. The use of alkaline agents in enhanced oil recovery processes. In: Bavière, M.(Ed.), Basic Concepts in Enhanced Oil Recovery Processes. Elsevier Science, pp. 123–155.
11. Green, D.W., Willhite, G.P., 1998. Enhanced Oil Recovery. Society of Petroleum Engineers, Dallas.
12. C, C. T., & Krumrine, P. H. (1979). Laboratory Studies On Alkaline Waterflooding. 1-3.
13. Carcoana, A. (1992). Applied Enhanced Oil Recovery. In C. Aurel, *Applied Enhanced Oil Recovery* (p. 160). New Jersey: Prentice-Hall.

14. Guo, J., Liu, Q., Li, M., Wu, Z., & Alfred, A. C. (2005). The effect of alkali on crude oil/water interfacial properties and the retention of crude oil emulsions. *Journal of colloids and surface A:Physicochem.Eng.Aspect* , 213-218.
15. Hoeiland, S., Barth, T., Blokhus, A., & Skauge, A. (2001). The effect of crude oil acid fraction on wettability as studied by interfacial tension and contact angles. *Journal of Petroleum Science and Engineering* , 91-103.
16. J, X., B, C., & Leung, L. (2008). Design and Implementation of a Caustic flooding EOR Pilot at Court Bakken Heavy Oil Reservoir . *Journal Of Canadian Petroleum Technology* , 1-7.
17. Fan, T., & Buckley, J. (2006). Acid Number Measurement Revisited. *Symposium Improved Oil Recovery* , 1-6.
18. Lijuan, J. S., Benxian, X. S., & Gongqun, Q. W. (2008). Removal of Naphthenic Acids from Beijiang Crude Oil by Forming Ionic. *Energy and Fuels* , 4177-4181.
19. Danielsson, I.; Lindman, B. (1981).*Colloids Surface*. *A*, 3, 391.
20. P.A, F., N, D., J.T, K., R.M, W., & T.F, Y. (1979). Participation of Selective Native Petroleum Fraction in Lowering Interfacial Tension of Aqueous Alkaline Systems. *ACS Symposium Series:American Chemical Society* , 103-113.
21. Skauge, A., Standal, S.H., Boe, S.O., Skauge, T., Blokhus, A.M.,(1999). Effects of organic ac ids and bases, and oil compositionon wettability, SPE Paper 56673, Presented at the 1999 SPE Annual Technical Conference and Exhibition, Houston, Texas 3–6, Oct. 1-9
22. Jill S, B., & Tianguang, F. (2005). Crude oil/brine interfacial tensions. *Presentation at the internatrional symposium of society of core analysis held in Toronto,Canada* , 1-12.
23. M.H, S., & M.S, A.-B. (1993). Laboratory and Economic Study on Saudi Oil Recovery by Alkaline Flooding. *Journal King Saud University Volume 6, Engineering Science* , 295-314.
24. Mun Sik, C. M., & Darsh T, W. (1980). Emulsion characteristics associated with an alkaline water flooding process. *SPE fifth International Symposium on Oilfield and Geothermal Chemistry* , 255-258.
25. J, L.-S., & I, L. (1999). Effect of alkaline material on interfacial rheological properties of oil-water systems. *Colloid Polym Sci 277* , 41-47.

APPENDIXS

1. Properties of fluid at 70 degree Celcius

Density of crude oil (de-acidified) g/cc	0.798
Density of crude oil (acidic) g/cc	0.809
Density of brine (1% NaCl) g/cc	1.010
Density of alkaline (1% NaCl + 1.5% NaOH) g/cc	1.023
Density of alkaline (1% NaCl + 1.5% Na_2CO_3) g/cc	1.019
Viscosity of crude oil (de-acidified) cp	3.960
Viscosity of crude oil (acidic) cp	4.170
Viscosity of brine (1% NaCl) cp	1.010
Viscosity of alkaline (1% NaCl + 1.5% NaOH) cp	1.120
Viscosity of alkaline (1% NaCl + 1.5% Na_2CO_3) cp	1.070
Reactivity Index of alkaline (1% NaCl + 1.5% NaOH)	1.3427
Reactivity Index of alkaline (1% NaCl + 1.5% Na_2CO_3)	1.3422

2. Core flooding input data for all runs

Flow rate (ml/min)	1.5
Temperature/celcius	70
Inlet Pressure (initial condition)/psig	1000
Overburden Pressure (initial condition)/psig	1500

2. Length of water separated from oil and its percentage

For alkaline solution 1.5%
NaOH + 1% NaCl

Acidic crude oil

Time/hour	0	1	12	24	36	48	60	72	84
length oil/cm	4.5	2.2	2.2	2.6	3	3	3.4	3.4	3.5
length microemelusion/cm	0	7.1	7.1	6.5	2.4	2.4	1.4	1.4	1.3
length water/cm	7.3	2.5	2.5	2.7	6.4	6.4	7	7	7
total length/cm	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8
percentage oil separate from water %	100	48.89	48.89	57.78	66.67	66.67	75.56	75.56	77.78

De-acidified crude oil

Time/hour	0	1	12	24	36	48	60	72	84
length oil/cm	4.5	2.2	2.5	2.6	2.8	3	3	3.2	3.4
length microemelusion/cm	0	7.1	6.3	6	5	4.5	3.8	3.5	3.2
length water/cm	7.3	2.5	3	3.2	4	4.3	5	5.1	5.2
total length/cm	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8
percentage oil separate from water %	100	48.89	55.56	57.78	62.22	66.67	66.67	71.11	75.56

For alkaline solution 1.5%
Na_2CO_3 + 1% NaCl

Acidic crude oil

Time/hour	0	1	12	24	36	48	60	72	84
length oil/cm	1.6	1.3	1.3	1.4	1.5	1.5	1.6	1.6	1.6
length microemelusion/cm	0	1	1	0.8	0.7	0.7	0.4	0.2	0.1
length water/cm	2.4	1.7	1.7	1.8	1.8	1.8	2	2.2	2.3
total length/cm	4	4	4	4	4	4	4	4	4
percentage oil separate from water %	100	81.25	81.25	87.5	93.75	93.75	100	100	100

De-acidified crude oil

Time/hour	0	1	12	24	36	48	60	72	84
length oil/cm	1.6	1	1.1	1.3	1.5	1.55	1.55	1.6	1.6
length microemelusion/cm	0	0.8	0.7	0.4	0.2	0.05	0.05	0	0
length water/cm	2.4	2.2	2.2	2.3	2.3	2.4	2.4	2.4	2.4
total length/cm	4	4	4	4	4	4	4	4	4
percentage oil separate from water %	100	62.5	68.75	81.25	93.75	96.875	96.875	100	100

3. Dynamic IFT measurement in 500 minute for de-acidified and acidic crude oil

For De-acidified crude oil in alkaline solution 1.5% Na_2CO_3 + 1% NaCl

Time /min	IFT (N/Nm)	Speed /rpm
1	2.614	4000
2	2.614	3999.6
3	2.643	4000.1
4	2.63	3999.9
5	2.6	4001
6	2.614	4000.6
7	2.615	4000.2
8	2.524	4000.2
9	2.642	4000.2
10	2.634	4000
11	2.635	3999.9
12	2.608	4000.1
13	2.503	4000.8
14	2.491	4000.2
15	2.61	4000
16	2.621	4000.9
17	2.608	4000.6
18	2.607	4000.8
19	2.645	4000.1
20	2.537	4000.8
21	2.625	4000.6
22	2.497	4000
23	2.498	4000.2
24	2.508	4000.6
25	2.612	4000.8
26	2.653	3999.9
27	2.644	4000.2
28	2.508	4001.2
29	2.616	4001.2
30	2.535	4000.6
31	2.52	4000.6
32	2.505	4000.1
33	2.615	4000.7
34	2.515	4000.5
35	2.522	4000.5
36	2.502	4000
37	2.52	4000
38	2.52	4000.6
39	2.536	4000.7
40	2.543	4000.7
41	2.551	4001.2
42	2.521	4000.5
43	2.534	4001.2
44	2.502	4000.8
45	2.52	4000
46	2.522	4000.3
47	2.546	4000.7
48	2.536	4000.1
49	2.56	3999.9
50	2.519	4000.6
51	2.546	4000.6
52	2.544	4001.2
53	2.536	3999.4
54	2.524	4000
55	2.523	4000.5
56	2.548	3999.9
57	2.548	4000.6
58	2.507	3999.9
59	2.575	4000.9
60	2.548	4000.3
61	2.509	4000.6
62	2.494	4000.1
63	2.514	3999.9
64	2.494	3999.9
65	2.536	4000.6
66	2.499	4000.9
67	2.5	4000.3
68	2.499	4000.3
69	2.494	3999.9
70	2.523	4000.5
71	2.52	4000.5
72	2.518	4000.2
73	2.519	4000.2
74	2.52	4000
75	2.535	4000.3
76	2.529	3999.9
77	2.536	4000.1
78	2.496	4000.2
79	2.534	4000.2
80	2.497	4000.6
81	2.543	4000.6
82	2.545	4000.3
83	2.543	4000.7
84	2.514	4000.7
85	2.528	3999.9
86	2.502	4000.5
87	2.399	4001.5
88	2.494	4000.2
89	2.528	4000.6
90	2.41	4000.3
91	2.434	4000.7
92	2.552	4000.5
93	2.54	4000.5
94	2.555	4000.6
95	2.396	4000
96	2.499	4000.6
97	2.545	3999.8
98	2.556	4000.3
99	2.495	4000.5
100	2.53	4000.5
101	2.496	4000.6
102	2.496	4000.9
103	2.513	4000.2
104	2.515	3999.8
105	2.538	4000
106	2.494	4000.8
107	2.525	4000.8
108	2.412	4000.6
109	2.414	4000.6
110	2.485	4000
111	2.404	4000
112	2.434	3999.6
113	2.492	4000.5
114	2.563	3999.9
115	2.542	4000.5
116	2.516	4000.6
117	2.502	4000.2
118	2.524	4000.6
119	2.49	4000
120	2.523	4000.1
121	2.524	3999.9
122	2.513	4000.2
123	2.524	4000.6
124	2.546	4000.6
125	2.52	4000
126	2.55	4000.2
127	1.969	3999.9
128	2.501	4000.5
129	2.541	3999.9
130	2.554	4000.6
131	2.517	3999.9
132	2.616	4000.2
133	2.499	4000
134	2.532	4000
135	2.388	4000.3
136	2.53	4000.7
137	2.496	4000.1
138	2.507	4000.5
139	2.511	3999.6
140	2.528	3999.9
141	2.535	4000.2
142	2.533	4000.3
143	2.537	4000.7
144	2.551	4000.3
145	2.566	4000.2
146	2.548	4000.2
147	2.523	4000.2
148	2.535	4000.6
149	2.558	4000.9
150	2.543	4001
151	2.541	4000.1
152	2.498	4000.5
153	2.498	4000.5
154	2.498	4000.6
155	2.501	3999.9
156	2.523	4000.5
157	2.526	4000
158	2.529	4000.6
159	2.443	4000.2
160	2.429	4000.2
161	2.398	4000.2
162	2.399	4000
163	2.422	3999.9
164	2.414	4000.2
165	2.458	4000.6
166	2.408	4000
167	2.439	3999.6
168	2.314	4000.6
169	2.307	4000
170	2.42	4000.5
171	2.41	4000.2
172	2.433	4000.5
173	2.4	4000.2
174	2.418	4000.2

175	2.423	4000.6
176	2.421	4000.2
177	2.41	4000.3
178	2.433	4000.2
179	2.37	4000.8
180	2.409	4000
181	2.293	4000.2
182	2.309	4001.5
183	2.399	4000
184	2.408	4000.1
185	2.452	4000.2
186	2.415	4000.8
187	2.424	4000.6
188	2.412	4000.2
189	2.519	4000.9
190	2.437	4000.9
191	2.394	4000.3
192	2.41	4000.5
193	2.534	4000.8
194	2.427	3999.9
195	2.5	4000.2
196	2.502	4000.3
197	2.554	4000.6
198	2.52	3999.6
199	2.574	4000.5
200	2.537	4000.1
201	2.541	3999.9
202	2.537	3999.9
203	2.518	4000.2
204	2.532	4000.2
205	2.529	4000.3
206	2.53	4000.5
207	2.504	4000.1
208	2.551	4000.3
209	2.498	4000.6
210	2.502	4001.2
211	2.5	3999.4
212	2.521	4000.3
213	2.517	4000.6
214	2.527	4000.6
215	2.44	4000.8
216	2.502	3999.9
217	2.433	3999.9
218	2.472	4000.5
219	2.33	4000.3
220	2.426	4000.6
221	2.427	4000.6
222	2.44	3999.9

223	2.31	4000.3
224	2.435	4000.1
225	2.401	4000.5
226	2.433	4000.8
227	2.437	4000.2
228	2.403	4000.2
229	2.407	4000.6
230	2.427	4000.3
231	2.393	4000.1
232	2.352	4000.5
233	2.309	4000.2
234	2.339	4000.9
235	2.316	4000.9
236	2.301	4000.6
237	2.285	4000.7
238	2.303	4000.1
239	2.292	4000.1
240	2.327	4000.1
241	2.345	3999.9
242	2.437	4000.2
243	2.394	4000.9
244	2.3	3999.6
245	2.44	4000.3
246	2.449	4000.5
247	2.426	4000.1
248	2.44	4000.6
249	2.392	3999.9
250	2.452	4000.2
251	2.432	4000.3
252	2.448	4000.3
253	2.396	4002.3
254	2.389	4000.1
255	2.392	4000.5
256	2.453	4000.2
257	2.427	4000
258	2.394	4000.5
259	2.39	4000
260	2.394	4000.7
261	2.395	4000.8
262	2.395	4000.5
263	2.395	4000.2
264	2.441	4000
265	2.436	4000.6
266	2.389	4000.2
267	2.411	4001
268	2.405	4000.3
269	2.404	4000.5
270	2.44	4000.2

271	2.417	4000
272	2.412	4000
273	2.331	4000.2
274	2.409	4000.7
275	2.397	4000.1
276	2.408	4001.2
277	2.294	4000.1
278	2.435	4000.2
279	2.452	4000.6
280	2.333	4000.2
281	2.474	4000.5
282	2.494	4000.1
283	2.411	4000.5
284	2.391	4000.5
285	2.425	4000.6
286	2.402	4000.9
287	2.44	4000.2
288	2.43	4000.7
289	2.437	3999.4
290	2.438	3999.8
291	2.428	4000.5
292	2.544	4000.2
293	2.412	4000
294	2.45	4000.6
295	2.444	4000
296	2.47	3999.6
297	2.455	4000.5
298	2.401	3999.8
299	2.397	3999.9
300	2.396	4000.2
301	2.4	4000.9
302	2.421	3999.6
303	2.432	4000.7
304	2.434	4000.2
305	2.413	4000.2
306	2.395	4000.2
307	2.559	4000.5
308	2.418	3999.8
309	2.423	3999.9
310	2.53	4000.2
311	2.423	3999.9
312	2.396	4000.9
313	2.434	4000.3
314	2.413	3999.8
315	2.409	4000.7
316	2.469	4000.1
317	2.469	4000.2
318	2.539	4000.6

319	2.457	4000
320	2.392	4000.3
321	2.436	4000.1
322	2.437	4000.1
323	2.42	3999.9
324	2.444	3999.9
325	2.442	4000.2
326	2.414	4000.2
327	2.414	4000.9
328	2.467	3999.8
329	2.469	4000.7
330	2.398	4000.5
331	2.452	3999.9
332	2.439	4000
333	2.435	4000.2
334	2.439	4000
335	2.303	4000.3
336	2.402	4000
337	2.451	4000.1
338	2.453	3999.9
339	2.39	4000.2
340	2.447	4000.9
341	2.446	4000.6
342	2.405	4000.3
343	2.454	4000.2
344	2.421	4000.5
345	2.39	4000.8
346	2.435	4000.5
347	2.386	4000
348	2.44	4000.9
349	2.409	4000
350	2.391	4000
351	2.473	4000.7
352	2.393	4000.2
353	2.425	4000.2
354	2.429	4000
355	2.402	4000
356	2.405	4000.6
357	2.437	4000
358	2.4	3999.9
359	2.413	4000.2
360	2.437	4000.8
361	2.418	4000.2
362	2.394	4000.2
363	2.4	4000.9
364	2.312	4001.3
365	2.4	4000.5
366	2.322	4000.8

367	2.437	4000.8
368	2.433	4000.6
369	2.424	4000.2
370	2.414	4000.6
371	2.321	4001.5
372	2.334	4000.1
373	2.395	4000.5
374	2.392	4000.5
375	2.395	4000
376	2.388	4000.6
377	2.43	4000.3
378	2.401	4000
379	2.399	4000.3
380	2.436	4000.5
381	2.403	4000.1
382	2.343	3999.9
383	2.313	4000.2
384	2.321	4000.6
385	2.335	4001.9
386	2.284	4000
387	2.334	4000.2
388	2.288	4000.8
389	2.302	4000.6
390	2.324	4000.6
391	2.293	4000.3
392	2.331	4000.5
393	2.339	3999.8
394	2.338	4000.2
395	2.293	3999.9
396	2.382	4000
397	2.295	4000.2
398	2.292	3999.6
399	2.292	4000.5
400	2.315	4000.1
401	2.294	4000.2
402	2.304	4000.2
403	2.309	4000
404	2.29	4000
405	2.317	4000.9
406	2.416	4000.8
407	2.288	4000.1
408	2.293	4000.5
409	2.299	4000.2
410	2.302	4000.9
411	2.302	4000.9
412	2.29	4000.6
413	2.336	3999.8
414	2.31	4000.3
415	2.301	4000.5
416	2.336	3999.9
417	2.322	4000.2
418	2.333	4000.2
419	2.323	4000.6
420	2.295	3999.8
421	2.312	4000.5
422	2.302	4000.5
423	2.312	4000.1
424	2.291	4000.6
425	2.307	4000.2
426	2.297	4000
427	2.317	4000
428	2.321	4000.3
429	2.3	4000.1
430	2.293	4000.1
431	2.298	3999.9
432	2.309	4000.2
433	2.331	4000.9
434	2.297	4000.3
435	2.296	4000.3
436	2.296	4000.1
437	2.291	4000.1
438	2.301	4000.6
439	2.311	4000.6
440	2.316	4000.2
441	2.289	4000.2
442	2.297	4000.7
443	2.312	4000.5
444	2.333	4000.5
445	2.303	4000.5
446	2.316	4000.6
447	2.328	4000.2
448	2.327	4000
449	2.309	4000.6
450	2.294	4000.1
451	2.302	4000.7
452	2.325	4000.5
453	2.326	4000.1
454	2.221	4000.2
455	2.311	4000.6
456	2.335	4000
457	2.305	4001
458	2.319	3999.8
459	2.329	4000.5
460	2.316	3999.5
461	2.314	4000.6
462	2.329	4000.2
463	2.319	4000
464	2.308	4000.3
465	2.29	4000
466	2.324	4000.8
467	2.323	3999.9
468	2.297	4000.6
469	2.329	4000.6
470	2.321	4000
471	2.326	3999.8
472	2.333	4000.7
473	2.317	4000.1
474	2.301	4000.5
475	2.308	4000.6
476	2.321	4000.2
477	2.327	4000
478	2.297	4000.1
479	2.319	4000
480	2.295	4000.8
481	2.295	4000.8
482	2.332	4000.6
483	2.327	4000.6
484	2.436	4000.2
485	2.297	4000.3
486	2.316	4000.9
487	2.322	4000.5
488	2.32	3999.8
489	2.447	4000.2
490	2.327	4000.2
491	2.317	4000.9
492	2.307	4000
493	2.325	4000
494	2.416	4000.8
495	2.295	4000.1
496	2.332	3999.9
497	2.296	4000.6
498	2.344	4000.9
499	2.293	4000
500	2.297	4000.9

For De-acidified crude oil in alkaline solution 1.5% NaOH + 1% NaCl

Time /min	IFT (N/Nm)	Speed /rpm
1	3.962	4000.1
2	3.967	4000.4
3	3.959	3999.5
4	3.953	4000.4
5	3.957	4000.4
6	3.942	3999.1
7	3.966	4000.3
8	3.964	3999.7
9	4.028	4000.3
10	4.359	3999.7
11	4.362	4000
12	4.355	4000.1
13	4.362	3999.5
14	4.352	3999.1
15	4.35	3999.8
16	4.35	3999.3
17	4.371	4000.3
18	4.389	4000.3
19	4.353	4000.2
20	4.386	4000.1
21	4.392	3999.8
22	4.397	3999.8
23	4.435	4000
24	4.299	3999.6
25	4.441	3999.5
26	4.35	3999.7
27	4.31	3999.7
28	4.323	4000.1
29	4.346	3999.5
30	4.328	3999.8
31	4.395	3999.3
32	4.393	4000.2
33	4.328	3999.7
34	4.344	3999.7
35	4.399	4000.4
36	4.466	3999.3
37	4.395	4000
38	4.399	4000

39	4.469	4000.1
40	4.398	4000.1
41	4.454	3999.5
42	4.463	3999.5
43	4.406	3999.4
44	4.442	4000.1
45	4.519	4000.1
46	4.498	3999.3
47	4.474	4000
48	4.487	3999.4
49	4.47	4000.1
50	4.408	4000.4
51	4.445	3999.8
52	4.403	3999.5
53	4.416	4000.3
54	4.416	3999.4
55	4.521	4000.1
56	4.406	3999.8
57	4.419	3999.5
58	4.422	4000.2
59	4.482	4000.3
60	4.495	3999.8
61	4.491	3999.5
62	4.467	3999.8
63	4.477	3999.8
64	4.475	4000.7
65	4.471	4000.3
66	4.488	3999.7
67	4.468	4000.1
68	4.465	4000.1
69	4.435	3999
70	4.482	4000.3
71	4.485	3999.7
72	4.484	3999.7
73	4.487	3999.7
74	4.476	3999
75	4.495	3999.5
76	4.476	3999.1
77	4.565	4000
78	4.478	4000.4
79	4.483	3999.8
80	4.483	4000
81	4.542	4000
82	4.54	3999.4
83	4.479	4000.3
84	4.55	3999.7
85	4.555	3999.6
86	4.472	3999.4

87	4.553	3999.7
88	4.49	3999.7
89	4.479	3999.7
90	4.475	3999.5
91	4.476	3999.8
92	4.479	3999.4
93	4.553	3999.4
94	4.481	3999.1
95	4.425	3999.8
96	4.555	4000
97	4.578	3999
98	4.578	4000.1
99	4.478	3999.6
100	4.516	3999.5
101	4.567	4000.4
102	4.564	4000.2
103	4.551	3999.5
104	4.584	4000.1
105	4.526	3999.1
106	4.479	3999.1
107	4.521	4000.3
108	4.513	4000
109	4.557	4000.1
110	4.502	3999.1
111	4.493	3999.3
112	4.562	3999.6
113	4.486	3999.4
114	4.492	3999.7
115	4.558	4000.1
116	4.495	4000.1
117	4.489	3999.7
118	4.558	3999.1
119	4.574	3999
120	4.559	4000.5
121	4.549	4000.1
122	4.56	4000.1
123	4.561	4000.1
124	4.555	3999.8
125	4.553	4000
126	4.548	3999.7
127	4.547	4000.1
128	4.552	4000.7
129	4.551	3999.7
130	4.553	4000.1
131	4.507	3999.7
132	4.554	3999.4
133	4.486	4000.7
134	4.513	3999.1

135	4.484	3999.7
136	4.483	4000
137	4.526	3999.4
138	4.505	4000.3
139	4.48	3999.5
140	4.514	3999.8
141	4.511	3999.7
142	4.492	3999.7
143	4.483	3999.7
144	4.497	4000.2
145	4.503	3999.3
146	4.508	4000.3
147	4.508	3999.8
148	4.509	3999.5
149	4.515	3998.9
150	4.502	3999.3
151	4.577	3999.4
152	4.481	3999.4
153	4.517	3999.7
154	4.584	3999.7
155	4.56	4000.1
156	4.509	3999.5
157	4.554	3999.5
158	4.599	4000.1
159	4.578	3999.7
160	4.647	4000.4
161	4.504	3999.6
162	4.484	4000.1
163	4.489	3999.7
164	4.571	3999.7
165	4.507	3999.7
166	4.503	4000
167	4.563	3999.7
168	4.496	3999.7
169	4.564	4000.4
170	4.559	4000.4
171	4.557	3999.8
172	4.561	3999.7
173	4.564	3999.7
174	4.513	4000.1
175	4.565	3999.7
176	4.562	4000
177	4.564	4000.1
178	4.516	4000.7
179	4.553	3999.5
180	4.563	3999.7
181	4.56	3999.5
182	4.568	3999.7

183	4.561	4000.8
184	4.551	4000.3
185	4.556	4000.1
186	4.545	3999.5
187	4.558	4000
188	4.597	4000
189	4.552	4000.1
190	4.561	4000.3
191	4.555	3999.7
192	4.597	4000.1
193	4.556	4000.2
194	4.563	3999.4
195	4.584	4000.1
196	4.55	4000.1
197	4.561	3999.5
198	4.601	3999.8
199	4.554	3999.6
200	4.553	3999.6
201	4.557	4000.3
202	4.557	4000.7
203	4.577	4000.4
204	4.554	4000.1
205	4.556	3999.7
206	4.592	4000
207	4.565	4000.4
208	4.559	3999.8
209	4.601	4000.2
210	4.572	3999.7
211	4.61	3999.7
212	4.591	4000.1
213	4.584	4000.1
214	4.578	4000.3
215	4.572	4000.1
216	4.556	3999.7
217	4.577	3999.6
218	4.56	3999.7
219	4.562	3999.7
220	4.584	3999.7
221	4.576	3999.8
222	4.569	4000.2
223	4.558	4000.3
224	4.564	4000.1
225	4.562	3999.3
226	4.601	3999.7
227	4.57	3999.7
228	4.58	3999.7
229	4.573	3999.7
230	4.574	4000.2

231	4.604	4000
232	4.574	4000.3
233	4.598	4000.1
234	4.618	3999.7
235	4.579	3999.8
236	4.575	3999.6
237	4.566	4000.9
238	4.568	4000
239	4.581	3999.5
240	4.56	3999.6
241	4.564	3999.7
242	4.581	4000.1
243	4.595	3999.3
244	4.593	3999.6
245	4.588	3999.4
246	4.585	4000
247	4.589	3999.5
248	4.594	4000.1
249	4.626	3999.3
250	4.56	4000
251	4.585	4000
252	4.601	3999.4
253	4.592	4000
254	4.607	3999.8
255	4.58	4000.1
256	4.618	3999.5
257	4.569	3998.9
258	4.579	4000
259	4.599	3999.4
260	4.605	3999.7
261	4.592	3999.7
262	4.57	3999.8
263	4.596	3999.4
264	4.59	4000.1
265	4.596	3999.5
266	4.598	3999.7
267	4.579	4000
268	4.589	3999.6
269	4.604	4000.4
270	4.578	3999.5
271	4.638	3999.6
272	4.592	4000.7
273	4.572	4000
274	4.575	3999.7
275	4.599	4000.4
276	4.577	3999.7
277	4.603	4000.2
278	4.576	4000

279	4.609	4000.3
280	4.621	4000.5
281	4.584	3999.7
282	4.585	4000.2
283	4.582	4000
284	4.664	3999.4
285	4.588	3999.6
286	4.657	3999.8
287	4.577	4000.1
288	4.587	4000.7
289	4.599	3999.8
290	4.601	3999.3
291	4.591	4000.3
292	4.643	3999.6
293	4.584	3999.7
294	4.638	3999.7
295	4.598	3999.6
296	4.596	4000.2
297	4.593	3999.3
298	4.59	3999.5
299	4.571	3999.6
300	4.607	3999.6
301	4.575	4000.1
302	4.589	4000.4
303	4.566	3999.6
304	4.584	4000.7
305	4.611	3999.7
306	4.584	3999.5
307	4.691	4000
308	4.648	3999.7
309	4.593	3999.5
310	4.573	4000
311	4.648	3999.7
312	4.578	3999.8
313	4.584	3999.3
314	4.615	4000.1
315	4.595	3999.5
316	4.58	3999.5
317	4.64	4000.1
318	4.611	4000.2
319	4.593	3999.6
320	4.593	4000
321	4.596	3999.7
322	4.643	3999.7
323	4.598	3999.4
324	4.638	4000.4
325	4.567	3999.5
326	4.597	3999.6

327	4.591	3999.6
328	4.664	4000.3
329	4.568	3999.7
330	4.675	4000.4
331	4.584	3999.3
332	4.64	4000.1
333	4.574	3999.7
334	4.643	3999.5
335	4.597	4000.1
336	4.589	4000.1
337	4.642	3999.7
338	4.579	4000.5
339	4.637	3999.6
340	4.602	4000.3
341	4.581	3999.7
342	4.582	3999.3
343	4.588	4000.2
344	4.673	3999.7
345	4.696	3999.8
346	4.585	3999.8
347	4.575	3999.1
348	4.584	4000.1
349	4.591	4000.1
350	4.67	3999.4
351	4.589	4000.4
352	4.648	3999.7
353	4.645	4000
354	4.587	3999.7
355	4.578	3999.4
356	4.59	4000.4
357	4.593	3999.4
358	4.637	3999.7
359	4.641	4000.3
360	4.588	3999.7
361	4.685	4000.3
362	4.592	4000
363	4.576	3999.7
364	4.668	4000.3
365	4.67	3999.5
366	4.594	3999.7
367	4.599	3999.5
368	4.639	3999.7
369	4.669	4000.7
370	4.675	3999.3
371	4.593	3999.4
372	4.668	3999.4
373	4.653	4000.3
374	4.589	4000.7

375	4.671	3999.7
376	4.595	4000.3
377	4.614	4000
378	4.574	3999
379	4.596	4000.4
380	4.6	4000.1
381	4.586	3999.5
382	4.572	4000.3
383	4.603	3999.4
384	4.591	4000.4
385	4.673	4000.3
386	4.65	3999.7
387	4.582	3999.5
388	4.572	3998.6
389	4.59	4000
390	4.593	4000
391	4.591	3999.1
392	4.582	4000.4
393	4.573	4000.4
394	4.583	3999.5
395	4.593	3999.5
396	4.711	3999.6
397	4.638	3999.6
398	4.577	4000.4
399	4.574	3999.7
400	4.641	4000
401	4.654	3999.7
402	4.576	3999.5
403	4.59	4000.1
404	4.657	3999.6
405	4.614	4000.2
406	4.575	4000.1
407	4.675	4000
408	4.697	4000.1
409	4.608	4000.4
410	4.604	4000.2
411	4.588	4000
412	4.593	4000.3
413	4.66	3999.5
414	4.668	3999
415	4.579	3999.4
416	4.709	3999.8
417	4.607	3999.1
418	4.598	4000
419	4.688	4000.3
420	4.578	4000.7
421	4.667	4000.4
422	4.64	4000.2

423	4.601	4000.1
424	4.594	3999.7
425	4.672	3999.4
426	4.65	3999.5
427	4.682	4000
428	4.59	3999.8
429	4.599	3999
430	4.689	4000.4
431	4.671	4000.1
432	4.595	4000.1
433	4.585	3999.8
434	4.662	3999.4
435	4.665	3999.7
436	4.662	3999.3
437	4.579	4000.3
438	4.669	3999.8
439	4.643	4000.1
440	4.668	3999.3
441	4.654	3999.3
442	4.595	3999.6
443	4.662	4000
444	4.68	3999.7
445	4.639	4000.1
446	4.675	3999.5
447	4.671	3999.5
448	4.667	4000
449	4.67	4000
450	4.67	4000.1
451	4.695	3999.5
452	4.643	3999.8
453	4.674	3999.8
454	4.59	3999.7
455	4.667	4000.1
456	4.573	4000.1
457	4.659	3999.4
458	4.679	4000.1
459	4.647	3999.6
460	4.583	3999
461	4.642	4000
462	4.639	3999.5
463	4.607	4000.4
464	4.671	4000.3
465	4.64	3999.7
466	4.643	4000.7
467	4.657	3999.8
468	4.65	4000.5
469	4.594	4000.3
470	4.605	3999.7
471	4.588	3999.6
472	4.639	3999.7
473	4.606	4000.1
474	4.666	3999.3
475	4.659	3999.8
476	4.658	4000
477	4.662	4000
478	4.663	3999.4
479	4.597	4000.4
480	4.606	3999.1
481	4.679	3999.5
482	4.676	4000.3
483	4.67	3999.7
484	4.735	4000.8
485	4.647	3999.3
486	4.577	3999.7
487	4.665	3999.6
488	4.673	3999.7
489	4.659	3999.7
490	4.675	3999.7
491	4.661	3999.7
492	4.68	4000.1
493	4.66	3999.7
494	4.67	3999.3
495	4.674	3999.7
496	4.651	4000.1
497	4.577	4000.1
498	4.669	3999.7
499	4.607	3999.5
500	4.682	4000

For Acidic crude oil in alkaline solution 1.5% Na_2CO_3 + 1% NaCl

Time /min	IFT (N/Nm)	Speed /rpm
1	0.399	3999.6
2	0.403	3999.7
3	0.406	3999.7
4	0.399	3999.7
5	0.411	4000.1
6	0.398	3999.8
7	0.411	3999.6
8	0.419	3999.8
9	0.41	3999.7
10	0.418	3999.7
11	0.42	3999.5
12	0.418	3999.8
13	0.423	3999.3
14	0.416	3999.4
15	0.411	3999.7
16	0.409	4000.4
17	0.418	3999.3
18	0.418	4000.2
19	0.423	4000
20	0.424	3998.9
21	0.428	3999.8
22	0.428	4000
23	0.422	3999.8
24	0.428	4000.2
25	0.432	4000.2
26	0.424	3999.8
27	0.43	3999.5
28	0.434	4000.5
29	0.438	3999.5
30	0.418	3999.8
31	0.429	3999.6
32	0.425	4000.1
33	0.434	3999.7
34	0.426	4000.5
35	0.419	3999.5
36	0.437	4000.4
37	0.428	3999.3
38	0.431	3999.1
39	0.434	4000.2
40	0.448	3999.4
41	0.439	3999.7
42	0.432	4000.1
43	0.437	4000.1
44	0.438	4000.4
45	0.436	4000.4
46	0.436	4000.1
47	0.434	3999.7
48	0.435	3999.7
49	0.439	3999.4
50	0.451	4000.4
51	0.439	4000.4
52	0.453	4000.2
53	0.436	4000.1
54	0.439	4000.1
55	0.45	3999.3
56	0.437	4000.1
57	0.448	4000.1
58	0.446	3999.4
59	0.454	4000.1
60	0.447	4000.1
61	0.447	4000
62	0.454	3999.7
63	0.454	4000.1
64	0.446	4000
65	0.455	4000.1
66	0.447	4000.1
67	0.447	3999.7
68	0.447	4000.7
69	0.455	3999.8
70	0.458	4000.1
71	0.451	4000.4
72	0.446	3999.3
73	0.448	4000.4
74	0.447	4000.3
75	0.457	3999.5
76	0.46	4000.1
77	0.469	3999.5
78	0.471	4000.1
79	0.458	4000.3
80	0.448	4000.1
81	0.467	4000.1
82	0.47	3999.1
83	0.466	3999.7
84	0.469	4000.4
85	0.468	3999.3
86	0.467	4000.7
87	0.47	3999.7
88	0.471	3999.5
89	0.467	3999.5
90	0.466	3999.5

91	0.466	3999.4
92	0.462	4000.4
93	0.448	3999.8
94	0.463	4000.1
95	0.461	4000.4
96	0.463	3999.7
97	0.466	3999.4
98	0.461	3999.7
99	0.462	4000.1
100	0.463	3999.7
101	0.463	4000.2
102	0.462	4000
103	0.461	3999.4
104	0.477	4000.1
105	0.47	3999.8
106	0.461	3999.6
107	0.482	4000.7
108	0.471	3999.8
109	0.462	4000
110	0.461	4000.1
111	0.466	4000.1
112	0.462	4000
113	0.462	4000.5
114	0.467	3999.7
115	0.461	3999.5
116	0.462	3999.8
117	0.466	4000
118	0.476	4000.1
119	0.478	4000.4
120	0.476	3999.4
121	0.461	4000
122	0.462	3999.4
123	0.477	3999.7
124	0.478	3999.7
125	0.462	3999.7
126	0.482	3999.7
127	0.462	3999.5
128	0.476	4000.7
129	0.478	4000.3
130	0.486	4000.1
131	0.476	3999.7
132	0.478	4000.1
133	0.499	3999.5
134	0.477	4000.1
135	0.478	3999.1
136	0.476	3999.7
137	0.499	4000
138	0.487	3999.7

139	0.486	4000.1
140	0.485	4000.3
141	0.498	4000.1
142	0.499	4000.1
143	0.484	4000
144	0.503	4000.3
145	0.491	3999.4
146	0.499	4000.1
147	0.481	4000.3
148	0.492	3999.7
149	0.499	4000
150	0.499	4000
151	0.491	3999.8
152	0.486	3999.7
153	0.492	4000.3
154	0.493	4000.1
155	0.481	4000.3
156	0.495	4000.3
157	0.499	3999.4
158	0.491	3999.4
159	0.491	4000.1
160	0.498	3999.7
161	0.488	3999.8
162	0.499	4000
163	0.494	3999.6
164	0.486	4000
165	0.502	4000.1
166	0.491	3999.6
167	0.492	3999.5
168	0.501	4000.4
169	0.491	4000
170	0.5	3999.6
171	0.501	4000
172	0.501	3999.6
173	0.499	4000.1
174	0.498	3999.1
175	0.502	3999.5
176	0.496	3999.6
177	0.501	4000
178	0.5	4000.3
179	0.514	4000
180	0.494	4000
181	0.496	4000.4
182	0.491	3999.3
183	0.506	4000
184	0.51	4000
185	0.509	4000
186	0.494	3999.6

187	0.519	3999.4
188	0.503	4000.1
189	0.509	4000.4
190	0.491	3999.4
191	0.517	3999
192	0.518	4000
193	0.502	4000.1
194	0.492	3999.4
195	0.518	4000.3
196	0.502	3999.1
197	0.514	3999.7
198	0.516	4000.2
199	0.501	4000
200	0.508	4000.1
201	0.493	4000
202	0.493	3999.8
203	0.517	3999.7
204	0.501	4000.4
205	0.514	4000.4
206	0.509	4000
207	0.509	4000.2
208	0.507	3999
209	0.51	3999.8
210	0.492	3999.8
211	0.51	3999.4
212	0.511	4000.7
213	0.507	4000.4
214	0.509	3999.8
215	0.517	3999.6
216	0.509	4000.3
217	0.508	4000.4
218	0.508	4000.1
219	0.51	3999.8
220	0.505	3999.8
221	0.509	4000.3
222	0.507	4000.4
223	0.517	4000.4
224	0.519	3999.3
225	0.507	3999.1
226	0.507	4000.3
227	0.494	3999.5
228	0.519	3999.8
229	0.507	4000
230	0.508	4000.1
231	0.519	3999.7
232	0.51	4000
233	0.507	3999.8
234	0.516	3999.7

235	0.507	3999.4
236	0.52	4000.1
237	0.52	4000.1
238	0.517	3999.4
239	0.533	4000.4
240	0.532	4000.1
241	0.531	4000
242	0.533	3999.7
243	0.533	3999.5
244	0.508	4000
245	0.534	3999.8
246	0.531	3999.5
247	0.515	3999.4
248	0.519	3999.7
249	0.509	4000.1
250	0.519	4000.2
251	0.532	3999.8
252	0.519	4000.4
253	0.519	3999.8
254	0.527	3999.7
255	0.532	3999.8
256	0.517	4000
257	0.531	3999.7
258	0.519	4000.1
259	0.508	3999.6
260	0.528	3999.8
261	0.531	4000.1
262	0.526	3999.3
263	0.525	4000.4
264	0.518	3999.7
265	0.524	4000.2
266	0.523	3999.7
267	0.519	3999.7
268	0.514	3999.8
269	0.528	4000.1
270	0.53	3999.7
271	0.531	3999.6
272	0.52	4000.1
273	0.524	4000.1
274	0.518	3999.3
275	0.523	4000.1
276	0.528	4000.1
277	0.514	3999.1
278	0.526	4000
279	0.533	4000.4
280	0.519	3999.7
281	0.523	3999.7
282	0.534	3999.5

283	0.526	3999.7
284	0.552	4000.3
285	0.527	3999.5
286	0.527	3999.4
287	0.522	3999.8
288	0.522	3999.7
289	0.525	3999.7
290	0.524	3999.7
291	0.526	3999.5
292	0.525	4000.1
293	0.528	3999.7
294	0.543	3999.7
295	0.523	3999.5
296	0.524	3999.5
297	0.525	3999.5
298	0.534	3999.6
299	0.542	3999.6
300	0.524	4000.1
301	0.544	4000.1
302	0.526	3999.7
303	0.526	4000
304	0.551	4000
305	0.525	4000.1
306	0.533	3999.7
307	0.532	4000.4
308	0.525	4000
309	0.526	4000.1
310	0.525	4000.4
311	0.526	3999.4
312	0.525	3999.4
313	0.548	4000.4
314	0.543	3999.7
315	0.532	3999.5
316	0.54	3999.4
317	0.54	3999.7
318	0.543	4000.4
319	0.548	3999.6
320	0.525	4000
321	0.542	4000.1
322	0.541	3999.4
323	0.525	4000.7
324	0.542	3999
325	0.542	4000
326	0.542	3999.7
327	0.542	4000.1
328	0.543	4000.1
329	0.526	4000.3
330	0.566	3999.7

331	0.561	4000.1
332	0.541	4000.1
333	0.564	4000.3
334	0.546	4000.4
335	0.535	3999.1
336	0.564	3999.7
337	0.549	3999.7
338	0.563	3999.4
339	0.564	3999.7
340	0.543	4000.4
341	0.544	3999.7
342	0.543	3999.7
343	0.545	4000.4
344	0.545	4000.3
345	0.541	4000.7
346	0.541	3999.7
347	0.557	4000
348	0.543	4000
349	0.55	4000
350	0.543	4000.3
351	0.543	3999.1
352	0.555	4000.4
353	0.525	3999.6
354	0.542	3999.7
355	0.551	4000
356	0.543	3999.7
357	0.565	3999.6
358	0.554	4000.2
359	0.552	3999.4
360	0.554	4000
361	0.554	3999.4
362	0.564	4000
363	0.553	4000
364	0.562	3999.7
365	0.566	4000.3
366	0.566	3999.6
367	0.534	3999.7
368	0.563	4000.3
369	0.553	3999.4
370	0.526	4000.3
371	0.553	3999.6
372	0.547	3999.4
373	0.559	3999.7
374	0.543	3999.5
375	0.553	3999.3
376	0.553	4000.3
377	0.564	4000.3
378	0.564	4000.3

379	0.554	4000.1
380	0.551	3999.3
381	0.553	3999.7
382	0.553	3999.5
383	0.553	3999.7
384	0.563	3999.7
385	0.565	3999.7
386	0.563	3999.8
387	0.568	3999.6
388	0.552	4000.3
389	0.546	3999.7
390	0.565	4000.1
391	0.567	3999.3
392	0.562	4000
393	0.543	3999.4
394	0.564	4000.1
395	0.559	3999.5
396	0.563	3999.7
397	0.558	4000.2
398	0.552	3999.6
399	0.563	4000.3
400	0.563	3999.5
401	0.563	4000.1
402	0.559	4000.4
403	0.543	4000.1
404	0.558	3999.8
405	0.559	3999.7
406	0.567	3999.5
407	0.566	4000.2
408	0.564	3999.7
409	0.563	3999.7
410	0.565	4000.1
411	0.542	3999.8
412	0.561	3999.8
413	0.558	4000
414	0.565	3999.8
415	0.565	4000.4
416	0.56	3999.6
417	0.542	3999.8
418	0.566	4000.3
419	0.563	4000.1
420	0.549	4000.2
421	0.551	4000.3
422	0.541	3999.8
423	0.56	3999.7
424	0.554	4000.1
425	0.565	4000.3
426	0.567	3999.5

427	0.554	3999.6
428	0.565	3999.6
429	0.551	3999.7
430	0.567	3999.5
431	0.557	3999.8
432	0.565	4000.1
433	0.56	3999.4
434	0.555	3999.5
435	0.557	3999.5
436	0.566	4000
437	0.556	3999.5
438	0.552	3999.5
439	0.567	3999.6
440	0.561	4000.1
441	0.564	4000.4
442	0.559	3999.5
443	0.558	3999.5
444	0.556	4000.5
445	0.558	4000.1
446	0.557	4000
447	0.569	4000.3
448	0.558	3999.5
449	0.558	4000.1
450	0.559	4000.1
451	0.556	3999.8
452	0.56	4000.3
453	0.556	3999.5
454	0.567	4000.4
455	0.555	4000.1
456	0.56	4000.1
457	0.557	4000.3
458	0.555	4000.1
459	0.565	4000.1
460	0.565	3999.3
461	0.558	4000
462	0.555	4000
463	0.557	4000.4
464	0.56	4000.1
465	0.557	3999.8
466	0.556	4000.1
467	0.558	4000.1
468	0.56	3999.6
469	0.558	3999.4
470	0.56	3999.1
471	0.578	3999.3
472	0.555	3999.6
473	0.56	4000.4
474	0.555	4000.2

475	0.56	4000.1
476	0.559	3999.7
477	0.577	3998.9
478	0.587	3999.7
479	0.56	4000.1
480	0.56	4000.4
481	0.559	3999.7
482	0.558	3999.6
483	0.561	3999.4
484	0.578	4000.4
485	0.559	3999.6
486	0.578	3999.7
487	0.578	3999.4
488	0.56	3999.7
489	0.587	4000.4
490	0.559	3999.5
491	0.555	4000.1
492	0.572	3999.7
493	0.559	3999.1
494	0.561	4000.1
495	0.567	3999.7
496	0.588	4000.1
497	0.559	4000
498	0.578	3999.4
499	0.579	4000.1
500	0.559	3999.7

For Acidic crude oil in alkaline solution 1.5% NaOH + 1% NaCl

Time /min	IFT (N/Nm)	Speed /rpm
1	1.717	3999.4
2	1.75	4000
3	1.723	4000.2
4	1.727	3999.5
5	1.753	4000.3
6	1.756	3999.4
7	1.718	3999.5
8	1.758	4000
9	1.72	3999.3
10	1.755	4000
11	1.72	3999.5
12	1.757	3999.5
13	1.78	3999.7
14	1.78	3999.5
15	1.753	3999.7
16	1.765	4000.2
17	1.724	3999.4
18	1.752	4000.4
19	1.755	4000.1
20	1.751	3999.8
21	1.72	4000.2
22	1.722	4000
23	1.715	4000.1
24	1.752	3999.5
25	1.718	4000.1
26	1.742	4000.2
27	1.756	3999.5
28	1.76	3999.1
29	1.746	3999.6
30	1.758	3999.4
31	1.727	4000.4
32	1.757	3999.8
33	1.758	4000.1
34	1.753	4000
35	1.761	3999.7
36	1.763	4000.1
37	1.754	4000.3
38	1.795	4000.3
39	1.78	3999.7
40	1.769	3999.3
41	1.789	3999.7
42	1.79	4000.3
43	1.792	3999.3
44	1.789	3999.7
45	1.783	3999
46	1.798	3999.4
47	1.759	4000.1
48	1.793	4000
49	1.799	4000.4
50	1.812	4000.4
51	1.79	3999.6
52	1.791	4000.1
53	1.813	3999.4
54	1.785	3999.7
55	1.778	4000.4
56	1.769	3999.8
57	1.781	3999.4
58	1.793	4000.1
59	1.792	4000.2
60	1.792	3999.7
61	1.809	4000
62	1.793	4000.1
63	1.757	3999.7
64	1.806	3999.3
65	1.758	4000
66	1.794	3999.7
67	1.804	3999.6
68	1.79	3999.7
69	1.8	4000.1
70	1.79	4000.2
71	1.801	4000.7
72	1.794	3999.5
73	1.821	4000.4
74	1.794	3999.7
75	1.801	4000.2
76	1.791	3999.4
77	1.795	3999.7
78	1.801	3999.8
79	1.806	3999.4
80	1.797	3999.3
81	1.793	4000.1
82	1.8	3999.1
83	1.797	4000.1
84	1.793	4000
85	1.79	3999.4
86	1.797	3999.7
87	1.83	3999.3
88	1.794	3999.6
89	1.804	4000.1
90	1.794	4000.3
91	1.801	4000.7
92	1.792	4000.3
93	1.831	4000.2
94	1.856	4000.3
95	1.852	3999.7
96	1.838	3999.5
97	1.841	3999.8
98	1.828	3999.3
99	1.832	4000
100	1.829	4000.7
101	1.829	4000.1
102	1.854	4000
103	1.834	3999.8
104	1.855	3999.4
105	1.831	4000.3
106	1.83	3999.8
107	1.834	3999.3
108	1.832	3998.9
109	1.833	4000
110	1.834	4000.3
111	1.834	3999.5
112	1.834	3999.8
113	1.832	3999.6
114	1.834	4000.2
115	1.831	4000.5
116	1.874	4000.4
117	1.832	3999.5
118	1.83	4000
119	1.834	3999.5
120	1.836	4000.1
121	1.887	3999.4
122	1.836	4000.1
123	1.872	3999.6
124	1.872	3999.6
125	1.794	3999.7
126	1.838	3999.4
127	1.83	4000
128	1.835	3999.7
129	1.832	3999.7
130	1.867	4000.2
131	1.839	3999.1
132	1.833	4000.4
133	1.832	3999.5
134	1.87	4000
135	1.833	3999.4
136	1.864	3999.7
137	1.832	3999.5
138	1.853	4000.1
139	1.871	3999.3
140	1.841	3999.6
141	1.872	4000.3
142	1.875	4000

143	1.888	3999.7
144	1.898	3999.8
145	1.868	3999.1
146	1.89	4000.2
147	1.888	3999.6
148	1.871	4000.1
149	1.871	3999.6
150	1.884	3999.3
151	1.897	4000.2
152	1.872	4000.3
153	1.879	3999.7
154	1.882	4000.1
155	1.881	3999.8
156	1.872	3999.8
157	1.874	4000.2
158	1.884	3999.8
159	1.887	4000.1
160	1.873	4000.1
161	1.874	3999.8
162	1.874	4000.2
163	1.88	4000.1
164	1.883	4000.7
165	1.887	4000.1
166	1.88	3999.1
167	1.877	3999.5
168	1.883	4000.3
169	1.871	3999.7
170	1.876	4000.4
171	1.879	3999.1
172	1.88	3999.1
173	1.876	4000
174	1.883	3999.7
175	1.874	4000.4
176	1.881	3999.5
177	1.87	3998.9
178	1.879	4000.3
179	1.879	4000.1
180	1.871	4000.1
181	1.872	4000.4
182	1.878	3999.6
183	1.883	4000.3
184	1.877	3999.5
185	1.879	3999.7
186	1.916	4000.4
187	1.878	4000.1
188	1.875	3999
189	1.877	4000.1
190	1.912	4000.4

191	1.909	4000
192	1.871	3999.5
193	1.873	3999.7
194	1.878	3999.7
195	1.881	3999.5
196	1.883	4000.2
197	1.911	3999.6
198	1.88	3999
199	1.873	3999.5
200	1.912	4000.1
201	1.88	3999.7
202	1.879	4000.4
203	1.872	3999.6
204	1.876	3999.5
205	1.911	4000.4
206	1.878	4000
207	1.88	3999.7
208	1.911	3999.7
209	1.914	4000.4
210	1.946	4000.2
211	1.909	3999.7
212	1.946	3999.7
213	1.911	4000.1
214	1.912	3999.7
215	1.886	4000.4
216	1.911	3999.7
217	1.91	3999.4
218	1.951	4000.1
219	1.91	3999.5
220	1.908	3999.1
221	1.881	3999.5
222	1.911	3999
223	1.875	4000.1
224	1.879	3999.7
225	1.949	3999.7
226	1.91	3999.8
227	1.91	3999.6
228	1.952	4000.1
229	1.911	4000.4
230	1.948	4000
231	1.912	3999.7
232	1.916	3999.8
233	1.912	4000.7
234	1.95	3999.7
235	1.91	3999.4
236	1.913	3999.7
237	1.915	3999.8
238	1.921	4000

239	1.918	3999.5
240	1.951	3999.4
241	1.911	4000.1
242	1.95	4000.1
243	1.949	3999.6
244	1.95	4000
245	1.95	3999.4
246	1.912	4000.1
247	1.912	4000.4
248	1.952	3999.6
249	1.912	4000
250	1.914	3999.4
251	1.959	3999.7
252	1.96	3999.5
253	1.941	4000.1
254	1.966	3999.7
255	1.954	3999.6
256	1.955	3999.6
257	1.957	4000.5
258	1.955	3999.5
259	1.954	4000
260	1.957	3999.8
261	1.964	3999.5
262	1.953	3999.5
263	1.958	3999.6
264	1.962	4000.2
265	1.954	3999.5
266	1.964	3999.7
267	1.953	4000.4
268	1.913	4000
269	1.934	3999.6
270	1.919	4000.1
271	1.921	3999.7
272	1.92	3999.5
273	1.921	3999.7
274	1.953	4000.3
275	1.952	3999.5
276	1.976	3999.7
277	1.952	3999.7
278	1.98	3999.7
279	1.972	4000.4
280	1.949	3999.6
281	1.953	4000.2
282	1.958	3999.1
283	1.949	3999.7
284	1.951	4000.1
285	1.954	3999.6
286	1.917	4000.2

287	1.915	4000.3
288	1.914	3999.7
289	1.954	4000.2
290	1.965	4000.1
291	1.911	3999.7
292	1.92	3999.7
293	1.916	4000.1
294	1.916	3999.5
295	1.885	3999.8
296	1.919	4000
297	1.923	3999.4
298	1.916	4000
299	1.912	4000.4
300	1.952	3999.7
301	1.956	3999.8
302	1.957	4000.1
303	1.917	3999.7
304	1.919	4000.7
305	1.955	3998.9
306	1.922	4000
307	1.953	4000.3
308	1.916	3999.7
309	1.952	4000.1
310	1.951	4000.2
311	1.958	3999.5
312	1.923	3999.4
313	1.911	3999.7
314	1.913	3999.5
315	1.925	4000.3
316	1.921	3999.4
317	1.92	3999.7
318	1.912	4000
319	1.912	3999.5
320	1.949	4000.5
321	1.918	3999.6
322	1.912	4000.1
323	1.95	3999.7
324	1.952	4000.4
325	1.954	4000.5
326	1.915	4000
327	1.922	4000.1
328	1.922	3999.6
329	1.919	3999.6
330	1.924	4000.1
331	1.911	4000.1
332	1.911	3999.8
333	1.913	3999.6
334	1.911	4000

335	1.911	4000
336	1.916	4000
337	1.913	3999.5
338	1.915	3999.6
339	1.918	4000.2
340	1.911	3999.4
341	1.911	4000
342	1.935	4000.1
343	1.916	3999.7
344	1.932	4000.1
345	1.927	3999.6
346	1.927	4000
347	1.93	4000
348	1.931	4000.1
349	1.935	3999.7
350	1.931	3999.8
351	1.934	4000.4
352	1.875	4000.2
353	1.878	3999.6
354	1.874	3999.7
355	1.875	3999.7
356	1.878	3999.8
357	1.911	4000.2
358	1.913	3999.6
359	1.909	3999.5
360	1.913	4000.1
361	1.923	3999.8
362	1.877	4000.2
363	1.888	3999.6
364	1.871	3999.6
365	1.912	3999
366	1.914	3999.7
367	1.881	4000.1
368	1.924	4000.4
369	1.911	3999.8
370	1.889	3999.1
371	1.887	3999.6
372	1.919	3999.7
373	1.88	4000.1
374	1.882	3999.7
375	1.88	3999.7
376	1.873	3999.1
377	1.919	3999.5

378	1.908	4000
379	1.882	3999.5
380	1.923	4000.1
381	1.886	4000.2
382	1.892	3999.8
383	1.889	4000
384	1.881	3999.6
385	1.879	4000.1
386	1.889	4000.1
387	1.876	3999.5
388	1.881	3999.8
389	1.889	3999.8
390	1.894	3999.6
391	1.846	3999.6
392	1.889	3999.4
393	1.895	4000.1
394	1.912	4000.7
395	1.889	3999.5
396	1.872	3999.7
397	1.841	4000.3
398	1.893	3999.8
399	1.856	4000.1
400	1.833	3999.4
401	1.834	3999.7
402	1.837	4000.7
403	1.838	4000.1
404	1.836	3999.5
405	1.837	4000
406	1.835	3999.4
407	1.835	4000.1
408	1.835	3999.8
409	1.873	3999.7
410	1.835	3999.6
411	1.873	4000.3
412	1.873	3999.7
413	1.846	3999.5
414	1.842	4000.1
415	1.846	4000
416	1.896	3999.4
417	1.873	3999.7
418	1.839	4000.1
419	1.836	3999.5
420	1.83	3999.6

421	1.873	3999.7
422	1.837	3999.5
423	1.85	4000.1
424	1.847	4000.4
425	1.845	3999.8
426	1.839	3999.8
427	1.875	4000
428	1.837	4000.3
429	1.882	4000.1
430	1.871	4000.1
431	1.848	4000.1
432	1.875	3999.5
433	1.871	4000.1
434	1.872	3999.6
435	1.878	3999.7
436	1.831	4000
437	1.872	3999.7
438	1.871	3999.1
439	1.872	3999.7
440	1.872	3999.7
441	1.851	4000.1
442	1.884	4000.1
443	1.869	3999.8
444	1.843	3999.6
445	1.846	4000.1
446	1.868	3999.6
447	1.869	3999.7
448	1.872	4000.1
449	1.872	3999.5
450	1.848	4000.1
451	1.871	3999.3
452	1.872	3999.7
453	1.841	3999.4
454	1.873	3999.8
455	1.839	4000.1
456	1.844	3999.6
457	1.867	4000
458	1.873	3999.7
459	1.873	3999.5
460	1.873	4000.3
461	1.87	4000
462	1.872	4000
463	1.872	3999.7

464	1.872	3999.4
465	1.871	4000.1
466	1.884	3999.6
467	1.872	4000
468	1.873	3999.6
469	1.873	4000.1
470	1.873	4000.1
471	1.868	3999.8
472	1.873	4000
473	1.871	4000
474	1.871	4000.1
475	1.872	3999.4
476	1.873	3999.5
477	1.873	4000.1
478	1.872	3999
479	1.872	3999.8
480	1.873	3999.6
481	1.873	4000
482	1.872	3999.7
483	1.872	3999.7
484	1.868	4000.2
485	1.867	3999.5
486	1.873	3999.7
487	1.873	4000.1
488	1.873	3999.4
489	1.872	4000.2
490	1.871	3999.4
491	1.872	3999.6
492	1.873	3999.7
493	1.871	4000.1
494	1.873	3999.6
495	1.872	3999.7
496	1.873	4000.1
497	1.868	4000.1
498	1.872	3999.8
499	1.873	3999.8
500	1.872	3999.4

4. Core flooding result and end-point relative permeability of water

Displacement result for Run 1 & 2

Oil Saturate	**Run 1**
Original Water Saturation (cc)	16.52
Displaced Brine (cc)	9.97
Original-Oil-in-place (cc)	9.97
Residual Water (cc)	6.55
Oil Saturation, So (Ratio)	0.603
Critical Water Saturation, Swc (Ratio)	0.397
Water Flooding	
Displaced Oil (cc)	5.8
Residual Oil (cc)	4.17
Water Saturation (cc)	12.35
Critical Oil Saturation, Sor (Ratio)	0.252
Water Saturation, Sw (Ratio)	0.748
Alkaline Flooding	
Oil in Place before Alkaline (cc)	4.17
Additional Oil Displacement (cc)	1.1
Residual Oil (cc)	3.07
Critical Oil Saturation, Sor (Ratio)	0.186

Oil Saturate	**Run 2**
Original Water Saturation (cc)	14.54
Displaced Brine (cc)	9.97
Original-Oil-in-place (cc)	9.97
Residual Water (cc)	4.57
Oil Saturation, So (Ratio)	0.68
Critical Water Saturation, Swc (Ratio)	0.32
Water Flooding	
Displaced Oil (cc)	5.8
Residual Oil (cc)	4.17
Water Saturation (cc)	10.37
Critical Oil Saturation, Sor (Ratio)	0.287
Water Saturation, Sw (Ratio)	0.713
Alkaline Flooding	
Oil in Place before Alkaline (cc)	4.17
Additional Oil Displacement (cc)	0.82
Residual Oil (cc)	3.35
Critical Oil Saturation, Sor (Ratio)	0.23

Core properties for Run 1 & 2

Run 1	
Length	2.96 inch
Diameter	1.48 inch
Gas Permeability	155.24 mD
Gas Porosity	19.69%
Permeability infinite	126.03 mD
Grain Density	2.62 g/cc
Grain Volume	67.37 cc
Bulk Density	2.11 g/cc
Bulk Volume	83.90 cc
Pore Volume	16.52 cc
weight	174.36 g

Run 2	
Length	3.00 inch
Diameter	1.48 inch
Gas Permeability	78.29 mD
Gas Porosity	17.84%
Permeability infinite	68.77 mD
Grain Density	2.68 g/cc
Grain Volume	66.96 cc
Bulk Density	2.14 g/cc
Bulk Volume	81.50 cc
Pore Volume	14.54 cc
weight	174.36 g

Table for Volume in Run 1 and 2 after alkaline flooding

Run 1		
Dedicated cylinder	Volume displaced in recovery	
	oil/mL	alkaline/mL
1	0.1	9.6
2	0.05	9.4
3	0.05	10
4	0.05	9.8
5	0	9.4
6	0	9.4
7	0.15	11.2
8	0.1	9.2
9	0.1	10
10	0.1	10
11	0.1	10
12	0.1	10.4
13	0.05	10.2
14	0.05	10.4
15	0.05	10
16	0.05	10
17	0	40
Total	**1.1**	199

Run 2		
Dedicated cylinder	Volume displaced in recovery	
	oil/mL	alkaline/mL
1	0	9.8
2	0	10
3	0.1	10.4
4	0.1	9.6
5	0.2	9.8
6	0.2	9.8
7	0.1	10
8	0	10
9	0.05	10
10	0.05	10
11	0.02	10
12	0	10
13	0	10
14	0	10
15	0	10
16	0	10
17	0	10
18	0	10
19	0	20
Total	**0.82**	199.4

Run 1: Water Flooding

Elapsed Time minutes	Inlet Pressure psig	Outlet Pressure psig	Overburden Pressure psig	delta Pressure psig	Core Temperature °C	Permeability md	end point relative permeability
1	1019.4	1007.34	1531.46	12.06	70.62	21.12133	0.186
2	1007.34	999.09	1530.83	8.25	70.62	0	0.000
3	927.99	925.45	1525.12	2.54	70.62	0	0.000
4	919.11	915.93	1521.94	3.18	70.62	80.10163	0.705
5	966.71	962.27	1518.77	4.44	70.62	57.37009	0.505
6	1023.21	1013.69	1516.23	9.52	69.98	26.75664	0.235
7	1023.21	1011.15	1513.06	12.06	69.98	21.12133	0.186
8	1025.75	1010.51	1509.25	15.24	69.98	16.71412	0.147
9	1029.56	1010.51	1507.34	19.05	69.98	13.3713	0.118

10	1033.37	1010.51	1504.17	22.86	69.98	11.14275	0.098
11	1034.64	1009.88	1501.63	24.76	69.98	10.28769	0.091
12	1034	1009.24	1500.36	24.76	69.98	10.28769	0.091
13	1033.37	1008.61	1497.82	24.76	69.98	10.28769	0.091
14	1032.73	1007.34	1496.55	25.39	69.98	10.03242	0.088
15	1030.83	1006.07	1495.28	24.76	69.98	10.28769	0.091
16	1029.56	1005.44	1493.38	24.12	69.98	10.56066	0.093
17	1027.65	1003.53	1492.11	24.12	69.98	10.56066	0.093
18	1025.75	1001.63	1491.47	24.12	69.98	10.56066	0.093
19	1024.48	1001.63	1489.57	22.85	69.98	11.14762	0.098
20	1023.21	1000.36	1488.93	22.85	69.98	11.14762	0.098
21	1022.58	999.09	1488.3	23.49	69.98	10.8439	0.095
22	1021.94	998.45	1487.67	23.49	69.98	10.8439	0.095
23	1021.31	997.82	1487.03	23.49	69.98	10.8439	0.095
24	1020.67	997.18	1485.13	23.49	69.98	10.8439	0.095
25	1018.77	996.55	1484.49	22.22	69.98	11.46369	0.101
26	1018.77	995.28	1483.86	23.49	69.98	10.8439	0.095
27	1018.13	994.01	1483.22	24.12	69.98	10.56066	0.093
28	1016.86	993.38	1483.22	23.48	69.98	10.84852	0.095
29	1014.96	992.74	1482.59	22.22	69.98	11.46369	0.101
30	1014.96	991.47	1482.59	23.49	69.98	10.8439	0.095
31	1014.32	991.47	1481.32	22.85	69.98	11.14762	0.098
32	1014.32	990.2	1481.32	24.12	69.98	10.56066	0.093
33	1014.32	990.84	1480.68	23.48	69.98	10.84852	0.095
34	1013.69	990.2	1480.68	23.49	69.98	10.8439	0.095
35	1013.05	989.57	1480.68	23.48	70.62	10.84852	0.095
36	1012.42	989.57	1480.05	22.85	69.98	11.14762	0.098
37	1013.05	990.2	1480.05	22.85	69.98	11.14762	0.098
38	1013.69	990.2	1480.05	23.49	69.98	10.8439	0.095
39	1013.69	990.84	1480.05	22.85	69.98	11.14762	0.098
40	1014.32	991.47	1479.41	22.85	69.98	11.14762	0.098
41	1014.96	991.47	1479.41	23.49	69.98	10.8439	0.095
42	1015.59	992.74	1479.41	22.85	69.98	11.14762	0.098
43	1015.59	992.74	1478.78	22.85	69.98	11.14762	0.098
44	1015.59	993.38	1478.78	22.21	69.98	11.46885	0.101
45	1016.86	993.38	1478.78	23.48	69.98	10.84852	0.095
46	1017.5	994.01	1478.78	23.49	69.98	10.8439	0.095
47	1017.5	993.38	1478.78	24.12	69.98	10.56066	0.093
48	1017.5	994.65	1478.78	22.85	70.62	11.14762	0.098
49	1018.77	996.55	1477.51	22.22	70.62	11.46369	0.101
50	1020.67	997.18	1477.51	23.49	69.98	10.8439	0.095
51	1021.31	998.45	1477.51	22.86	70.62	11.14275	0.098
52	1021.94	999.09	1477.51	22.85	70.62	11.14762	0.098

53	1022.58	999.09	1476.87	23.49	70.62	10.8439	0.095
54	1022.58	999.09	1477.51	23.49	70.62	10.8439	0.095
55	1023.21	1000.36	1476.87	22.85	70.62	11.14762	0.098
					Average	**12.202**	**0.108**

Run 1: Alkaline Flooding (NaOH)

Elapsed Time minutes	Inlet Pressure psig	Outlet Pressure psig	Overburden Pressure psig	delta Pressure psig	Core Temperature °C	Permeability md	end point relative permeability
1	955.29	949.58	1560.03	5.71	70.62	0.000	0.000
2	950.85	945.77	1559.4	5.08	70.62	0.000	0.000
3	945.77	938.78	1557.49	6.99	70.62	40.4099169	0.321
4	1006.71	986.39	1554.95	20.32	70.62	13.90085232	0.110
5	1008.61	985.76	1551.14	22.85	70.62	12.36172075	0.098
6	1008.61	985.12	1546.06	23.49	70.62	12.0249178	0.095
7	1008.61	984.49	1543.53	24.12	69.98	11.71083413	0.093
8	1009.88	985.12	1540.99	24.76	69.98	11.40813082	0.091
9	1010.51	986.39	1539.08	24.12	69.98	11.71083413	0.093
10	1011.15	986.39	1536.54	24.76	69.98	11.40813082	0.091
11	1013.05	988.3	1534	24.75	69.98	11.41274017	0.091
12	1014.32	988.93	1532.73	25.39	69.67	11.1250618	0.088
13	1015.59	990.2	1531.46	25.39	69.67	11.1250618	0.088
14	1016.86	990.84	1529.56	26.02	69.98	10.8557002	0.086
15	1017.5	991.47	1528.93	26.03	69.67	10.85152974	0.086
16	1018.77	993.38	1528.29	25.39	69.98	11.1250618	0.088
17	1019.4	994.01	1527.02	25.39	69.67	11.1250618	0.088
18	1020.67	994.65	1525.75	26.02	69.98	10.8557002	0.086
19	1021.94	996.55	1525.12	25.39	69.98	11.1250618	0.088
20	1021.94	997.18	1525.12	24.76	69.98	11.40813082	0.091
21	1023.21	998.45	1524.48	24.76	69.98	11.40813082	0.091
22	1020.67	995.28	1523.85	25.39	69.98	11.1250618	0.088
23	1022.58	997.82	1523.21	24.76	69.98	11.40813082	0.091
24	1027.02	1002.26	1523.21	24.76	69.98	11.40813082	0.091
25	1027.65	1002.9	1521.31	24.75	69.98	11.41274017	0.091
26	1029.56	1004.8	1520.04	24.76	69.98	11.40813082	0.091
27	1029.56	1005.44	1518.77	24.12	69.67	11.71083413	0.093
28	1029.56	1005.44	1516.87	24.12	69.98	11.71083413	0.093
29	1032.73	1008.61	1516.23	24.12	69.67	11.71083413	0.093
30	1032.73	1009.24	1513.06	23.49	69.67	12.0249178	0.095
31	1034	1009.24	1511.15	24.76	69.67	11.40813082	0.091

32	1034.64	1010.51	1509.25	24.13	69.67	11.7059809	0.093
33	1034.64	1009.88	1507.34	24.76	69.67	11.40813082	0.091
34	1034	1005.44	1505.44	28.56	69.67	9.890242265	0.078
35	1030.19	1006.07	1504.17	24.12	69.67	11.71083413	0.093
36	1036.54	1012.42	1502.9	24.12	69.67	11.71083413	0.093
37	1037.81	1013.05	1501.63	24.76	69.67	11.40813082	0.091
38	1038.44	1014.32	1501	24.12	69.67	11.71083413	0.093
39	1040.98	1016.86	1500.36	24.12	69.67	11.71083413	0.093
40	1044.79	1019.4	1499.73	25.39	69.67	11.1250618	0.088
41	1046.06	1020.67	1499.09	25.39	69.67	11.1250618	0.088
42	1049.87	1024.48	1496.55	25.39	69.67	11.1250618	0.088
43	1051.14	1026.38	1495.28	24.76	69.67	11.40813082	0.091
44	1045.43	1021.31	1493.38	24.12	69.35	11.71083413	0.093
45	1053.04	1029.56	1492.11	23.48	69.67	12.03003914	0.095
46	1056.85	1031.46	1490.84	25.39	69.67	11.1250618	0.088
47	1058.12	1033.37	1488.93	24.75	69.67	11.41274017	0.091
48	1059.39	1035.27	1487.67	24.12	69.35	11.71083413	0.093
49	1062.57	1036.54	1487.03	26.03	69.35	10.85152974	0.086
50	1058.12	1031.46	1485.13	26.66	69.67	10.59509824	0.084
51	1057.49	1032.73	1485.13	24.76	69.35	11.40813082	0.091
52	1057.49	1033.37	1484.49	24.12	69.67	11.71083413	0.093
53	1065.11	1039.08	1485.13	26.03	69.67	10.85152974	0.086
54	1066.37	1040.98	1485.13	25.39	69.67	11.1250618	0.088
55	1067.64	1041.62	1485.13	26.02	69.67	10.8557002	0.086
56	1068.91	1042.25	1485.13	26.66	69.67	10.59509824	0.084
57	1072.72	1045.43	1487.03	27.29	69.67	10.35050638	0.082
58	1073.99	1046.7	1487.03	27.29	69.67	10.35050638	0.082
59	1073.99	1047.33	1485.13	26.66	69.67	10.59509824	0.084
60	1075.26	1048.6	1487.03	26.66	69.67	10.59509824	0.084
61	1075.9	1049.24	1487.03	26.66	69.67	10.59509824	0.084
62	1077.17	1049.87	1487.03	27.3	69.67	10.34671499	0.082
63	1077.8	1050.51	1487.67	27.29	69.67	10.35050638	0.082
64	1075.26	1047.33	1487.67	27.93	69.67	10.11333044	0.080
65	1079.07	1051.77	1488.3	27.3	69.67	10.34671499	0.082
66	1079.07	1051.77	1488.93	27.3	69.67	10.34671499	0.082
67	1080.97	1053.04	1489.57	27.93	69.67	10.11333044	0.080
68	1079.7	1053.04	1490.84	26.66	69.98	10.59509824	0.084
69	1079.7	1053.04	1491.47	26.66	69.98	10.59509824	0.084
70	1079.7	1053.04	1492.11	26.66	69.98	10.59509824	0.084
71	1062.57	1035.27	1491.47	27.3	69.98	10.34671499	0.082

72	1071.45	1043.52	1491.47	27.93	69.98	10.11333044	0.080
73	1071.45	1043.52	1492.11	27.93	69.98	10.11333044	0.080
74	1069.55	1041.62	1492.11	27.93	69.98	10.11333044	0.080
75	1069.55	1041.62	1492.74	27.93	69.98	10.11333044	0.080
76	1069.55	1041.62	1493.38	27.93	69.98	10.11333044	0.080
77	1069.55	1040.98	1494.65	28.57	69.98	9.886780507	0.078
78	1067.01	1039.08	1495.28	27.93	69.98	10.11333044	0.080
79	1067.01	1039.08	1495.92	27.93	69.98	10.11333044	0.080
80	1065.11	1035.27	1496.55	29.84	69.98	9.465995948	0.075
81	1067.01	1038.44	1497.19	28.57	69.98	9.886780507	0.078
82	1069.55	1040.98	1497.82	28.57	69.98	9.886780507	0.078
83	1068.91	1039.71	1499.73	29.2	70.62	9.673469832	0.077
84	1063.84	1036.54	1500.36	27.3	70.62	10.34671499	0.082
85	1063.2	1034.64	1500.36	28.56	70.62	9.890242265	0.078
86	1062.57	1034.64	1500.36	27.93	70.62	10.11333044	0.080
87	1065.11	1035.27	1501	29.84	70.62	9.465995948	0.075
88	1039.08	1012.42	1500.36	26.66	70.62	10.59509824	0.084
89	1057.49	1030.19	1501.63	27.3	70.62	10.34671499	0.082
90	1058.12	1030.19	1502.9	27.93	70.62	10.11333044	0.080
91	1058.12	1030.19	1503.53	27.93	70.62	10.11333044	0.080
92	1057.49	1028.92	1504.17	28.57	70.62	9.886780507	0.078
93	1055.58	1027.65	1504.8	27.93	70.62	10.11333044	0.080
94	1054.95	1026.38	1505.44	28.57	70.62	9.886780507	0.078
95	1053.68	1025.11	1507.34	28.57	70.62	9.886780507	0.078
96	1053.68	1025.11	1507.98	28.57	70.62	9.886780507	0.078
97	1051.77	1023.21	1508.61	28.56	70.62	9.890242265	0.078
98	1051.14	1023.21	1509.25	27.93	70.62	10.11333044	0.080
99	1049.24	1020.67	1509.88	28.57	70.62	9.886780507	0.078
100	1047.33	1021.94	1509.88	25.39	70.62	11.1250618	0.088
101	1049.87	1019.4	1509.88	30.47	70.62	9.270276308	0.074
102	1048.6	1020.67	1509.88	27.93	70.94	10.11333044	0.080
103	1048.6	1020.67	1509.88	27.93	70.62	10.11333044	0.080
104	1045.43	1017.5	1509.88	27.93	70.62	10.11333044	0.080
105	1046.7	1018.77	1509.88	27.93	70.62	10.11333044	0.080
106	1046.7	1018.13	1511.15	28.57	70.62	9.886780507	0.078
107	1045.43	1017.5	1511.15	27.93	70.62	10.11333044	0.080
108	1044.79	1016.86	1511.79	27.93	70.62	10.11333044	0.080
109	1044.79	1014.96	1512.42	29.83	70.62	9.469169262	0.075
110	1043.52	1014.96	1513.06	28.56	70.62	9.890242265	0.078
111	1037.81	1010.51	1513.06	27.3	70.62	10.34671499	0.082

112	1039.08	1011.15	1513.69	27.93	70.62	10.11333044	0.080
113	1039.08	1011.15	1514.96	27.93	70.94	10.11333044	0.080
114	1033.37	1006.71	1514.96	26.66	70.94	10.59509824	0.084
115	1039.71	1011.15	1514.96	28.56	70.94	9.890242265	0.078
116	1039.08	1010.51	1515.6	28.57	70.94	9.886780507	0.078
117	1037.81	1009.88	1515.6	27.93	70.94	10.11333044	0.080
118	1037.81	1009.24	1515.6	28.57	70.94	9.886780507	0.078
119	1037.17	1009.24	1516.23	27.93	70.94	10.11333044	0.080
120	1036.54	1008.61	1516.87	27.93	70.94	10.11333044	0.080
121	1035.27	1006.71	1516.87	28.56	70.94	9.890242265	0.078
122	1029.56	994.01	1516.87	35.55	70.94	7.945578596	0.063
123	1021.31	993.38	1517.5	27.93	70.94	10.11333044	0.080
124	1027.02	998.45	1518.77	28.57	70.94	9.886780507	0.078
125	1029.56	1001.63	1520.04	27.93	70.94	10.11333044	0.080
126	1029.56	1000.36	1520.04	29.2	70.94	9.673469832	0.077
127	1027.65	999.09	1520.67	28.56	70.94	9.890242265	0.078
128	1027.02	998.45	1521.94	28.57	70.94	9.886780507	0.078
129	1027.02	998.45	1523.21	28.57	70.94	9.886780507	0.078
130	1026.38	998.45	1523.85	27.93	70.94	10.11333044	0.080
131	1027.02	997.82	1524.48	29.2	70.94	9.673469832	0.077
132	1026.38	997.82	1525.75	28.56	70.94	9.890242265	0.078
133	1026.38	998.45	1527.02	27.93	70.94	10.11333044	0.080
134	1026.38	997.82	1527.66	28.56	70.94	9.890242265	0.078
135	1025.75	997.18	1528.29	28.57	70.94	9.886780507	0.078
136	1025.11	996.55	1528.93	28.56	71.25	9.890242265	0.078
137	1024.48	996.55	1530.83	27.93	71.25	10.11333044	0.080
138	1024.48	995.28	1530.83	29.2	70.94	9.673469832	0.077
139	1023.21	994.65	1532.1	28.56	71.25	9.890242265	0.078
140	1022.58	994.01	1532.73	28.57	71.25	9.886780507	0.078
141	1021.31	993.38	1533.37	27.93	71.25	10.11333044	0.080
142	1021.94	993.38	1534	28.56	71.25	9.890242265	0.078
143	1021.31	992.74	1535.91	28.57	71.25	9.886780507	0.078
144	1020.67	991.47	1536.54	29.2	71.25	9.673469832	0.077
145	1019.4	990.84	1537.18	28.56	71.25	9.890242265	0.078
146	1019.4	990.84	1537.81	28.56	71.25	9.890242265	0.078
147	1018.77	990.84	1539.72	27.93	71.25	10.11333044	0.080
148	1018.13	990.2	1540.35	27.93	71.25	10.11333044	0.080
149	1018.13	990.2	1540.99	27.93	71.25	10.11333044	0.080
150	1016.86	987.03	1541.62	29.83	71.25	9.469169262	0.075
151	1016.86	988.93	1543.53	27.93	71.25	10.11333044	0.080

152	1015.59	988.3	1544.16	27.29	71.25	10.35050638	0.082
					Average	**10.484**	**0.083**

Run 2: Water Flooding

Elapsed Time minutes	Inlet Pressure psig	Outlet Pressure psig	Overburden Pressure psig	delta Pressure psig	Core Temperature °C	Permeability md	end point relative permeability
1	900.7	888.64	1690.79	12.06	70.62	0	0.000
2	893.72	881.66	1690.16	12.06	70.62	0	0.000
3	1067.64	1043.52	1692.06	24.12	70.62	10.56066	0.154
4	1101.29	1051.77	1690.79	49.52	70.62	5.143845	0.075
5	1111.44	1051.14	1689.52	60.3	70.62	4.224265	0.061
6	1124.14	1051.14	1688.25	73	70.62	3.489359	0.051
7	1135.57	1050.51	1686.35	85.06	70.62	2.99463	0.044
8	1146.36	1049.24	1685.72	97.12	70.62	2.622768	0.038
9	1164.13	1046.7	1685.08	117.43	70.62	2.169149	0.032
10	1187.62	1048.6	1685.08	139.02	69.98	1.832277	0.027
11	1206.66	1048.6	1685.08	158.06	70.62	1.61156	0.023
12	1223.8	1048.6	1685.08	175.2	70.62	1.453899	0.021
13	1242.21	1047.33	1685.08	194.88	69.98	1.307077	0.019
14	1260.62	1046.7	1685.72	213.92	70.62	1.19074	0.017
15	952.12	936.88	1676.19	15.24	70.62	16.71412	0.243
16	1014.32	997.18	1678.1	17.14	70.62	14.86133	0.216
17	1078.44	1051.77	1680.64	26.67	70.62	9.550926	0.139
18	1138.1	1080.97	1681.91	57.13	70.62	4.458659	0.065
19	1179.36	1086.05	1683.81	93.31	70.62	2.729859	0.040
20	1211.74	1090.5	1685.08	121.24	70.62	2.100983	0.031
21	1234.59	1089.23	1685.72	145.36	70.62	1.752361	0.025
22	1251.73	1093.04	1686.35	158.69	70.62	1.605162	0.023
23	1264.42	1094.94	1687.62	169.48	70.94	1.502969	0.022
24	1031.46	1014.32	1682.54	17.14	70.94	14.86133	0.216
25	1045.43	1025.75	1682.54	19.68	70.94	12.94325	0.188
26	1083.51	1061.93	1684.45	21.58	70.62	11.80367	0.172
27	1145.72	1112.08	1685.72	33.64	70.62	7.572033	0.110
28	1194.6	1118.43	1687.62	76.17	70.62	3.344141	0.049
29	1069.55	1021.94	1676.19	47.61	70.62	5.350204	0.078
30	1107.64	1023.21	1676.19	84.43	70.62	3.016975	0.044
31	1134.93	1023.21	1676.19	111.72	70.62	2.280014	0.033
32	1151.43	1021.31	1676.19	130.12	70.62	1.957602	0.028

33	1162.86	1021.94	1676.19	140.92	70.62	1.807573	0.026
34	1169.84	1021.31	1676.19	148.53	70.62	1.714961	0.025
35	1176.19	1020.67	1676.19	155.52	70.62	1.637881	0.024
36	1179.36	1020.67	1675.56	158.69	70.62	1.605162	0.023
37	1181.27	1014.96	1675.56	166.31	70.62	1.531617	0.022
38	1181.9	1014.96	1675.56	166.94	70.62	1.525837	0.022
39	1183.17	1014.32	1674.29	168.85	70.62	1.508577	0.022
40	1183.81	1014.32	1674.29	169.49	70.62	1.50288	0.022
41	1184.44	1013.69	1674.29	170.75	70.62	1.49179	0.022
42	1184.44	1013.05	1674.29	171.39	70.62	1.48622	0.022
43	1184.44	1012.42	1674.29	172.02	70.62	1.480777	0.022
44	1184.44	1010.51	1673.65	173.93	70.62	1.464516	0.021
45	1184.44	1010.51	1673.65	173.93	70.62	1.464516	0.021
46	1184.44	1009.88	1673.65	174.56	70.62	1.45923	0.021
47	1183.81	1009.24	1673.65	174.57	70.62	1.459146	0.021
48	1183.17	1008.61	1673.65	174.56	70.94	1.45923	0.021
49	1183.81	1007.34	1673.65	176.47	70.62	1.443436	0.021
50	1183.17	1006.71	1673.65	176.46	70.62	1.443518	0.021
51	1183.17	1006.07	1673.02	177.1	70.62	1.438301	0.021
52	1181.27	1005.44	1673.02	175.83	70.94	1.44869	0.021
53	1181.27	1004.8	1673.02	176.47	70.94	1.443436	0.021
54	1181.27	1003.53	1673.02	177.74	70.94	1.433122	0.021
55	1179.36	1002.9	1672.39	176.46	70.94	1.443518	0.021
					Average	**3.485**	**0.051**

Run 2: Alkaline Flooding (Na_2CO_3)

Elapsed Time minutes	Inlet Pressure psig	Outlet Pressure psig	Overburden Pressure psig	delta Pressure psig	Core Temperature °C	Permeability md	end point relative permeability
1	849.92	837.22	1608.91	12.7	70.62	21.24845	0.309
2	842.3	830.24	1608.27	12.06	70.62	22.37606	0.325
3	1056.85	970.52	1611.45	86.33	70.62	3.125857	0.045
4	1117.79	1017.5	1608.91	100.29	70.62	2.690749	0.039
5	1146.99	1016.86	1605.73	130.13	70.62	2.073736	0.030
6	1157.78	1015.59	1603.19	142.19	69.98	1.89785	0.028
7	1162.86	1014.32	1600.66	148.54	69.98	1.816718	0.026
8	1166.67	1013.69	1598.12	152.98	69.98	1.76399	0.026
9	1167.94	1013.05	1595.58	154.89	69.98	1.742238	0.025
10	1169.21	1011.15	1593.67	158.06	69.98	1.707296	0.025

11	1169.21	1010.51	1592.4	158.7	69.98	1.700411	0.025
12	1170.48	1009.88	1591.13	160.6	69.98	1.680294	0.024
13	1171.11	1008.61	1589.86	162.5	69.98	1.660648	0.024
14	1173.65	1006.71	1589.23	166.94	69.98	1.616481	0.024
15	1175.56	1006.07	1588.59	169.49	69.98	1.59216	0.023
16	1180	1005.44	1587.96	174.56	69.98	1.545917	0.022
17	1187.62	1004.8	1587.33	182.82	69.98	1.476071	0.021
18	1195.23	1003.53	1587.33	191.7	69.98	1.407696	0.020
19	1202.85	1002.9	1587.33	199.95	69.98	1.349614	0.020
20	1210.47	1001.63	1587.33	208.84	69.98	1.292163	0.019
21	1218.09	1001.63	1587.33	216.46	69.98	1.246675	0.018
22	1223.8	1000.36	1587.33	223.44	69.98	1.20773	0.018
23	1229.51	999.09	1587.33	230.42	69.98	1.171145	0.017
24	1234.59	998.45	1587.33	236.14	69.98	1.142777	0.017
25	1239.67	997.18	1587.96	242.49	69.98	1.112851	0.016
26	1246.65	997.18	1587.96	249.47	69.98	1.081714	0.016
27	1254.27	995.28	1587.96	258.99	69.98	1.041952	0.015
28	1261.89	995.28	1589.23	266.61	69.98	1.012172	0.015
29	1271.41	994.01	1589.23	277.4	69.98	0.972802	0.014
30	1282.83	993.38	1660.96	289.45	69.98	0.932304	0.014
31	1291.72	993.38	1660.96	298.34	70.62	0.904523	0.013
32	1299.34	991.47	1660.96	307.87	69.98	0.876523	0.013
33	1307.59	991.47	1660.96	316.12	69.98	0.853648	0.012
34	1313.94	990.84	1660.96	323.1	69.98	0.835207	0.012
35	1320.28	990.2	1661.59	330.08	69.98	0.817545	0.012
36	992.74	947.04	1798.71	45.7	70.62	5.904929	0.086
37	1101.29	983.22	1801.24	118.07	70.62	2.285553	0.033
38	1166.03	983.22	1801.88	182.81	70.62	1.476152	0.021
39	1211.74	983.22	1802.51	228.52	70.62	1.180882	0.017
40	1247.92	982.58	1804.42	265.34	70.62	1.017017	0.015
41	1274.58	981.95	1804.42	292.63	70.62	0.922172	0.013
42	1294.89	981.31	1805.05	313.58	70.62	0.860563	0.013
43	1313.94	981.31	1805.69	332.63	70.62	0.811278	0.012
44	1328.54	980.68	1806.32	347.86	70.62	0.775758	0.011
45	1339.33	980.68	1806.96	358.65	70.62	0.75242	0.011
46	1347.58	979.41	1808.23	368.17	70.62	0.732964	0.011
47	1353.29	978.78	1808.23	374.51	70.62	0.720556	0.010
48	1359.64	976.87	1808.23	382.77	70.62	0.705006	0.010
49	1365.35	977.51	1808.86	387.84	70.62	0.69579	0.010
50	1370.43	976.87	1808.86	393.56	70.62	0.685678	0.010

51	922.28	874.67	1797.44	47.61	70.62	5.668037	0.082
52	1034	965.45	1798.71	68.55	70.62	3.936619	0.057
53	1131.76	971.16	1800.61	160.6	70.62	1.680294	0.024
54	1193.96	972.43	1801.24	221.53	70.62	1.218143	0.018
55	1232.69	972.43	1801.88	260.26	70.62	1.036868	0.015
56	1261.89	970.52	1802.51	291.37	70.62	0.92616	0.013
57	1284.1	969.25	1802.51	314.85	70.62	0.857092	0.012
58	1303.15	969.89	1802.51	333.26	70.62	0.809744	0.012
59	1322.19	969.89	1804.42	352.3	70.62	0.765981	0.011
60	1338.06	969.25	1804.42	368.81	70.62	0.731692	0.011
61	1350.12	969.25	1804.42	380.87	70.62	0.708523	0.010
62	1358.37	969.25	1805.05	389.12	70.62	0.693501	0.010
63	1365.35	968.62	1805.05	396.73	70.62	0.680199	0.010
64	1371.07	967.35	1805.05	403.72	70.62	0.668422	0.010
65	1375.51	967.35	1805.05	408.16	70.62	0.661151	0.010
66	1379.32	967.35	1805.69	411.97	70.62	0.655036	0.010
67	1381.22	966.71	1805.69	414.51	70.62	0.651022	0.009
68	1383.76	966.71	1805.69	417.05	70.62	0.647057	0.009
69	1386.94	966.08	1805.69	420.86	70.62	0.6412	0.009
70	1388.84	966.08	1805.69	422.76	70.62	0.638318	0.009
71	1390.74	965.45	1806.32	425.29	70.62	0.634521	0.009
72	1391.38	966.08	1806.32	425.3	70.62	0.634506	0.009
73	1392.65	965.45	1806.32	427.2	70.62	0.631684	0.009
74	1394.55	964.81	1806.96	429.74	70.62	0.62795	0.009
75	1396.46	966.08	1806.96	430.38	70.62	0.627016	0.009
76	1398.36	966.71	1808.23	431.65	70.62	0.625171	0.009
77	1399.63	968.62	1808.23	431.01	70.62	0.6261	0.009
78	1401.54	968.62	1808.86	432.92	70.62	0.623337	0.009
79	1404.08	969.89	1809.5	434.19	70.62	0.621514	0.009
80	1404.71	972.43	1809.5	432.28	70.62	0.62426	0.009
81	1406.61	973.7	1809.5	432.91	70.62	0.623352	0.009
82	1407.88	974.33	1809.5	433.55	70.62	0.622432	0.009
83	1409.15	974.97	1809.5	434.18	70.62	0.621529	0.009
84	1410.42	974.97	1810.13	435.45	70.62	0.619716	0.009
85	1411.06	974.97	1809.5	436.09	70.62	0.618806	0.009
86	1412.33	974.97	1809.5	437.36	70.62	0.617009	0.009
87	1412.96	976.24	1810.13	436.72	70.62	0.617914	0.009
88	1413.6	974.97	1810.13	438.63	70.62	0.615223	0.009
89	1413.6	974.97	1810.13	438.63	70.62	0.615223	0.009
90	1414.87	974.97	1810.13	439.9	70.62	0.613447	0.009

91	1416.14	974.97	1810.13	441.17	70.62	0.611681	0.009
92	1416.77	974.33	1810.77	442.44	70.62	0.609925	0.009
93	1416.14	974.33	1810.77	441.81	70.62	0.610795	0.009
94	1416.77	974.33	1810.77	442.44	70.62	0.609925	0.009
95	1417.41	974.33	1810.77	443.08	70.62	0.609044	0.009
96	1417.41	971.16	1810.77	446.25	70.62	0.604718	0.009
97	1416.77	973.7	1810.77	443.07	70.62	0.609058	0.009
98	1417.41	973.7	1810.77	443.71	70.62	0.608179	0.009
99	1416.77	973.06	1811.4	443.71	70.62	0.608179	0.009
100	1418.67	973.7	1811.4	444.97	70.62	0.606457	0.009
101	1419.31	974.97	1811.4	444.34	70.62	0.607317	0.009
102	1419.94	977.51	1812.67	442.43	70.62	0.609939	0.009
103	1422.48	980.68	1812.67	441.8	70.62	0.610809	0.009
104	1425.02	983.22	1813.31	441.8	70.62	0.610809	0.009
105	1428.2	985.76	1813.94	442.44	70.62	0.609925	0.009
106	1430.74	988.93	1813.94	441.81	70.62	0.610795	0.009
107	1433.27	990.84	1813.94	442.43	70.62	0.609939	0.009
108	1435.81	991.47	1813.94	444.34	70.94	0.607317	0.009
109	1437.08	991.47	1813.94	445.61	70.62	0.605586	0.009
110	1438.99	991.47	1813.94	447.52	70.62	0.603002	0.009
111	1439.62	990.84	1813.94	448.78	70.62	0.601309	0.009
112	1440.26	991.47	1813.94	448.79	70.62	0.601295	0.009
113	1440.89	990.2	1814.57	450.69	70.62	0.59876	0.009
114	1440.89	990.2	1813.94	450.69	70.62	0.59876	0.009
115	1440.89	990.2	1814.57	450.69	70.94	0.59876	0.009
116	1439.62	986.39	1814.57	453.23	70.94	0.595405	0.009
117	1439.62	989.57	1814.57	450.05	70.62	0.599612	0.009
118	1439.62	988.93	1814.57	450.69	70.94	0.59876	0.009
119	1437.72	984.49	1814.57	453.23	70.62	0.595405	0.009
120	1437.72	984.49	1814.57	453.23	70.62	0.595405	0.009
121	1437.72	984.49	1814.57	453.23	70.62	0.595405	0.009
122	1437.08	979.41	1814.57	457.67	70.94	0.589628	0.009
123	1435.81	980.68	1814.57	455.13	70.94	0.592919	0.009
124	1435.81	980.68	1814.57	455.13	70.94	0.592919	0.009
125	1435.18	979.41	1815.21	455.77	70.94	0.592086	0.009
126	1434.54	978.78	1814.57	455.76	70.94	0.592099	0.009
127	1432.64	978.78	1814.57	453.86	70.62	0.594578	0.009
128	1432.01	978.78	1814.57	453.23	70.94	0.595405	0.009
129	1431.37	978.14	1814.57	453.23	70.62	0.595405	0.009
130	1430.74	978.14	1814.57	452.6	70.62	0.596233	0.009

131	1430.74	976.87	1814.57	453.87	70.94	0.594565	0.009
132	1430.74	976.87	1814.57	453.87	70.94	0.594565	0.009
133	1430.74	974.97	1814.57	455.77	70.94	0.592086	0.009
134	1429.47	974.97	1814.57	454.5	70.94	0.593741	0.009
135	1429.47	974.33	1814.57	455.14	70.94	0.592906	0.009
136	1429.47	973.7	1815.21	455.77	70.94	0.592086	0.009
137	1430.74	973.7	1814.57	457.04	70.94	0.590441	0.009
138	1429.47	973.06	1814.57	456.41	70.62	0.591256	0.009
139	1429.47	972.43	1814.57	457.04	70.94	0.590441	0.009
140	1428.83	971.16	1815.21	457.67	70.94	0.589628	0.009
141	1428.2	971.16	1814.57	457.04	70.94	0.590441	0.009
142	1428.2	970.52	1815.21	457.68	70.94	0.589616	0.009
143	1428.2	970.52	1814.57	457.68	70.94	0.589616	0.009
144	1427.56	969.89	1814.57	457.67	70.94	0.589628	0.009
145	1426.93	969.25	1814.57	457.68	70.94	0.589616	0.009
146	1426.93	969.25	1815.21	457.68	70.94	0.589616	0.009
147	1425.02	968.62	1814.57	456.4	70.94	0.591269	0.009
148	1425.02	968.62	1814.57	456.4	70.94	0.591269	0.009
149	1425.02	966.71	1814.57	458.31	70.62	0.588805	0.009
150	1425.02	967.35	1814.57	457.67	70.94	0.589628	0.009
151	1426.93	966.71	1814.57	460.22	70.94	0.586361	0.009
152	1426.93	966.71	1815.21	460.22	70.94	0.586361	0.009
					Average	**1.213**	**0.018**