Near Wellbore Asphaltene Damage Stimulation Using Ultrasonic Technology

by

Nur Zulaikar Binti Md Jusoh

Dissertation submitted in partial fulfillment of

the requirements for the

Bachelor of Engineering (Hons)

(Petroleum Engineering)

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CERTIFICATION OF APPROVAL

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Approved by,

(Dr Masoud Rashidi)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

September 2013

CERTIFICATION OF ORIGINALITY

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

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(NUR ZULAIKAR BINTI MD JUSOH)

ABSTRACT

Near wellbore asphaltene deposition is one of the major problems in oil and gas industry. Deposition can significantly affected the oil flow towards the wellbore thus decreasing the recovery. There are several factors contributing to asphaltene deposition such as changes in crude oil composition, and changes in reservoir pressure and temperature. In this project, the effectiveness of ultrasonic technology in removing near wellbore asphaltene deposition is studied. It is believed that ultrasonic cleaning is powerful enough to remove tough contaminants (asphaltene), yet gentle enough not to damage the formation. A series of experiments using sandstone core samples and Malaysian light oil is designed and carried out to examine the effect of ultrasonic cleaning on asphaltene deposition. Different stimulation times and temperatures were used in the ultrasonic stimulation in order to investigate the effect of both parameters versus formation permeability improvement. Before that, Dynamic flooding experiment has been introduced to create asphaltene deposition inside the core samples. Asphaltene deposition resulted in reduction of porosity and permeability of core samples, and low asphaltene content in exiting crude oil during CO2 injection. Results show that by increasing the stimulation time and temperature, the permeability also will increase. It is confirmed that ultrasonic cleaning technology is able to disrupt the deposition and dispersed the asphaltene. Besides, the ability of ultrasound to be applied selectively and in a controlled manner gives great advantages to well operators.

ACKNOWLEDGMENT

Alhamdulillah, all praise to Allah for the blessing and strength that He has given me for completing this research project.

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

Near wellbore formation damage can cause devastating effect on the oil recovery due to severe reduction in reservoir permeability. The dominant causes of wellbore damage vary from one well to another, but asphaltene deposition can be one of the major problem to this industry. Asphaltene precipitation has negatively affected relative and absolute permeability of rocks. As a result, the search for effective and environmental-friendly method to solve near wellbore asphaltene damage is a great concern in oil and gas production.

Asphaltene is defined as the heavy fraction of crude oil, which is soluble in aromatic solvent, but insoluble in normal heptanes. Asphaltene is a complex organic material that contains nitrogen, oxygen, and sulfur atoms in addition of carbon and hydrogen atoms within the repeating unit (Eric Y. Sheu, 1995). Under original reservoir condition, asphaltene is typically stable, and maintained in suspension by material called maltenes and resins in the crude oil. However, when the stabilize conditions are altered, asphaltene can be destabilized and precipitate.

Based on previous studies, asphaltene depositions followed several important steps as reported by Fisher and others (Fisher, 2003):

1. The first step is precipitation, this happen when asphaltene form a distinct phase and come out from crude oil.

2. This leads to the formation of larger groups called flocs which the small particles clump together and grow larger, this stages is called flocculation.
3. Third stage is deposition, a point when asphaltenes are large enough that they can no longer be supported by the crude oil and therefore settle out on solid surface.

The most two common causes of asphaltenes flocculation and deposition in near wellbore area is decreasing in reservoir pressure below the critical pressure at which asphaltenes flocculates, and mixing of reservoir fluid during enhanced oil recovery processes. Kosta (1997) pointed out that in the case of asphaltene deposition, asphaltenes can reduce the production by:

1. Blocking pore throats thus reducing pore permeability.
2. Adsorbing onto the rock and changing the formation wettability from water-wet to oil-wet, thus reducing the oil effective permeability.
3. Increasing the reservoir fluid viscosity, by nucleating water-in-oil emulsions.

In most cases, the dominant damage mechanism is the blockage of the pore throats by asphaltenes particles causing a reduction in rock permeability.

Different methods were developed to remove asphaltenes deposition and these methods can be either a mechanical or chemical treatment. In the mechanical methods, scraping is carried out. Coil tubing and a downhole hydraulic motor are used to scrape the deposit while water is pumped as circulating fluid. Another way is by applying pressure in the completely plugged well tubing to create considerable pressure differential across the asphaltenes to break it and create communication. The mechanical methods provide effective cleaning and minimum formation damage. However, these methods are expensive and may plug the perforations and increase the stability of oil-in-water emulsions.

Second method for asphaltenes removal is chemical methods, including solvent treatments, asphaltenes detergents and crystal modifiers. The most commonly used solvent is Xylene. However, the treatment is unable to remove all the deposits as only 70-80% can be removed through a combined chemical treatment which require at least 48 hours soak time and back and forth agitation (Shedid, 2004). Besides, all types of chemical treatments have shown many restrictions in application because of environmental safety and personnel exposure hazard concern.

Since a few decades ago, the use of high-power sound waves to remove plugging materials from the wellbore and near wellbore region has been investigated. Ultrasonic or ultrasound involves vibratory waves which are about the detection limits of human ears (about 20 kHz) (Gollapudi, 1994). Ultrasonic cleaning technology on the other hand involves the use of high-frequency sound waves (above the upper range of human hearing) to remove a variety of contaminants from parts immersed in aqueous media. It is believed that ultrasonic cleaning is powerful enough to remove asphaltene deposition, yet gentle enough not to damage the formation. Besides, studies reported that ultrasonic cleaning is successful in removing the deposition and the effects of the improved permeability will last for several months.

The cleaning mechanism involved during ultrasonic cleaning is acoustic cavitation. In cavitation process, micron-size bubbles form and grow due to alternating positive and negative pressure waves in a solution. The bubbles subjected to these alternating pressure waves continue to grow until they reach resonant size. Just prior to the bubble implosion, there has been a tremendous amount of energy stored inside the bubble itself. The temperature inside a cavitating bubble can be extremely high, with pressures up to 500 atm. The implosion event, when it occurs near a hard surface, changes the bubble into a jet about one-tenth the bubble size, which travels at speeds up to 400 km/hr toward the hard surface. With the combination of pressure, temperature, and velocity, the jet frees contaminants from their bonds with the substrate. Because of the inherently small size of the jet and the relatively large energy, ultrasonic cleaning has the ability to reach into small crevices and remove entrapped deposits very effectively. The aim of this paper is to investigate the role of ultrasonic wave on asphaltene damage stimulation in core plug scale through a series of experiments.

1.2 PROBLEM STATEMENT

Asphaltenes precipitation has been the subject of studies for decades. Deposition of asphaltene may happen near the wellbore, clogging the porous matrix of reservoir rock. Apart from causing the reservoir formation damage, asphaltene deposition could also result in reversal of rock wettability, from water-wet to oil-wet, which causing lower recovery. Although operators try their hardest in preventing the conditions where asphaltene precipitation from occurs, the potential accumulation of asphaltene deposit is inevitable.

A number of models have been developed for asphaltene precipitation and remedies. The current remediation methods for asphaltene deposition problem is injecting acidic solvents or dispersants to dissolve the deposit by soaking, or mechanical treatment by scrubbing the deposit, or hydraulic fracturing to overcome the damaged formation near wellbore. These methods are expensive and often only half effective. Thus, a new method, ultrasound wave has been studied. The ultrasonic cleaning technology is proven to be able to disrupt the precipitation and dispersed the asphaltene. If this technique is working, it can reduce the expenditure of taking corrective measure and also provide a green solution for oil and gas industry.

1.3 OBJECTIVES AND SCOPE OF STUDY

Asphaltene deposition is arguably the most frequent causes of formation pores plugging. In this work, the precipitation of asphaltene from a Malaysian light oil reservoir is studied. A series of experiments were designed and carried out to examine the effect of ultrasonic cleaning on asphaltene deposition. Deposition is created using Dynamic Carbon Dioxide flooding experiment on sandstone core samples. This dynamic displacement test stimulates reservoir condition and sandstone core samples are used to represent the reservoir formation. Final stage of this study is using ultrasonic cleaning to analyze the effectiveness of ultrasonic treatment on repairing permeability and porosity damage inside the core samples due to asphaltene deposition. Two parameters of ultrasonic sources are studied; radiation time and temperature.

The objectives of this study are to:

1. Describe the positive effect of ultrasonic waves for recovering the permeability of the damaged porous medium.

2. Investigate the optimum exposure time and temperature of ultrasonic wave; where after this point, the efficiency of stimulation is not changed significantly.

3. Prove that most asphaltene deposited in the porous medium are removed and exiting from the medium.

1.4 RELEVANCY OF THE STUDY

The idea of using ultrasonic technology on removing asphaltene deposition gave positive feedback on oil recovery. It could overcome some limitation of the existing methods, mechanical and chemical treatments. The ability of ultrasonic to be applied selectively and in a controlled manner gives great advantages to well operators. Besides, we can provide a new green solution, without impacting the environment by introducing this treatment.

1.5 FEASIBILITY OF THE STUDY WITHIN THE SCOPE AND TIME FRAME

All of the objectives stated earlier are achievable and feasible within the scope and time frame. This research comprises of three main phases which are material preparation, creating asphaltene deposition and lastly stimulation using ultrasonic cleaning. The author is using sandstone core plugs which are supplies by laboratory. Asphaltene damage will be conducted by using Dynamic core flooding method in the lab since the university has all the materials. Equipment for generating ultrasonic waves is also available in the university laboratory. Thus, since all equipment and materials that are required for this study are already available, this study can be conducted and finished within the time frame.

CHAPTER 2

LITERATURE REVIEW

2.1 CRUDE OIL CHARACTERIZATION

Crude oil is a mixture consisting of naturally occurring hydrocarbons, together with others organic compounds such as sulphur, nitrogen, and oxygen besides a trace amounts of metallic components of vanadium, nickel and iron. Crude oil or petroleum varies in terms of volatility, density, viscosity and color depend on the origin of the crude oil itself. Normally, crude oil is classified based on the viscosity (UNITAR definition) or density (API definition). “Light oil” is one of crude oil categories that has a relatively low viscosity; less than 100 mPa s and API gravity more than 20. Crude oil that is more viscous, and has lower API gravity, 10 up to 20 is called as “heavy oil”. Third categories of crude oil belong to “bitumen” which are extremely viscous and has API lower than 10.

Hydrocarbon components in crude oil consists of light fractions hydrocarbon, C1 up to C6 (methane, ethane, propane and so on) and plus fraction, C7 and extend up to C200. C7+ fraction is more complex than light fractions due to large number of isomer combinations available to hydrocarbons with increasing carbon number as well as the presence of heteroatoms (Tharanivasan, 2012). C7+ component normally belong to the following groups:

1. Paraffins

   Paraffin is straight chain alkanes, where carbon atoms are connected by single bonds, thus making it saturated.

2. Naphthenes

   Naphthenes are similar to paraffins with one or more cyclic structure. The carbon atoms in the cyclic structures are connected by single bonds.

3. Aromatics

   Aromatics are components with one or more cyclic structures containing double bonds. Aromatics may be linked with substituted naphthene rings and/or paraffin side-chains.

4. Resins

   Resins are very aromatic components and their structure is not well-defined. They are describing as polar, polynuclear molecules consisting of condensed aromatic rings, aliphatic side chains and few heteroatoms.

5. Asphaltenes

   Asphaltene in general is similar to resins, but are larger, denser, and more polar and aromatic.

2.2 ASPHALTENE

2.2.1 General Description

Asphaltene is defined as the heavy fraction of crude oil, which is soluble in aromatic solvents such as toluene or benzene, but will precipitate in crude oil, by addition of an excess amount of n-alkane solvents such as n-heptane or n-pentane (Eric Y. Sheu, 1995). Asphaltene is not a pure component and consists of thousands of species which have similar solubility behavior but may have different chemical structures, sizes, and shapes. Nevertheless, asphaltene species are made up from common components, which are nitrogen, oxygen, and sulfur atoms in addition of carbon and hydrogen atoms within the repeating unit.

There is no actual structure of asphaltene as it depends on the origin of oil as well as asphaltic materials. However, there are two fundamental views of asphaltenes structure, the condensed (island) structure and the dispersed (archipelago) structure. The condensed structure represents a typical asphaltene molecule as a core aromatic group containing a large number of fused rings, normally more than seven rings with aliphatic groups towards the periphery. Meanwhile, the dispersed structure represents asphaltene molecules as a collection of small aromatic groups linked by aliphatic bridges (Dickie, 1967). A recent study conducted by McKenna (2010) using high resolution mass spectrometry data suggests that both structures may actually exist in the oil. Both structures are shown in Figure 1 and Figure 2.

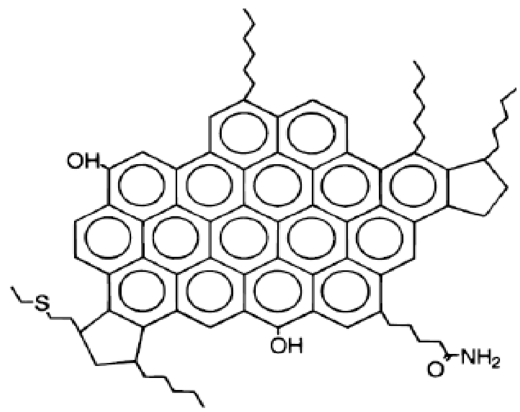


Figure 1: The Condensed Asphaltene Molecular Structure

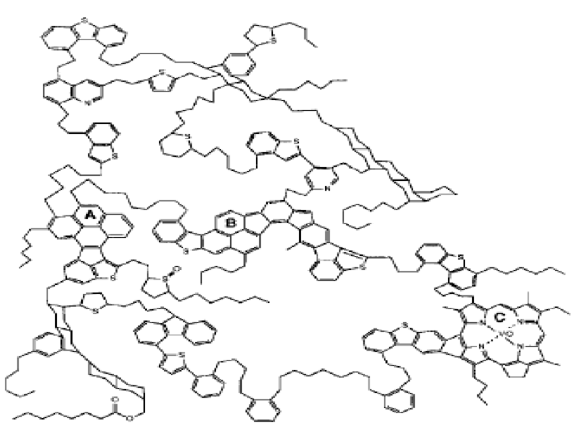


Figure 2: The Dispersed Asphaltene Molecular Structure

2.2.2 Asphaltene Precipitation

Under original reservoir condition, asphaltene is typically stable, and maintained in suspension by material called maltenes and resins in the crude oil. However, when the stabilize conditions are altered, asphaltene can be destabilized and precipitate. Asphaltene precipitate upon changes in crude oil composition, pressure and temperature. Composition induced precipitation occurs when the oil becomes less aromatic due to the addition of gases or paraffinic solvents to the oil **(**Tharanivasan**,** 2012**)**. For instance, during gas injection for enhanced oil recovery methods, the injected gases can induce precipitation when the dissolved gas concentration exceeds a certain limit at a given pressure and temperature.

Pressure induced precipitation can occur during normal operation of conventional crude oil well. Under normal condition, crude oil is understated and contain a high concentration of light hydrocarbon gases and high concentration of light paraffinic liquid compounds that act as a sub-solvent for asphaltenes. However, as the oil is depressurized during the production, the relative molar volumes of the solution gas and light components are increasing. Thus, asphaltene starts to precipitate at a certain pressure called the upper asphaltene precipitation onset pressure (Tharanivasan, 2012).

At the bubble point, crude oil has the highest content of dissolved gas by volume and therefore the maximum amount of asphaltene deposition will occur (Hammami, 2000). Below the bubble point, solution gas and other volatile components will escape from the oil as a gas phase resulting in the liquid phase becoming a better solvent for the asphaltenes. Hence, the precipitated asphaltenes will start to redissolve into the oil. The pressure at which the last of the precipitated asphaltenes redissolve is called lower asphaltene precipitation onset pressure. The third asphaltene precipitation induced factor, temperature has a minor effect on the precipitation of asphaltene compare to changes in pressure. The Asphaltene deposition condition can be described based on asphaltene precipitation envelope shown in Figure 3.

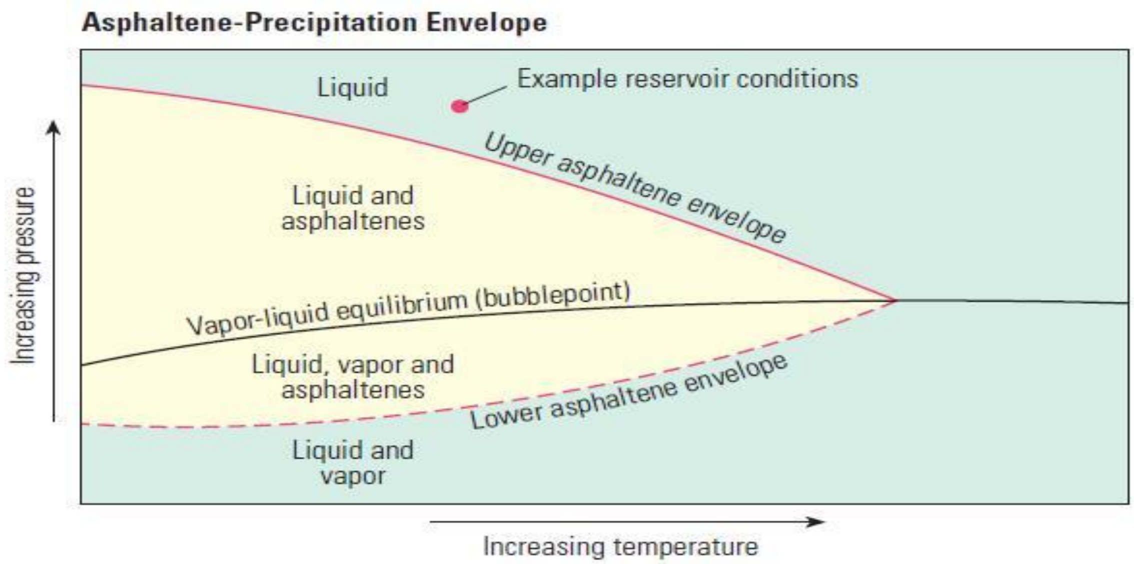
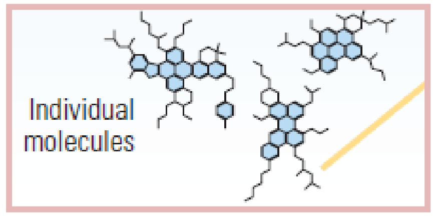


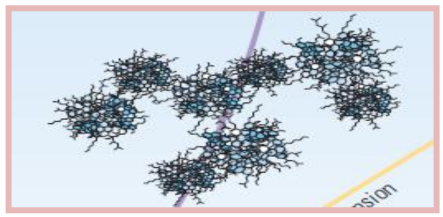
Figure 3: Asphaltene Precipitation Envelope

Based on previous studies, asphaltene depositions will be followed by several important steps as reported by Fisher (2003). The first step is precipitation, this happen when asphaltene form a distinct phase and come out from the crude oil. Once precipitate, asphaltene particles tend to flocculate. Flocculate is when small particles clump together and grow larger, forming flocs. The size of the flocs is an important factor in deposition as particles above a certain size would deposit. Later, when the flocs are large enough that they can no longer be supported by the crude oil and therefore settle out on solid surface. The last stage is called as deposition. These 3 steps are shown in Figure 4.

1. Precipitation



2. Flocculation



3. Deposition

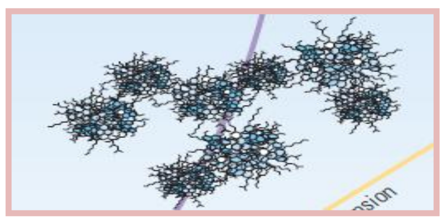


Figure 4: 3 Steps of Asphaltene deposition

The severity of asphaltene deposition differs from well to well depending on the asphaltene content of the crude oil, flowing wellhead pressure, productivity index, bubble point pressure, and other PVT parameters that change the thermodynamic state of crude oil. However, according to Gollapudi (1994), a crude oil with high asphaltene concentration may not necessarily show deposition problem. This has been proved by asphaltene problems in some Venezuelan medium crude oil, containing only 0.4 to 9.8% asphaltene as reported by Lichaa (1997). Interestingly, no asphaltene deposition was observed for a nearby Boscan heavy crude oil, even though this crude oil contained an asphaltene concentration higher than 17.2%.

2.2.3 Asphaltene Related Issues and Remedies

Asphaltene precipitation can occur during production of reservoir fluids, transportation and fluid processing in downstream operation. According to Kosta (1997), in the case of asphaltene deposition during reservoir fluid production, asphaltenes can reduce the production by:

1. Blocking pore throats thus reducing pore permeability. In asphaltene induced damage, the formation damage may occur many feet inside the reservoir, and in the case of miscible recovery formation damage can occur even deeper. In most cases, the blockage of the pore throats by asphaltenes particles is the dominant damage mechanism causing a reduction in rock permeability.

2. Adsorbing onto the rock and changing the formation wettability from water-wet to oil-wet, thus reducing the oil effective permeability. As asphaltene exhibit a positive intrinsic charge, it shows a strong tendency to attach to negatively charged surfaces, such as clays and sands. This in turn may result in wettablity reversal.

3. Increasing the reservoir fluid viscosity, by nucleating water-in-oil emulsions. However, if there is no water production, no emulsion of water-in-oil is expected.

Different methods were developed to remove asphaltenes deposition and these methods can be either a mechanical or chemical treatment. In the mechanical methods, scraping is carried out. Coil tubing and a downhole hydraulic motor are used to scrape the deposit while water is pumped as circulating fluid. Another way is by applying pressure in the completely plugged well tubing to create considerable pressure differential across the asphaltenes to break it and create communication. The mechanical methods provide effective cleaning and minimum formation damage. However, these methods are expensive and may plug the perforations and increase the stability of oil-in-water emulsions.

Second method for asphaltenes removal is chemical methods, including solvent treatments, asphaltenes detergents and crystal modifiers. The most commonly used solvent is Xylene. However, the treatment is unable to remove all the deposits as only 70-80% can be removed through a combined chemical treatment which require at least 48 hours soak time and back and forth agitation (Shedid, 2004). Besides, all types of chemical treatments have shown many restrictions on the application because of environmental safety and personnel exposure hazard concern. Others remedies for asphaltene deposition are thermal treatments, additional treatments and combination of two or more methods. Thermal treatment consists of hot oiling, bottomhole heaters, water or steam, and the use of heat-liberating chemicals. Bacteria treatment, production techniques and facilities modifications also have been applied under additional treatments method.

Method	Advantages	Disadvantages
Mechanical	• Effective cleaning • Minimum formation damage	• Expensive • May plug the perforation
Chemical	• Cheaper than mechanical treatment	• Unable to remove all the deposit • Hazardous

Table 1: Advantages and disadvantages of existing treatment

Since a few decades ago, the use of high-power sound waves to remove plugging materials from the wellbore and near wellbore region has been investigated. From the studies, the results concluded that ultrasonic wave represent an effective wellbore cleaning technology with the potential to be applied in removing various forms of wellbore-plugging material. As this method can be applied selectively and in a controlled manner, without impacting the environment and with standard wireline deployment techniques, ultrasound technology offers great advantages over the existing methods.

2.3 ULTRASONIC CLEANING

2.3.1 General Description

Ultrasonic cleaning involves the use of high-frequency sound waves (above the upper range of human hearing, or about 18 kHz) to remove a variety of contaminants from parts immersed in aqueous media. The impressing improvement of ultrasound technology in seismic techniques and other ultrasound applications in other fields of petroleum engineering have encouraged the study of ultrasonic radiation on asphaltenes deposition. Ultrasonic or ultrasound involves vibratory waves which are about the detection limits of human ears. The concept of using ultrasonic waves to improve well productivity is not new as several publications have been published under this topic. The predominant study has been presented by Aarts (1998) presenting a theoretical model and laboratory test results supporting the theory that radiation of ultrasound wave near wellbore region deforms the pore wall thus increasing the flow.

Furthermore, the ultrasonic cleaning method is reported to be successful in 40 to 50% from the previous studies, and the effects of the improved permeability will last for several months (Champion, 2004). Ultrasonic cleaning is powerful enough to remove tough contaminants, yet gentle enough not to damage the substrate. It provides excellent penetration and cleaning in the smallest pore space and between tightly grains. However, most of field tests have given an opposite result, yielding a limited success as little is known about the physical mechanism of the wave interaction with particles trapped and optimum wavefield parameters required to remove these particles. As the result, ultrasonic solution has received little consideration.

Ultrasonic wave is generated through the interaction of positive and negative pressure waves. In order to produce the positive and negative pressure waves in the aqueous medium, a mechanical vibrating device is required. Ultrasonic manufacturers make use of a diaphragm attached to high-frequency transducers. The transducers, which vibrate at their resonant frequency due to a high-frequency electronic generator source, induce amplified vibration of the diaphragm. This amplified vibration is the source of positive and negative pressure waves that propagate through the solution in the tank. The operation is similar to the operation of a loudspeaker except that it occurs at higher frequencies. The resonant frequency of the transducer determines the size and magnitude of the resonant bubbles. Typically, ultrasonic transducers used in the cleaning industry range in frequency from 20 to 80 kHz. The lower frequencies create larger bubbles with more energy, as can be seen by dipping a piece of heavy-duty aluminium foil in a tank. The lower-frequency cleaners will tend to form larger dents, whereas higher-frequency cleaners form much smaller dents.

Ultrasonic technology equipment for near wellbore application consists of the powerful ultrasonic generator and ultrasonic transducer, powered through a standard 3 core logging cable. The whole equipment, realizing the acoustic stimulation technology, is in coordination with the regular equipments of geophysical parties which does not cause any difficulty in its adaptation by the regular geophysical personnel. The acoustic stimulation technology consists in the processing of collector layers (in the open bore, filter interval or perforated holes) by powerful ultrasonic field aimed at the restoration of their filtering properties. Processing is carried out point wise (with 0.5-1.0 interval) selectively based on the “inflow stimulation profile” principle. Well and equipment preparation is practically the same as that for standard geophysical researches.

2.3.2 Cleaning Mechanism of Ultrasound Wave

The beneficial effect of ultrasonic cleaning has been put to use in various applications for quite some time. There are two cleaning mechanism involved to explain the cleaning effect of ultrasound, acoustic streaming and acoustic cavitation (Venkitaraman, 1995). In cavitation process, micron-size bubbles form and grow due to alternating positive and negative pressure waves in a solution. The bubbles subjected to these alternating pressure waves continue to grow until they reach resonant size. Just prior to the bubble implosion (Figure 5), there has been a tremendous amount of energy stored inside the bubble itself.

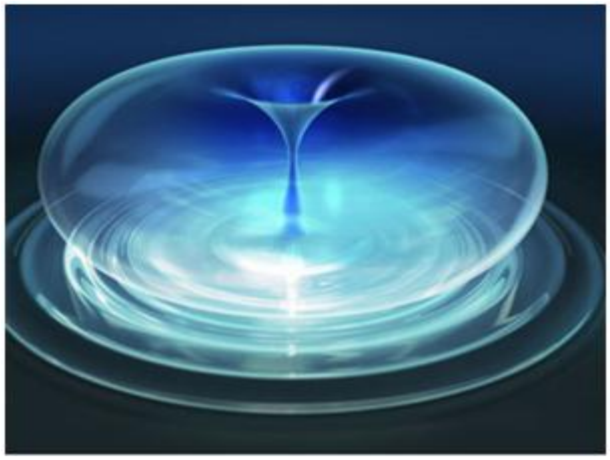


Figure 5: Illustration of an imploding cavity in a liquid irradiated with ultrasound

The temperature inside a cavitating bubble can be extremely high, with pressures up to 500 ATM. The implosion event, when it occurs near a hard surface, changes the bubble into a jet about one-tenth the bubble size, which travels at speeds up to 400 km/hr toward the hard surface. With the combination of pressure, temperature, and velocity, the jet frees contaminants from their bonds with the substrate. Because of the inherently small size of the jet and the relatively large energy, ultrasonic cleaning has the ability to reach into small crevices and remove entrapped deposits very effectively.

Acoustic streaming is when steady rotational flow is occurring as a result of the interaction of acoustic waves with physical inhomogeneties in a fluid, such as smooth boundaries and solid particles. Fluid agitation caused by acoustic streaming is not as violent as the one caused by cavitation, but streaming is very effective for liberating particles attached to the surfaces. However it is believed that for reservoir formation, cavitation induces further damage to porous medium. Thus, the frequency and power of the ultrasonic wave have to be maintained at a level which cavitation does not occur and the primary physical removal mechanism is acoustic streaming.

From studies conducted by Gollapudi (1994), the removal of asphaltenes damage near wellbore is happen when a sound wave passing through viscous crude oil, and creates a vibration pattern that set the liquid in motion. The ultrasonic vibration patterns form crude oil molecule layers that stretch, compress, bend, and relax. Interacting layers generate tiny vacuum spaces called cavitations within the liquid. Imploding cavitations scrub part surfaces and pull away foreign materials. The study has concluded that the use of ultrasound wave is a promising and potentially useful since it can be extended to high pressure range wave.

CHAPTER 3

METHODOLOGY

3.1 RESEARCH METHODOLGY

The method in completing this project is divided into five main stages. Figure 6 below shows how this project is being conducted during the given time.

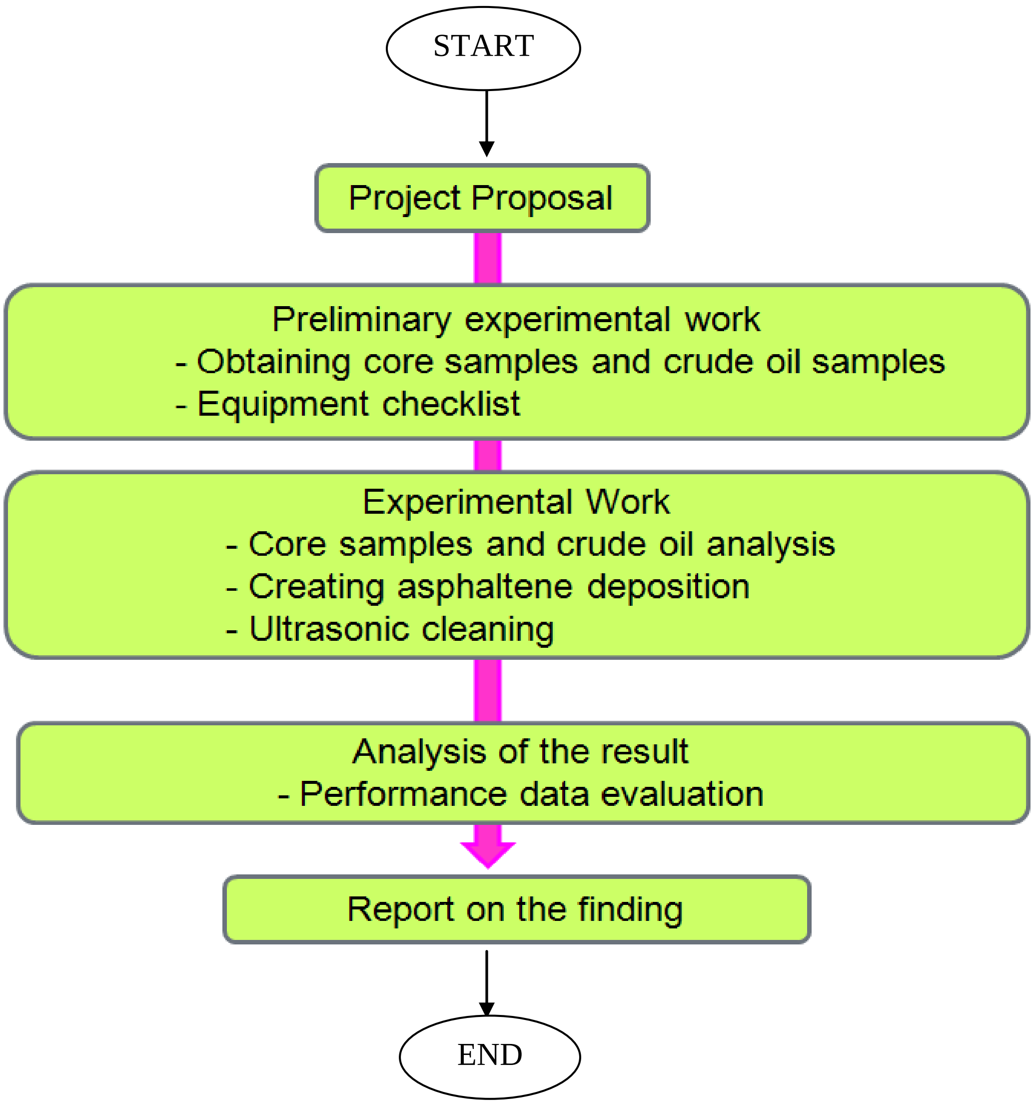


Figure 6: Project Main Flow

3.2 PROJECT ACTIVITIES (EXPERIMENTAL PROCEDURE)

3.2.1 Material

In this study, sandstone core plugs and Malaysian Light Crude Oil sample will be used. Both core plug and crude oil samples will be analyzed before main experiment is conducted. The lists of analysis being carried out are:

3.2.1.1 Core Samples analysis

For the study, two Berea Sandstone core are used as formation representative. Rock properties tests are conducted for each core sample by Helium gas in Poroperm equipment. Through Helium Porosimeter (Poroperm) (shown in Figure 7) analysis, properties such as permeability and porosity are identified for each core sample.

Figure 7: Helium Porosimeter (Poroperm)

Besides, other properties such as diameter and length of the core samples are also measured.

3.2.1.2 Dulang Crude Oil Analysis

Since light oils are the most common candidates for asphaltene problem, Dulang crude oil samples are chosen in this research. This crude is obtained from Malaysian oil reservoir in Terengganu. ASTM D3279-07 Standard Test Method for n-Heptane Insoluble is applied to measure the initial asphaltene content. ASTM D3279-07 is a method to determine the mass percent of asphaltenes as defined by insolubility in normal heptanes solvent. Knowing the initial value will provide the change to study asphaltene content variations during carbon dioxide injection in the Dynamic flooding experiment. The configuration of the experiment can be seen below. The standard procedure is shown in figure 8 and 9.

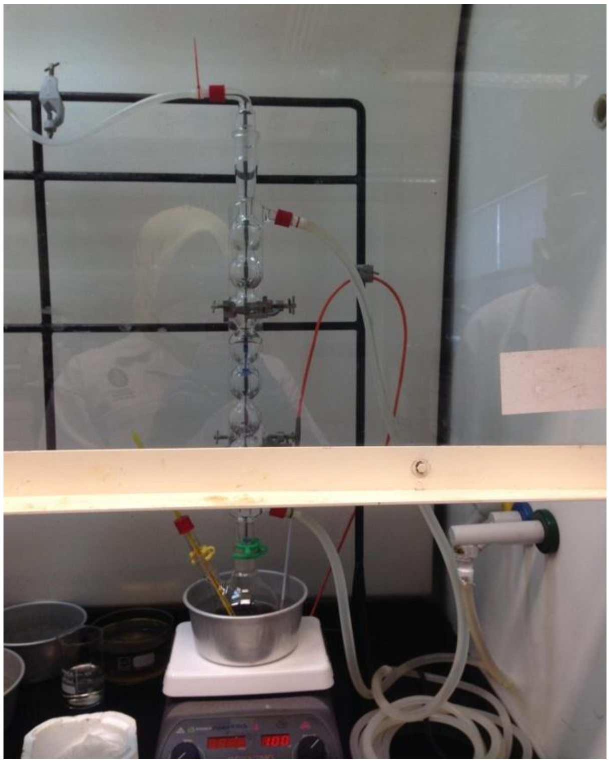


Figure 8: ASTM D3279-07 Standard Test Method for n-Heptane Insoluble (Precipitation)

Figure 9: ASTM D3279-07 Standard Test Method for n-Heptane Insoluble (Filtration)

3.2.2 Dynamic Carbon Dioxide Flooding

In order to create asphaltene deposition inside the core samples, Dynamic Carbon Dioxide flooding experiment is conducted. In this research relative permeability core flooding equipment is used to recreate reservoir condition.

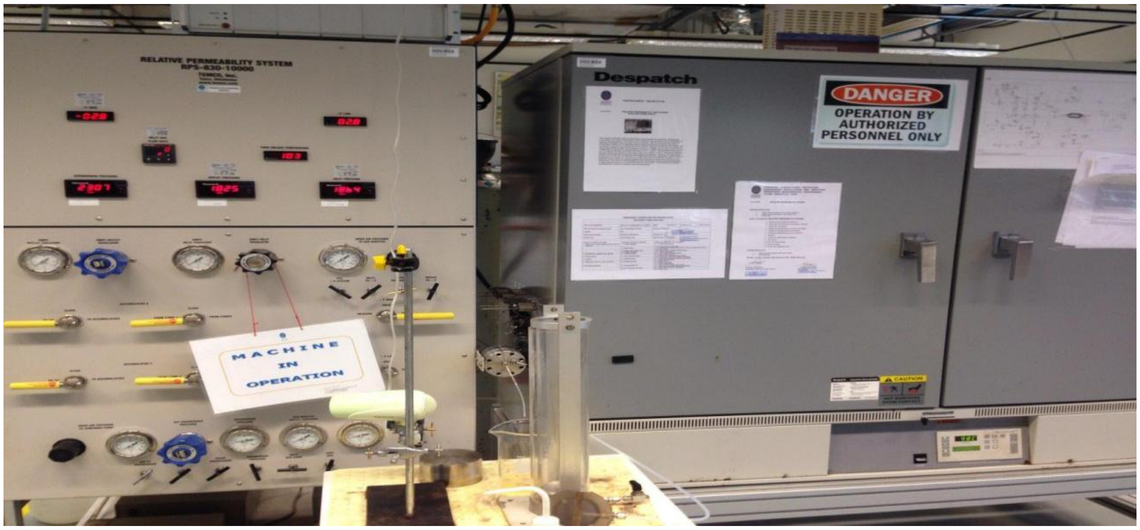


Figure 10: Relative Permeability System

3.2.2.1 Brine Preparation

Brine is used to represent the formation water inside the reservoir. Since the normal brine saturation for Dulang field is 30,000 ppm, 30,000 ppm brine saturation is prepared. Specific amount of Sodium Chloride, NaCl is weighed and dissolved in distilled water in a beaker. The weight and volume of water required are based on the following calculation:

Molar mass of NaCl = 58.44 g/l

58.44 g/l dissolved in 1 litre of distilled water yield 58,440 ppm of brine

By dilution:

$M_1V_1 = M_2V_2$

M_1 = Original concentration (eg: 30000 ppm)

V_1 = Original Volume (eg: 1 litres)

M_2 = Final Concentration

V_2 = Final Volume

For 100 ml of 30000 ppm brine:

$$V1 = \frac{M2V2}{M1} = \frac{30000\ ppm\ (100\ ml)}{58\ 440\ ppm} = 51.33 \text{ ml}$$

So, measure 51.33 ml of 58440 ppm brine, and add distilled water until reach 100 ml. The NaCl and distilled water are stirred in the beaker for 30 minutes.

3.2.2.2 Core Preparation

All cores will be cleaned by using a soxhlet extractor with toluene and methanol. Then, it will be dried at 100 ^{o}C in the oven for two days. The cleaned core will be put into a vacuum cell and saturated with brine (30,000 ppm) for 36 hours as shown in figure 11.

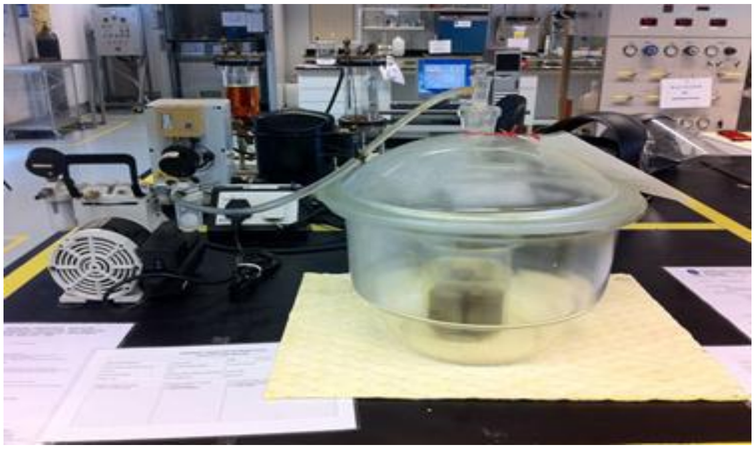


Figure 11: Saturation of Core Sample with Brine

3.2.2.3 Carbon Dioxide Flooding

Asphaltene deposition is created by injecting Dulang crude into pore volumes of sandstone plug. In this experiment, relative permeability core flood equipment was used to recreate reservoir condition. Simple schematic of core flood equipment is shown in figure 12 below:

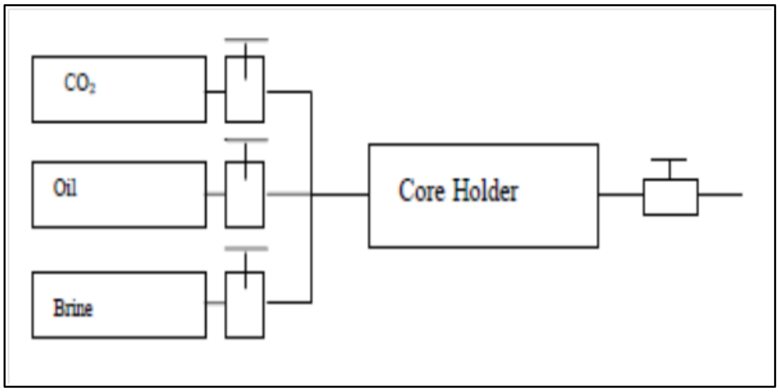


Figure 12: Simple Schematic of Core Flood Equipment

The procedure of the flooding is as follows for both cores:

1. The operating conditions of the equipment are fixed at 2500 psig and 98'C.
2. Core sample is injected with brine at 0.3 cc/min at injection pressure 1700 psig to make sure 100% brine saturation is achieved, also known as steady state condition.
3. Next, crude oil is injected at 1700 psig into the brine saturated core at the rate of 0.3cc/min until no more water is recovered.
4. Injection is continued until no more water is produced. This indicates irreducible water saturation.
5. Secondary brine is injected at pressure 1700 psig and 0.3 cc/min.
6. Later, carbon dioxide is injected at 1700 psig with flowrate at 0.3 cc/min. CO2 is continuously injected until there is no more produced oil.
7. Crude oil exiting is collected and samples are analyzed for asphaltene content changes.

3.2.3 Asphaltene Precipitation on Formation.

In order to ensure there are asphaltene deposited inside both core samples, two tests have been conducted; rock properties test on core samples and ASTM D3279-07 test on exiting Dulang crude sample.

3.2.3.1 Porosity and permeability reduction of core samples

Given that the influence of deposited asphaltene in core samples are indicated by changes in porosity and permeability of the samples, changes in porosity and permeability of the core samples due to the presence of asphaltene are examined. In order to see the asphaltene precipitation influence on core characteristics, each core was treated with suitable solvent in such a way that removes residual oil while only asphaltene remain inside the core samples. Thus, Soxhlet Extractor is used but instead of using toluene, n-heptane is used. The core is cleaned for 2 weeks to ensure all residues are removed. The setup is shown in figure 13:

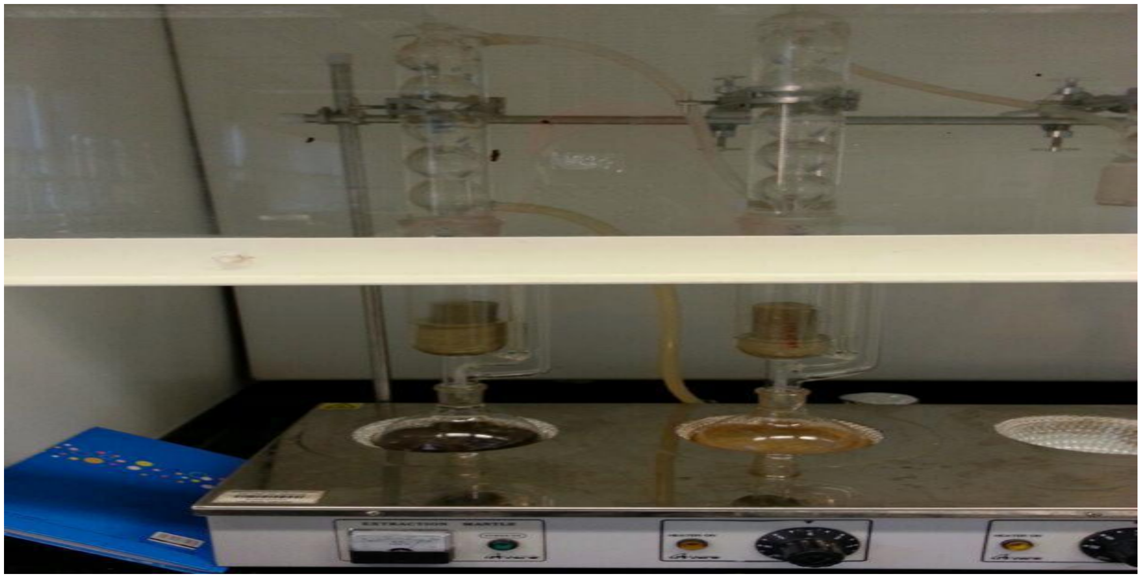


Figure 13: Core cleaning using n-heptane

Then, it will be dried at 100 ^oC in the oven for two days. After that, the new porosity and permeability of both samples are measured using Helium Porosimeter. By doing this, we can investigate the changes in rock properties due to asphaltene deposition.

3.2.3.2 Asphaltene content reduction of Dulang Crude Samples

In order to confirm there are deposition occurred in both core samples, crude oil exiting from the core samples after Carbon Dioxide flooding is examined. The same method, ASTM D3279-07 Standard Test Method for n-Heptane Insoluble has been used. The difference in the value of asphaltene content before and after the flooding will represent the asphaltene trap inside the core samples.

3.2.4 Ultrasonic Stimulation

A 100-watt ultrasonic tank is used in this experiment. Ultrasonic tanks are generally rectangular and can be manufactured in just about any size. Transducers are placed in the bottom of the tank and welded directly into the tank. The tank is filled up with aqueous solution as it serves as vibration medium between the ultrasonic source and core sample. Before being sonicated or cleaned with the ultrasonic tank, core samples are saturate with formation brine, 30,000 ppm. Formation brine represents the formation fluid inside the formation. After that, core samples are sonicated according to the chosen intervals. After each interval, the new permeability of the core samples is measured using Benctop Permeability System. This enables the changes in permeability to be recoded.

Figure 14: Ultrasonic Tank

3.2.4.1 Benchtop permeability system

Benchtop permeability system is equipment used to perform simple liquid permeability test. In this experiment, formation brine, 30,000 ppm is injected into both core samples. Brine is injected at 0.5 ml/min. This stage is repeated for each radiation interval in order to measure the changes in permeability.

Figure 15: Benchtop Permeability System

3.2.4.2 Ultrasonic Stimulation

Ultrasonic wave is exposed to the core and the stimulated permeability was measured at different conditions:

1. <u>Radiation time</u>

- Three radiation time intervals are used in this experiment, 60 minutes, 120 minutes, and 180 minutes.
- After each interval, the core samples are analyzed using Benchtop Permeability System to know the changes in porosity and permeability of the core samples after ultrasonic radiation.

2. <u>Solution Temperature</u>

- Two difference solution temperatures are used in this experiment, 70 ^{o}C and 98 ^{o}C
- After each interval, core samples are examined to know the changes in porosity and permeability of the core samples after ultrasonic radiation.

3.3 KEY MILESTONE

DATE								2.Jul.13	9-11.Jul.13			1.Aug.13			
No	Detail/Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Topic Selection / Proposal		■	■											
2	Preliminary Research Work			■	■	■	■								
3	Submission of Extended Proposal							●							
4	Proposal Defense (Oral Presentation)								●						
5	Project Work Continues								■	■	■	■			
7	Submission of Interim Report											●			

● Suggested Milestone

■ Process

Table 2: Key Milestone

3.4 GANTT CHART

The function of the Gantt chart is for guidance and proper schedule throughout this internship period. Working accordance with the timeline greatly benefit in finishing this project. This project is conducted during two semesters which divided into two parts; FYP1 and FYP2. Table 3 below shows both timelines for FYP 1 and FYP 2.

ACTIVITIES	FINAL YEAR PROJECT 1														FINAL YEAR PROJECT 2													
WEEK	1	2	3	4	5	6	7	8	9	10	11	12	13	14	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Information gathering																												
Submission of extended proposal defense																												
Experiment procedure preparation																												
Proposal defense																												
Sample preparation																												
Submission of interim report																												
Experimental Set-up																												
Submission of Progress report																												
Discussion of result																												
Submission of draft report																												
Oral Presentation																												
Submission of project dissertation																												

Table 3: Gantt chart

CHAPTER 4

RESULTS AND DISCUSSIONS

Since this project is divided into several stages, results obtained will also be discussed according to the same stages; material properties before displacement test, measuring asphaltene deposition on formation, and permeability improvement due to ultrasonic stimulation

.

3.1 MATERIAL PROPERTIES BEFORE DISPLACEMENT TEST

3.1.1 Core Properties

There are two sandstone core samples used for this experiment, labeled C8 and C4. Rock properties tests were conducted for each core sample by Helium gas in Poroperm equipment, the result for porosity and permeability measurement are shown in table below.

	Core 8 (C8)	Core 4 (C4)
Weight (g)	172. 187	178.68
Diameter (mm)	39.695	39.317
Length (mm)	72.44	75.787
Kair (mD)	84.425	63.677
K∞ (mD)	72.569	51.105
φ (%)	29.71	16.64

Table 4: Core properties before displacement test

3.1.2 Dulang Crude Properties

As it was mentioned, Dulang Crude oil sample was selected and ASTM D3279-07 Standard Test Method for n-Heptane Insoluble was applied to measure initial asphaltene content. The Dulang properties are shown below.

Name	Dulang
API	37.8
Viscosity (Cst) @ 50℃	3.63
Density (g/cm3) @25 ℃	0.85707
Asphaltene Content (wt%)	0.36

Table 5: Dulang crude properties

3.2 ASPHALTENE DEPOSTION ON FORMATION

In order to create precipitation inside the core samples, Dynamic asphaltene precipitation test was carried out with carbon dioxide injection. Given the influence of deposited asphaltene in the core sample are indicated by changes in porosity and permeability of the core samples, changes in the porosity and permeability of the core samples due to the presence of the asphaltene deposition were examined. Besides, in order to confirm the asphaltene precipitation inside the core samples, the amount of asphaltene content in Dulang Crude samples at the end of the Dynamic test is analyzed for asphaltene content changes. Asphaltene deposition will resulted in a reduction of porosity and permeability of core samples, and low apshaltene content in the exiting crude oil during CO_2 injection.

3.2.1 Porosity and permeability reduction of core samples

As mentioned earlier, permeability and porosity of the core samples were measured before core flooding test. After the test, the new porosity and permeability for both core samples are shown below:

Sample	Porosity (%)		Porosity Reduction (%)	Permeability (mD)		Permeability Reduction (%)
	Initial	After		Initial	After	
C8	29.71	15.51	47.80	84.425	75.135	11.00
C4	16.64	14.82	10.94	63.677	52.426	17.67

Table 6: Changes of Porosity and Permeability

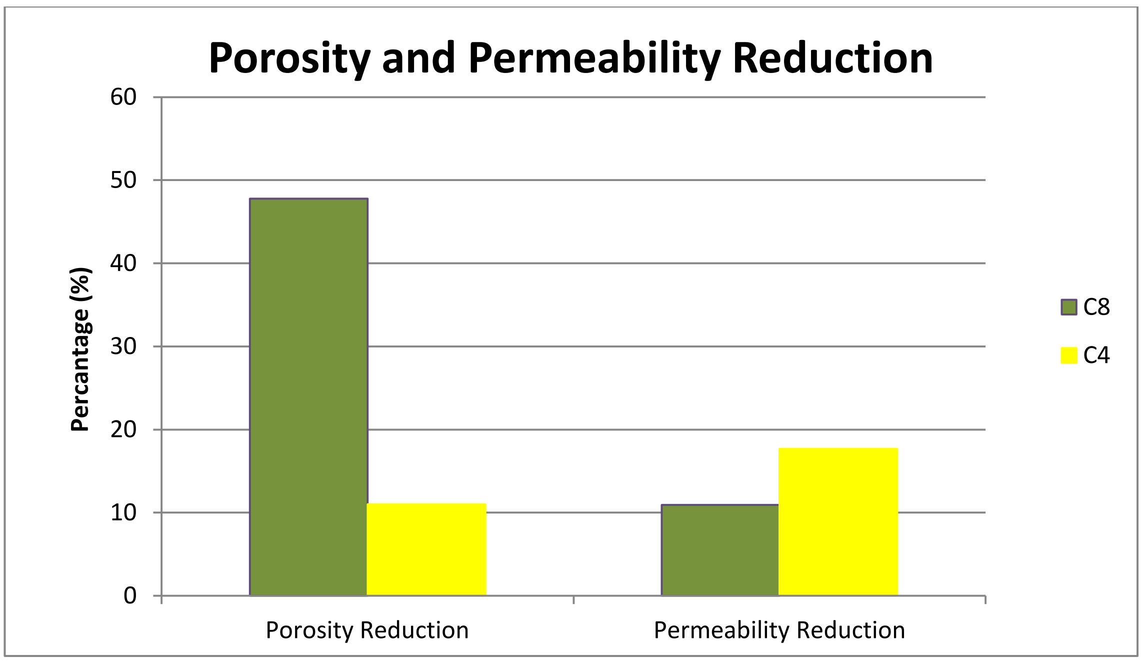


Figure 16: Sample permeability and porosity reduction

Obtained results, which are illustrated in figure 16, shown that there is an obvious reduction in permeability and porosity due to the presence of asphaltene.

3.2.2 Asphaltene content reduction of Dulang Crude Samples

Dulang sample was collected at the end of the CO2 injection when no more produced oil is observed. Again, the sample was analyzed for asphaltene content changes using ASTMD3279-07 Standard Test Method for n-Heptane Insoluble. The result and shown below:

	CORE 8 (C8)		CORE 4 (C4)	
	Before	After	Before	After
Asphaltene Content (wt%)	0.36	0.11	0.36	0.13

Table 7: Dulang asphaltene content

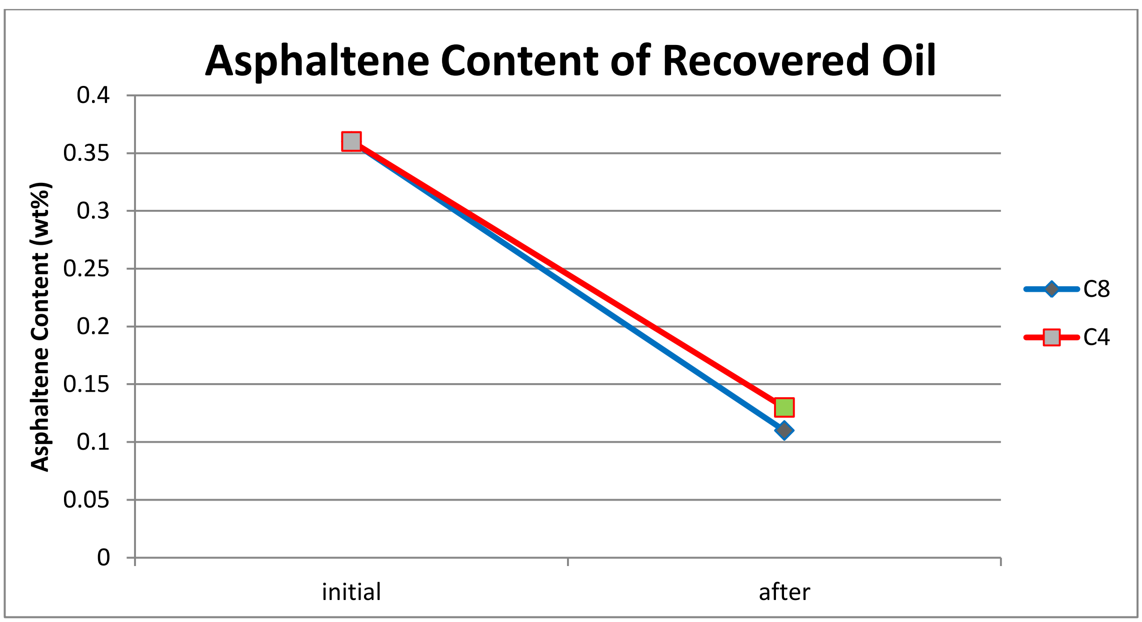


Figure 17: Asphaltene Reduction in Crude Samples

As it can be seen from both samples, asphaltene precipitation occurred. This clearly can be seen as less asphaltene content in crude oil after Carbon dioxide injection.

3.3 PERMEABILITY IMPROVEMENT DUE TO STIMULATION

The changes in permeability of core samples with temperature and stimulation time are shown on the table below:

Sample	Temperature (˚C)		Stimulation Time			
			Initial	1 hour	2 hours	3 hours
C8	70	Permeability (mD)	15.78	22.18	24.14	24.93
C4	98	Permeability (mD)	15.93	26.26	29.26	29.54

Table 8: Core Samples permeability after ultrasonic cleaning

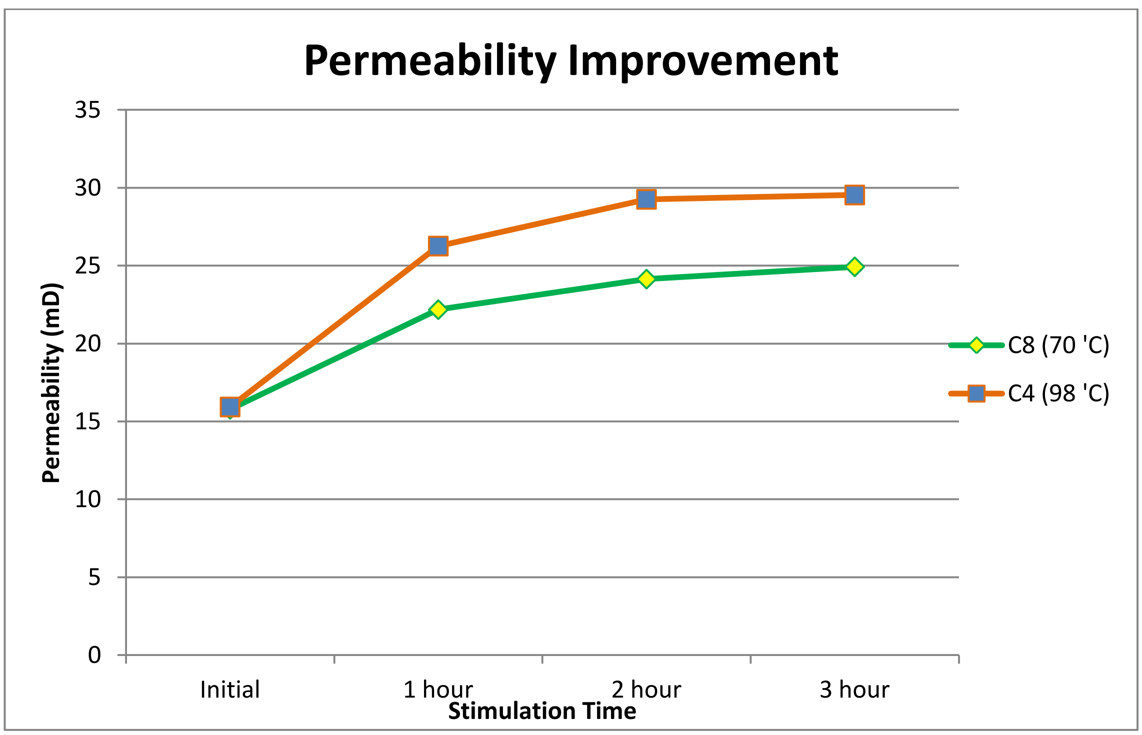


Figure 18: Permeability Improvement with Stimulation Time and Temperature

3.3.1 Influence of stimulation time on permeability

From the result, permeability of both core samples increases as the stimulation time increase. This can be due to more cavitation happen inside the core as longer stimulation time is conducted. However, the rate of improvement is slowing down after 1 hour of stimulation, which can be seen from declining improvement rate during 2 hours of stimulation. Later, after 3 hours of stimulation there are barely any changes in the permeability of both core samples. This can be considered as the limitation of ultrasonic cleaning efficiency in repairing permeability damage due to asphaltene deposition.

3.3.2 Influence of solution temperature on permeability

Based on figure above, 98 ^{o}C of stimulation temperature gives a faster rate of permeability improvement compare to 70 ^{o}C. Besides, the cleaning efficiency at 98 ^{o}C also higher compare to 70 ^{o}C. Thus, it is proved that temperature has a profound effect on ultrasonic cleaning effectiveness as higher temperatures will result in higher cavitation intensity and better cleaning. Somehow, it needs to consider that the ultrasonic will not be efficient at bubble point condition. This is due to the effect of gas bubbles on the cavitation bubbles. For ultrasonic cleaning to be efficient inside the wellbore, it must be conducted at temperatures at least 6ºC (10ºF) below the reservoir bubble point during the stimulation.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

As conclusion, it is proved that ultrasonic cleaning is a powerful technique to clean near wellbore asphaltene deposition. The non-damaging nature of ultrasonic cleaning has a great advantage over mechanical as well as chemical treatments in treating asphaltene deposition. Results obtained show that ultrasonic efficiency will increase with stimulation time up to the maximum limit of ultrasonic cleaning. This can be seen when there is no improvement in permeability after continuous stimulation. Other than that, solution temperature also has a profound effect on removing asphaltene deposition. Increase in stimulation temperature will increase the cleaning efficiency. Somehow, the stimulation temperature must not be closed to bubble point condition as this will affect the efficiency of ultrasonic cleaning. Furthermore, the ability of ultrasound to be applied selectively and in a controlled manner gives great advantages to well operators. We can also provide a new green solution, without impacting the environment by introducing this treatment.

5.2 RECOMMENDATIONS

There are several recommendations the author would like to suggest for this study, which are:

- For gaining a better understanding, it is recommended to study rock composition, heterogeneity, and porosity and permeability distribution along with precipitation phenomenon. Although the reduction value might not be very significant, but one has to consider the fact that it is associated with a small core sample, still in reservoir scale even a small decline in permeability and porosity may have a negative effect on oil production.
- Further experiments under different temperatures and pressures are recommended to demonstrate the removal efficiency of ultrasound with respect to mechanical and chemical treatments currently applied in the fields.

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APPENDIX A

HELIUM POROPERM DATA

(PERMEABILITY MEASUREMENT)

1. DATA BEFORE CO_2 FLOODING

No.	Description		Job No. :
1	Sample ID		C8
2	Temperature (^0C)	Max	25.2
		Min	25.0
3	Humidity (%)	Max	68.0
		Min	67.6
4	Specimen Length, L (mm)		72.44
5	Specimen Diameter ,D_o (mm)		39.695
6	Specimen weight (g)		172.187
7	Pressure confining (Psig)		400
8	Sample Porosity Φ (%)		16.607
9	Pore volume Vp (cc)		14.888
10	Sample bulk volume Vb (cc)		89.648
11	Grain volume Vg (cc)		74.76
12	Grain density (assuming sample is weighed) ρg (g/cc)		2.303

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No.	Description		Job No. :
1	Sample ID		C4
2	Temperature (^{0}C)	Max	24.9
		Min	24.8
3	Humidity (%)	Max	68.7
		Min	68.0
4	Specimen Length, L (mm)		75.787
5	Specimen Diameter ,D_o (mm)		39.317
6	Specimen weight (g)		178.68
7	Pressure confining (Psig)		400
8	Sample Porosity Φ (%)		13.818
9	Pore volume Vp (cc)		12.715
10	Sample bulk volume Vb (cc)		92.012
11	Grain volume Vg (cc)		79.298
12	Grain density (assuming sample is weighed) ρg (g/cc)		2.253

2. DATA AFTER CO_2 FLOODING

LFSU/GPE/TPO6/F02C

REPORT No:	PAGE: 2 OF 2

Test Result

No	Description		Job No.
1	Sample ID		C5
2	Temperature (°C)	Max	26.2
		Min	[illegible]
3	Humidity (%)	Max	99.4
		Min	96.3
4	Specimen Length, L (mm)		74.44
5	Specimen Diameter, D_o (mm)		36.154
6	Specimen weight (g)		172.603
7	Pressure confining (Psig)		445
8	Sample Porosity Φ (%)		18.145
9	Pore volume Vp (cc)		16.214
10	Sample bulk volume Vb (cc)		89.645
11	Grain volume Vg (cc)		73.305
12	Grain density (assuming sample is weighed) ρg (g/cc)		2.36

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Page 2

LFSU/GPE/TPOA/F02C

REPORT No	PAGE 1 OF 2

Test Result

No.	Description		Job No
1	Sample ID		[illegible]
2	Temperature (°C)	Max	[illegible]
		Min	[illegible]
3	Humidity (%)	Max	[illegible]
		Min	[illegible]
4	Specimen Length, L (mm)		[illegible]
5	Specimen Diameter ,D, (mm)		[illegible]
6	Specimen weight (g)		[illegible]
7	Pressure confining (Psig)		[illegible]
8	Sample Porosity Φ (%)		[illegible]
9	Pore volume Vp (cc)		[illegible]
10	Sample bulk volume Vb (cc)		[illegible]
11	Grain volume Vg (cc)		[illegible]
12	Grain density (assuming sample is weighed) ρg (g/cc)		[illegible]

APPENDIX B

BENCHTOP PERMEABILITY SYSTEM DATA

(PERMEABILITY MEASUREMENT)

1. C8 (INITIAL)

Date	>> 11/18/2013
Time	>> 11:30 AM
Core ID	>> c8
Length	>> 7.244
Diam	>> 3.970
Viscos	>> 1.000
Notes	>> initial perm

Perm	Rate	dP	dPLow	dPHigh	Temp
15.765	0.5	4.547	0.225	4.547	20.652
15.966	0.5	4.49	-0.051	4.49	20.726
15.872	0.5	4.517	0.482	4.517	20.464
15.634	0.5	4.585	0.524	4.585	20.393
15.621	0.5	4.589	0.155	4.589	20.51
15.673	0.5	4.574	-0.067	4.574	20.443
15.531	0.5	4.616	0.262	4.616	20.608
15.353	0.5	4.669	0.448	4.669	20.241
15.403	0.5	4.654	0.009	4.654	20.621
15.082	0.5	4.753	-0.016	4.753	20.677
15.441	0.5	4.642	0.452	4.642	20.347
15.34	0.5	4.673	0.063	4.673	20.259
15.118	0.5	4.742	-0.024	4.742	20.322
15.13	0.5	4.738	0.197	4.738	20.622
15.328	0.5	4.677	0.455	4.677	20.646
15.328	0.5	4.677	0.166	4.677	20.704
15.429	0.5	4.646	0.133	4.646	20.451
15.403	0.5	4.654	0.445	4.654	20.274
15.378	0.5	4.662	-0.068	4.662	20.511
15.353	0.5	4.669	0.149	4.669	20.567
15.353	0.5	4.669	0.354	4.669	20.182
15.505	0.5	4.623	0.392	4.623	20.324
15.391	0.5	4.658	-0.103	4.658	20.827
15.543	0.5	4.612	0.258	4.612	20.5
15.441	0.5	4.642	0.568	4.642	20.567
15.531	0.5	4.616	0.423	4.616	20.758
15.378	0.5	4.662	-0.159	4.662	20.922
15.543	0.5	4.612	0.386	4.612	20.296
15.634	0.5	4.585	0.439	4.585	20.747
15.595	0.5	4.597	-0.139	4.597	20.582

15.818	0.5	4.532	0.202	4.532	20.79
15.66	0.5	4.578	-0.043	4.578	20.565
15.699	0.5	4.566	0.391	4.566	20.728
15.595	0.5	4.597	0.283	4.597	20.69
15.621	0.5	4.589	-0.094	4.589	20.849
15.531	0.5	4.616	0.249	4.616	20.589
15.939	0.5	4.498	0.415	4.498	20.556
15.686	0.5	4.57	0.07	4.57	20.709
15.712	0.5	4.562	0.049	4.562	20.294
15.699	0.5	4.566	0.513	4.566	20.665
15.712	0.5	4.562	0.328	4.562	20.494
15.805	0.5	4.536	-0.163	4.536	20.558
15.872	0.5	4.517	-0.043	4.517	20.553
15.98	0.5	4.486	0.521	4.486	20.648
15.621	0.5	4.589	0.02	4.589	20
15.872	0.5	4.517	-0.102	4.517	20.653
15.582	0.5	4.601	0.397	4.601	20.671
15.792	0.5	4.539	0.377	4.539	20.566
15.912	0.5	4.505	-0.08	4.505	20.399
15.752	0.5	4.551	0.263	4.551	20.781
15.858	0.5	4.52	0.461	4.52	20.693
15.673	0.5	4.574	0.121	4.574	20.348
15.925	0.5	4.501	-0.126	4.501	20.457
15.898	0.5	4.509	0.486	4.509	20.475
15.925	0.5	4.501	0.068	4.501	20.346
15.952	0.5	4.494	-0.167	4.494	20.732
15.845	0.5	4.524	0.293	4.524	20.55
15.858	0.5	4.52	0.412	4.52	20.609
15.792	0.5	4.539	0.151	4.539	20.475
15.98	0.5	4.486	-0.099	4.486	20.602
15.925	0.5	4.501	0.466	4.501	20.663
16.089	0.5	4.456	0.587	4.456	20.808
15.885	0.5	4.513	-0.07	4.513	20.538
15.845	0.5	4.524	0.026	4.524	20.56
15.805	0.5	4.536	0.575	4.536	20.617

Average Perm 15.77986

2. C8 (1 HOUR)

Date	>> 11/19/2013
Time	>> 7:54 AM
Core ID	>> c8
Length	>> 7.240
Diam	>> 3.969
Viscos	>> 1.000
Notes	>> after 1 hour sonicate

Perm	Rate	dP	dPLow	dPHigh	Temp
22.312	0.5	3.212	-0.306	3.212	17.568
22.259	0.5	3.22	-0.27	3.22	17.645
22.259	0.5	3.22	0.248	3.22	17.602
22.418	0.5	3.197	0.205	3.197	17.418
22.526	0.5	3.181	-0.164	3.181	17.753
22.634	0.5	3.166	-0.097	3.166	17.183
22.259	0.5	3.22	0.189	3.22	17.798
22.102	0.5	3.242	0.415	3.242	18.01
22.882	0.5	3.132	0.117	3.132	17.791
22.18	0.5	3.231	-0.304	3.231	17.648
22.445	0.5	3.193	-0.001	3.193	17.92
22.102	0.5	3.242	0.448	3.242	17.471
22.553	0.5	3.178	0.283	3.178	17.546
22.18	0.5	3.231	-0.129	3.231	17.746
22.259	0.5	3.22	-0.284	3.22	17.663
22.259	0.5	3.22	0.087	3.22	17.658
22.499	0.5	3.185	0.375	3.185	17.488
22.365	0.5	3.204	0.175	3.204	17.76
21.921	0.5	3.269	-0.241	3.269	17.308
22.391	0.5	3.201	-0.178	3.201	17.768
21.921	0.5	3.269	0.328	3.269	18.011
22.445	0.5	3.193	0.142	3.193	17.828
22.024	0.5	3.254	-0.285	3.254	17.426
22.799	0.5	3.143	-0.223	3.143	17.471
22.607	0.5	3.17	0.14	3.17	17.899
22.128	0.5	3.239	0.412	3.239	17.854
22.285	0.5	3.216	0.084	3.216	17.764
22.285	0.5	3.216	-0.255	3.216	17.969
22.232	0.5	3.223	0.094	3.223	17.663
22.076	0.5	3.246	0.377	3.246	17.736

22.418	0.5	3.197	-0.214	3.197	17.596
22.418	0.5	3.197	0.047	3.197	17.588
21.998	0.5	3.258	0.361	3.258	17.523
22.128	0.5	3.239	0.184	3.239	17.682
22.102	0.5	3.242	-0.198	3.242	17.422
21.947	0.5	3.265	-0.243	3.265	17.962
22.05	0.5	3.25	0.243	3.25	17.823
22.391	0.5	3.201	0.301	3.201	17.32
22.154	0.5	3.235	-0.22	3.235	17.482
22.18	0.5	3.231	-0.28	3.231	17.343
22.128	0.5	3.239	0.046	3.239	17.497
22.024	0.5	3.254	0.347	3.254	17.548
22.232	0.5	3.223	-0.169	3.223	17.79
22.365	0.5	3.204	0.025	3.204	17.729
22.232	0.5	3.223	0.425	3.223	17.232
22.154	0.5	3.235	-0.022	3.235	17.699
22.05	0.5	3.25	-0.288	3.25	17.755
22.154	0.5	3.235	0.105	3.235	17.507
22.128	0.5	3.239	0.198	3.239	17.46
22.128	0.5	3.239	0.355	3.239	17.566
22.391	0.5	3.201	-0.09	3.201	17.441
22.024	0.5	3.254	-0.285	3.254	17.407
21.972	0.5	3.262	0.077	3.262	17.897
22.391	0.5	3.201	0.376	3.201	17.62
22.18	0.5	3.231	-0.019	3.231	17.606
21.87	0.5	3.277	-0.244	3.277	17.437
22.285	0.5	3.216	-0.103	3.216	17.941
21.921	0.5	3.269	0.397	3.269	17.612
21.718	0.5	3.3	0.348	3.3	17.414
22.445	0.5	3.193	-0.154	3.193	17.729
22.259	0.5	3.22	-0.228	3.22	17.637
22.05	0.5	3.25	0.168	3.25	17.882
22.391	0.5	3.201	0.409	3.201	17.687
22.418	0.5	3.197	0.023	3.197	17.491
22.154	0.5	3.235	-0.209	3.235	17.553
22.472	0.5	3.189	0.015	3.189	17.499

Average Perm	22.1753

3. C8 (2 HOURS)

Date	>> 11/20/2013
Time	>> 7:54 AM
Core ID	>> c8
Length	>> 7.240
Diam	>> 3.969
Viscos	>> 1.000
Notes	>> after 2 hours sonicate

Perm	Rate	dP	dPLow	dPHigh	Temp
24.85	0.5	2.884	-0.059	2.884	18.406
24.493	0.5	2.926	0.326	2.926	18.863
24.784	0.5	2.892	0.1	2.892	18.706
25.284	0.5	2.834	-0.156	2.834	18.711
24.883	0.5	2.88	-0.004	2.88	18.999
24.589	0.5	2.914	0.371	2.914	19.136
24.982	0.5	2.869	0.301	2.869	18.74
24.493	0.5	2.926	-0.161	2.926	18.722
24.784	0.5	2.892	-0.245	2.892	18.791
24.916	0.5	2.876	0.085	2.876	18.483
24.719	0.5	2.899	0.391	2.899	18.487
24.949	0.5	2.872	0.077	2.872	18.85
24.557	0.5	2.918	-0.265	2.918	19
24.622	0.5	2.911	0.063	2.911	19.037
24.85	0.5	2.884	0.306	2.884	18.526
24.589	0.5	2.914	0.353	2.914	18.703
24.784	0.5	2.892	-0.028	2.892	18.58
24.461	0.5	2.93	-0.168	2.93	18.564
24.949	0.5	2.872	0.034	2.872	18.941
24.654	0.5	2.907	0.347	2.907	18.535
24.85	0.5	2.884	0.194	2.884	18.606
24.557	0.5	2.918	-0.284	2.918	18.312
24.982	0.5	2.869	-0.08	2.869	18.288
24.24	0.5	2.956	0.339	2.956	18.593
24.883	0.5	2.88	0.166	2.88	18.724
24.883	0.5	2.88	-0.209	2.88	18.957
24.335	0.5	2.945	-0.122	2.945	18.405
24.43	0.5	2.934	0.384	2.934	18.4
24.784	0.5	2.892	0.233	2.892	18.657

23.993	0.5	2.987	0.349	2.987	18.027
23.75	0.5	3.017	0.108	3.017	18.098
23.841	0.5	3.006	-0.299	3.006	18.402
24.023	0.5	2.983	0.03	2.983	18.421
23.81	0.5	3.01	0.396	3.01	18.07
23.631	0.5	3.033	0.213	3.033	18.174
24.147	0.5	2.968	-0.017	2.968	18.431
23.901	0.5	2.998	-0.267	2.998	17.842
24.303	0.5	2.949	0.178	2.949	18.218
24.054	0.5	2.979	0.391	2.979	18.237
23.901	0.5	2.998	0.289	2.998	17.9
23.69	0.5	3.025	-0.254	3.025	17.904
23.72	0.5	3.021	-0.105	3.021	18.271
23.901	0.5	2.998	0.326	2.998	18.098
24.054	0.5	2.979	0.101	2.979	18.399
23.841	0.5	3.006	-0.238	3.006	18.127
24.116	0.5	2.972	-0.105	2.972	18.293
24.147	0.5	2.968	0.324	2.968	17.858
23.993	0.5	2.987	0.346	2.987	18.276
24.147	0.5	2.968	0.033	2.968	18.021
24.147	0.5	2.968	-0.253	2.968	17.867
23.962	0.5	2.991	0.04	2.991	18.027
23.395	0.5	3.063	0.303	3.063	18.18
23.454	0.5	3.056	0.344	3.056	18.099
23.962	0.5	2.991	-0.2	2.991	18.164
23.542	0.5	3.044	-0.266	3.044	17.99
23.871	0.5	3.002	0.147	3.002	18.176
23.932	0.5	2.995	0.319	2.995	18.221
23.66	0.5	3.029	0.072	3.029	18.127
23.901	0.5	2.998	-0.301	2.998	17.619
23.75	0.5	3.017	-0.007	3.017	17.575
23.871	0.5	3.002	0.354	3.002	18.137
23.72	0.5	3.021	0.047	3.021	17.742
23.81	0.5	3.01	-0.252	3.01	17.832

Average Perm	24.14133

4. C8 (3 HOURS)

Date	>> 11/21/2013
Time	>> 11:51 AM
Core ID	>> c8
Length	>> 7.244
Diam	>> 3.970
Viscos	>> 1.000
Notes	>> after 3 hours sonicate

Perm	Rate	dP	dPLow	dPHigh	Temp
25.34	0.5	3.017	0.124	3.017	17.274
25.631	0.5	2.983	0.116	2.983	17.251
25.054	0.5	3.052	0.652	3.052	17.405
25.18	0.5	3.036	0.546	3.036	17.314
24.992	0.5	3.059	-0.008	3.059	17.596
25.697	0.5	2.975	0.503	2.975	17.502
24.899	0.5	3.071	0.683	3.071	17.577
24.961	0.5	3.063	0.204	3.063	17.91
24.992	0.5	3.059	0.039	3.059	17.559
25.023	0.5	3.056	0.681	3.056	17.423
25.117	0.5	3.044	0.655	3.044	17.644
24.745	0.5	3.09	0.026	3.09	17.167
24.992	0.5	3.059	0.218	3.059	17.478
24.654	0.5	3.101	0.659	3.101	17.427
24.837	0.5	3.078	0.251	3.078	17.592
25.566	0.5	2.991	0.094	2.991	17.214
24.899	0.5	3.071	0.6	3.071	17.749
25.212	0.5	3.033	0.562	3.033	17.768
24.806	0.5	3.082	0.088	3.082	17.632
25.086	0.5	3.048	0.333	3.048	17.442
25.18	0.5	3.036	0.699	3.036	17.717
25.054	0.5	3.052	0.036	3.052	17.431
24.837	0.5	3.078	0.129	3.078	17.656
25.276	0.5	3.025	0.742	3.025	17.606
25.023	0.5	3.056	0.661	3.056	17.274
25.117	0.5	3.044	-0.031	3.044	17.514
24.745	0.5	3.09	0.52	3.09	17.521
24.473	0.5	3.124	0.713	3.124	17.754
25.404	0.5	3.01	0.172	3.01	17.114

24.443	0.5	3.128	0.6	3.128	17.392
24.533	0.5	3.117	0.053	3.117	17.505
25.023	0.5	3.056	0.308	3.056	17.535
24.745	0.5	3.09	0.662	3.09	17.64
24.776	0.5	3.086	0.355	3.086	17.378
25.212	0.5	3.033	0.045	3.033	17.441
24.745	0.5	3.09	0.513	3.09	17.327
24.868	0.5	3.075	0.672	3.075	17.525
24.961	0.5	3.063	0.208	3.063	17.476
24.178	0.5	3.162	0.039	3.162	17.382
24.806	0.5	3.082	0.765	3.082	17.219
24.899	0.5	3.071	0.446	3.071	17.363
25.086	0.5	3.048	-0.088	3.048	17.42
24.715	0.5	3.094	0.583	3.094	17.432
24.624	0.5	3.105	0.678	3.105	17.398
24.684	0.5	3.098	0.385	3.098	17.802
25.276	0.5	3.025	-0.105	3.025	17.279
24.266	0.5	3.151	0.301	3.151	17.355
24.961	0.5	3.063	0.755	3.063	17.431
25.308	0.5	3.021	0.372	3.021	17.621
24.593	0.5	3.109	-0.087	3.109	17.622
24.899	0.5	3.071	0.36	3.071	17.542
24.899	0.5	3.071	0.569	3.071	17.149
25.023	0.5	3.056	0.499	3.056	17.621
25.023	0.5	3.056	-0.056	3.056	17.786
25.149	0.5	3.04	0.133	3.04	17.161
24.961	0.5	3.063	0.687	3.063	17.524
25.023	0.5	3.056	0.055	3.056	17.453
24.684	0.5	3.098	0.3	3.098	17.325
25.117	0.5	3.044	0.5	3.044	17.537

Average Perm 24.93312

5. C4 (INNITIAL)

Date	>> 11/18/2013
Time	>> 3:49 PM
Core ID	>> c4
Length	>> 7.579
Diam	>> 3.932
Viscos	>> 1.000
Notes	>> initial perm

Perm	Rate	dP	dPLow	dPHigh	Temp
16.075	0.5	4.833	-0.073	4.833	18.317
16.088	0.5	4.829	0.297	4.829	18.647
16.268	0.5	4.776	-0.104	4.776	18.488
15.962	0.5	4.868	-0.395	4.868	18.263
16.075	0.5	4.833	-0.203	4.833	18.231
15.924	0.5	4.879	0.294	4.879	18.704
16.139	0.5	4.814	0.291	4.814	18.366
16.152	0.5	4.81	-0.127	4.81	18.605
16.101	0.5	4.826	-0.42	4.826	18.412
16.229	0.5	4.787	-0.025	4.787	18.702
16.062	0.5	4.837	0.306	4.837	18.323
15.974	0.5	4.864	0.059	4.864	18.384
16.164	0.5	4.807	-0.402	4.807	18.293
16.025	0.5	4.848	0.249	4.848	18.706
16.139	0.5	4.814	0.227	4.814	18.373
16.088	0.5	4.829	-0.225	4.829	18.845
16.025	0.5	4.848	-0.404	4.848	18.185
16.152	0.5	4.81	0.045	4.81	18.35
15.999	0.5	4.856	0.32	4.856	18.357
16.025	0.5	4.848	0.019	4.848	18.479
16.062	0.5	4.837	-0.414	4.837	18.702
15.937	0.5	4.875	-0.187	4.875	18.486
16.012	0.5	4.852	0.119	4.852	18.738
16.037	0.5	4.845	0.252	4.845	18.225
16.075	0.5	4.833	-0.278	4.833	18.448
16.062	0.5	4.837	-0.342	4.837	18.641
15.924	0.5	4.879	0.163	4.879	18.493
16.088	0.5	4.829	0.335	4.829	18.607

16.025	0.5	4.848	-0.409	4.848	18.315
15.899	0.5	4.887	0.018	4.887	18.549
15.924	0.5	4.879	0.277	4.879	18.706
15.862	0.5	4.898	-0.251	4.898	18.383
15.912	0.5	4.883	-0.394	4.883	18.713
15.875	0.5	4.894	0.141	4.894	18.885
15.974	0.5	4.864	0.163	4.864	18.086
15.752	0.5	4.932	-0.173	4.932	18.466
15.862	0.5	4.898	-0.215	4.898	18.584
16.075	0.5	4.833	-0.012	4.833	18.229
15.838	0.5	4.906	0.213	4.906	18.384
15.862	0.5	4.898	0.244	4.898	18.575
16.025	0.5	4.848	-0.178	4.848	18.628
15.789	0.5	4.921	-0.326	4.921	18.17
15.801	0.5	4.917	0.067	4.917	18.528
15.752	0.5	4.932	0.275	4.932	18.214
15.838	0.5	4.906	0.144	4.906	18.644
15.912	0.5	4.883	-0.399	4.883	18.137
16.05	0.5	4.841	-0.219	4.841	18.184
15.924	0.5	4.879	0.096	4.879	18.157
15.924	0.5	4.879	0.297	4.879	17.968
15.74	0.5	4.936	-0.254	4.936	18.43
15.875	0.5	4.894	-0.327	4.894	18.518
15.838	0.5	4.906	0.008	4.906	18.454
15.825	0.5	4.91	0.291	4.91	18.3
15.813	0.5	4.913	-0.174	4.913	18.489
15.924	0.5	4.879	-0.332	4.879	18.399
15.825	0.5	4.91	0.274	4.91	18.575
15.85	0.5	4.902	0.206	4.902	18.443
15.776	0.5	4.925	-0.354	4.925	18.129
15.937	0.5	4.875	-0.037	4.875	18.389
15.862	0.5	4.898	0.338	4.898	18.889

Average Perm 15.93476

6. C4 (1 HOUR)

Date	>> 11/19/2013
Time	>> 11:50 AM
Core ID	>> c4
Length	>> 7.579
Diam	>> 3.932
Viscos	>> 1.000
Notes	>> after 1 hour sonicate

Perm	Rate	dP	dPLow	dPHigh	Temp
26.1	0.5	2.747	-0.103	2.747	17.517
27.117	0.5	2.644	-0.034	2.644	17.814
27.156	0.5	2.64	0.515	2.64	17.454
27.039	0.5	2.651	0.359	2.651	17.651
26.505	0.5	2.705	-0.146	2.705	17.296
26.807	0.5	2.674	0.472	2.674	17.288
26.807	0.5	2.674	0.504	2.674	17.59
26.769	0.5	2.678	0.017	2.678	17.555
26.028	0.5	2.754	-0.065	2.754	17.445
26.769	0.5	2.678	0.599	2.678	17.911
27.635	0.5	2.594	0.191	2.594	17.39
26.542	0.5	2.701	-0.145	2.701	17.615
26.43	0.5	2.712	0.289	2.712	17.582
26.731	0.5	2.682	0.515	2.682	17.647
26.356	0.5	2.72	-0.152	2.72	17.645
26.58	0.5	2.697	0.013	2.697	17.673
26.468	0.5	2.708	0.502	2.708	17.589
27.039	0.5	2.651	0.059	2.651	17.183
26.846	0.5	2.67	-0.162	2.67	17.445
26.884	0.5	2.666	0.307	2.666	17.537
26.693	0.5	2.686	0.607	2.686	17.34
26.173	0.5	2.739	-0.056	2.739	17.53
26.542	0.5	2.701	0.047	2.701	17.728
26.807	0.5	2.674	0.562	2.674	17.258
26.319	0.5	2.724	0.316	2.724	17.707
27.039	0.5	2.651	-0.118	2.651	17.562
25.956	0.5	2.762	0.364	2.762	17.381
26.136	0.5	2.743	0.423	2.743	17.771
26.731	0.5	2.682	0.049	2.682	17.65

25.778	0.5	2.781	0.383	2.781	17.831
26.618	0.5	2.693	0.274	2.693	17.463
26.209	0.5	2.735	-0.184	2.735	17.769
26.209	0.5	2.735	0.377	2.735	17.835
26.028	0.5	2.754	0.582	2.754	17.768
25.813	0.5	2.777	0.108	2.777	17.561
26.246	0.5	2.731	-0.02	2.731	17.82
26.136	0.5	2.743	0.285	2.743	17.434
26.209	0.5	2.735	0.39	2.735	17.671
25.992	0.5	2.758	-0.145	2.758	17.637
26.846	0.5	2.67	0.478	2.67	17.497
26.173	0.5	2.739	0.572	2.739	17.195
26.1	0.5	2.747	-0.163	2.747	17.543
26.618	0.5	2.693	0.224	2.693	17.957
26.283	0.5	2.728	0.579	2.728	17.766
25.672	0.5	2.792	0.118	2.792	17.979
26.064	0.5	2.75	-0.147	2.75	17.724
26.064	0.5	2.75	0.419	2.75	17.843
26.393	0.5	2.716	0.504	2.716	17.721
26.43	0.5	2.712	-0.075	2.712	17.626
26.209	0.5	2.735	0.179	2.735	17.717
26.393	0.5	2.716	0.569	2.716	17.756
26.1	0.5	2.747	0.491	2.747	17.818
26.283	0.5	2.728	-0.15	2.728	17.901
25.884	0.5	2.769	0.378	2.769	17.739
26.028	0.5	2.754	0.465	2.754	17.68
25.602	0.5	2.8	0.148	2.8	17.912
26.028	0.5	2.754	-0.032	2.754	17.679
26.028	0.5	2.754	0.501	2.754	17.76

Average Perm 26.26007

7. C4 (2 HOURS)

Date	>> 11/20/2013
Time	>> 11:46 PM
Core ID	>> c4
Length	>> 7.579
Diam	>> 3.932
Viscos	>> 1.000
Notes	>> after 2 hours sonicate

Perm	Rate	dP	dPLow	dPHigh	Temp
29.002	0.5	2.636	0.006	2.636	22.01
29.645	0.5	2.579	-0.253	2.579	21.462
28.918	0.5	2.644	-0.624	2.644	21.982
29.822	0.5	2.563	-0.182	2.563	21.614
29.086	0.5	2.628	0.083	2.628	21.839
28.835	0.5	2.651	-0.274	2.651	21.583
29.341	0.5	2.605	-0.487	2.605	21.844
29.427	0.5	2.598	-0.489	2.598	21.523
29.002	0.5	2.636	0.049	2.636	22.025
28.876	0.5	2.647	-0.225	2.647	21.537
29.866	0.5	2.56	-0.515	2.56	21.691
29.471	0.5	2.594	-0.106	2.594	21.634
30.272	0.5	2.525	-0.051	2.525	21.363
30.136	0.5	2.537	-0.087	2.537	22.078
29.298	0.5	2.609	-0.522	2.609	21.715
29.514	0.5	2.59	-0.491	2.59	21.897
29.256	0.5	2.613	0.073	2.613	21.721
29.822	0.5	2.563	0.055	2.563	21.359
29.384	0.5	2.602	-0.135	2.602	21.722
29.427	0.5	2.598	-0.659	2.598	21.593
29.044	0.5	2.632	-0.276	2.632	21.602
29.777	0.5	2.567	-0.015	2.567	21.808
29.213	0.5	2.617	0.064	2.617	21.75
29.645	0.5	2.579	-0.337	2.579	21.723
29.341	0.5	2.605	-0.599	2.605	21.678
29.086	0.5	2.628	-0.251	2.628	21.639
28.265	0.5	2.705	0.049	2.705	21.818
28.711	0.5	2.663	-0.116	2.663	22.005
28.96	0.5	2.64	-0.434	2.64	21.946

29.002	0.5	2.636	-0.401	2.636	21.746
29.17	0.5	2.621	-0.139	2.621	21.625
29.341	0.5	2.605	-0.002	2.605	21.173
29.427	0.5	2.598	-0.49	2.598	21.426
29.17	0.5	2.621	-0.598	2.621	21.372
29.777	0.5	2.567	-0.112	2.567	21.776
28.876	0.5	2.647	-0.006	2.647	21.887
29.002	0.5	2.636	-0.428	2.636	21.657
29.341	0.5	2.605	-0.369	2.605	21.71
29.514	0.5	2.59	0.123	2.59	21.459
28.918	0.5	2.644	-0.016	2.644	21.693
28.835	0.5	2.651	-0.553	2.651	21.434
28.67	0.5	2.666	-0.5	2.666	21.501
29.128	0.5	2.625	-0.021	2.625	21.448
28.835	0.5	2.651	-0.276	2.651	21.414
29.256	0.5	2.613	-0.601	2.613	21.386
29.777	0.5	2.567	-0.519	2.567	21.797
28.507	0.5	2.682	-0.268	2.682	21.361
29.17	0.5	2.621	-0.025	2.621	22.137
28.918	0.5	2.644	-0.13	2.644	21.469
29.17	0.5	2.621	-0.59	2.621	21.857
29.514	0.5	2.59	-0.5	2.59	21.529
29.384	0.5	2.602	-0.097	2.602	21.762
29.044	0.5	2.632	0.02	2.632	21.441
29.341	0.5	2.605	-0.201	2.605	21.65
29.384	0.5	2.602	-0.598	2.602	21.857
28.793	0.5	2.655	0.021	2.655	21.755
28.588	0.5	2.674	-0.318	2.674	21.457
28.711	0.5	2.663	-0.66	2.663	21.59
30	0.5	2.548	-0.45	2.548	21.773

Average Perm 29.25786

8. C4 (3 HOURS)

Date	>> 11/21/2013
Time	>> 7:32 AM
Core ID	>> c4
Length	>> 7.579
Diam	>> 3.900
Viscos	>> 1.000
Notes	>> after 3 hours sonicate

Perm	Rate	dP	dPLow	dPHigh	Temp
32.586	0.5	2.346	-0.318	2.346	21.73
32.961	0.5	2.319	-0.344	2.319	21.731
32.271	0.5	2.369	-0.378	2.369	21.626
32.853	0.5	2.327	0.038	2.327	22.34
31.609	0.5	2.419	-0.13	2.419	22.047
30.974	0.5	2.468	-0.602	2.468	21.826
31.51	0.5	2.426	-0.405	2.426	21.793
30.596	0.5	2.499	-0.004	2.499	21.555
30.784	0.5	2.483	-0.531	2.483	21.823
30.41	0.5	2.514	-0.394	2.514	21.776
30	0.5	2.548	-0.006	2.548	21.909
31.07	0.5	2.46	-0.011	2.46	22.068
30.272	0.5	2.525	-0.536	2.525	22.13
30.318	0.5	2.522	-0.169	2.522	21.586
29.558	0.5	2.586	-0.181	2.586	21.845
29.514	0.5	2.59	-0.648	2.59	21.845
29.911	0.5	2.556	-0.308	2.556	22.162
30.318	0.5	2.522	0.044	2.522	21.884
29.558	0.5	2.586	-0.205	2.586	22.112
29.384	0.5	2.602	-0.65	2.602	21.627
29.689	0.5	2.575	-0.287	2.575	21.988
29.128	0.5	2.625	-0.013	2.625	22.329
29.427	0.5	2.598	-0.514	2.598	21.854
28.918	0.5	2.644	-0.35	2.644	21.573
29.341	0.5	2.605	0.009	2.605	21.71
29.911	0.5	2.556	-0.129	2.556	21.65
30.181	0.5	2.533	-0.532	2.533	21.567
29.427	0.5	2.598	-0.196	2.598	21.46
29.384	0.5	2.602	0.134	2.602	21.465

30	0.5	2.548	0.111	2.548	21.949
29.256	0.5	2.613	-0.351	2.613	21.592
29.427	0.5	2.598	-0.57	2.598	21.681
29.558	0.5	2.586	0.012	2.586	21.53
29.086	0.5	2.628	-0.083	2.628	21.779
29.384	0.5	2.602	-0.598	2.602	21.651
29.471	0.5	2.594	-0.188	2.594	21.932
29.427	0.5	2.598	0.078	2.598	22.093
28.426	0.5	2.689	-0.666	2.689	21.668
29.514	0.5	2.59	0.001	2.59	21.75
28.629	0.5	2.67	-0.198	2.67	21.776
29.911	0.5	2.556	-0.601	2.556	21.744
29.384	0.5	2.602	-0.514	2.602	21.701
29.086	0.5	2.628	-0.002	2.628	21.85
29.733	0.5	2.571	-0.04	2.571	21.814
29.128	0.5	2.625	-0.609	2.625	21.903
29.298	0.5	2.609	-0.185	2.609	21.826
29.777	0.5	2.567	0.105	2.567	22.014
29.213	0.5	2.617	-0.318	2.617	21.732
29.689	0.5	2.575	-0.59	2.575	21.738
28.918	0.5	2.644	0.1	2.644	21.991
29.645	0.5	2.579	-0.238	2.579	21.8
29.384	0.5	2.602	-0.605	2.602	21.381
29.471	0.5	2.594	-0.428	2.594	21.769
29.086	0.5	2.628	0.021	2.628	21.4
28.876	0.5	2.647	-0.593	2.647	21.922
28.96	0.5	2.64	-0.432	2.64	22.251
29.601	0.5	2.583	-0.12	2.583	21.69
28.876	0.5	2.647	-0.014	2.647	21.821
29.384	0.5	2.602	-0.447	2.602	21.55
29.911	0.5	2.556	-0.386	2.556	21.662
28.711	0.5	2.663	-0.157	2.663	21.871
29.341	0.5	2.605	-0.241	2.605	21.562

Average Perm 29.54462