Performance Of Different Acids For Acidizing Treatment In Sandstone Formation (Terengganu)

By

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12109

A project dissertation sumbitted to the
Petroleum Engineering Programme
Universiti Teknologi PETRONAS
In partial fulfillment of the requirement for the
Bachelor of Engineering (Hons)
(Petroleum Engineering)

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CERTIFICATION OF APPROVAL

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(AP AUNG KYAW)

Project Supervisor

CERTIFICATION OF ORIGINALITY

I hereby verify that this report was written by me, Noor ‘Aliaa Amira Bt Mohd Fauzi (12109). I am resposible for the work I have been submitted in this project, the work have that had been done is my pwon except as specified in the references and acknowledgements.

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(NOOR ‘ALIAA AMIRA MOHD FAUZI)

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

There are four factors that contributed to the development of the petroleum system which includes reservoir rocks, source rocks, trap and permeable layer. Reservoir rocks usually are rock that contains petroleum and have both porosity and permeability. Reservoir rocks are dominantly sedimentary such as sandstones and carbonates. Sandstones are commonly found at most in oil fields. Sandstones are clastic sedimentary rock that composed mainly of sand-sized minerals or rock grains. The minerals that can be found in the sandstone are quartz and feldspar because these minerals are the most common minerals that can be found in the earth's crust. Sandstone has the property of high porosity where it can store large quantities of fluid that makes them to be valuable aquifers and petroleum reservoirs. Other minerals such as clay can be found in the sandstone, for instance chlorite, illite, kaolinite, smectite and mixed layer clays. Figure 1 shows the fundamental components of sedimentary rocks.

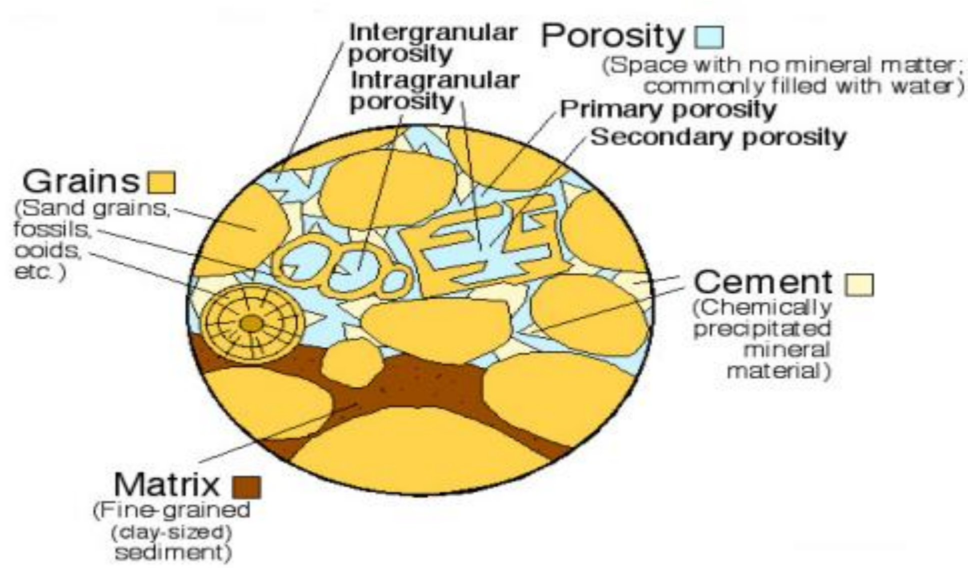


Fig 1: Fundamental Components of Sedimentary Rock

Sandstone acidizing in particular requires careful handling because sandstones in general are composed of several minerals compared with rocks such as limestones or dolomites that are commonly composed of only one or two major minerals. Each mineral in a sandstone behaves or reacts differently in contact with acidizing fluids. Different behavior implies different reaction kinetics, physical and chemical characteristics and many other parameters which create a very complex reaction process when it is reacting with treatment fluids[18].

In the oil and gas industry, acidizing had became one of the normal routine in order to improve the porosity and permeability as well as increase the production of the well. This technique also is one of the oldest well stimulation techniques. Matrix acidizing act as a treatment of reservoir formation by using a stimulation fluid that contain reactive acid. The acids react with the soluble substances in the formation thus enlarging the pore spaces. The stimulation will remove the formation damage to restore the original permeability of the formation. A routinely used fluid for this purpose is mud acid that has the capability of dissolving the most common damaging minerals.

The purpose of this project is to identify which combination of acids will have better increment in permeability of the formation. The type of sand that will be used for this project is Terengganu sands where it will be mixed with resin and hardener to produce the rock sample. The first combinations of the acids are formic acid and hydrofluoric acid while the second acid combination made up of hydrochloric acid and fluoboric acid. Hydrofluoric acid has the ability to dissolve aluminosilicates while formic acid has the ability to help to maintain low pH, which is necessary to keep the reaction products soluble. On the other hand, fluoboric acid has the ability to dissolve clays that act as binder that bind the grains in the sand together while hydrochloric acid able to dissolve clay materials that are abundance in the sandstone. This project is significant in order to determine which combination of acids that will best dissolve minerals in the sandstone formation to improve the permeability and porosity.

1.2 Problem Statement

For several years, it has been recognized that traditional combination of 15% of hydrochloric acid (HCl) and 3% of hydrofluoric acid (HF) systems are effective only at removing silicate damage within 1 ft of the wellbore. However, it has been realized that the mixture combination does not suit deep penetration as the reaction rate with clays and grain cementing material is rapid at formation temperature. In an acid system, it is required for the acid mixture to not react rapidly with the formation so that acidizing for deep penetration zone can be done. The purpose of the project is to determine how the response of minerals is related to the acids combination.

1.3 Objectives

1. To determine the best combination of acids to be used in acidizing treatment for each Terengganu sandstone.
2. To compare the improvement of samples after acidizing treatment between combination of formic acid and hydrofluoric acid and combination of hydrochloric acid and fluoboric acid.

1.4 Scope of Study

1. Conducting research and finding related information related to matrix acidizing for sandstone.
2. Conducting experiments to examine all of the objectives by using laboratory approach.

1.5 Feasibility of the Project within the Scope and Time Frame

The project is basically a laboratory based project and to be able to conduct the experiment, there are some things that need to be prepared beforehand. The things include experimental procedure to conduct the experiment, the materials (eg. chemical, core sample) and historical data that had been done previously. Thus, it is possible for the author to achieve the objectives as the time frame given is about seven months.

CHAPTER 2
LITERATURE REVIEW

2.1 Literature Review

Matrix acidizing is one of the well stimulation techniques that had been practiced since 1895. However for sandstone acidizing, the first service company started to developed the treatment was Halliburton which is in May 1993. Generally, matrix acidizing is the activity that had been practiced to improve the formation porosity and permeability so that the production can be enhanced. Mud acid is being used in the treatment and the first combination made by Halliburton consists of hydrochloric acid and hydrofluoric acid. In theory, the acids will react with the formation by dissolving the soluble substances to enlarge the pore spaces. The main function of the mud acid is to remove the drilling mud filter cake from the wellbore. Unfortunately, the first attempt was unsuccessful as the acids caused sand production into the wellbore [1].

Matrix acidizing has application in both carbonate and sandstone formations. In sandstone formations, matrix acidizing treatments should be designed to remove or dissolve "acid-removable" damage or plugging in the perforations and in the formation pore network near the wellbore (Kalfayan Leynord, 2000). Matrix acid treatments to remove near-wellbore damage within sandstone formation are an old, but still widely used procedure [2]. The side reactions that occur in almost all mud acid treatments, lead to the formation of precipitates that will plug pore spaces and reduce permeability [3].

As mentioned before, the combination of HCl and HF lead to many problems especially when the formation at high temperature. Thus, formic acid was used to remove carbonate minerals as a preflush and with the main HF stage [4]. Research had been done by using the combination of formic acid and hydrofluoric acid. The results of the research shown that at room temperature, formic acid solution damages sandstone core sample and it is also known that it is not effective in removing carbonates in the sandstone formation. It is also had been found that high concentration of HF can remove more alluminosilicates but it causes precipitate of calcium fluoride [4].

The common acid used for sandstone formation is hydrofluoric acid (HF) that dissolves siliceous minerals. As for the concentration of the acids, it may vary depending on the formation of the reservoir. If the sandstone has high carbonate mineral content, it is advised to avoid the usage of HF and replaced the acid with hydrochloric acid (HCl). HF reacts preferentially with the high-surface-area particles [1]. The continuing research for an effective deep-penetrating sandstone acidizing system has focused on fluoboric acid (HBF_4). It has been shown that there is limitation in the usage of HBF_4 in the field. The temperature dependence of the HBF_4 decomposition precludes any significant advantage over conventional HF under typical well conditions [5].

Stimulation of sandstone reservoirs is aimed at removing the formation damage caused by drilling, workover or completion processes, thus to restore the original permeability of the formation. There are three conventional steps involved for acid treatment design that consist of acid preflush, main flush and post flush. It is known that when organic acid is used as the preflush, 5 wt% ammonium chloride (NH_4Cl) should be included based on previous research where acetic acid was so weak that ion exchange between H+ and Na+ on bentonite clay could not [6]. The main purpose of the preflush stage is to remove carbonates minerals in the formation prior to injection of the main HF acid mixture. The standard preflush that is commonly used in the industry is HCl about 5-15%. Organic acids such as acetic and formic can also be used by themselves, in combination with each other or in combination with HCl. Organic acids are especially useful in high-temperature applications because they are less corrosive than HCl. If the preflush cannot be injected because of very severe damage, it may be necessary to break down the formation by pumping above fracturing pressure. This method is acceptable as long as the injection is returned to matrix rate which is below fracture pressure as soon as possible. Another alternative is to forego the preflush and break down the severely damaged formation with the main HF acid phase initially.

The purpose of the main acid stage is to dissolve siliceous particles that are restricting near-wellbore permeability, plugging perforations or gravel packs. The main acid phase is a mixture of two acids commonly strong acid being mixed with organic acid. There are some risks associated with acidizing such as fines migration, precipitation of reaction products and rock deconsolidation normally can be minimized with proper volumes and concentrations of acids used.

On top of that, the main purpose of post flush is to displace the acid phase away from the wellbore. By using this method, precipitation reactions that inevitably take place will only occur well away from the near-wellbore region, where the effect on productivity will be insignificant. Ammonium chloride solution, weak HCl, acetic acid, filtered diesel or lease crude can be used in post flush stage. For gas wells and extremely water-sensitive formations, nitrogen is an effective post flush. Diesel or lease crudes are used when it is require reestablishing oil saturation near the wellbore. Table 1 shows the recommended fluid volumes for basic treatment procedure. (*Source: An Improved Method for Acidizing Oil Wells in Sandstone Formation*)

Permeability Range (mD)				
	1-10	**10-25**	**25-100**	**100 +**
Preflush	25	25-50	35-75	50-150
Main Flush	25-50	25-50	75-100	75-150
Post Flush	Oil wells: > Main Flush volume			

Table 1: Recommended Fluid Volumes for Basic Treatment

Based on research and studies that had been done on sandstone acidizing by using the combinations of hydrofluoric acid and formic acid, it shows that at room temperature, formic acid solution damages the sandstone core [6]. Ammonium chloride can act as clay stabilizer and alleviate the damage. It is also been found that formic acid is not effective in removing carbonates in a sandstone reservoir; however it became effective at higher temperature. More concentrated HF also able to remove alluminosilicates but it can also caused precipitation of calcium fluoride. According to other studies, it has been found that if HF is injected into a core previously acidized with HCl, the permeability will begin to rise immediately without exhibiting a period of initial damage [9]. Identical behavior from tests on a wide variety of other core material supports the general validity of this observation. Apart from that, the sample also being tested for brine permeability and freshwater sensitivity where the net stimulation occurred only within the first 30 cm of the input face. The first 10 cm of the core, which had experienced about 100 PV of HF, was unconsolidated. Although net stimulation only occurred out to 30 cm, it is significant that freshwater sensitivity was removed from the entire core.

According to H.O.McLeod, there are some significant factors that contributes to successful matrix acidizing. The factors include good evaluation of candidate wells using completion and production histories, producing well flow analysis and formation composition analysis as well as design for effective coverage of all damaged perforations. The selection of solvents, acids and acid compositions also contributes to successful matrix acidizing and last but not least is effective well preparation and job supervision.

According to Nicholas Kume et al., the process of candidate selection must involve a thorough analysis of the production history. The system analysis includes type of skin damage, reservoir pressure, well inflow performance indicator (WIQI<0.5), BSW<40%, PI<10 and PI decline>30% is usually considered. The matrix acidizing for this study shows that the production and injectivity increases, damage skin reduction, payback time and job cost minimization. Overall, the technical and economical aims were accomplished as nine well treated with the new HF acid system, show over 400% economic and technical improvement.

A detailed examination of sandstone acidizing done by Gidley was to determine the response of sandstone formations is related to the individual components of acid treatments employed on them. Mud acid possesses the ability to dissolve clay materials. Mud acids performance affected by formation permeability, temperature, clay content, volumes, after flush types as well as type of wells involved. One feature of the data that stands out clearly is the individual differences between treatment responses for gas wells, oil wells and water injection wells. Of the three well types studied, gas wells appear to respond to the treatment most uniformly and predictably. On the other hand, oil wells experience a maximum in their well response as a function of the amount of acid used. Treatment success does not appear to increase uniformly with formation permeability and after flush-to-acid volume ration does not affect buildup uniformly throughout the time period examined. As for water injection wells, the results show that the odd response of having the greatest buildup to the least acid treatment.

Acidizing is the activity to remove the formation damage near the wellbore and skin is a common name used in describing formation damage. It is a parameter that is used in Darcy's equation in order to calculate the damaged wellbore [12]. The definition of skin can be described in a formula as:

$$S + \ln\left(\frac{r_a}{r_w}\right) = \frac{k_e}{k_a}\ln\left(\frac{r_a}{r_w}\right) \; or \; S = \left(\frac{k_e}{k_a} - 1\right)\ln\left(\frac{r_a}{r_w}\right)$$

s = skin (dimensionless)

r_a = damaged radius

r_W= wellbore radius

k_a= damaged zone permeability

k_e= reservoir permeability

In order to determine whether the formation damaged at the wellbore has been removed or fixed is by doing skin calculation where if the skin has negative value, it means that the formation damage has been removed and vice versa.

CHAPTER 3

METHODOLOGY/ PROJECT WORK

3.1 Project Work

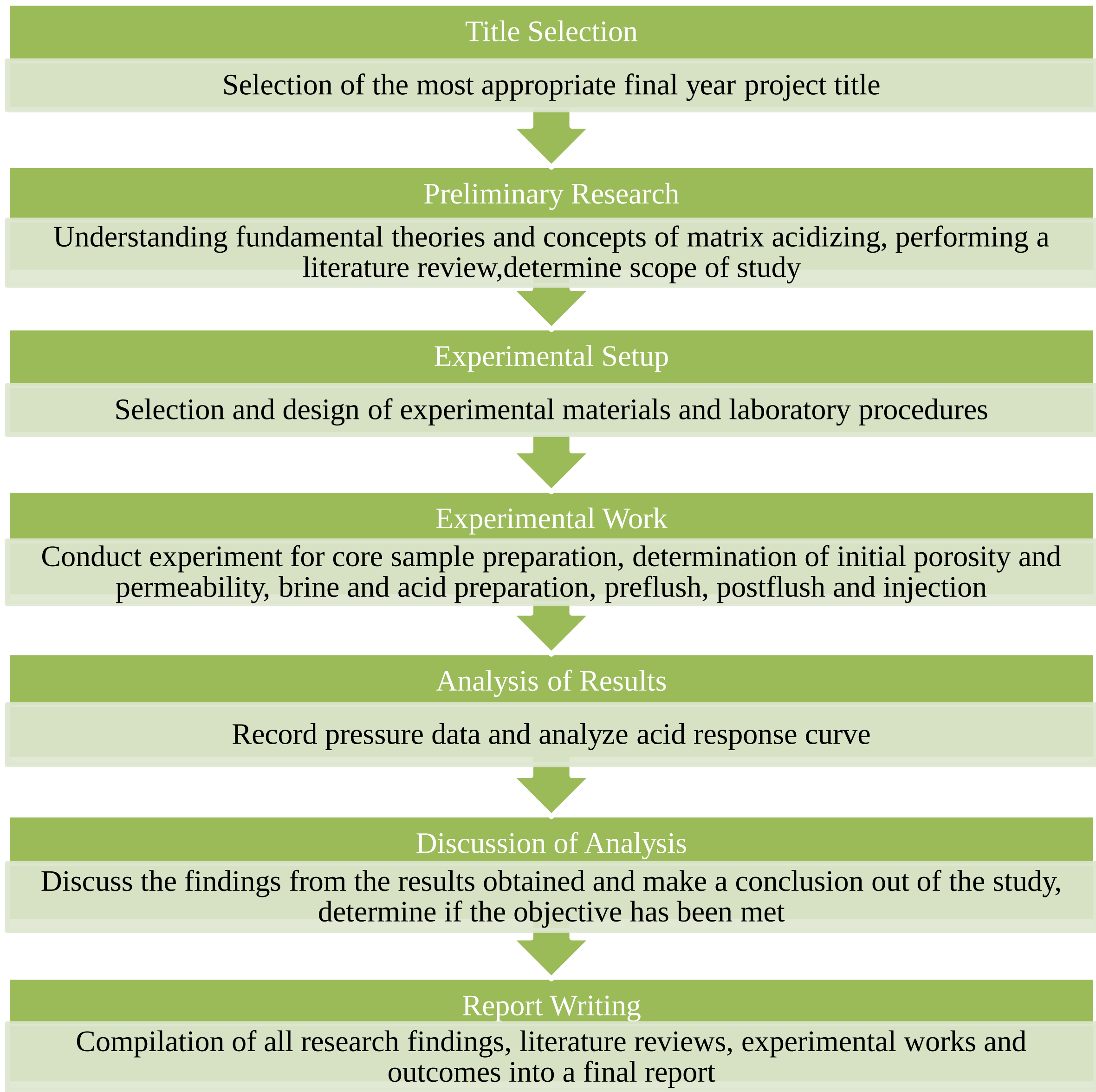


Figure 2: Project Activities Flow

3.2 Research Methodology

Research is a method taken in order to gain information regarding the major scope of the project. The sources of the research cover the handbook of acid stimulation, e-journal, e-thesis and several trusted link. As the project is a laboratory based, the experimental procedure is being designed carefully to ensure the safety as well as to get the required result.

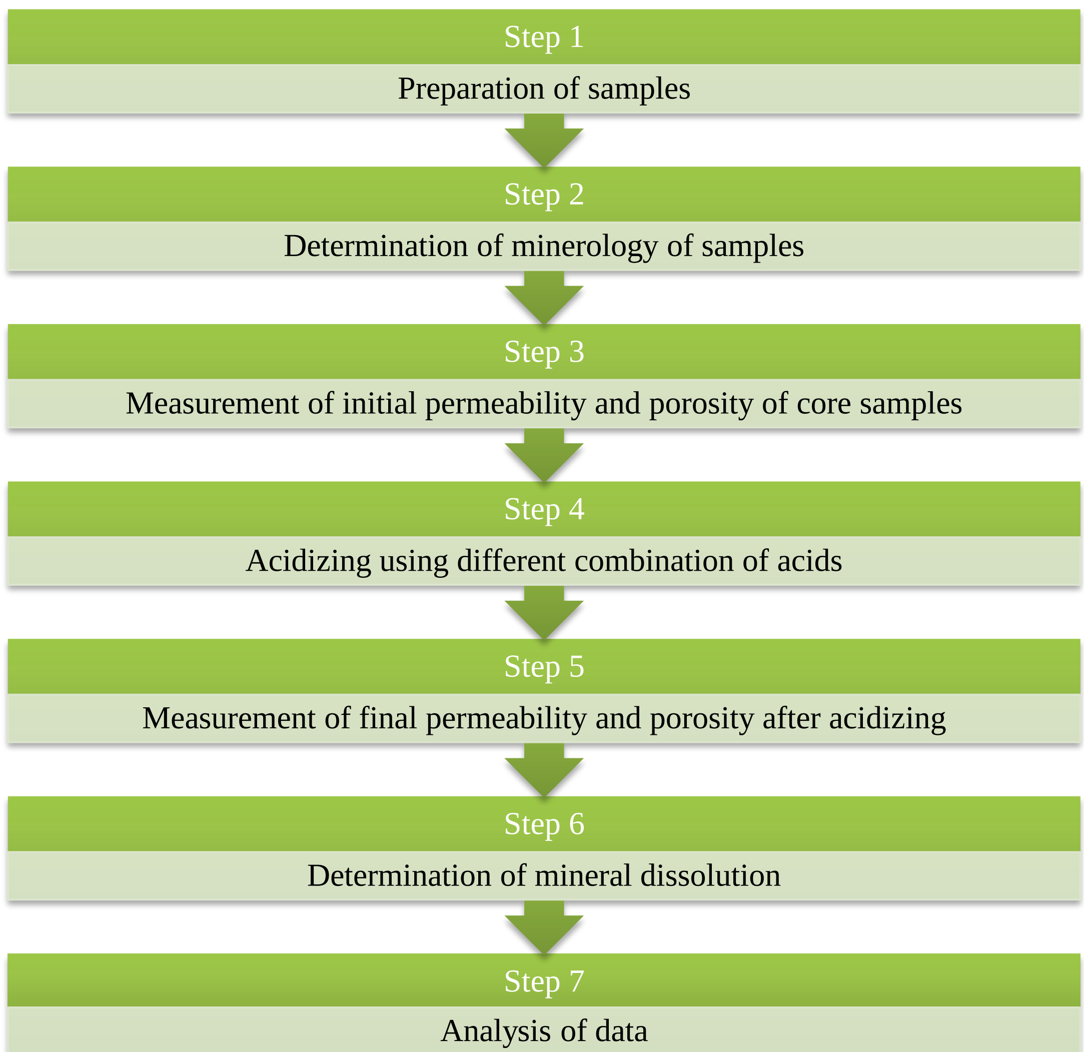


Figure 3: Experimental Procedure

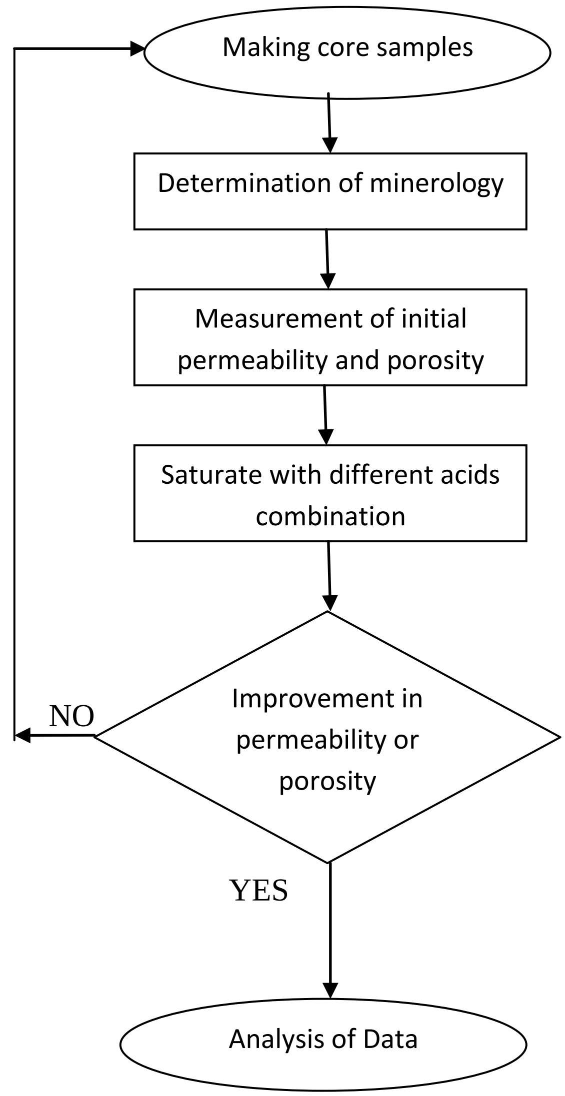


Figure 4: Flowchart of Experimental Project Methodology

1. **Sand sample preparation**

The preparation of the sample starts by taking the sand from Terengganu shore. The sample should be taken near the shore area where the sand formation is quite uniform as it is not affected by the strong current and it is needed for the sample to be dug from a feet or two feet deep. Then, the sample need to be washed and dried under the hot sun. The sample is washed to remove the turbidity that will affect the chemical reactions when acid is being injected during acidizing.

2. **Sieving the sample**

The sample will then be sieved by using the sieving unit in order to determine the size of the sand grains in the collected sample. It is also one of the method to remove any contamination in the sample such as shells. The size of the grain that will be used to make core samples will be depending on the most sand retained at the sieving unit. The size of the sand sample that will be used for this experiment sand retained at 300µm and passed 450µm.

3. **Making core sample**

Resin and hardener is needed to hold the sand sample together. In simple word, resin acts like a glue that will hold the sand grains together so that it will be easier to prepare the core sample. The mixing ratio depends on the type of resin and hardener being used. For this project, the ratio of resin and hardener is 9:1. Only 5% of resin will be mixed to the sand sample, for instance if the sand used is about 200 gram, the resin that will be used is about 10 gram.

4. **Determination of mineralogy**

The mineralogy of the core sample is determined by using thin section process. Thin section process is the process where a piece of rock specifically prepared to study its optical properties. The sample will be ground to 0.03 millimeter thickness, and then it is polished and placed between two microscope slides.

5. Determination of porosity and permeability

The initial value of the porosity and permeability of the core samples will be obtained by using POROPERM machine.

6. Core sample saturation with acid

Then, the core sample will be saturated with the acid with different combinations as well as different concentration and the reactions are to be monitored. After the acidizing, the final porosity and permeability are then will be measured again.

3.3 Gantt Chart

The figure below shows the milestone for FYP I and FYP II.

No	Detail/Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
1	**Selection of Project Topic:** Performance of Different Acids with for Terengganu Sandstone																												
2	**Preliminary Research Work:** Research on literatures related to the topic																												
3	Submission of Preliminary Report																												
4	Proposal Defense (Oral Presentation)																												
5	**Project work continues:** Further investigation on the project and do modification if necessary																												
6	Submission of Interim Draft Report							Mid sem break													Mid sem break								
7	Submission of Interim Report																												
8	Lab Work																												
9	Submission of Progress Report																												
10	Lab Work																												
11	Pre-SEDEX																												
12	Submission of Draft Report																												
13	Submission of Technical Report																												
14	Submission of Dissertation																												
15	Oral Presentation																												

Figure 5: Combined Gantt chart

3.4 Experimental Methodology

3.4.1 List of Materials

Some of the materials that will be used for the experiment:

General Name	Description
Sand sample from Terengganu	Size of 150-425 µm
Resin and hardener	Ratio of 9:1
Hydrochloric acid	37% concentrated
Hydrofluoric acid	40% concentrated
Formic acid	98-100% concentrated
Acetic acid	100% concentrated
Fluoboric acid	50% concentrated
Distilled water	

Table 2: List of Materials

3.4.2 List of Equipment

Some of the equipment that will be used throughout the experiment:

1. Sieving unit.
2. Mixing machine.
3. Electronic mass balance.
4. Rock cutting machine.
5. Desiccators and vacuum pump.
6. POROPERM machine.
7. Scanning Electronic Micrograph (SEM) instrument.
8. 1000 ml beaker.

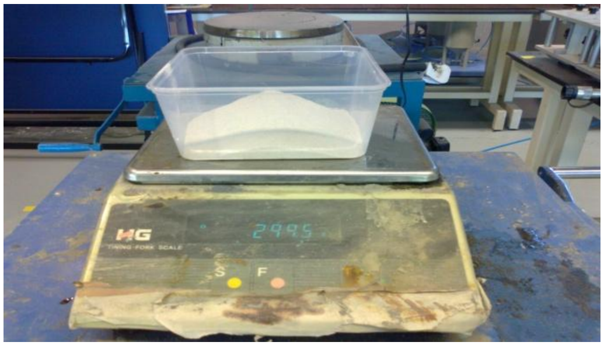
3.4.3 Procedures

The experimental work can be divided into four parts that includes core sample preparation, preparation of acid solution, saturation of core sample and determination of permeability and porosity. For core sample preparation, the materials used are sand sample, acetone, resin and hardener.

Preparation of Core Sample

1. Sieve the sand by taking the sand that has the size of 150-425 µm. The sand passed 425 µm and it retained at 300 or 150 µm.

2. Weigh the sand about 1000 gram by using electronic mass balance.



3. Calculate volume of resin and hardener by using the ratio of 9:1.

4. Then, mix the sand with resin and hardener by using mixing machine. Mixed for about 5 minutes and then add about 10 ml of acetone and continue mixing until the machine automatically stopped.

5. Then, take out the mixture and put it into the mould and left for three days.

6. After that, take out the sample from the mould and cut it with rock cutting machine.

7. Dry the sample in the oven that has the temperature of 60ºC.

Preparation of Acid Solution

1. Calculation of volume of acid is calculated by using the formula of $M_1V_1 = M_2V_2$. **For instance:**

   <u>Volume of fluoboric acid(50%)</u>

   $(50)V_1 = (3)(1000)$

   $V_1 = 60$ ml

   <u>Volume of Hydrochloric acid (37%)</u>

   $(37)V_1 = (12)(1000)$

   $V_1 = 324$ ml

   <u>Volume of distilled water</u>

   1000- 60- 324 = 616 ml

2. Then, mix the acid to the distilled water in small doses in the fume chamber.

3. All protective equipments must be wear during the experiment to ensure the safety of the people and surrounding.

Saturation of core sample

1. Prepare the desiccators and vacuum pump.
2. Immerse the sample in 1000 ml of acid solution (pre-flush).
3. Place the lid on the desiccators and open the tap and cover with appropriate sized safety cage.
4. Connect the tap to the vacuum pump and open the tap slowly to evacuate the desiccators.
5. After the samples had been dried, close the tap and disconnect the vacuum supply.
6. Repeat the entire step by using the acid solution after the pre-flush stage.

Determination of permeability and porosity

1. The initial permeability and porosity is determined by using POROPERM machine.
2. After the samples had been saturated with the acid, the final permeability and porosity is then being measured as well.

CHAPTER 4
RESULTS AND DISCUSSION

For this project, it is expected for the core sample to have increment in the permeability as well as the porosity after being saturated in the acid. Preflush stage is needed for this experiment to remove carbonate and iron compounds. The combination used is acetic acid and HCl where the organic acids are especially useful in high-temperature applications as they are less corrosive compared to HCl. The data tabulation for the experiment can be seen as follows:

Percentage of acid to water (%)	Ratio (HF : HCOOH)	Ki (mD)	Kf (mD)	Øi	Øf
8.11	1.5 : 4.5	6595.78	4635.09	40.853	43.581
12.36	1.5 : 8	6786.99	4666.873	40.764	40.049
16.28	2 : 10	6937.45	5430.883	41.006	43.616
17.65	3: 9	6897.58	6648.963	40.567	45.691

Table 3: Effect of HF and HCOOH on porosity and permeability

Percentage of acid to water (%)	Ratio (HBF_4 : HCl)	Ki (mD)	Kf (mD)	Øi	Øf
33.33	3 : 9	6215.33	6623.107	41.233	49.267
25	3 : 12	6932.47	4947.005	40.807	44.843
22.22	3 : 13.5	6154.3	4864.823	40.915	45.485
41.67	5 : 12	6328.15	5353.383	41.325	45.026

Table 4: Effect of HBF4 and HCl on porosity and permeability

The value of the initial permeability and porosity is determined by using POROPERM machine after the core sample has been dried in the oven with the temperature of 60ºC for one day. This is to ensure that the sample has been completely dried so that more accurate value of permeability and porosity can be obtained. For this experiment, all of the samples initial values of porosity and permeability were measured.

The tables above show the final permeability and porosity of the core samples after being saturated with two different types of combination of acids. It can be seen that for combination of HF and HCOOH, the value of the final porosity has slight decrement about 1.6%. As for the second combination (HBF_4 and HCl), all of the samples showed the value of the final porosity increases compared to the initial porosity.

As for the value of the final permeability, HF and HCOOH combinations show that the permeability decreased from the original value. However, one of the samples saturated with combination of HBF_4 and HCl shows slight increment in permeability. This shows that the combination that suits Terengganu sand is 3% of HBF_4 and 9% of HCl.

The decrement value in permeability might be because of precipitation of some minerals with the acids that being used. According to Yang (2012), formic acid can trigger fines flocculation. This might damage the initial effective permeability of the sample thus affecting the final permeability of the sample. Apart from that, HF acid is known to dissolve aluminosilicates, however the reaction rate was found to be very sensitive to the temperature (Gdanski, 1999). The temperature used for the experiment is 37ºC which is the room temperature and is kept constant due to safety constraint while doing the experiment. On the whole, better permeability can be achieved at higher temperature when formic acid and HF used in the main stage.

According to Kunze and Shaughnessy (1983), a problem encountered during HBF_4 acidizing was the tendency of a sparingly soluble precipitate, chemically identified as KBF_4. It has the ability to plug backpressure regulators and pipelines which will reduce the production. This precipitate also might be responsibility for a decrease in the permeability of the core. The decreased in permeability after injecting HBF_4 probably were caused by silica precipitation. It is also has been discovered that HBF_4 is temperature dependence that affect the performance of the acid itself. HBF_4 is a strong acid that dissociates completely upon dilution or consumption of HF by clays, this equilibrium will readjust to produce more HF by BF_4 decomposition. The experiment was done at room temperature contributes to retardation of HBF_4 acid. On the other hand, HCl acid reacts with calcium carbonate which is commonly found in every sandstone formation thus improving the porosity of the sample. In the experiment, the confining pressure which is the pressure applied when using POROPERM machine is 400psi using Helium gas.

The figures below show the comparison of initial porosity and initial permeability versus final porosity and final permeability for both combination of acid.

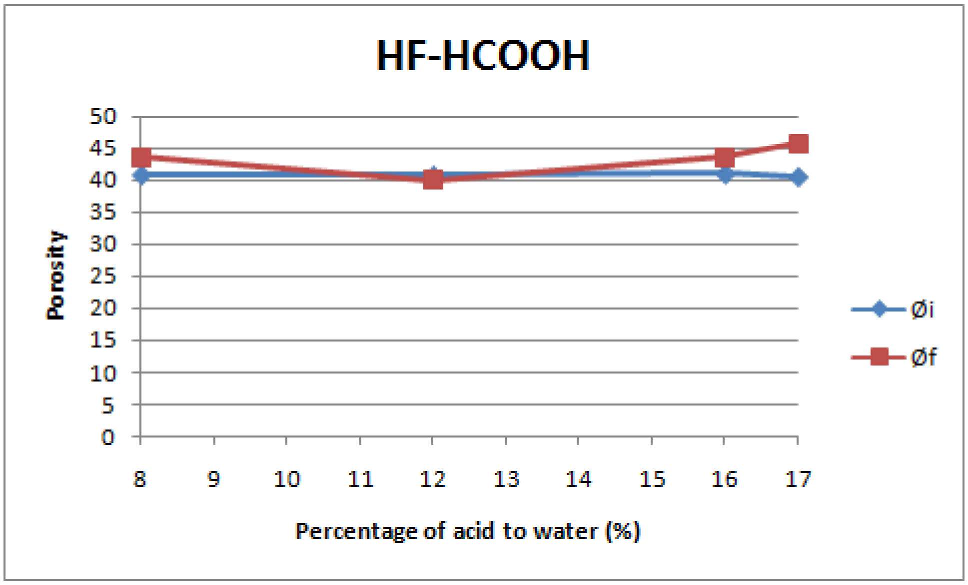


Figure 6: Porosity vs Percentage of acid to water (HF+HCOOH)

From Figure 6, most of the final porosity has increased compared to the initial value. At the point of 12.36 percentage of acid to water, the porosity is slightly decreased which has difference about 0.804 (2% reduction). The reason might be that formic acid does not remove carbonate effectively at room temperature. According to Yang, formic acid will work more effective at higher temperature. At this point, the ratio of concentration between HF and formic acid is 1.5:8 which concentration of HF is the lowest compared to other combinations. Low concentration of HF does not remove much alluminosilicates thus, might causes some pore to plug as the minerals are not being remove completely. The reaction below shows that multiple silicon fluorides and aluminum usually coexist that causes precipitation.

$$SiO_2 + 4HF \rightarrow HSiF_4 + 2H_2O$$

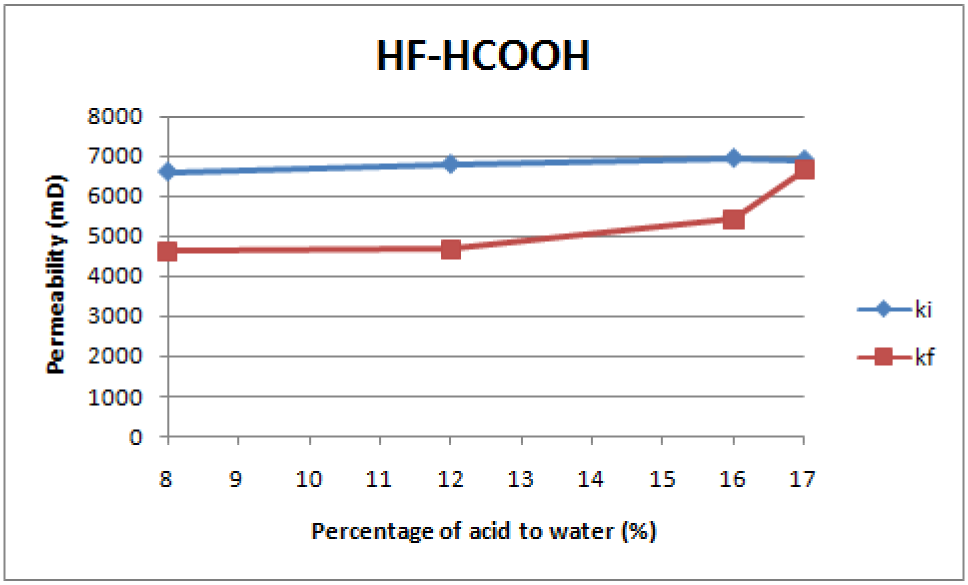


Figure 7: Permeability vs Percentage of acid to water (HF+HCOOH)

Figure 7 shows that the final permeability is lower compared to the initial permeability. The lowest final permeability belongs to sample T1 with the value of 4666.87mD. This happened may be due to the temperature that being applied in the experiment. According to Yang, better permeability improvement can be achieved with high temperature. The permeability decreased also because of calcium precipitation when the sample is being saturated in the acid solution. In the industry, it is known that the first reaction of HF is being pumped down hole, and mixed with spent acid; CaF_2 was precipitated that contributes to Ca precipitation (Muhammad *et al*, 2011).

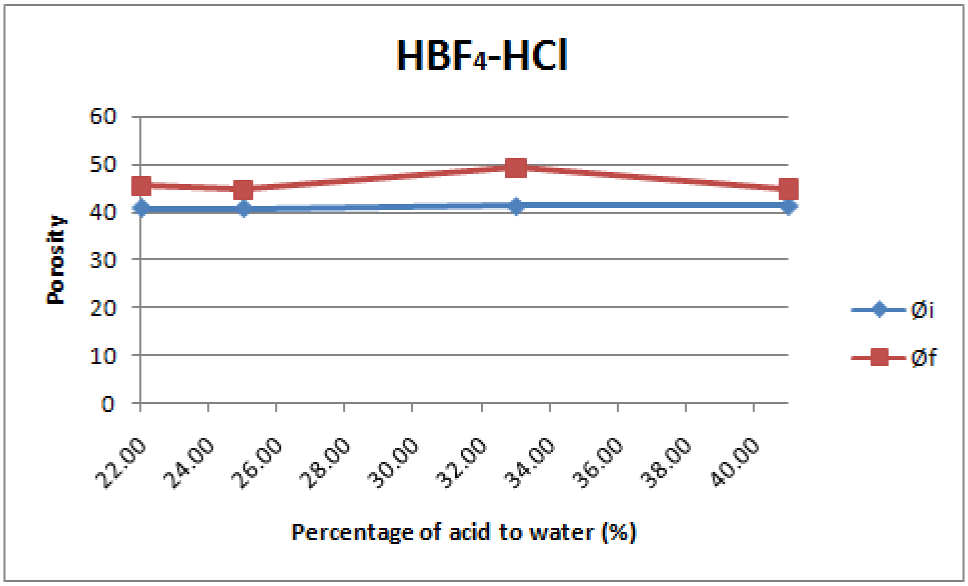


Figure 8: Porosity vs Percentage of acid to water (HBF_4+HCl)

Figure 8 shows that porosity of the sample has increased for all the samples. The highest increment in porosity can be seen at point three which the concentration is 33.33%. At this point, the ratio of HBF_4 and HCl is 3:9. The porosity increases because HCl dissolve all the carbonaceous minerals in the sample more effectively. As the concentration of HCl increases, the increment of the porosity in the other sample does not increases. This proves that the suitable concentration of acids to be used for this sample is 3:9 (HBF_4: HCl).

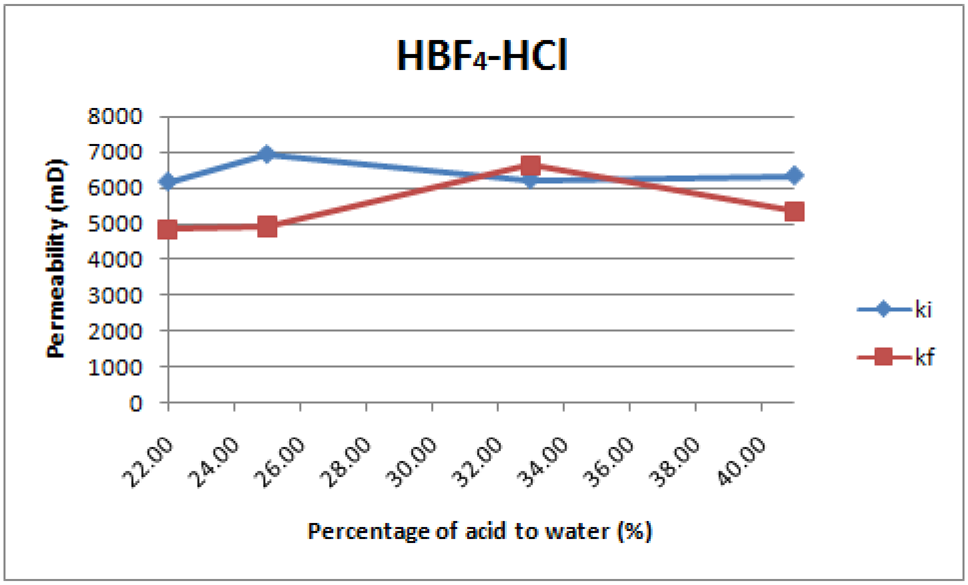


Figure 9: Permeability vs Percentage of acid to water (HBF_4 + HCl)

From Figure 9, it can be seen that there is increment in permeability at point of 33.33% of acid to water. The ration between HBF4 and HCl is 3:9. This combination of acid might be suitable for the sample formation that causes the permeability to increase. Value of permeability is only increased slightly might be due to the property of HBF_4 that is dependence on the temperature. As for this project, the temperature is kept constant due to safety reason. According to Kunze and Shaughnessy, the initial attack of HF on clay resulted on solubilization of aluminum and silicon layers. However, the spent acid reacted with the clay and causes the silicon in the solution to precipitate.

Field Emission Scanning Electron Microscopy or also known as FESEM is one type of electron microscope that can produces images of a sample. FESEM operated by scanning the sample with a focused beam of electrons. The electrons will interact with the sample's electrons that will produce various signals. These signals can detect and contain information about the surface topography and composition of the sample.

For this project, FESEM is used in order to determine the mineral content of the sample as well as to discover the porosity as well. FESEM produced mapping on the mineral content of the sample and it has been discovered that the sample content carbon, magnesium, aluminum, oxygen, silicon, chloride, calcium and potassium. By knowing the minerals content, one can determine the reaction of the mineral with the acid that is used in the experiment. Figures of the elements can be found below.

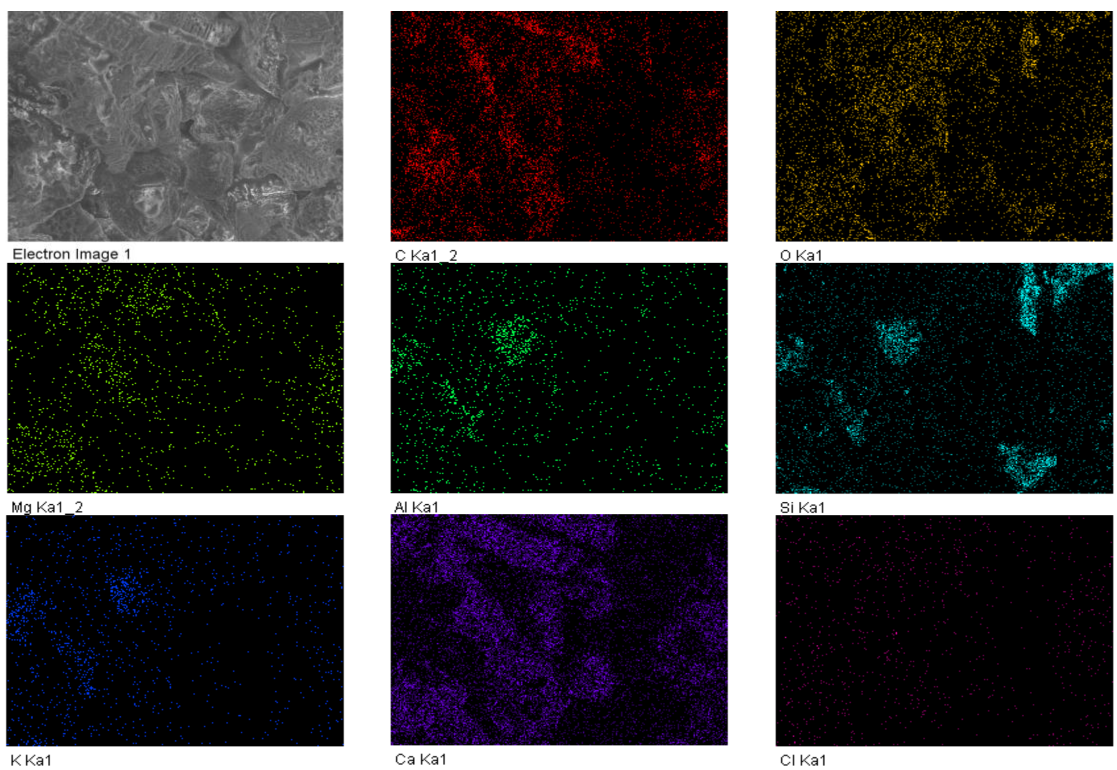


Figure 10: Elements presents in the sample

From the figure, we can see the minerals content in the sample whether the minerals present are abundance or small percentage. On the other hand, main elements that can be found in this sample can be seen in the table and figure below.

Table 5: Elements of the sample

Element	Weight%	Atomic%
C K	28.41	40.54
O K	44.46	47.62
Si K	1.31	0.80
Ca K	25.82	11.04

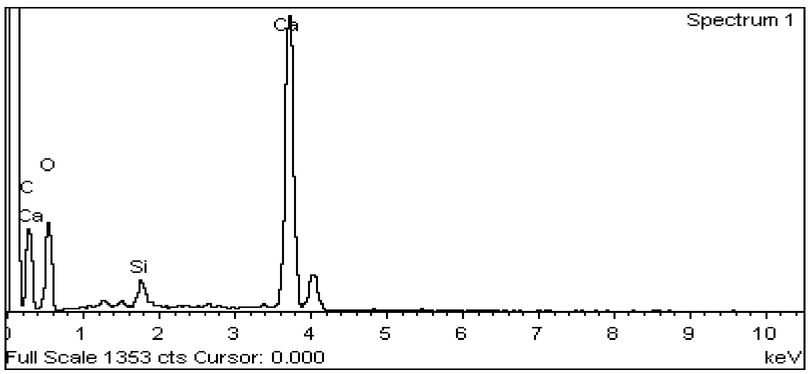


Figure 11: Graph of minerals content

Porosity can also be seen in the figure below. The sample has high porosity where there are lots of pore spaces between the grains.

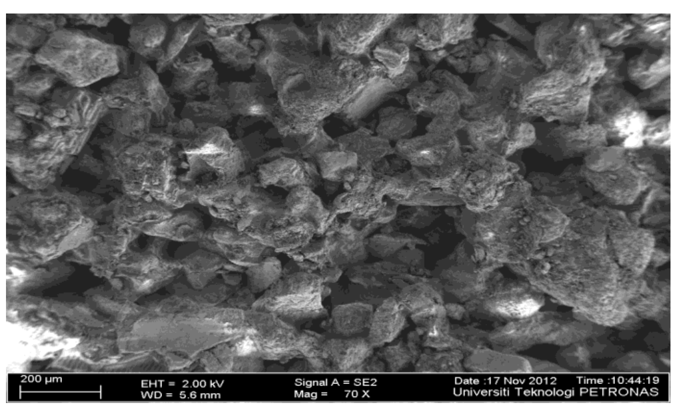


Figure 12: 200µm grain size, with magnification of 70x

As we all are aware, well stimulation costs quite a big amount of expenses. While doing acidizing, it is usually been done with solution of combined acids that might induce severe corrosion attack on production tubing, downhole tools and casing. For instance, according to Matthew, the total annual cost of corrosion in the oil and gas production industry is estimated to be $1.372 billion. $59 million is spent on surface facilities and facility costs, $463 million annually in downhole tubing expenses and another $320 million in capital expenditure related to corrosion. Thus, it is best to come out with the solution on the management of corrosion in order to maximize the revenue. The field operators, pipeline engineers, have to beware and updated on the corrosion in the oil and gas industry so that smooth and uninterrupted production can be achieved. Corrosion can be controlled by selecting highly corrosion resistant materials and the suitable corrosion inhibitors for the combination of acids that is used for acidizing.

CHAPTER 5
CONCLUSION AND RECOMMENDATION

This project is one of well stimulation technique in order to improve the productivity of the producing well. It is very much related to the current conditions of the wells that are producing sands and water instead of hydrocarbons. From the studies, one can determine the proper type of acids based on the formation of the wells as well as the proper concentration to be used so that it will not damaged the formation even further hence, reduce the production. In order to do so, research on the minerals and the acids need to be done because different acids will react differently on different minerals.

From the experiments that had been carried out, the combination of fluoboric acid and hydrochloric acid shows that the decrease in permeability is much lower compared to the combination of hydrofluoric acid and formic acid. These might be due to some factors while doing the experiment such as the temperature, pressure and method of saturating the sample itself.

In a nutshell:

1. The better combination of acids to be used for Terengganu sandstone is the combination of fluoboric acid and hydrochloric acid with the ratio of percentage 3:9.
2. Formic acid becomes more effective at removing carbonates at higher temperature.
3. Hydrofluoric acid can remove alluminosilicates but it can cause calcium fluoride precipitation.
4. Fluoboric acid can remove aluminum but causes silicon precipitation.

To improve the integrity and relevancy of this project, a few recommendations and improvisation can be made as follows:

i. To improvise the experimental setup for more accurate reading.
ii. To provide sandstone core sample directly from the existing wells.
iii. To provide core flooding machine where acids can be used as injecting parameter.
iv. To design an experimental condition that similar to the wellbore conditions (pressure, temperature).
v. To include post flush in the experimental procedure.
vi. To synchronize the duration for saturation of the sample in acid solutions.
vii. To manipulate the ratio of combinations of acids to see the effect clearly.

CHAPTER 6
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