PERFORMANCE OF DIFFERENT ACIDS FOR ACIDIZING TREATMENT IN SANDSTONE FORMATION (PANGKOR SAND)

by

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Dissertation submitted in partial fulfilment of
the requirements for the
Bachelor of Engineering (Hons)
(Petroleum Engineering)

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Approved by,

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(AP Aung Kyaw)

UNIVERSITI TEKNOLOGI PETRONAS
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CERTIFICATE OF ORIGINALITY

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

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(MUHAMMAD ASLAM YUSUF BIN MUSA)

ABSTRACT

As more technologies to enhance oil production recovery are being developed, well stimulation has been introduced and it acts as one of the important roles to fulfill the demand of world for energy. Well stimulation is a well intervention performed on an oil or gas well to increase production by improving the flow of hydrocarbons from the drainage area into the wellbore. Well stimulation generally uses fluids which create or enlarge the flow channels of formation so that it can overcome low permeability of formation. A most common and one of the most successful well stimulation is matrix acidizing. In matrix acidizing, acids are injected at matrix pressure below formation fracturing pressure. These acids will react to remove mineral phases that restrict the flow in the formation.

The permeability of formation will be increased either by removing the pore-plugging materials in the formation or by creating new or enlarged flow paths in the rock depending on the formation and acid types. In the formation, acid-removable damage may be present. The right type of acid or combination of acids must be used to remove the damage. Thus, careful acid choice and treatment design are critical for a successful matrix acidizing.

In this project, determination on which combination of acids used are the best in acidizing treatment in term of increasing porosity and permeability to dissolve minerals in sandstone formation is being clarified. Different combinations of acids are used as the first combinations are between formic acid and hydrochloric acid and the second combinations are between hydrochloric acid and fluoboric acid. Apart from that, in each combination of different acids, the most suitable acid formulations are being obtained. The samples that will be used for experimental works in this project are the sands that came from Pangkor Island.

ACKNOWLEDGEMENT

In the name of Allah, the Most Gracious, the Most Merciful, Praise to Him the Almighthy that His blessing and guidance in giving me strength, courage, patience, and perseverance to endure this two semesters for Final Year Project.

Special thanks to my Final Year Project supervisor, A.P. Aung Kyaw who becomes the most important person to teach and guide me in conducting the project. His strong support and willingness to share the knowledge and expertise has given me a very important experience in this project study.

In this opportunity, I would like to thank friends and lab assistants who helped me to complete the project especially in conducting the laboratory work. I really appreciate their help and the sharing of information in order for me to gain good result during the experiment.

Last but not least, deepest gratitude to my family and friends in UTP for their continuous support and encouragement which enabled me to do my best for this project. I hope after this project completion, all the findings and knowledge that I shared through this project report can be useful for everyone in the study field.

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ABBREVIATION AND NOMENCLATURE

$(CH_3)_2CO$	: Acetone
HCl	: Hydrochloric acid
CH_3COOOH	: Acetic acid
HCOOH	: Formic acid
HF	: Hydrofluoric acid
HBF_4	: Fluoboric acid
K∞I/F	: Initial / Final Permeability
ΦI/F	: Initial / Final Porosity
SEM	: Scanning Electron Micrograph
μm	: Micron meter (x 10^{-6})
UTP	: Universiti Teknologi PETRONAS

INTRODUCTION

1.1 Background of the Project

Matrix acidizing treatments are designed to remove or bypass formation damage by injecting fluids of low pH which is known as acids into the reservoir below fracturing pressure. Matrix acid stimulation is a relatively simple technique that is one of the most cost-effective methods to enhance well productivity and improve hydrocarbon recovery. Compared to hydraulic fracturing, matrix acidizing can be a much simpler, more economical and at times a relatively lower-risk stimulation technique.

For many years, many combination of acids are being used in matrix acidizing were patterned for well stimulation to increase the oil recovery of wells. The use single acid or combination of different type acids such as hydrochloric acid (HCl), hydrofluoric acid (HF), organic acids and acetic acids are being introduced to the oil and gas industry.

The use of different combinations of acids are needed for different type of formation as in sandstone formation, matrix acidizing is used to remove any existing formation damage or to restore the reservoir permeability or the physical properties of the formation itself.

This project highlighted on the best combination of acids in acidizing treatment in term of increasing porosity and permeability to dissolve minerals in sandstone formation using sand sample from Pangkor Island.

1.2 Problem Statement

1.2.1 Problem Identification

It is known that different formation needed different kinds of acids formulation because of the different in physical properties of the formation itself. Traditional acidizing treatment uses combination of hydrochloric acid (HCl) and hydrofluoric acid (HF) cannot be applied to all formations. This combinations of acid which is also known as “mud acid” is only effective for formation which is near to the wellbore as it does not create a deep penetration. In acidizing process, the use of acid which does not react with rapidly with the formation is crucial to create a deep penetration zone during the acidizing treatment. The challenge of this project is to find the best combination of different acid for acidizing for sand samples that were coming from Pangkor Island. Therefore, by doing experimental work, the most suitable acid formulation can be attained.

The success of this treatment depends to a great extend upon proper acid combination selection. Using a suitable or correct acid combination in acidizing treatment is really beneficial as this treatment can be done with a low cost. However, if the selection of acids is wrong, serious damage to the formation will happen as the reaction between the acid and the formation will create a precipitation. This precipitate will cause pore spaces between the rocks of formation to be plugged or clogged that surely will reduce both permeability and porosity of the formations. The use of acid especially a high concentration of acid can cause problems to the tools that are being used during the acidizing as acidizing process causes corrosion. Therefore, proper tools for handling acid during acidizing should be taken in consideration before treatment is started.

1.2.2 Significance of the Project

This project is really significant upon completion of this project. This project can become a reference to the future matrix acidizing treatment so that further studies on matrix acidizing can be done. Besides that, the author will be able enhance his understanding in Petroleum Engineering especially in well stimulation techniques.

1.3 Objective and Scope of Study

1.3.1 Objectives of the Project

There are two main objectives of this project which are:

1. To find the best acid combination for Pangkor sandstone.
2. To determine the porosity and permeability improvement of sandstone formation.

1.3.2 Scope of Study

The completion of this project will help the future engineers to have better understanding on the matrix acidizing for Pangkor sandstone by using different combinations of acids. The engineers who desire to do matrix acidizing in sandstone formation can use the result of this project as a reference and guideline. So, it will be an advantage for them in term of time as they do not have to do the similar acidizing treatment. Thus, they can focus on using different combinations of acids or using the combinations of acids that have been used in this project for their acidizing treatment.

1.4 The Relevancy of the Project

This project will be very relevant judging on certain criteria and circumstances. From above abstract and project background, this project depends solely on experimental works to be analyzed.

During the past decades, implementation of using acidizing treatment as well stimulation technique has increased from time to time. This is due to the beneficial advantages of matrix acidizing.

It is known that different formation will require a different type of acid to be used in the matrix acidizing. By doing this project, the best combination of acids to be used as formulation for acidizing treatment in sandstone formation can be generalized. Using sand sample from Pangkor Island will able present or future researchers to understand more about mineralogy and the effect or dissolution of acids used during acidizing treatment on the sand samples obtained.

Judging from above criteria and circumstances, the development of this project is very relevant.

1.5 Feasibility of the Project within the Scope and Time Frame

The development and completion of the project is feasible judging from its objective and scope of studies stated. The time given to complete the project is approximately 8 months. This project will focus on matrix acidizing in sandstone formation by using sand sample that will be collected from Pangkor Island. Using combination of different acids formulation, the best combination for acidizing treatment can be known.

This project mainly will focus on experimental works. So, in order to complete this project, it is accessible to do the experimental works as most of the project activities will be done in the laboratories at Universiti Teknologi PETRONAS (UTP). All equipments, apparatus and material will be provided by UTP. Thus, it is feasible to complete this project within the time frame. As this project will be focused on experimental work that will be conducted in UTP, proper procedures and precautions steps should be studied before handling equipments, tools, apparatus and materials to ensure accurate result to be collected as well as avoiding unnecessary accidents from happening.

2. LITERATURE REVIEW AND THEORY

2.1 Literature Review

The science of acidizing has its origins over 100 years ago when Herman Frasch of Standard Oil patented the use of hydrochloric acid to stimulate carbonate formations in Lima, Ohio, at Solar Refinery in the year 1896 [1]. However, it was not until the 1930's that attempts we made to improve production from sandstone reservoirs by injecting mixtures of hydrochloric and hydrofluoric acids. These early treatment were not particularly successful, however, and this relegated these HCl/HF mixtures to only occasional use in those wells that were deemed to have suffered drilling mud damage. It was not until the 1960's that treatments containing hydrofluoric acid again saw widespread use in well remediation [2].

Matrix acidizing treatments are designed to remove or bypass formation damage by injecting fluids of low pH into the reservoir below fracturing fracture. In sandstones, the primary objective is to remove any existing formation damage and restore the reservoir permeability (in the near-wellbore region) to its original state or as close as possible [3].

Different acids are use in conventional acidizing treatment such as hydrofluoric acid, hydrochloric acid, acetic acid and much more. Hydrochloric acid is the most common acid used. Organic acids, acetic and formic acid came into use because they are less corrosive than hydrochloric acid. Therefore, their primary benefit is for high-temperature applications [4]. A routinely used fluid for this purpose is mud acid, which is a mixture of hydrofluoric and hydrochloric acids (HF/HCl) that is capable of dissolving most of the common damaging minerals. The side reactions that occur in almost all mud acid treatments, lead to the formation of precipitates. Precipitates will plug the pore spaces and reduce the formation permeability [5].

In spite of widespread use, however, many formations do not respond satisfactorily to conventional HCl/HF treatments. This is normally attributed to rapid spending of HF near the wellbore. Some wells initially show good stimulation but later experience unusually rapid decline in production rate. Such production declines commonly are observed in wells producing from both consolidated and unconsolidated sands. The declines usually are attributed to plugging by migratory clays and other fines [6].

Formation damage or restriction to flow through natural flow paths in the formation can be categorized to three basic types. These are absolute permeability damage, relative permeability changes, and viscosity effects. Absolute permeability damage is that from particulate material occupying all or a portion of the formation pore space. This blockage reduces the permeability and must be moved or bypassed to overcome the effect. Relative permeability changes often result in reduced permeability to the desired producing fluid. This change in relative permeability can occur from oil wetting a water wet hydrocarbon producing formation and/or by the change in fluid saturations. These changes can occur from a previous treatment, workover, etc. Increased fluid viscosity in the formation from emulsions, polymers, etc can result in restricted flow rates [7].

Matrix acidizing is classified based upon rock type to be carbonate and sandstone. Carbonate acidizing is used to dissolve calcite (calcium carbonate and dolomite). Carbonate reservoir rocks are usually classified according to their calcite: dolomite ratio, those with a higher than 50% ratio are typically called limestone. Sandstone acidizing is mainly used to dissolve or remove the wellbore hole damage [8].

The objective of carbonate acidizing is the bypassing of near wellbore damage through the creation of new, highly conductive channels called wormholes. Wormholes effectively act as an infinitely conductive pathway from their tip to the wellbore. Therefore, the longer and deeper penetration of the wormholes, the greater the reduction of the formation skin. Thus, more effective the treatment. Once wormholes are initiated in the rock surrounding the face of the perforation tunnel, it is desirable to extend them into the formation as far as possible. As acid reacts with the pore walls, they get bigger and are able to receive more live acid. The ultimate shape, pattern and length of the wormholes depend on many parameters, including injection rate, type of fluid and temperature [9].

Sandstone acidizing consist of three stages. The first stage is pre flush. The second stage is main flush and the last stage of sandstone acidizing is post flush. Pre flush is to displace the existence salt water and to dissolve carbonates whereas main flush is to dissolve clay, feldspar or any other material near the wellbore are. Lastly, the function of post flush is to displace main flush or also known as mud acid stage [10].

By examining the reasons for the inconsistency of results between successful and unsuccessful application of sandstone matrix acidizing, conclusion has been made [2].

The principal reasons for poor response following acidizing are:

1. Poor candidate selection
2. Lack of mineralogical information
3. Wrong acid design (strength, volume, etc)
4. Use of inappropriate acid additives
5. Insufficient iron control
6. Use of contaminated/dirty fluids or neglecting to pickle tubing string
7. Improper placement of acid (lack of diversion, plugged perforation, etc)
8. Long shut-in time without recovering injected fluids

The six-step process to successful sandstone acidizing is as follows [4]:

1. Determine the presence of acid-removable skin damage
2. Determine appropriate fluids, acid types, concentrations, and treatment volumes
3. Determine proper treatment additive program
4. Determine treatment placement program
5. Ensure proper treatment execution and quality control
6. Evaluate the treatment

2.2 Theory

There are two general categories of acid treatments which are matrix acidizing and fracture acidizing. In matrix acidizing, the acid treatment is injected at matrix pressures, or below fracturing pressure. In fracture acidizing, all or at least a significant portion of the acid treatment is intentionally pumped above formation fracturing pressure.

In fracturing acidizing, etching of sealed fractures also will happen and it will provide a well stimulation which is not only for damage removal. Fracture acidizing treatments are generally confined to carbonate formations. Acid fracturing treatments of carbonates are conducted either to bypass formation damage or to stimulate undamaged formation. This can include vugular and naturally fractured chalks, limestones, and dolomites.

Matrix acidizing is a treatment of a reservoir formation with a stimulation fluid containing a reactive acid. In matrix acidizing, its application is for 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. Theoretically, acid flows through the pore system, dissolving solids and fines entrained in pore throats and pore spaces that impede oil or gas flow whereas in carbonate formation, the acid will dissolves the entire formation and forming conductive channels which is called ‘wormhole’ through the formation rock.

The majority of acid reaction is with pore-plugging or pore-lining solids and minerals. Therefore, in sandstone formations, matrix acidizing has application as a formation damage removal treatment. Generally, a sandstone acidizing treatment only has a chance for success if acid-removable plugging, or formation damage is present. Matrix treatment of an undamaged formation cannot significantly increase production. There are certain exceptions such as naturally fractured reservoirs.

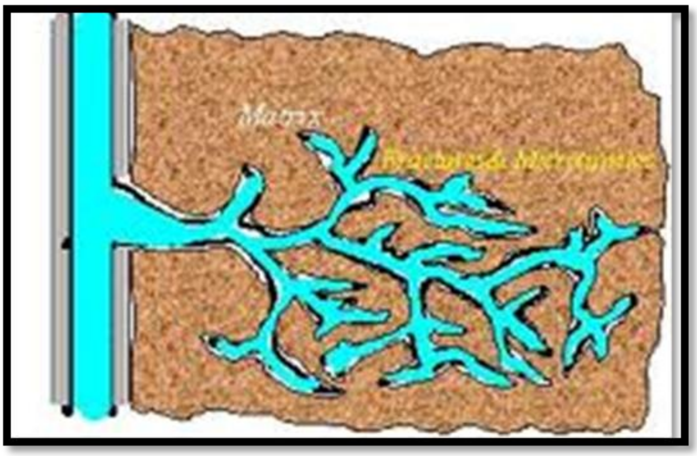

Figure 1: 'Wormhole' created by matrix acidizing in Carbonate Formation

(Source: http://www.yennai.com/acidization.htm)

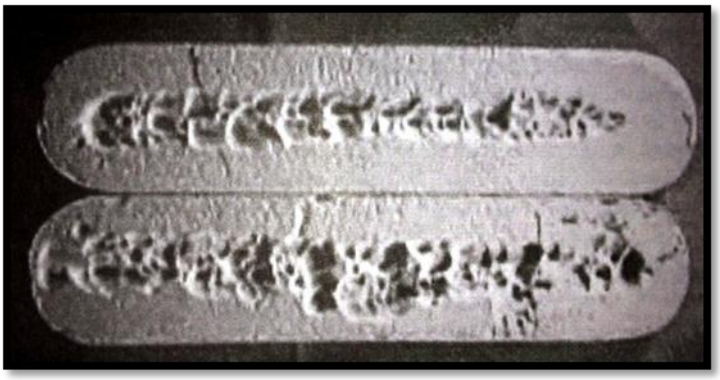

Figure 2: Acid dissolution created in formation

(Source: Kalfayan L, 2000)

Basically, the objectives of matrix acidizing are:

1. To create conductive flow channels through a damaged zone, using acid to reduce skin
2. To increase the formation permeability near the wellbore by restoring fluid flow
3. To allow dissolution of scaling deposits in fractures

In sandstone matrix acidizing, the common acids used are hydrochloric acid, acetic acid, formic acid, and hydrofluoric acid. Hydrofluoric acid is used most commonly in combination with hydrochloric acid. It should never be pumped alone.

It may also be used in combination with the organic acids, acetic acids and formic acids, or in combination with other acids or known as “acid blends” such as acetic-formic, HCl-acetic, and HCl-formic. Other organic acids, such as citric acid or proprietary organic systems, also may be combined with hydrofluoric acid in matrix acidizing treatments of sandstone formations.

3. METHODOLOGY

3.1 Project Planning

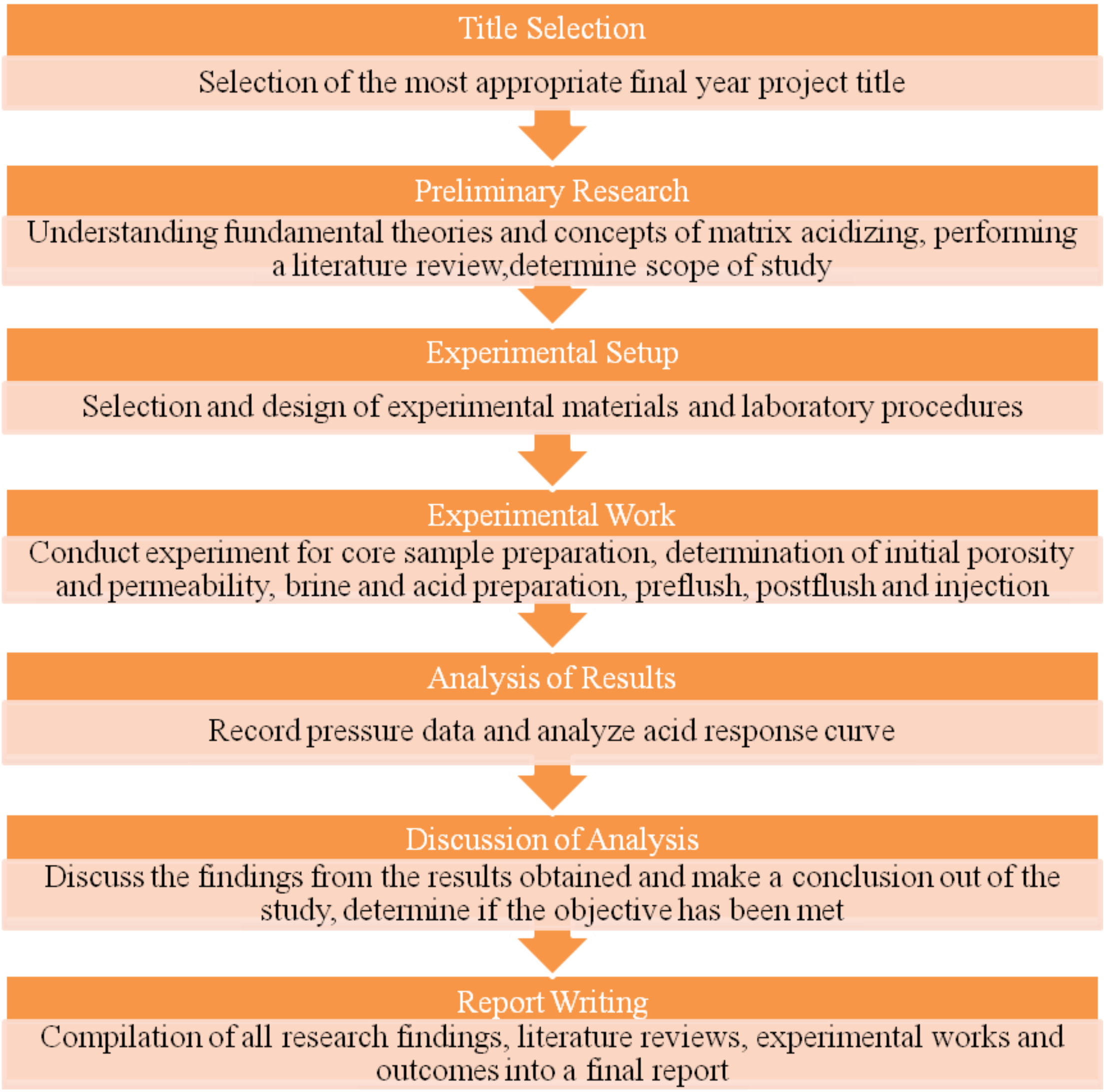

Figure 3: Project Activities Flow

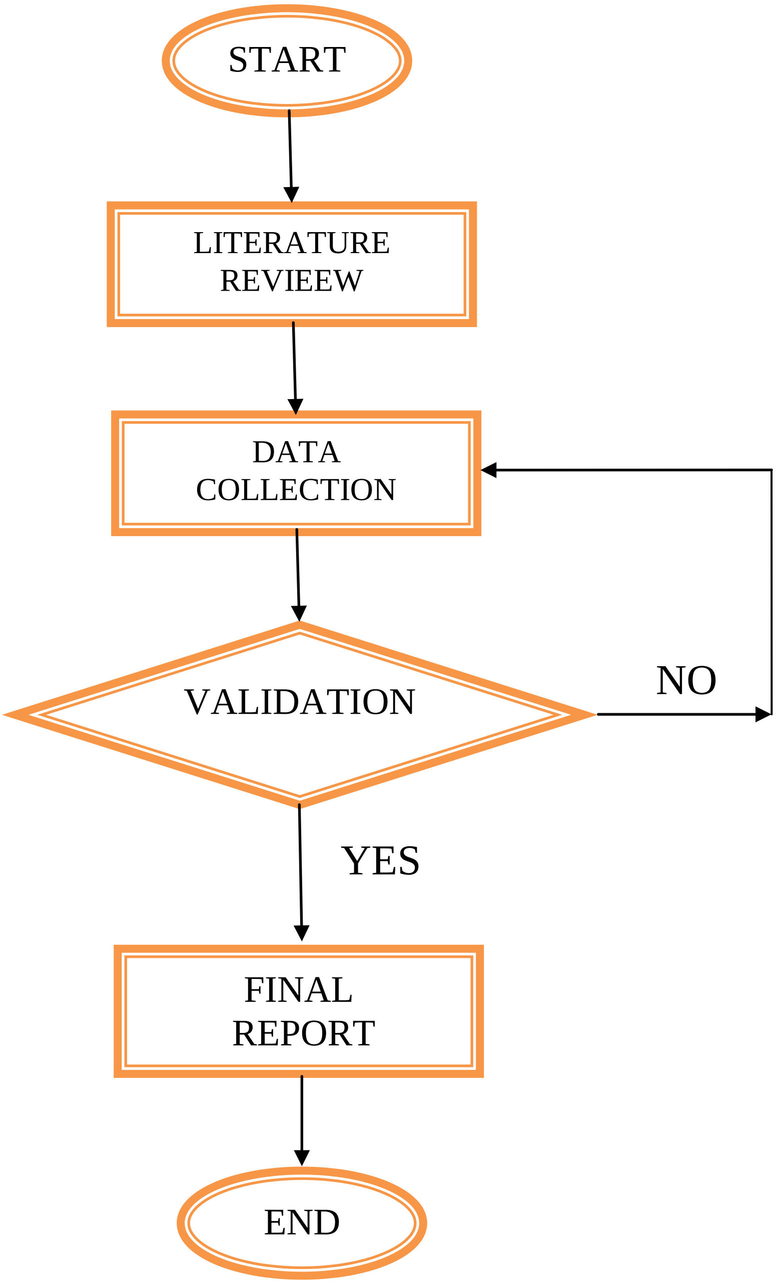

Figure 4: Project Flow Chart

3.2 Research Methodology

After the selection of title for the final year project, some research has been made to fully understand the topic that has been selected and fundamentals knowledge such as the process of acidizing has been covered. As this project is base on laboratory works, selection and design of experimental materials and laboratory procedures were carefully identified.

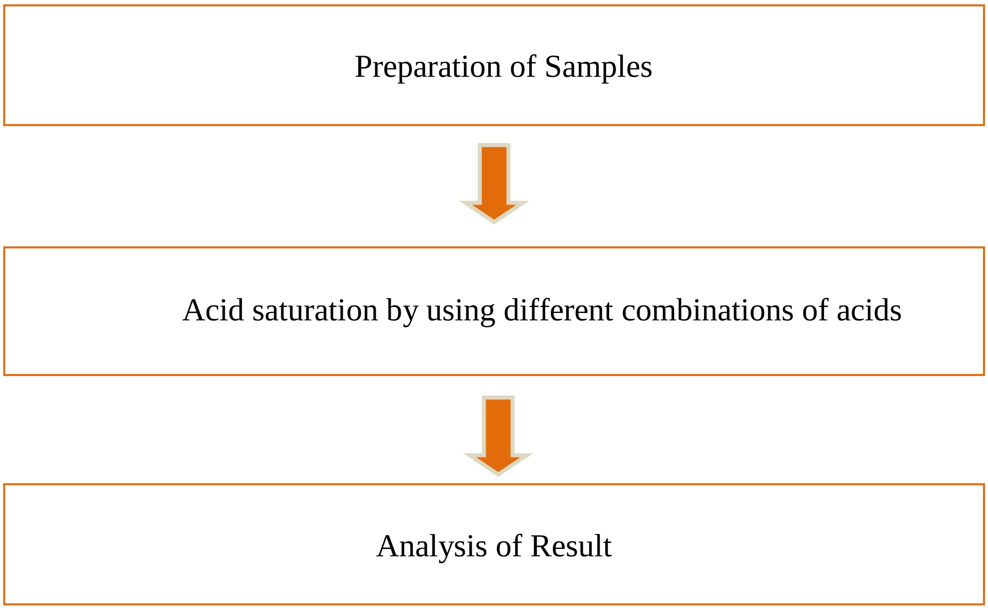

Figure 5: Experimental Procedures

1. Preparation of samples

The first procedure is the preparation of samples. The samples that will be prepared by taking the sand grain from Pangkor Island. Furthermore, the samples were taken from a location which is near to the shore, approximately around 100-150 meters. For a uniform formation, the formation will be dug about a feet deep. The collected sand samples will be washed and dried under the sun.

After that, sieving of these sand samples will be taken place using a sieving unit. By using this sieving unit, different size of sand grains can be collected and if there are contaminants in the samples such sea shells and dried woods, they can be separated from the sand samples. The size of the grain to be chosen that will be used to make core samples depends on the majority of the sand retained at one sieving size. In this case, a sieve size of 0.2μm is used.

Figure 6: Sieving unit

In order for these sand grains to form into core sample, resin and hardener should be mixed together with the sand sample, so that the formation structure can be strengthened. Apart from that, acetone also has been added into the mixture as it will strengthen the bond of the sand grains. Mixing of sand sample with resin and hardener and also acetone was done by using a mortar mixer. Later on, the mixture will be left in a steel molder at a certain period of time. Next, the mixture was cut by using coring device to get the desired size of core sample which is about 1.5 inch.

Figure 7: Mortar mixer

Figure 8: Steel molder

Figure 9: Core samples

After that, the mineralogy of the collected core sample will be determined by using thin section process. Some part of the core samples will be cut and grounded into optically flat which will be put under a microscope to determine the properties of the minerals in the formation.

Next, before proceeding to acidizing treatment, by using POROPERM instrument, initial porosity and permeability of the core samples obtained can be measured. In the acidizing process, the core samples were saturated by using different combination of acids and different acid strength.

Figure 10: POROPERM instrument

2. Acid saturation by using different combinations of acids

The core samples will be saturated with acids for a specific time frame. For acid saturation in this experiment was conducted in two stages. The first one is the preflush. The purpose of preflush is to remove the unwanted minerals such as carbonate in the core sample before the actual acid saturation is conducted. Preflush is conducted by using acid combination of 7.5% hydrochloric acid, HCl + 2.5% acetic acid, CH_3COOOH. The next stage is the mainflush. There were two acid combinations that were used during the mainflush and it can be seen in Table1. Both preflush and mainflush stages should be done in a fume hood to avoid fume to evaporate which will be hazardous. By using desiccators with pump, the process can happen faster as it will cause the core sample to be fully saturated with acid. It should be noted here that using acid will corrode the apparatus or tools when doing this experiment. After the acidizing process of core samples, determination of final permeability and porosity was measured by using POROPERM instrument.

The acid combinations that will be used are listed in the table below:

No	Acids Combination
1.	Hydrofluoric acid, HF + Formic acid, HCOOH
3.	Fluoboric acid, HBF_4 + Hydrochloric acid, HCl

Table 1: Lists of acid combinations for mainflush stage

Figure 11: Desiccators with vacuum pump

3. Analysis of result

After the acid saturation, porosity and permeability of the core sample will be measured. Then, the collected data can be studied and analyzed.

3.3 Activities/ Gantt Chart and Milestone

No	Detail/Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	**Selection of Project Topic:** Performance of different acids for acidizing treatment in sandstone formation with for Pangkor sand	■	■												
2	**Preliminary Research Work:** Research on literatures related to the topic		■	■	■	■									
3	Submission of Preliminary Report						●								
4	Proposal Defense (Oral Presentation)							**Mid Semester Break**	■	■					
5	Project work continues: Further investigation on the project and do modification if necessary										■	■	■		
5	Submission of Interim Draft Report													●	
6	Submission of Interim Report														●

Table 2: Activities Gantt chart for FYP 1

No	Detail/Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Project Work Continues	■	■	■	■	■	■								
2	Submission of Progress Report								●						
3	Project Work Continues								■	■	■	■	■		
4	Pre-SEDEX										●				
5	Submission of Draft Report							**Mid Sem Break**				●			
6	Submission of Dissertation (soft bound)												●		
7	Submission of Technical Paper												●		
8	Oral Presentation													●	
9	Submission of Project Dissertation (Hard Bound)														

Table 3: Activities Gantt chart for FYP 2

3.4 List of Materials

There are six materials that will be used in this project which are:

1. Sand samples from Pangkor Island.
2. Resin and hardener.
3. Acetone, $(CH_3)_2CO$.
4. Hydrochloric acid, HCl.
5. Acetic acid, CH_3COOOH.
6. Formic acid, HCOOH.
7. Hydrofluoric acid, HF.
8. Fluoboric acid, HBF_4.

3.5 List of Apparatus and Equipments

There are several apparatus and equipments that will be used in this project which are:

1. Sieving unit.
2. Grinder.
3. Mortar mixer.
4. Steel molder.
5. Coring device.
6. POROPERM instrument.
7. Desiccators with vacuum pump.

4. RESULT AND DISCUSSION

The aim of this project is to find the best combination of acids in sandstone formation for Pangkor sand. By finding the most effective and appropriate porosity and permeability change before and after acid saturation has been made, the most suitable acid combination can be determined. The expected result is to find the most increase in permeability and porosity of sandstone formation.

All the objectives listed for this project will be achieved by using experimental result from the laboratory works. So, in order to improve the project and experimental result, there are several recommendations that need to be considered which are:

1. The experiment need to be conducted in a proper procedures and tools.
2. Repetition of measurement should be practice to gain more reliable and more accurate result.

Before the mainflush of the acidizing treatment was conducted, all of the core samples will be preflushed by using acid combination of 7.5% hydrochloric acid, HCl + 2.5% acetic acid, CH_3COOOH. Table 4 shows the result for eight samples with respective acid combination used in mainflush. The initial porosity, Φ_i and final porosity, Φ_f are shown below. K_∞ is the corrected permeability that is calculated by POROPERM equipment. The percentage of difference for porosity and permeability were also calculated and shown in Table 4. All the acid combinations involved in the experiment are 3% HF + 9% HCOOH, 1.5 % HF + 8% HCOOH, 2% HF + 10% HCOOH, 1.5% HF + 4.5% HCOOH, 3% HBF_4 + 12% HCl, 3% HBF_4 + 9% HCl, 3% HBF_4 + 12% HCl and 3% HBF_4 + 13.5% HCl. Result on Table 4 are plotted in graph bar in Figure 12. The relationship between acid saturation and the result for both permeability and porosity after the mainflush fluid can be observed clearly. Based on the experimental results, all the samples show increment in porosity. However, only two samples show increment in permeability which are 3% HBF_4 + 12% HCl and 3% HBF_4 + 9% HCl. On the other hand, the other six samples show decrease in permeability.

Core number	Acid formulation	Diameter (mm)	Length (mm)	Initial Porosity, Φi	Final Porosity, Φf	Initial Permeability, K∞I	Final Permeability, K∞F	Change in Φ (%)	Change in K∞ (%)
1	3% HF + 9% HCOOH	37.55	64.72	19.231	28.367	4538.665	3543.994	47.506	-21.915
2	1.5 % HF + 8% HCOOH	37.52	65.27	19.038	28.849	4498.376	3205.381	51.534	-28.744
3	2% HF + 10% HCOOH	37.50	64.67	18.691	24.922	4510.547	3845.168	33.337	-14.752
4	1.5% HF + 4.5% HCOOH	37.45	64.52	20.011	27.068	4522.177	3975.981	35.266	-12.078
5	3% HBF_4 + 12% HCl	37.52	63/07	19.044	22.236	4538.665	4683.539	16.761	3.192
6	3% HBF_4 + 9% HCl	37.54	64.76	18.932	20.396	4500.635	4566.524	7.733	1.464
7	3% HBF_4 + 12% HCl	37.50	64.65	21.029	28.714	4411.211	4129.064	36.545	-6.382
8	3% HBF_4 + 13.5% HCl	37.53	64.71	19.378	19.739	4529.846	3955.899	2.031	-12.670

Table 4: Acid saturation for mainflush result

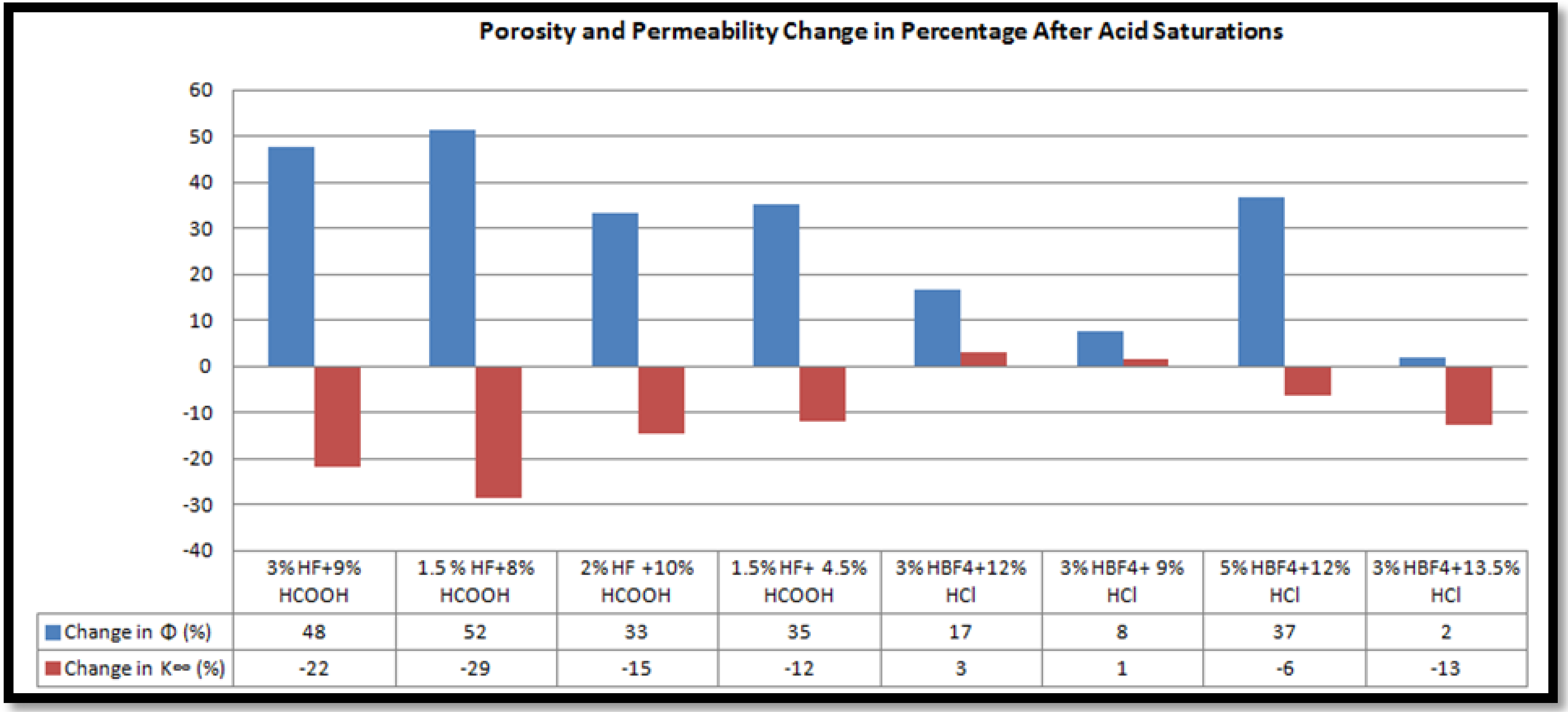

Figure 12: Porosity and permeability change in percentage after acid saturation for mainflush

The initial permeability for the samples is too high. This high value of permeability probably happened due to the human error. During the preparation of samples, the core compression for the entire core probably are different because it was done manually by hand without any appropriate tools. Thus, compression throughout the samples may not be homogeneous. Furthermore, the use of resin and hardener during the preparation of samples to bind the sand grains may not be well compacted and it will result in a lot of pore spaces inside the samples. Thus, it will leave the core samples to have a high value of permeability. By using a Scanning Electron Microscope (SEM) which is an imaging tool, a clear microscopic image of the sample can be captured. Observation from the Figure 13 below shows a clear image of sample which the grains of sand do not pack well in the samples.

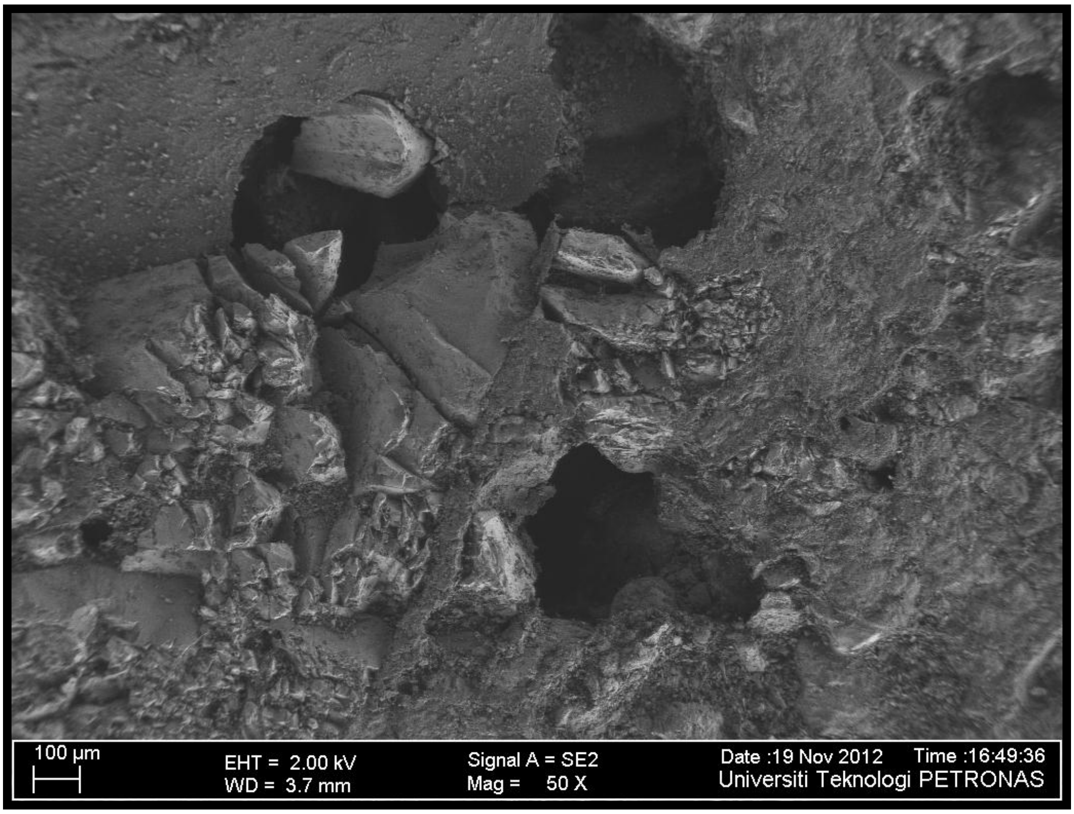

Figure 13: SEM for core sample

From the result of acidizing treatment, the permeability of the most samples show a decrease in permeability. This reduction of permeability is mainly due to formation of precipitate in the sample after the acid saturation. This precipitate probably caused by the use of high concentration of acid during the acid saturation such as hydrochloric acid and fluoboric acid.

Moreover, the other cause for reduction of permeability is the improper use of equipment. Acid saturation was conducted by using desiccators with vacuum pump which will introduce the samples to a vacuum condition. In vacuum condition, acid can penetrate deeper in the samples. However, the use of this type of equipment has a disadvantage as it will create only a static flow. If the precipitate is formed, the precipitate cannot be flushed out from the samples. On the other hand, the use of core flooding equipment by injection of acid from one direction to another will create a dynamic flow where the flow is continuous throughout the experiment. Although the precipitate is formed, it still can be flushed out from the samples due to the dynamic flow. Thus, the use of the core flooding equipment will prevent the reduction of permeability of the samples.

Saturation period for acidizing treatment for both preflush and mainflush may be too long. In the experiment, the saturation time for acid saturation may have been too long especially for high concentration of acid such as hydrochloric acid and fluoboric acid. This will cause a higher probability of precipitate to form. Thus, it will decrease the permeability of the core samples.

5. CONCLUSION AND RECOMMENDATION

As mention before, the project's objective is to find the most suitable acids combination for sandstone formation (Pangkor Sand). By comparing the permeability and porosity improvement of each acids combination after acidizing treatment, we can determine the best acid combination for the sandstone formation which is obtained from Pangkor Island.

From the result collected after the acid saturation, it can be said that acid combination of hydrofluoric acid, HF with formic acid, HCOOH is not good for sandstone formation compared to acid combination of fluoboric acid, HBF_4 with hydrochloric acid, HCl. Moreover, it can be concluded that the acid combination of 3% HBF_4 + 12% HCl is the best acid combination for sandstone formation for Pangkor sand as it will give the highest increment in permeability and a proper increase in porosity. This conclusion may be differ if there is a further study in this project in the future.

Mineral investigation is really important and crucial for this study as it will give us an understanding of the reaction of acid combination used to the mineral of the samples. Unfortunately, the mineralogy of the samples cannot be identified in this project due to the unavailability of the equipment. If the time allocated to complete this project is longer, the mineralogy of the samples can be identified. Mineralogy of the sample can help us understand which mineral component from sand samples dissolve by the particular acid used. If the sample mineralogy is known, the acid combination to be used also can be known.

There are a lot of human errors involved in this project. One of the recommendations to reduce the human error is to use a compressing unit to compress the sand during the preparation of samples. Compression of sand should be uniform and homogeneous throughout the core sample as it will cause the porosity and permeability of core samples to be consistent.

The other recommendation to improve this project is the use of appropriate equipment for acidizing treatment. In this project, acidizing treatment for core samples was done by using a desiccators with vacuum pump. This equipment is not suitable for acidizing treatment as if there is any precipitate formed, it cannot be flushed out from the sample. So, it will cause the final permeability of core samples to be reduced. Thus, by using better or suitable equipment such as core flooding equipment, the final permeability of samples can be greatly improved. Unfortunately, in this project, this suggested equipment cannot be used as the use of high concentration of acid will corrode the materials of the equipment which mainly made of steel.

Furthermore, it is important to include afterflush in acidizing treatment to remove unwanted precipitates in the samples. Conventional afterflush fluid such as combination of 3% ethylene glycol monobutyl ether (EGMBE) with diesel will flush out the precipitates from the samples and will result in an increment in permeability. In this project, the afterflush fluid is unavailable to be used as it will take around 6 months for the afterflush fluid to arrive. If the duration to complete the project is longer, afterflush can be introduced in the acidizing treatment. In the future, in author's opinion, studies about the correct combination for afterflush should be done to be able to identify the best afterflush fluid to remove the remaining precipitates that formed in the samples.

There are still a lot of rooms for improvement in this project. All the procedures used in the experiment for this project is the combination of researches and ideas from the laboratory technologist. The result of this project is hoped to be used by engineers and researchers in the future to understand more about matrix acidizing in sandstone formation as one of the well stimulation techniques to increase hydrocarbon production in a reservoir. Therefore, to conclude, this project is a success.

6. REFERENCES

[1] Frasch H. 'Increasing The Flow of Oil Wells' US Pat 556, 669 (March 17, 1896).

[2] Rae Phil. and Di Lullo G. 'Achieving 100 Percent Success In Acid Stimulation of Sandstone Reservoirs', paper SPE 77808 presented at 2002 SPE Asia Pacific Oil and Gas Conference and Exhibition held in Melbourne, Australia, 8-10 October.

[3] Aboud R., Smith K., Forero L., Kalfayan L. 'Effective Matrix Acidizing in High-Temperature Environments', paper SPE 109818 presented at 2007 SPE Annual Technical Conference and Exhibition held in Anaheim, California, USA, 11-14 November.

[4] Kalfayan L. (2000). An Improved Method for Acidizing Oil Wells in Sandstone Formation.

[5] Ziauddin M., Berndt O., Robert J. 'An Improved Sandstone Acidizing Model: The Importance of Secondary and Tertiary Reactions', paper SPE 54728 presented at 1999 SPE European Formation Damage Conference held in The Hague, The Netherlands, 31 May–1 June.

[6] Thomas R. and Crowe C. 'Matrix Treatment Employs New Acid System for Stimulation and Control of Fines Migration in Sandstone Formations', paper SPE 7566 presented at 1978 SPE Annual Technical Conference and Exhibition held in Houston, USA, 1-3 October.

[7] Coulter G. and Jennings A. 'A Contemporary Approach to Matrix Acidizing', paper SPE 56279 presented at 1997 SPE Annual Technical Conference and Exhibition held in San Antonio, Texas, USA from 5-8 October.

[8] Shedid A. 'An Experimental Approach of Matrix Acidizing of Permeability-Damaged Carbonate Reservoirs' paper SPE 106956 presented at 2007 SPE Europec/EAGE Annual Conference and Exhibition held in London, United Kingdom, 11-14 June.

[9] Filho H., Gabriel E., Junk E., Boucher A., and Baumann C. 'Effective Perforating Design for Matrix Acidizing in Pre-Salt Carbonates' paper SPE 130379 presented at 2010 SPE EUROPEC/EAGE Annual Conference and Exhibition held in Barcelona, Spain from 14-17 June.

[10] J.L Gidley, E. B. (1996). An Improved Method for Acidizing oil Wells in Sandstone Formation.