Sand Control Using Organic Acid Catalysed Resin

by

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14371

Dissertation submitted in partial fulfilment of the requirement for the

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CERTIFICATION OF APPROVAL

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Approved by,

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(Noor Ilyana Bt. Ismail)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

September 2014

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 acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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MOHD FIZDRUL HAQEEM BIN MOHD LETFINUDDIN

ABSTRACT

Recent resin injection for sand consolidation in the oil wells can give up to 600-700 psia of the compressive strength (Wasnik, Mete, & Ghosh, 2005). This would be enough to withstand high pressure from the formations and drilling activities in short period of time. However, resin injection alone is not effective to produce long lasting permanent result. Catalyst need to be added together with the resin injection to enhance the consolidation treatment. Resin injection alone also takes longer period to cure and hardened. Hence, addition of catalyst into the treatment is crucial to reduced curing time. Previous resin treatment on multi layered formation in Peninsular Malaysia has used Hydrochloric acid (HCl) as the catalyst (Keith et al., 2013). Unfortunately, strong acid like Hydrochloric acid cause serious corrosion problems to the equipment. Acetic acid which is an organic acid is chose as the main catalyst for the resin injection treatment. An experiment was conducted to determine the effectiveness of Acetic acid as main catalyst for epoxy resin in formation sand consolidation treatment. Parameters tested were curing time, permeability and compressive strength. The experiment considers whether Acetic acid catalysed resin could give high curing rate, high compressive strength and also better permeability to the consolidated sand. Results obtained for curing test is economical viable as the resin cured in less than 24 hour. Permeability test for organic acid catalysed resin produced good results as 4 of the samples permeability values are in the range of normal formation permeability which is 0-500 md. While, the rest 5 samples recorded values greater than 500 md. For compression test, all samples indicates results of greater than 700 psi which is better than previous uncatalysed resin treatment.

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Sand production is one of the main problems facing by oil and gas industry recently. Usually most of the sand production comes from sandstone formation wells which are unconsolidated. The real challenges of the sand production is it can cause erosion and failure to the flowlines, pumps, separators and many other equipment. High maintenance cost of these equipment could cause to the closure for some oil producing wells. Reduced in oil production also could be happen because of this sand production. The produced sand that enter through perforated production tubing will settle down in the bottom hole of the wellbore which eventually lead to the production reduction. Apart from that, well integrity is also affected due to the sand production. Sand that produced can affect formation stability.

There are several factors of leading to sand production in oil wells. Carlson et al. (1992) stated that, in better cemented rocks, sanding may be induced throughout incidents in the well's production life. For instance, excessively reduced in production rates, fluctuation of reservoir pressure, alteration of gas and liquid ratio, and water influx has becomes the major elements in introducing sanding during oil and gas production. As reaction to this, many solutions had been introduced to eventually reduced the sand production in most oil wells globally. The most popular present methods of controlling sand are based on two principles; bridging of sand grain and consolidation of the sand in-situ (Dewprashad, Abass, Meadows, Weaver, & Bennett, 1993). 'Bridging' of the sand grains could be achieved by using gravel packs, slotted liners, and sand screens techniques. For in-situ sand consolidation, proper plastics (polymers) or other cement based materials were used to attach the sand grains together without great impact in permeability reduction.

However, following the current trend, chemical based formation consolidation are preferable rather than mechanical based consolidations. This is due to economical consideration as mechanical based sand control technique are more expensive compared to polymer injection application. According to Wasnik et al. (2005), one of the advantages of resin consolidation is; it is cheaper as compare to gravel packing and frac packing technique.

Therefore, it is crucial to determine which techniques should be applied and the decision largely depend on the reservoir properties and financial status of the operators. In this research, details of the polymers injection technique used in sand control is studied to come out with better post-treatment result.

1.2 Problem Statement

Currently, the available resins injection for sand consolidation in the oil wells can give up to 600-700 psia of the compressive strength (Wasnik et al., 2005). This probably would be enough to withstand high pressure from the formations and the drilling activities in shorter period. However, to ensure formations sand remained consolidated for longer period of time, the compressive strength of the consolidated sand should be increased. This can prevent from repeating the same treatment as it require huge budgets to run each treatment. Long well shut-in period for sand consolidation treatment also could cause economical loss as production stops. Previous resin treatment usually takes up to 24 hours for the resin to cure.

To overcome those problems, some operators used resin catalysed by Hydrochloric acid for sand consolidation treatment (Keith et al., 2013), but, there are problems related to this method. Externally catalysed Hydrochloric acid could cause corrosion especially to the production tubing. The most straight forward way by bull heading the treatment fluid from surface to formation cannot be done due to stated problem. It need proper ways of fluid conveyance in determining the success of the treatment. Hence, in this project, organic acid is introduced to replace Hydrochloric acid as the catalyst for resin injection. This is due to its less reactive to the metal and more convenient to use.

1.3 Objectives

- To determine the compressive strength of sand consolidation when treated with resin catalysed by Organic Acid
- To determine the curing time of the sand consolidation when treated with resin catalysed by Organic Acid.
- To determine the permeability of the organic acid catalysed resin for sand consolidation treatment
- To compare the treatment results between resin catalysed by organic acid, inorganic acid (Hydrochloric acid), and uncatalysed resin.

1.4 Scope of study

This study focuses on the use of polymer (resins) for sand consolidation in the gas and oil wells. The resins will be treated and catalysed with Organic acid in order to increase compressive strength and also it is expected to reduce hardening time after the placement. The principle is; the resins will be injected into the formations in order to coagulate and bound the sand particles together. The compressive strength and hardening time of the consolidated sand that is injected with catalysed resins and without catalyse will be recorded. The results will be analysed to determine whether the catalyst (Organic Acid) is effective to enhance the parameters stated. The results between catalysed resin by organic acid and catalysed resin by inorganic acid(Hydrochloric acid) also will be compared.

1.5 Relevancy and Feasibility

This project is related the author's field of study since sand control is one of the major subject in Petroleum Engineering field. In project perspective, the author are trying to find an alternative solution to the current available resin injection techniques. The organic acid catalyst was introduced to accommodate the problems related to curing rate and uniaxial compressive strength of the resin consolidated sand. Apart from that, this project also aimed to solve the problem of previous resin catalysed by hydrochloric acid which cause serious corrosion issue after the treatment. Hence, as a Petroleum engineer, the author carried out some experimental work to determine the effectiveness of Acetic acid as a catalyst for sand consolidation treatment.

In addition, this project is feasible by taking into account the time constraint and the capability of final year student with the assistance from the supervisor and coordinator. It is a big hope that the project is accomplished.

CHAPTER 2

LITERATURE REVIEW

2.1 Sand Production

Sand grains in undisturbed reservoirs is held together by friction and cohesion forces between the grains (Saether, 2010). Sand production occurs when the pressure and stresses around the well bore is higher than the formation strength. Then the sand grains will lose the contact and transformed from solid rock to sand. Once the sand is detached, it follows the fluid stream through the perforations and into the well. During its transport along with the fluid stream, the sand grains- and fragments are subjected to effects from gravity and hydrodynamic forces.

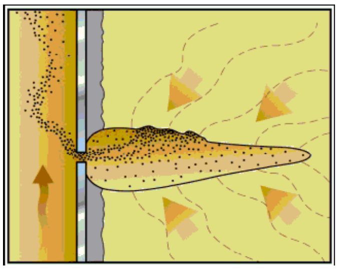


Figure 1: Sand production (Saether, 2010)

2.2 Causes of Sanding

In unconsolidated formations, sand production may be triggered during the first flow of formation fluid due to drag from the fluid or gas turbulence (Carlson et al., 1992). This has caused the sand grains to be detached from the sand rock and being carried to the perforations and thus produced together with the oil and gas in the production flowlines.

Another reason that lead to the sanding is; fluctuations or excessively reduced in production rates. The reduction of the production rates will affect the perforation cavity stability. The inconsistent in production rates will affect the stability of the sand arches. An arch is in curvy shaped and function to interlock the sand grains. This arch is stable at constant flow rate and production rate. Any changes in the production rates will results in collapse of the arch and thus leading to sanding until the new arches formed.

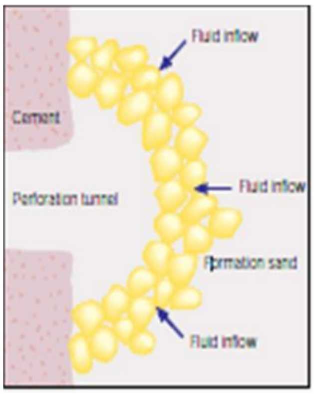


Figure 2: Sand arches (Carlson et al., 1992)

Furthermore, water influx also plays important role in causing the sand production. Water that break through from the surrounding aquifers will reduce capillary pressure between the sand grains (Mcleod, 1997). The sand grains will detached by the effect of flow friction as the results of water contact.

Other than that, perforating activities also could lead to the sand production of the oil and gas formations. Perforation process will alter the permeability of the surrounding perforation cavity's surface. This has weaken the formation especially near to well bore. As a result, this weakened formations may be collapsed and produced sand when the production rates fluctuated.

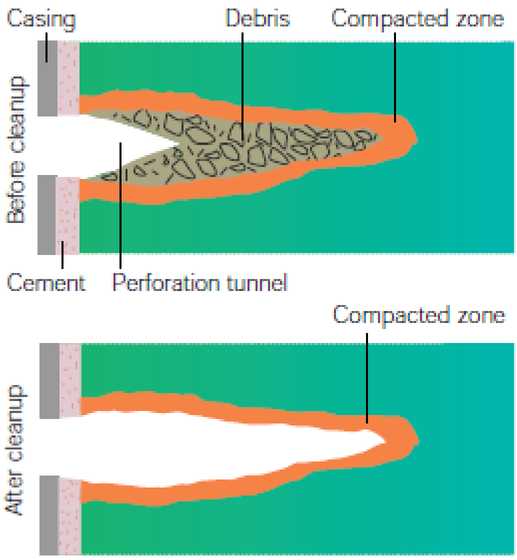


Figure 3: Debris and damage in the perforation tunnel (Carlson et al., 1992)

2.3 Sand Production Categories

2.3.1 Transients

Sand production usually happen during clean up after perforation and acidizing process. At this conditions, sand production will decreases with time at a constant production flow rates.

2.3.2 Continuous

Sand that produced in unconsolidated reservoirs which is not equipped with sand control equipment.

2.3.3 Catastrophic

This is the worst case scenario of the sand production in unconsolidated sandstone formations. Usually, at this sand production category, the large amount of sand produced due to excessive production of reservoir fluids. The differences in hydraulic pressure leading to fluid transport into the well and changes of pressure near the well bore of the formations has caused the instability of the shale, clays, and sandstones. As the shales is exposed to the drilling mud, the cations and anions in the mud filtrate are repelled while the uncharged water is freely contacted to the structure of shale. Thus, it caused the clay to swells and leading to stress build up in the shale. As the result, shale caving and fragmentation formed.

2.4 Effect of Sand production

Production of sand causes many problems. Sand that produced from sandstone formation introduced a number of potentially and costly problems (Waltman, 2010). Most of them are due to economics related. Below are listed several problems related to sand production:

1. Affect functionality of regularity for many equipment such as production flowlines, valves, and separators.
2. Sand that fills and settled down in the separators, storage tanks, and transportation vessel could lead to process problems and this may cause shut downs and operations removal for some oil and gas rig.
3. Loss of production due to too much of sand production would result in shut in wells in order to run the cleaning process in the flowlines.
4. Casing collapse. The sand produced from the sandstones formations will leave an empty space behind the casing (caving). The extra pressure from the drilling process would result in casing collapsing.

2.5 Method of Sand Control

Recently, there are various available methods that being used to control sand production from the formations. Some of these techniques include mechanical, cement packing and gravel packing (Karian, 2000). Most researchers used polymers and plastics like furan resins for sand consolidation treatments (Friedman, 1991a,1999b,1989). Basically, the current techniques of sand consolidations and sand control can be classified into two categories, which are mechanical methods and chemical methods.

2.5.1 Mechanical methods

This type of sand control method require mechanical components and equipment to reduce and prevent the sand from being produced together with formation fluids. The available mechanical methods composed of :

- Gravel packing
- Pre-slotted liners
- Pre-packed screens
- Frac-packing

2.5.2 Chemical methods

Sand control by chemical consolidation involves the process of injecting chemical into the semi consolidated or unconsolidated formation (Wasnik et al., 2005). The chemical used usually comes from resins or polymer liquid resin. Polymers or plastic consolidation is one of the invented technique to control sand production. Generally, as the polymer solution is injected into the formation, it gets either adsorbed or becomes attached to the walls (lahalih & Ghloum, 2010). However, sand consolidation using polymers treatments should consider some requirements to ensure its effectiveness. First is, polymers injection should give and provide sufficient compressive strength to the unconsolidated sand. The other one is, the operators should ensure that the polymers injected into the well does not affect too much on the formation permeability. This is because alteration in permeability will result in loss of reservoir fluid formation.

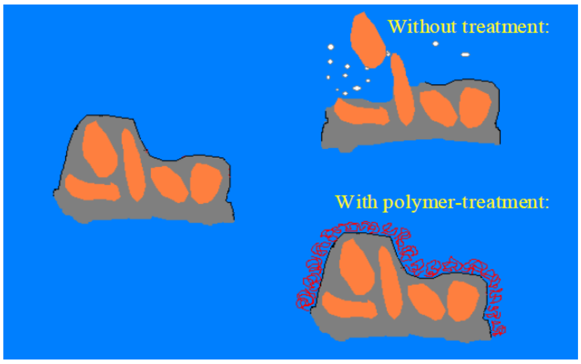


Figure 4: Principle of sand control polymer treatment (Zaitoun & Pichery, 2009)

2.5.2.1 Resin injection

The use of resins for artificial sand consolidation was first mentioned in 1947 and from the 1960's onwards, sand consolidation gained in popularity as an alternative to gravel packing (Fader, Surles, Shotts, & Littlefield, 1992). Resin injection are broadly used as the sand consolidation technique in order to mitigate and reduced sand production from an unconsolidated sand stones formations. The resins functioned by coating the sand grains which is then followed by an over flushed to enhance permeability. Few hours after the treatments, resins injected will harden and thus forming permeable consolidated sandstones. Basically, the main objectives of resins injection is to enhance compressive strength of the formation especially in well bore surrounding area. As consequence, sand grains will not be detached although in fluctuations production rates condition.

2.5.2.2 Resins can be divided into two categories:

2.5.2.2.1 Thermosetting resins

Generally, thermosetting resins are a type of resin which can transform irreversibly under heat influences from a fusible and soluble material into infusible and insoluble through formation of a covalently cross-linked thermally stable network. Relatively, thermosetting usually contains low molecular weight which is about less than 10000 daltons. Curing process has chemically transform the chains into a molecule by cross-links. Effect of heating, chemical reaction and under severe conditions can intently break the chemical bonds between the chains. The most popular thermosetting resins available recently are formaldehyde condensation products with phenol (phenolic resin) or with urea or melamine (amino resins). Besides, polyester resins are epoxy resins are broadly used for surface coating and many other functions. Thermosetting resins are chemically stable for indefinite time over a wide range of temperature, inert to wellbore fluids, rocks and greens to the environment.

2.5.2.2.2 Thermoplastic resins

Thermoplastic resins are a type of resins which can soften and flow as it is introduced to heat and pressure, the changes is reversible. It consists of monomers building blocks which linked up chains with high molecular weight, approximately more than 10000 daltons. Cohesion force of the polymer matrix is provided through physical bonds between the chains. However, by heating and dissolving the chains, the physical bonds can easily broken. Polyethylene, polypropylene and polystyrene are several examples of available thermoplastic resins.

2.5.2.3 Resin Treatment Advantages

- Unneeded the use of sand gravel which could limit the reservoir fluid production.
- Unneeded of internal screen when comes to resin consolidation, thus eliminate mechanical risks associated to screen placement.
- Treatment can be done only through existing tubing or coiled tubing.
- Treatment is cheaper as compared to gravel packing and frac packing techniques.
- Treatment is effective in fine sand, which are complicated to control using gravel packing.
- Increase compressive strength of the formation while retaining 60-90% of the original permeability.
- Yield approximately 90% or even more than the original productivity.

2.5.2.4 Epoxy resin

Epoxy resins, which is also known as polyepoxides are a class of reactive prepolymers and polymers which contain epoxide functional group. It is a common name for a type of strong adhesive used for sticking things together and covering surfaces. Epoxy resins reacted by cross-linked either with themselves through catalytic homopolymerisation, or with a wide range of co-reactants including polyfunctional amines, acids, phenols, alcohol, and thiols. Reaction of polyepoxides with themselves or with polyfunctional hardeners forms a thermosetting polymer, often with strong mechanical properties as well as high temperature and chemical resistance. Curing of epoxy resins referred reaction of the linear epoxy resin with suitable curatives to form 3D cross-linked thermoset structures. Curing may be achieved by reacting an epoxy itself (homopolymerisation) or by forming a copolymer with functional curatives or hardeners (Pascault et al., 2002). Basically, any molecule containing reactive hydrogen may react with epoxide groups of the epoxy resin. Epoxy curing reaction may be accelerated by addition of small quantities of accelerators. tertiary amine, carboxylic acids and alcohols are effective accelerators.

2.5.2.5 Catalyst

The word catalyst can be described as the substance used to increase in the rate of chemical reaction of one or more reactants due to participation of an additional substance under the process called 'Catalysis'. In this project perspective, the action of catalyst is needed to enhance the performance of the resin injection for sand consolidation purpose. Suitable catalyst are needed to increase the mechanical strength of the consolidated formation and control the curing or solidification time depending on the various downhole temperature. For low temperature application, a strong organic acid is used, while for high temperature applications, a weak organic acid is used (Fader et al., 1992). By this injection of catalyst together with resin, the rate of polymerization of the chemical reaction system can be adjusted ranging from few minutes up to few hours depends on amount of catalyst injected. The injected catalysed resin are also expected to produce great result as compared to non catalysed resin injection. Therefore, experimental procedures must be conducted to determine whether catalyst added up together with resin injection can boost up the compressive strength or not.

2.5.2.6 Organic acid

Organic acid defined as organic compounds with acidic properties. Generally, organic acid is a weak acid and do not dissolve completely in water as compared to strong mineral acids(inorganic acids). In oil and gas industry, simple organic acids such as acetic or formic acids are widely used for oil and gas well stimulation treatments. This is due to its less reaction to metal as compared to strong inorganic acids likes sulphuric and hydrochloric acid. Keith et al. (2013) in their research has used Hydrochloric acid (inorganic) as the catalyst in resin injection for well consolidation treatment. Although the treatment was successful, the placement or conveying method became their main problem in this treatment. Externally catalyzed resin would cause corrosion especially to the production tubing. Based on this, organic acids are used at high temperature conditions or when it need longer contact time between the pipes and acids. This usually happen when acids need to be injected into greater depth of reservoirs. In this project, organic acid is going to be used as reaction catalyst to furan resin for formation consolidation treatment. The function is to enhance the curing period of the resin's treatment and also provides extra compressive strength to the consolidated formations. As described earlier, in some cases organic acid is used as external catalyst to regulate the curing temperature of the resin's consolidation treatment.

2.5.2.7 Acetic acid

Among the available organic acids, Acetic acid was chosen as the catalyst in the resin injection for formation consolidation treatment. Acetic acid, containing the group CH_3COOH. This type of acid can be thought of as ethanoic acid and it gives vinegar with sour taste and pungent smell. It is relatively considered as weak acid and partially dissociated acid in an aqueous solution. Acetic acid is one of the simplest carboxylic acid. They are usually colourless and non oxidizing which means more convenient to use. In industry, Acetic acid broadly used in many applications and one of them as for catalyst reaction. In easiest way, general acid catalysis means all species capable of donating protons contribute to reaction rate acceleration. With carbonyl compounds such as esters, synthesis and hydrolysis go through a tetrahedral transition state, where central carbon has an oxygen, an alcohol group, and the original alkyl group. Acids can generally protonate the carbonyl, which makes the oxygen positively charged (Röper et al., 2000). This has make it easy in receiving double bond electron when the alcohol attacks the carbonyl carbon. This enables ester synthesis and hydrolysis. The reaction is an equilibrium between the ester and its cleavage to carboxylic acid and alcohol; **acid + alcohol** **ester + water**. Generally, the main objective of acid catalyst in resin system is to accelerate the condensation reaction of resin treatment and thus increase the cure rate. Organic acid such as Acetic acid could act as cross-linkers for polymeric material including resin. Besides, Acetic acid can also act as cross-linker on the compressive strength of actual solid cores (lahalih & Ghloum, 2010). Since the proppant samples is from bank sand, it may contains fine particles of sea shells which is carbonate material. The heated and oxidized carbonate materials during thermal reclamation will convert carbonates to water soluble and very alkaline lime, or calcium oxide (CaO). The presence of lime in the sand must be neutralized by the acid catalyst before it can start to cure the resin. Acetic acid was chosen due to its catalytic strength, reliability, availability and cost effective compared to other organic acids.

2.5.2.8 Resin Curing

"Cross-linking" or "curing" is the process that changes liquid formed resins into 3D solid network. Building blocks that consists of small monomer or oligomer molecules aggregating into clusters are called 'cross-linking' process. The clusters will then continue to aggregate and becoming larger until a network is formed that spans the reacting mass. Viscosity can be seen increasing during clusters build-up due to extension of Stoke's law for velocity which when clusters size increase, clusters movement slowly becomes restricted (Wasnik et al., 2005). The cluster network will span the reacting mass and any movement in large quantity is restricted at the so-called gel point. At the gel time, viscosity of the fields will drops asymptotically to infinity. Before this to be happens, the system need to be in target well bore as fluid cannot be squeezed after this stage. Until the gel time, the viscosity will remain constant. Resin curing rate or solidification time plays important role in determining the success of formation consolidation treatment. Basically, temperature and catalyst are the two parameters which dominantly determine the curing rate of the treatment. Presence of catalyst could reduce eventually half of the actual curing time. In some cases, it would take up to 7 days to fully cure the injected resins at 70^{o} F reservoir temperature. Villesca et al. (2010) recommended that addition of catalyst only for wells with bottom hole temperature 160^{0}F of below. This to prevent from any premature curing occur during resin consolidation treatment. Other than that, integrity of the consolidated formation could be affected due to presence of catalyst for resins injection at higher reservoir temperature. $Al_{z(}(SO_4)_3$, $AlCl_{3,}$ and NH_4Cl are examples of lewis acid catalysts that enhance ionic polymerization.

CHAPTER 3

METHODOLOGY

For FYP I, the method and the project flow process consists of preliminary study and pre experimental work.

3.1 Preliminary Studies

In this section, it focuses on understanding the project fundamental and theories. Preliminary studies have been highlighted in project planning and literature review. It includes study on the type of resin and possible catalyst that can be used in the experiment. Journals and articles related to the study subject would be really helpful to get clear view about the project. The main objectives of this research project are to determine the compressive strength and the curing time of the formation when treated with catalysed resin. The result will be compared with the resin catalysed by Hydrochloric acid treatment.

3.2 Pre experimental studies

In this part, catalysed resin experiment is prepared. Below are the list of parameters required for the experiment.

- Sand sizes : ranges from 212 - 600 microns
- Source of sand : Pantai Teluk Batik, Lumut, Perak
- Resin : Epo Thin Epoxy Resin
- Hardener : Epo Thin Epoxy Hardener
- Amount of resin : 10%, 20%, 30%
- Brine water (3% KCl) : 420 ml
- Type of catalyst: 2 Mole of Acetic acid and Hydrochloric acid
- Amount of acid catalyst : (1/5) of the resin concentration
- Amount of sand : 420.4 gram per pack
- Equipment required : Rock permeability machine, Uniaxial compression machine, sand mould, Sand screening machine
- Curing period (H)

- Curing temperature (^{o}C)
- Permeability (md)

3.3 Experimental flow process:

1. Proppant consolidation treatment
2. Permeability test
3. Compressive strength test : Uniaxial compressive strength Triaxial Compression test
4. Curing period test : Oven (temperature constant @70^{o} C)

3.4 Experimental Designs (for FYP II)

3.4.1 Test cores preparation

To conduct the experiment, sand sample is first being collected from coastal beaches near Lumut. The reason of sand collected around that area is because the beach sand properties are similar with sandstone reservoirs in offshore fields. This sand samples is going to be used as man-made proppant to prepare the proppant pack. A flow cell is a type of equipment that widely used in preparing the proppant pack.

Figure 5: Sand samples taken from Pantai Teluk Batik, Lumut

3.4.2 Experiment Procedures

Sand samples near Teluk Batik beach was first collected and screened. Sand size of 212-600 microns being weighted at 420.4 g for each samples. The sand is saturated with 420 ml completion brine (3% KCl) as pre-flush treatment to enhance sand consolidation. Then, sand was mixed with resin and 2 Mole acid for 10%, 20%, and 30% resin concentration ratio to sand weight. For instance, at 10% resin concentration, 1/10 of the total sand weight is the amount of resin used. Acid catalyst amount will be 1/5 of the resin amount, and hardener is 2/5 of the resin amount. The procedures were repeated for 20% and 30% resin concentration. A custom made mould with inside diameter of 55 mm and length of 110 mm was used in preparing sand core samples. Prior to this, the grease was first put on the interior wall of mould to prevent the cured samples stuck inside the mould. As the mould was vertically positioned, the mixture of sand, resin, and acid was slowly poured into the mould while the mould was slightly tamped to enhance packing of the sand grains. The packed sand cores was then placed in an oven for curing at 70^{o}c. The curing duration for each samples was recorded. Cured sand cores were then undergoes permeability and compression strength test.

3.4.3 Calculations

3.4.3.1 Resin, Hardener and acid concentration

Sand amount : 420.4 gram

1. - For 10% resin concentration:
   0.1×420.4 g = 42.04 g (resin amount)
   - Hardener : 2/5 of the resin amount
   $2/5 \times 42.04$ g = 16.816 g (hardener amount)
   - Acid (Hydrochloric / Acetic) : 1/5 of the resin amount
   $1/5 \times 42.04 = 8.408$ g (Acid amount)

2. -For 20% resin concentration:
   0.2×420.4 g = 84.04 g (resin amount)
   -Hardener : 2/5 of the resin amount
   $2/5 \times 84.04$ g = 33.63 g (hardener amount)
   -Acid (Hydrocholric / Acetic) : 1/5 of the resin amount
   $1/5 \times 84.04$ g = 16.82 g (Acid amount)

3. -For 30% resin concentration:
   0.3×420.4 g = 126.12 g (resin amount)
   -Hardener : 2/5 of the resin amount
   $2/5 \times 126.12$ g = 50.45 g (hardener amount)
   -Acid (Hydrocholric / Acetic) : 1/5 of the resin amount
   $1/5 \times 126.12$ g = 25.224 g (Acid amount)

3.4.3.2 Permeability

For the permeability test, the data obtained from Rock Permeability machine will be put inside the Darcy equation in order to determine the permeability of the sand core samples. The machine provides the pressure to run the test (ΔP). For the permeability test, the initial pressure recorded at 1000 kPa. The flow rate (m^3/s) of the water flowing inside the core can be obtained from the volume of water collected divided by test time. For the other parameters, the values are as follows:

Core Area : 0.00238 m^2

(ΔP) : 1000 kPa

μ (water) : 8.9×10^{-4} Pa.s

Core Length : 0.11 m

Test time : 5 min

After running the test, the permeability can be calculated through following Darcy's equation:

Darcy Equation:

$$Q\ (m3/s) = \frac{k\ A\ \Delta\ P}{\mu\ L}$$

From the Darcy's equation, the value of permeability (k) obtained is in (m^2). Then, it needed to be converted into Darcy using conversion factor of 1 Darcy = $9.86923 \times 10^{-13}\ m^2$.

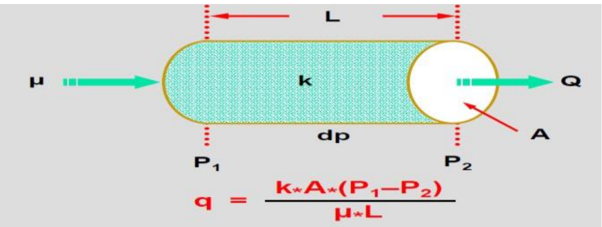
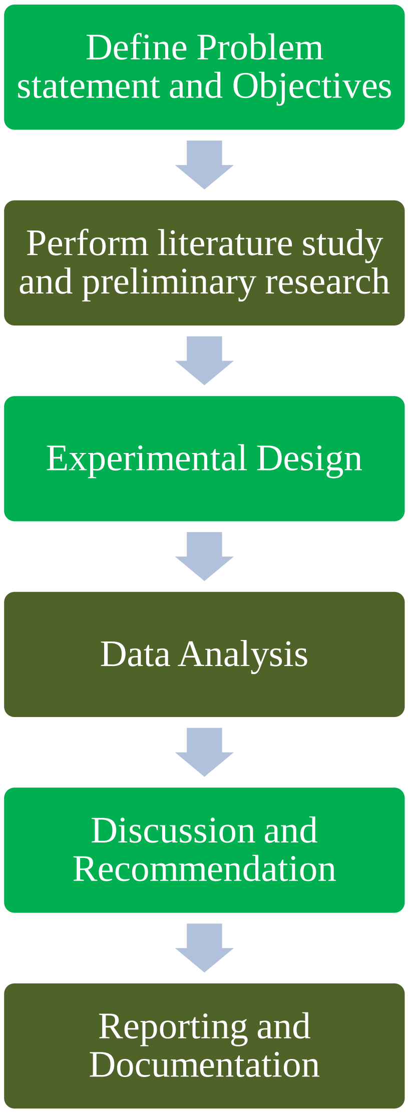
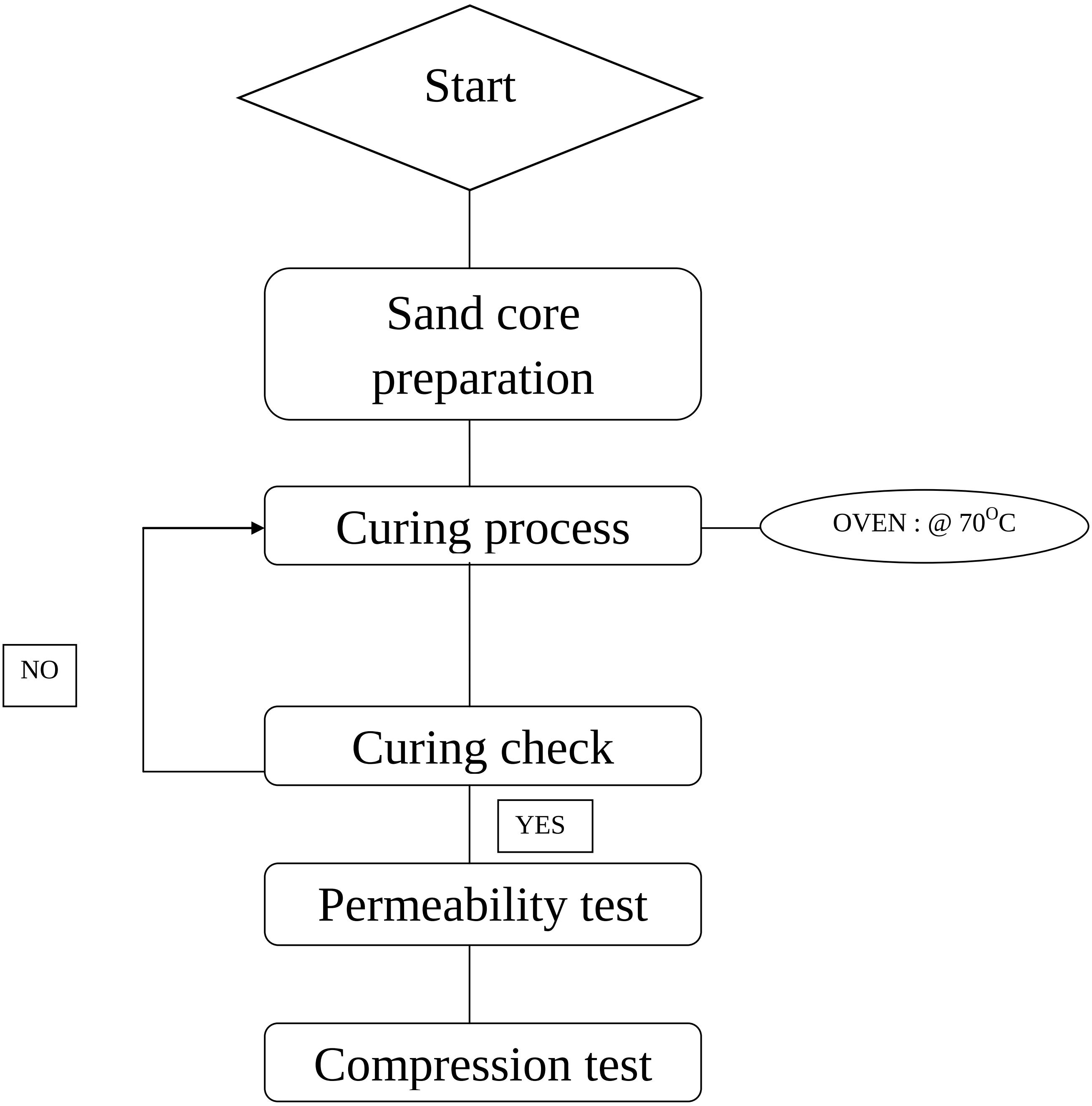


Figure 6 : Permeability calculation

3.5 Research Methodology and Project Activities



3.6 Experiment Flow Chart



Activities in FYP 1	week													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Project title selection and meeting with FYP supervisor	■	■	■ ●											
Study the factors of sand production				■	■									
Analyse the available methods of sand control				■	■									
Study resin consolidation treatment for sand control application					■	■	■							
Draft the methodology of the project					■	■	■							
Extended proposal submission								■ ●						
Proposal defence									■ ●					
Write abstract and expected results										■	■	■		
Submission of interim draft report													■ ●	
Submission of final interim report														■ ●

Legend	
■	Project section timeline
●	Project milestones (important weeks)

Figure 7: Project Gantt Chart and key milestones for FYP I

Activities in FYP II	week															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Project work commences	■	■	■	■	■	■	■	■	■	■	■					
Briefing and update on FYP II progress		■														
Chemicals Preparation		■	■	■												
Lab booking and registration				■	■											
Equipment Preparation : custom made the Sand Pack					■	■										
Submission of Progress Report							●									
Result Analysis							■	■	■							
Pre-SEDEX/ Poster Exhibition									●							
Submission of Final draft/ Technical paper												●				
SEDEX 33												●				
Final oral presentation/ Viva														●		
Submission of hardbound copies																●

Figure 8: Project Gantt chart and key milestones for FYP II

Legend	
■	Project section timeline
●	Project milestones (important weeks)

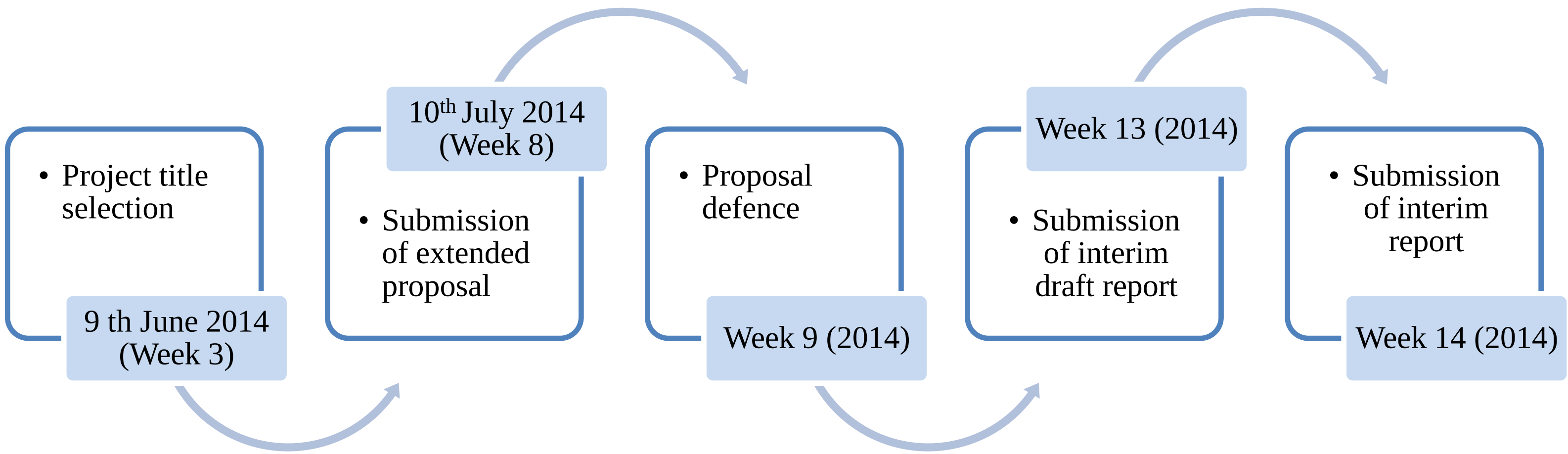


Figure 9: Important dates for FYP I

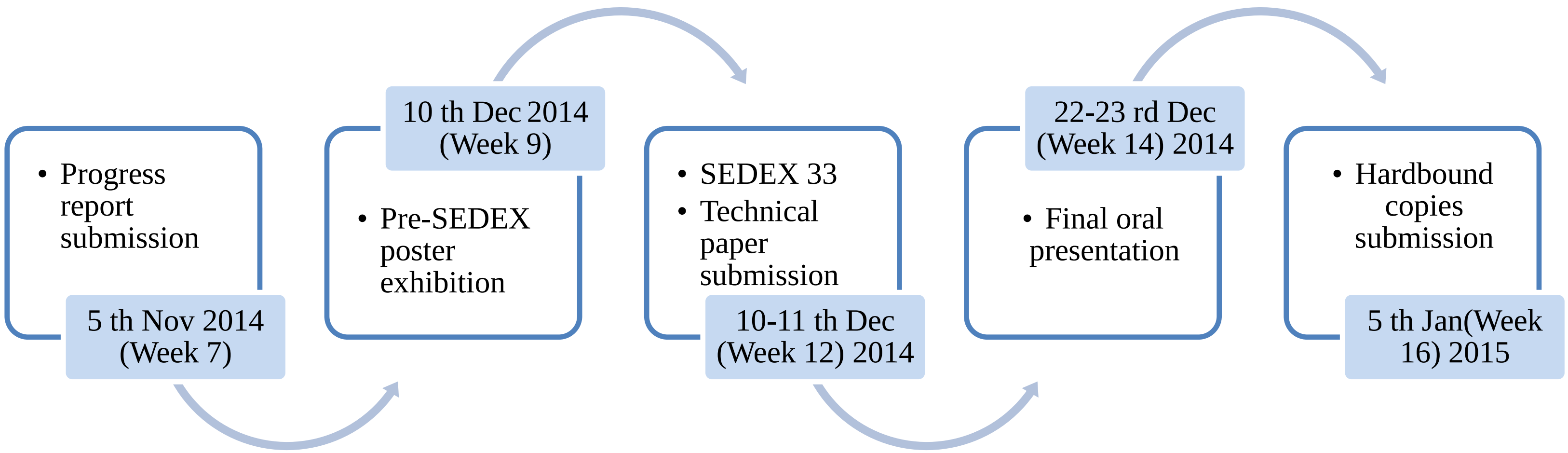


Figure 10: Important Dates for FYP II

3.7 Tools Required

1. Mould: Sand pack preparation
2. Uniaxial compression machine
3. Rock permeability machine
4. Sand screening machine

	
Figure 11: Custom made Sand mould (size: 55mm×110mm)	Figure 12: Uniaxial compression machine

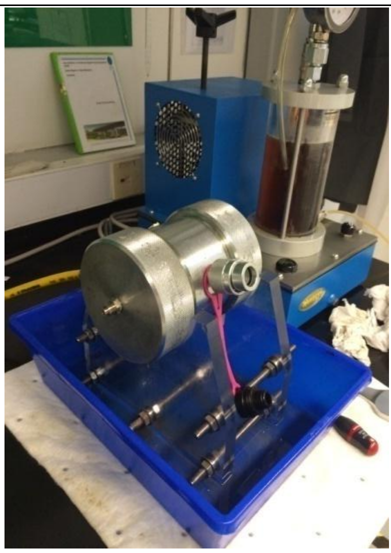



Figure 13: Rock permeability machine	Figure 14: Sand screening machine

*Noted that all of the equipment are taken from UTP Geosciences lab at block 14 and 15.

CHAPTER 4

RESULTS & DISCUSSIONS

4.1 Curing Time

Table 1: Curing time vs. Resin concentration

Type of resin	Resin concentration (%)	Curing time (Hour)
Uncatalyzed Resin	10	9
	20	15
	30	20
Resin + Acetic acid	10	7
	20	13.5
	30	16
Resin + HCL	10	5
	20	11
	30	14

Based on the table(1) and figure(16) , it is clear that amount of injected resin is proportional to the curing and hardening period. As the resin concentrations increase, the longer it takes for the resin coated sand to cure. For each resin concentration, addition of acids catalyst had reduced the curing period of the sand samples. However, Hydrochloric acid catalysed resin gives quite shorter period for the samples to cure as compared to Acetic acid catalysed resin. This is due to Hydrochloric acid is stronger acid as compared to Acetic acid. Catalytic reaction is much effective in stronger acid. (Van Rhijn, De Vos, Sels, & Bossaert, 1998)

Figure 15: Resin coated sand

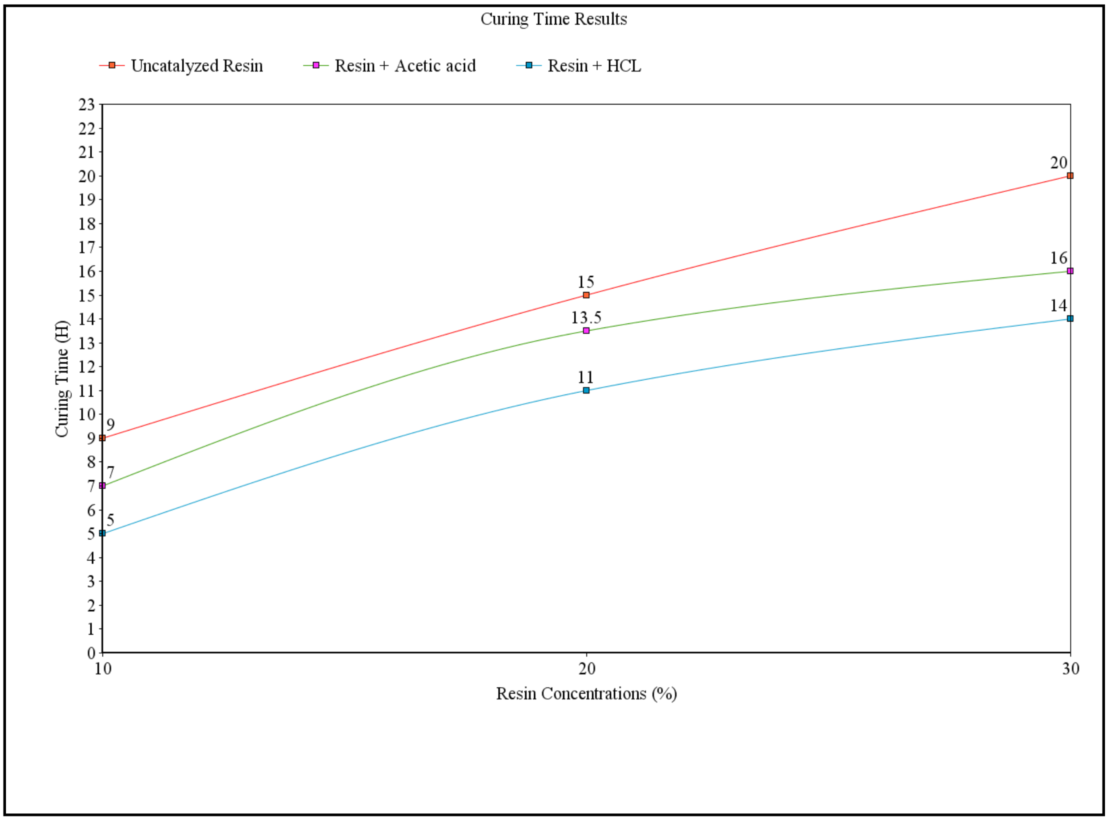


Figure 16: Curing time results

4.2 Permeability

Table 2: Permeability vs. Resin concentration

Type of resin	Resin concentration (%)	Permeability (md)
Uncatalyzed Resin	10	434
	20	255
	30	237
Resin + Acetic acid	10	542
	20	510
	30	474
Resin + HCL	10	866
	20	818
	30	773

Table (2) and figure (17) shows the summary of permeability of resin coated sand with different types of catalyst and resin concentration. It can be seen that the resin concentration is inversely proportional to the permeability values of the resin-coated sand. As the resin concentration increase, the permeability values decrease. This is because the cross-linked formed between the grains increased as the resin concentration increase and this will thus reduced the permeability of the fluid to flow. It was observed that both Hydrochloric acid and Acetic were good enough to permit the fluid flows. Hydrochloric acid shows better permeability with 10% resin results in 434 md, 20% resin concentration for 818 md, and 30% resin concentration for 773 md. While, Acetic acid gives 542, 510, and 474 md for 10%, 20%, and 30% resin concentrations. Since normal range of acceptable permeability is 0-500 md, and the difference was not too much from Hydrochloric acid catalysed resin, Acetic acid is considerable to replace Hcl for resin catalyst in real well scenario.

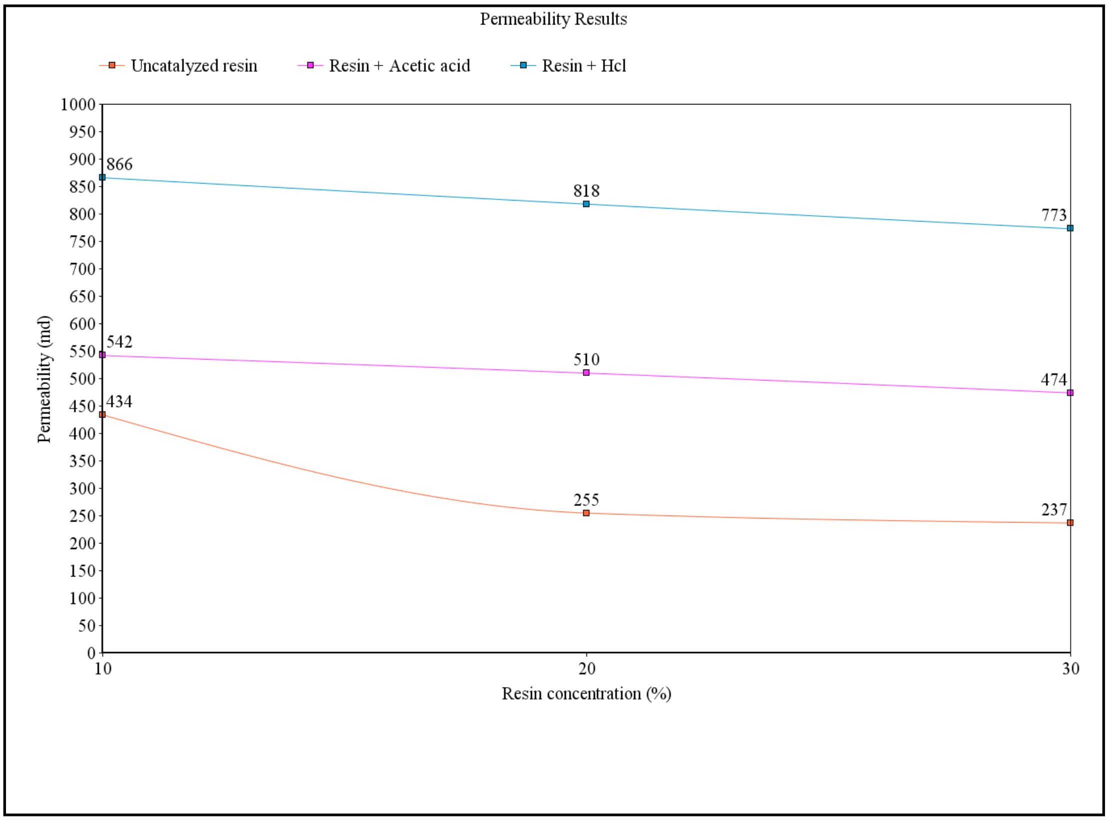


Figure 17 : Permeability results

4.3 Compressive Strength

Table 3: Compressive strength vs. Resin concentration

Type of resin	Resin concentration (%)	Compressive Strength (Psi)
Uncatalyzed Resin	10	1358.11
	20	1406.90
	30	1493.90
Resin + Acetic acid	10	1482.28
	20	1662.13
	30	1972.51
Resin + HCL	10	1914.49
	20	2432.28
	30	2494.65

Table (3) shows relationship between resin concentration for each type of resin with the compressive strength of the sand core samples. Compressive strength test on the sand core samples found that HCl catalysed resin gives higher strength than Acetic acid catalysed resin with 1914.50 psi, 2432.28 psi, 2494.65 psi for each 10%, 20%, and 30% of resin concentration. While, for Acetic acid acid catalysed resin, it shows 1482.28 psi, 1662.13 psi, 1972.51 psi for 10%, 20%, and 30% resin concentrations. Dewprashad et al. (1998) stated that from SEM micrograph, it was observed that as the resin concentration increase, it will thus increase in areas and numbers of contact points between grains. Hence, the higher of resin concentration, the stronger grain-to-grain bond of the sand will be. Although, HCl catalyst is much better in strength, but Acetic acid catalysed resin could also produce long lasting result and bear with high formation pressure since Wasnik et.al (2005) stated that previous resin injection treatment results in 600-700 psi compressive strength.

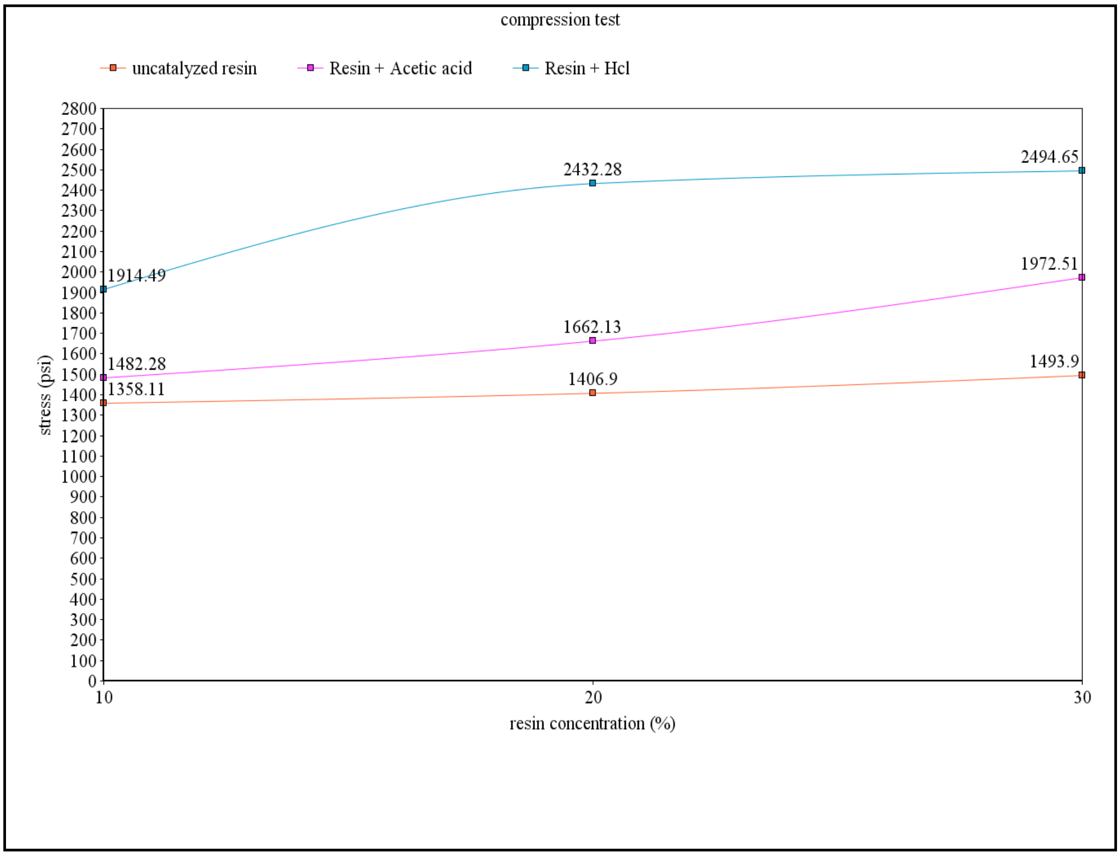


Figure 18: Compressive strength results

4.4 Permeability vs. Compressive strength

Figure (19),(20,(21) summarized the relationship between permeability and compressive strength of the core samples. It can be seen that for different type of catalyst and resin concentrations, permeability value is inversely proportional to the compressive strength of the sand core samples. As the resin concentration increase, the permeability of the resin core samples decrease. This is because, the increase in grain-to-grain bonds as results of increasing in resin concentrations caused reduced in permeability to fluid flow. For Acetic acid catalysed resin, 10% resin concentration does not give much difference between permeability and core samples compressive strength. However, for increasing in resin concentrations, there is major drop in permeability as the compressive strength increased. The same situation occurs for the Hydrochloric acid catalysed resin. At initial resin concentration, permeability and compressive strength still in tolerance mode, but, as the resin concentration increase, it is obviously be seen that increase in compressive strength results in major drop in permeability values of the sand core samples.

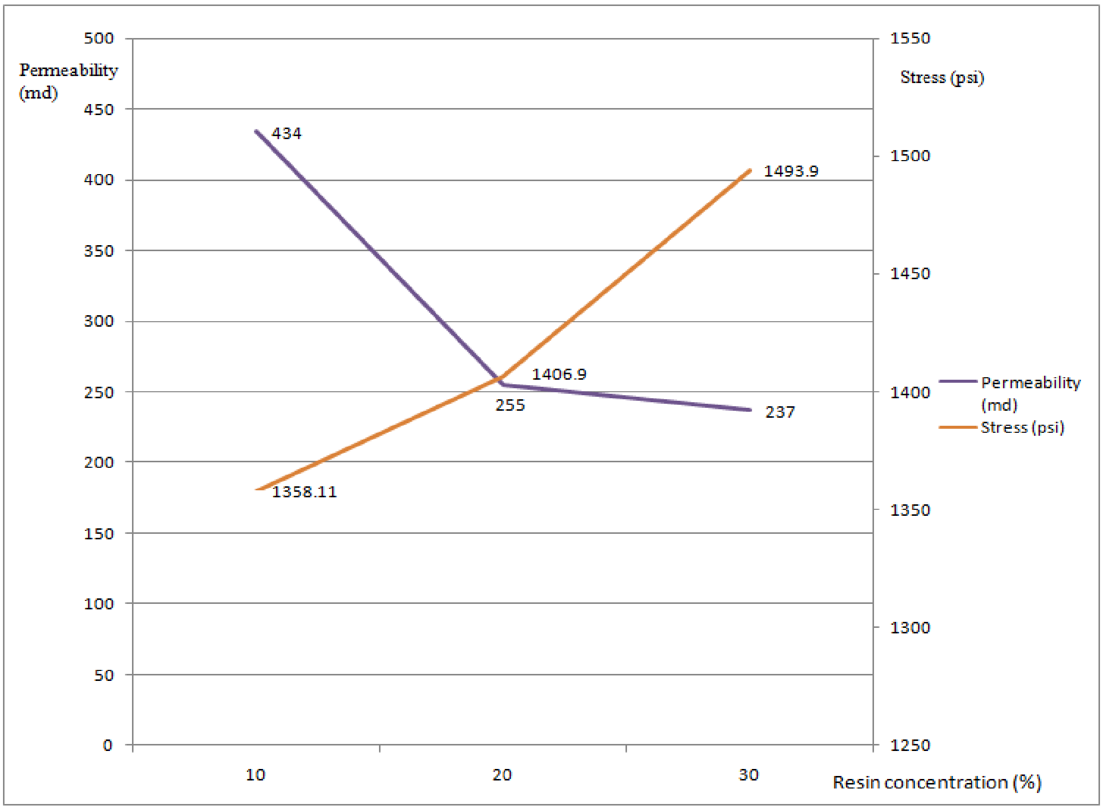


Figure 19: Permeability vs. Compressive strength for Uncatalysed resin

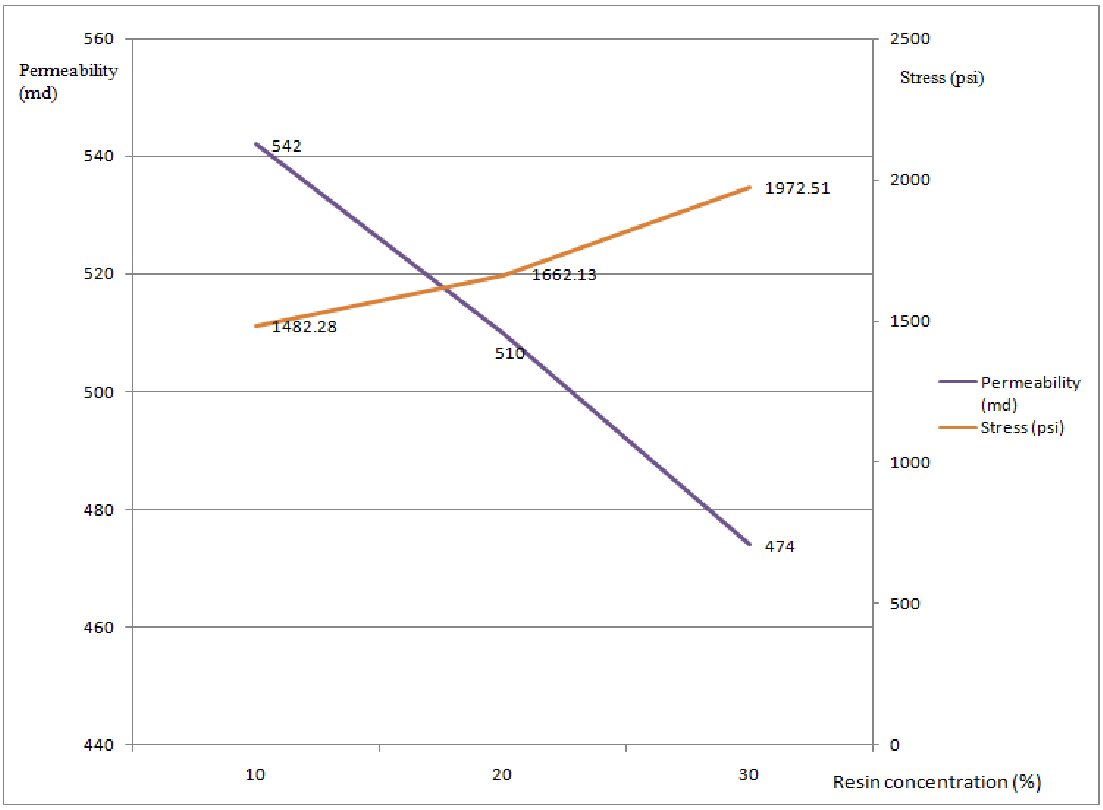


Figure 20: Permeability vs. Compressive strength for Acetic acid catalysed resin

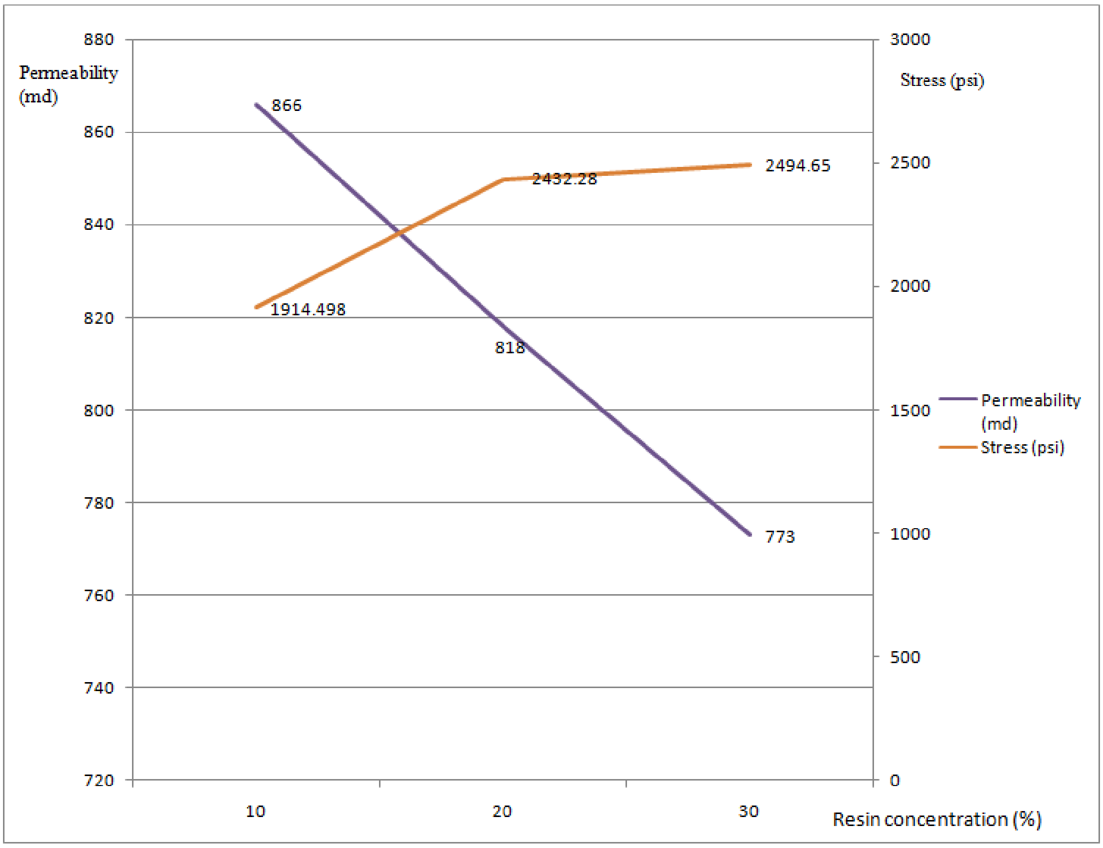


Figure 21: Permeability vs. Compressive strength for Hydrochloric acid catalysed resin

CHAPTER 5

CONCLUSIONS & RECOMMENDATIONS

The study of resin coated sand using acid catalyst has been successfully conducted for range of samples in different resin concentration from 10% to 30% by weight of sand. Based on the obtained results for each parameters tested, the objectives of the study are fully achieved. For the curing and hardening time, results gained for Acetic acid catalysed resin in each resin concentrations is within 24 hours. Shorter period of curing process is better due to economical reason. Permeability values for each samples of Acetic acid catalysed resin is good and acceptable as it in between 400-600 md which is in ranges of normal formation permeability. Besides, results from compressive strength test indicates that Acetic acid catalysed resin for sand consolidation treatment is more than enough to withstand high formation pressure in longer period of time as the values are greater than previous resin treatment strength (600-700 psi). Apart from its promising results, the reliability, availability and cost effectiveness has become the major factors of why Acetic was chosen.

Since the sand mould was custom made, the core samples produced does not perfectly formed cylindrical shape. This defect is less much effect the permeability and compressive strength results. It is recommended that UTP management could provide special mould for sand cores production. Besides, only 3 samples per different type of catalyst can be produced in this study due to time constrains. For the future, the number of samples should be added in order to obtain precise results data.

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