CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

Sand production is one of the oil and gas industry major problems that will create a number of potentially dangerous and costly problems. These problems refer to production loss, reservoir damage, sand erosion of downhole and surface equipment, and etc (Jon, Derrel, George, Colin, & Frank, 1992). Petroleum Engineering has developed a solid study of the best method to be used in the formation that produces sand (Waltman B. et al., 2010). Sand control method such as gravel packing or hydraulic fracturing is applied in the well to prevent this sand production problem. Proppant is a specific sized particle mixed with fracturing fluid and pump into the formation to hold fractures open after hydraulic fracturing.

Many Malaysia oil fields have encountered the sand production. One of well stimulation methods that apply in Malaysia is hydraulic fracturing. Hydraulic fracturing has made a significant contribution as a method for sand control and was introduced to oil and gas industry in 1949 (Veatch, 1983). It is a complex well stimulation method in which the fluid is pumped at a high pressure into a selection section of wellbore and the pressure creates a fracture from the wellbore penetrating into the rock formation (Ching, 1997). There are 4 main types of commercial proppant – silica sand, resin-coated sand, sintered bauxite, and high-strength ceramic material.

Sand is by far the most common propping agent currently use in the U.S. because of its low cost and great abandon. (Sinclair A.P., Sinclair C.P., Graham, Santrol Products, Inc., 1983). In the same way in Malaysia, there is plenty of natural silica sand but most of them are used for the purpose of glass-making and construction industry (Kwan, 2006). Based on the experimental result, local silica sand has a potential to use as a commercial propping agent with some adjustment such as resin-coated (Dahlila, 2011).

1.2 PROBLEM STATEMENT

Since the production of formation sand with the oil and/or gas from sandstone formation creates many problems, the predominant reason for the prevention of formation sand production is economics. Propping agent that uses in well stimulation method is extremely expensive because there is none of local company that manufactures or supplies fracturing proppant in Malaysia. Practically, oil and gas companies in Malaysian oilfield need to import proppant from foreign supplier such as U.S.A and china which will definitely increase the cost of well stimulation techniques. Therefore, the use of local silica sand as proppant would positively be an alternative to eliminate this problem. Earlier research and experiment show the significant and potential of local silica sand as commercial proppant but it needs some improvement for the strength which could be enhance by resin-coated method.

1.3 OBJECTIVES

1.3.1 To determine the porosity of resin coated silica sand

1.3.2 To measure the strength behavior and porosity of resin coated silica sand

1.3.3 To measure the permeability of resin coated silica sand

1.3.4 To investigate the solid production of resin coated in sand control application

1.4 SCOPE OF STUDY

In this project, several samples of local silica sand will be coated by different amount of resin and they will be tested their strength behavior and measured their porosity by using Uniaxial Compressive Strength Triaxial Compression Test machine and Mercury Pressure Porosimetry machine accordingly. Moreover, the samples will be investigated their ability while using in sand control application by using High Pressure High Temperature Cell Test.

CHAPTER 2

LITERATURE REVIEW

The study is focusing on resin coated proppant in sand control application. Detailed information that include in this literature review are introduction to sand control, available methods of sand control, proppant types, the API standards of proppant, comparison of characteristics of proppant, types of resin for coating, types of resin coated sand, and curable resin coated proppant in sand control application.

2.1 INTRODUCTION TO SAND CONTROL

2.1.1 Definition of Sand control

Sand control is the methods and/or techniques used to totally prevent the undesirable production of formation sand and maintain the ability to produce the reservoir fluids with minimal or no restriction to flow.

2.1.2 Basic Types of Sandstone Formation

From a geological aspect there are numerous types of sandstone formations. For the purpose of preventing formation sand production, sandstone formations can be classified into four basic types:

- Well Consolidated
- Friable
- Partially Consolidated
- Totally Unconsolidated

2.1.3 Reasons for Sand Production

The sand production mechanism is complex and influenced by each completion operation from first bit penetration of the producing zone to start of production in a given well (Jon, Derrel, George, Colin, & Frank, 1992).

However, the reason for sand production can be summarized as any one or a combination of the following:

- Unconsolidated Sandstones
- Production Rate
- Water Production
- Reservoir depletion
- Improper Well Completion Practices

Unconsolidated Sandstones

Any attempt to produce formation fluid from totally unconsolidated formations will result in production of large amounts of sand with the fluids.

In many sandstone formations the fluids producing though the sandstone create stresses on the sand grains which exceed the bonding strength of the cementitious materials bonging the sand grains together.

Production Rate

Stresses caused by production rates are due to fluid pressure differences friction and overburden pressures. Some wells will produce sand if the production rate is too high. This can possibly be overcome by reducing production rates or increasing size and perforation density. However, in many cases restriction of production rates will not be economical.

Water Production

The onset of water production is another cause of formation sand production. In some formations, the cementitious material is clay minerals and silt, which may be displaced/ displaced/dissolved by the produced water. When water production starts, the bond is weakened or destroyed and formation sand will be produced.

Reservoir depletion

Resulting in reduced reservoir pressure may cause the overburden to subside and increase the load on a poorly consolidated formation. This increased load can have a crushing effect on the weakly bonded sand grains and result in sand production as well as the serious effect on the casing.

Improper Well Completion Practices

Misuse of acid for drilling mud removal or stimulation may remove the small amount of calcareous bonding material in some weakly consolidated formations and may result in sand production

2.1.4 Why is Sand Production Undesirable?

The production of formation sand with the oil and/or gas from sandstone formation creates a number of potentially dangerous and costly problems (Waltman et al., 2010). The most common of these problems are:

- Safety and Well Control
- Reservoir Damage
- Sand erosion of down hole and surface equipment
- Production Loss
- Casing / Liner Collapse
- Sand Disposal – Environmental Concerns

The predominant reason for the prevention of formation sand production is economics; however, **safety and well control** go beyond economics. The erosion damage to subsurface safety valves can cause them to become inoperable. The failure of these safety valves can result in loss of life as well as tremendous economic loss particularly at offshore and inaccessible locations.

Loss of production can occur as a result of sand fill up or bringing in the well which can reduce or shut off production if the flow velocities of the well are insufficient to transport the produced sand to surface.

The erosion **damage to surface and subsurface equipment** can be extremely expensive to replace as well as the lost production during replacement and repair.

Formation damage is another severe problem with allowing a well to produce sand unchecked. The creation of void spaces behind the casing can leave the casing unsupported; it can also leave the overburden or any shaley streaks in the reservoir unsupported. The casing can become subjected to excessive compressive loading due to subsidence which may cause permanent buckling or collapse. The much less permeable shaley streaks or overburden can collapse in around the perforated casing causing severe and irreparable restrictions to production.

The **disposal of produced sand** can be extremely costly, particularly on offshore locations where environmental regulations required that the produced sand must be free of oil contaminants before disposal. The sand must be transported to cleaning facility, cleaned, and then transported to the landfill location. Failure to prevent formation sand production can therefore be very expensive in terms of lost revenue, additional operating cost and can create potentially very hazardous conditions at the well site.

2.2 AVAILABLE METHODS OF SAND CONTROL

There are many approaches to preventing the movement of formation sand into the well bore. All of these methods except one attempt to provide some means of mechanical support to the formation, adjacent to the producing interval, to prevent the movement of formation during stresses resulting from fluid production or pressure drop from reservoir to well bore necessary for the well to be produced. All of these methods can be categorized into three broad groups. However, from a field application point of view, there are four basic methods of sand control.

- Restrict Production
- Mechanical Methods
- Chemical Methods
- Combination

2.2.1 Production Restriction

Restricting the production rate is one method of sand control which can be used to prevent the production of formation sand. In some cases it may be a successful alternative to the other methods available. However, in most cases it is not a durable or economic solution.

2.2.2 Mechanical Methods

Of the three broad groups which attempt to provide some means of support to the formation the most commonly used are the mechanical methods. Mechanical sand control methods consist of some type of mechanical device to bridge of filter the sand out of the produced fluids or gases.

This group of devices includes:

- Slotted Liners
- Wire Wrapped Screens
- Pre-Packed Screens
- Mesh Screens

The most common use of these devices is in conjunction with some form of gravel packing. They are sometimes used by themselves to prevent sand production.

There are other types of sand control method that usually apply with the mechanical method. The use of natural silica sand or man-made proppant are widely used to block formation sand during production. Gravel packing and frac-packing are the most popular and the most effective methods.

2.2.3 Gravel Packs

This sand control method use the complete placement of selected gravel or sand across the production interval to prevent the production of formation fines or sand. The proppant is pumped in the well normally at perforation interval where the communication of wellbore and formation occur. Typical components of gravel packing method is shown in figure 2.1. Gravel pack can be divided into 2 main types – open hole gravel pack and case hole gravel pack.

2.2.4 Cased Hole Gravel Pack

A successful cased hole gravel pack requires that the perforations or fractures extending past any near-wellbore damage as well as the annular area between the OD of the screen and the ID of the casing be tightly packed with gravel (or man-made proppant). To accomplish this goal, cased hole gravel packing has evolved, in many cases into a two stage process. The first stage packs the perforations with pack gravel. The second stage packs the annulus between the screen and the casing ID with pack gravel.

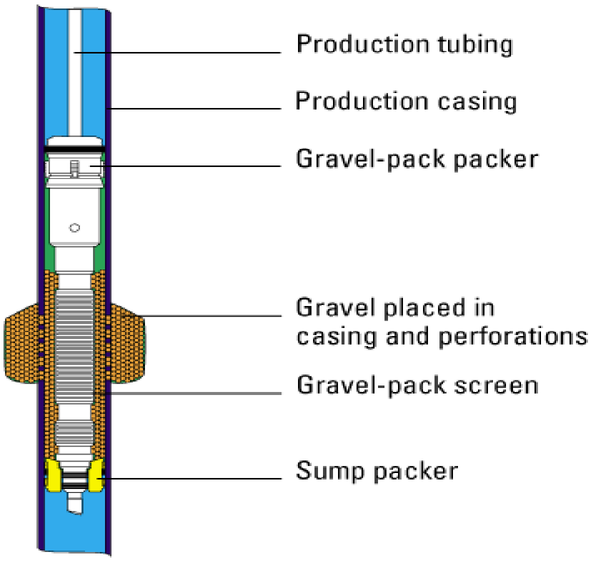


Figure 2.1 Typical component of gravel packing sand control. Schlumberger Oilfield Glossary, ID 2684. Retrieved from http://www.glossary.oilfield.slb.com/Display.cfm?Term=gravel%20pack

Fluid leakoff is a key element in achieving successful perforating packing and for packing the gravel or proppant in the casing/screen annulus. Unless the carrier fluid flows through the perforations and into the formation, gravel cannot be transported and packed into the perforation tunnels or into the fractures (if a fracture stimulation is being performed). The packed perforation tunnels and fractures are the vital link from an area of undamaged formation permeability to the wellbore.

2.2.5 Openhole Gravel Packs

A successful openhole gravel pack requires that the drilling operations be carried out in such a manner that it does not damage the formation unduly. This usually means that the casing is set above the zone of interest, drilling fluids are changed over to the relatively clean drill-in fluid, and the openhole section is drilled with a drill-in fluid such as a sized salt system or a calcium carbonate system. These systems have proven to perform well during the drilling operations and clean up easily during the completion and subsequent production operations. Underrearning the hole is an option. Underreaming is intended to eliminate any drilling damage around the near—wellbore area and to extend the radius of gravel packing around the screen.

The openhole gravel pack completion process requires only that the gravel be tightly packed in the annulus between the OD of the screen and the openhole. Because openhole completions eliminate perforations tunnels that exist within cased hole completions, using viscous fluids to ensure that the gravel is carried into perforations tunnels is unnecessary. Most openhole gravel packs are placed using a water pack system, although in openhole completions that are not highly deviated (>60 degrees), a viscous fluid can be an excellent carrier fluid, enabling a high concentration slurry for a fast job completion, coupled with good particle transport and little disturbance of the openhole filter cake.

2.2.6 Slurry Packs

Slurry packs generally are used to carry high gravel concentrations downhole around the screen and into the perforations. Viscous carrier fluids are used to transport gravel concentrations of 4 to 15 lb/gal. The main advantages to this type of system are that a minimal amount of water (if water is being used as a carrier fluid) is used to pump the slurry, and the pumping rate can be slowed so that pack gravel and the pumping rate can be · slowed so that pack gravel formation sand intermixing is minimal. The minimal amount of fluid required to transport a certain volume of gravel or proppant into the well means that the contact between the fluid and the formation is minimized thus minimizing any potential damage due to this interaction. However, the relatively low leakoff rates due to the viscous carrier fluid can result in incomplete dehydration of the slurry in the perforating tunnels and potentially in the wellbore/screen annulus. Other chemical products such as N—Flow filter cake removal systems, may be used to remove or degrade filter cakes formed by other drill—in—fluid systems.

Typical design parameters are as follows:

- Pump rate — l to 5 bpm
- Carrier fluid — 36 to 80 lb/Mgal gel loading
- Gravel concentration —up to 4 to 15 lbs gravel per gallon of gel

2.2.7 High Rate Water Packs

High-rate water packs were developed to enhance gravel placement into the perforations and to obtain higher completion efficiencies than water packs, which are pumped at lower rates. The more effective high-rate water packs are usually preceded by an acid prepack. Using a high-rate water—pack method requires a blender that can continuously mix gravel and water and supply it to the downhole pump at high rates, Halliburton uses the CLAM blender.

Typical design parameters are as follows:

- Pump rate — up to 4 to 10 bpm (lbpm per 10ft of perforations)
- Carrier fluid — completion brine, slick water
- Gravel concentration — up to 2 lb per gal of fluid

2.2.8 Water Packs

The water—pack system usually uses non-viscosified brine as the carrier fluid for the gravel or proppant. This system requires a blender that can continuously mix gravel and can continuously mix gravel and the carrier fluid and supply it to the downhole pump. ln recent years, water packs have become an increasingly popular alternative to conventional gelled slurry gravel packing methods using polymers that can potentially damage formation permeability. Water packs typically form very tight annular packs. One disadvantage of water packs is the potential for high leakoff rate in high-permeability zones, which can cause bridging in the screen/casing annulus at the point of leakoff. This bridging can cause a premature screenout of the treatment.

Typical design parameters are as follows:

- Pump rate — up to 2 to 5 bpm
- Carrier fluid — completion brine
- Gravel concentration - up to 2 lb per gal of fluid

2.2.9 Frac Packs

Fracpacks are an offshoot of the gravel pack where high pumping pressures and rates are used to create small fractures through the damaged zone around the wellbore.

Fracpacks are essentially a combination of sand control technique and a fracturing technique. The gravel is pumped above fracturing pressure, and is designed to pack both the fractures and annular space around the screen with pack sand or proppant. The major advantage is that the well productivity is usually much higher than for conventional gravel packs.

The FracPac process is the most reliable (with respect to long—term, high-rate production) design for sand control available in the industry today. FracPac service combines a highly conductive fracture with a gravel packed screen installation to provide both stimulation and formation sand control. The treatment involves pumping gravel or proppant into the perforations at rates and pressures that exceed the parting pressure of the formation using a tip screen out (TSO) frac treatment. The intention is to bypass any near—wellbore damage remaining from the drilling/perforating phase of the operations. A TSO frac is used to achieve a high proppant concentration in the near-wellbore area and achieve a highly conductive fracture connection between the wellbore and the reservoir. A gravel pack screen installation and annular pack are used to provide formation sand control. New technology, in the form of 3D frac design simulators, allows for the improved prediction of the frac geometry.

The key concept of the FracPac is the tip screenout design, which creates a wide, very high proppant concentration propped fracture at the wellbore. The frac conductivity at the wellbore is the key FracPac feature, not the long frac radius of the hardrock reservoir. However, current FracPac modeling takes the fracturing concept further by designing for the stabilization of formation sands, prediction of critical drawdown pressure, and control of fines migration by reducing radial flow velocity. As with any stimulation treatment, the removal of the effects of wellbore damage is important. Proppant concentration in the near-wellbore area is critical. While reaching wellbore screenout conditions is optional in conventional stimulation treatment design, in FracPac it is preferred, if not mandatory.

Treatment analysis and execution is facilitated with Halliburtons weight-dovvn FracPac service tool system, which allows the operator to monitor the Bottom hole treating pressure during the job through the annulus pressure.

- Typical FracPac procedures can include:
- Step rate test / minifrac
- Use of Fracpro PT or StimPlan or GOHFER program to design treatment
- Pump rates up to 60 bpm
- Wellbore deviations greater than 50 degrees are common
- Crosslinked frac fluid systems such as SeaQuest service with gel loadings typically 20 to 40 lb per Mgal
- Proppant concentrations up to 12 ppg are common

2.2.10 Chemical Consolidation

Sand control by chemical consolidation involves the process of injecting plastics or plastic forming chemicals into the naturally unconsolidated formation to provide grain to grain cementation. The objective of formation sand consolidation is to cement sand grains together at the contact points maintaining maximum permeability.

There are two basic types of chemical consolidation techniques:

1) Internally Activated Systems

2) Externally Activated Systems

2.2.11 Combination Methods

Combination methods are those which combine both a chemical consolidation system and a mechanical gravel pack system. In these systems a gravel pack is performed, usually without a screening device in the hole, using resin coated gravel packing sand. These systems are in very limited use today, but definitely have a market.

2.3 PROPPANT TYPES

The 4 main proppant types that are use commercially in oil and gas industry are sand, resin-coated, sintered bauxite, and intermediate strength proppant (Halliburton, 2002).

2.3.1 Sand

Ottawa Sand and Brady Sand are two major types of sand used as proppants in hydraulic fracturing or gravel packing. Ottawa Sand, from the Jordan Deposit, is a high-quality sand from the northern United States, is shown in figure 2.2. It is white in color, pure quartz composition, lack of dust, high roundness and sphericity, makes it ideal sand. Most of the grain is made up with monocrystalline, which results in high individual grain strength. Brady Sand, from the Hickory Deposit near Brady Texas, is another high-quality sand used for fracturing, characterized by its slight angularity and presence of feldspars. It's also known as Brown Sand because of its color, it is considered to be of lower quality sand comparing to Ottawa Sand. Ottawa and Brady sand provide the majority of material used in sand control operations, even though sands are available from other areas. The physical properties of commonly used types of sand are listed in Table 2.1.

**Table 2.1 Physical Properties of Sand.
Adapted from Halliburton Stimulation 1
Manual by Halliburton, 2002, *Proppant*, p. 8.**

Properties	Premium Sand (Jordan/Ottawa)		Standard Sand (Hickory/Brady)	
	12/20	20/40	12/20	20/40
Roundness	0.8	0.8	0.7	0.7
Sphericity	0.8	0.8	0.8	0.7
Specific Gravity	2.65	2.65	2.65	2.65
Bulk Density (lb/ft^3)	96	102	100	102
Acid Solubility (% by Weight)	1.3	1.2	0.9	1.6
Crush Resistance (% Fines)	2.4	1.8	11.1	11.0
Clustering (% by Weight)	0.3	0.1	0.8	0.3

Figure 2.2 – Ottawa Sand. Retrieved from http://www.sssand.com/products.php

Figure 2.3 – Resin-Coated Sand. Retrieved from http://www.momentive.com/Products/TechnicalDataSheet.aspx?id=3770

Figure 2.4 – Sintered Bauxite by Jiaozuo Fanghua Ceramics Co., Ltd. Retrieved from http://products.tradeindia.com/mineral-metals/non-metallic-mineral-products/

Figure 2.5 – ISP – Ceramics. Retrieved from http://taoceramics.com/tao-isp

2.3.2 Resin-Coated Sand

Resin-coated proppant are commonly used to improve well stimulation result in hydraulic fracturing to prevent proppant flow back, fracture evacuation, formation fines from migrating toward the well bore, reduction in fracture permeability resulting from crushing or embedment, and increase fracture conductivity (Sinclair, Graham, Santrol Products, Inc., 1983). The picture of resin-coated sand is shown in figure 2.3. Resin coatings are available on sands, ceramics, and bauxite proppants. The most commonly resin used to coat proppants are epoxy or phenolic resins (Dewprashad et al., 1993).

2.3.3 Sintered Bauxite

High-strength sintered bauxite and intermediate-strength sintered bauxite are produced by essentially the same manufacturing process and the sample is shown in figure 2.4. Bauxite ore is ground to a fine powder and formed into green pellets. After drying and screening, the pellets are fired in a kiln. The firing, or sintering process, fuses the edges of the individual particles of each pellet. The basic difference in the high strength and intermediate strength materials lies in the raw material used. Pure bauxite ore formed High-strength sintered bauxite to create corundum. This imparts the highest strength and also the density (approximately 3.7 specific gravity) for this proppant. Intermediate strength sintered bauxite is formed from a less pure bauxite ore. The processing of this ore produces both corundum and mullite. This mineral composition results in a less dense (approximately 3.25 specific gravity) and slightly weaker compound than the more pure sintered bauxite compound.

2.3.4 Intermediate Strength Proppant (ISP) – Ceramics

One of the large classes into which all useful solid materials can be divided is ceramic, i.e., metals, organics, and ceramics. Generally, a ceramic is any non-organic, non-metallic solid formed by high temperature processing (above 875°F) (Halliburton, 2002). The picture of ceramic is shown in figure 2.5. The disadvantage of the ceramic than the sintering is high temperature is required and the raw materials used are expensive (McDaniel et al., 2002) Ceramic proppants are produced in a different manner than the sintered bauxite proppants using fluidizing bed processing. The mullite (aluminum compound) with some additional silica compounds is mostly shown as the composition of the ceramic-type proppants. These ceramic proppants have less strength than the intermediate- and high strength sintered bauxite proppants but greater strength than sand.

2.4 API STANDARDS FOR PROPPANT

According to American Petroleum Institute (1995), The API publications dealing with proppants are API RP 56 for hydraulic fracturing sand, API RP 58 for gravel pack sand and API RP 60 for high strength hydraulic fractuing sand. These publications set limits on certain characteristics of proppant and the procedures used for testing them. Some characteristics of proppants used in hydraulic fracturing that need to be monitored are:

- Roundness & Sphericity
- Specific Gravity
- Bulk Density
- Sieve Size
- Acid Solubility
- Silt and Fine Particles
- Crush Resistance
- Clustering

2.5 COMPARISON OF CHARACTERISTICS OF PROPPANT

2.5.1 Comparison of Specific Gravity and Porosity in Different Size of Proppant Type

Table 2.2 – Diameter of Proppant in Different Mesh Size. Adapted from "Catalog/Handbook of Fine Chemicals," by Aldrich, 2004.

Mesh Size	Diameter	
	(in.)	(mm)
4	0.187	4.789
6	0.132	3.353
8	0.094	2.387
10	0.079	2.007
12	0.066	1.676
16	0.047	1.194
20	0.033	0.838
40	0.017	0.432
60	0.01	0.254

The diameter of the proppant in different mesh size is shown in table 2.2. This mesh size is according to the same mesh size in sand sieve analysis. It shows that the bigger of the mesh size is the smaller of the proppant's diameter.

Table 2.3 – Comparison of Specific Gravity and Porosity in Different Size of Proppant Type . Adapted from "*Well Production Practical Handbook*," by H.Cholet. (2008).

Proppant	Mesh size	Specific gravity	Porosity (%)
North White sand	12/20	2.65	38
	16/30	2.65	39
	20/40	2.65	40
Texas Brown sand	12/20	2.65	39
	16/30	2.65	40
	20/40	2.65	42
Curable resin-coated sand	12/20	2.55	43
	16/30	2.55	43
	20/40	2.55	41
Precured resin-coated sand	12/20	2.55	38
	16/30	2.55	37
	20/40	2.55	37
ISP	12/20	3.17	42
	20/40	3.24	42
ISP-lightweight	20/40	2.63	40
Sintered bauxite	16/20	3.7	43
	20/40	3.7	42
	40/70	3.7	42
Zirconium oxide	20/40	3.16	42

As shown in table 2.3 above, specific gravity of both white sand and brown sand is 2.65 regardless of the change of their mesh size and porosity is from 38 to 40 percent depending on the mesh. In the different way of white and brown sand, curable and precured resin-coated sand have lesser value of specific gravity by 0.1 but curable resin-coated sand has higher value in porosity from 41 to 43 percent (H. Cholet, 2008). Sintered bauxite has the highest value of specific gravity which is 3.7 for all mesh size with the porosity of 42 to 43 percent.

2.5.2 Mechanical Properties of Proppants

Table 2.4 – Specific gravity and Maximum closure stress of proppants. Adapted from "*Well Production Practical Handbook*," by H.Cholet. (2008).

Proppant	Specific gravity	Maximum closure stress (psi)
Sand	2.65	6000
Resin-coated sand	2.55	10000
ISP ceramics	2.7-3.3	14000
High-strength proppant	3.4	>10000

Figure 2.6 is a graph of proppant application range (R. LaFollette, 2010). It shows the range of closure stress (psi) that is suitable for each type of proppants. The type that can hold the lowest closure stress is brown sand which has the maximum closure stress around 4500 psi. Following the brown sand, white sand has the maximum value of 6500 psi. The lowest range to the highest range of proppants are brown sand, white sand, regular resin-coated sand, premium resin coated sand, low-weight ceramic, resin-coated low weight ceramic, intermediate strength proppant, sintered

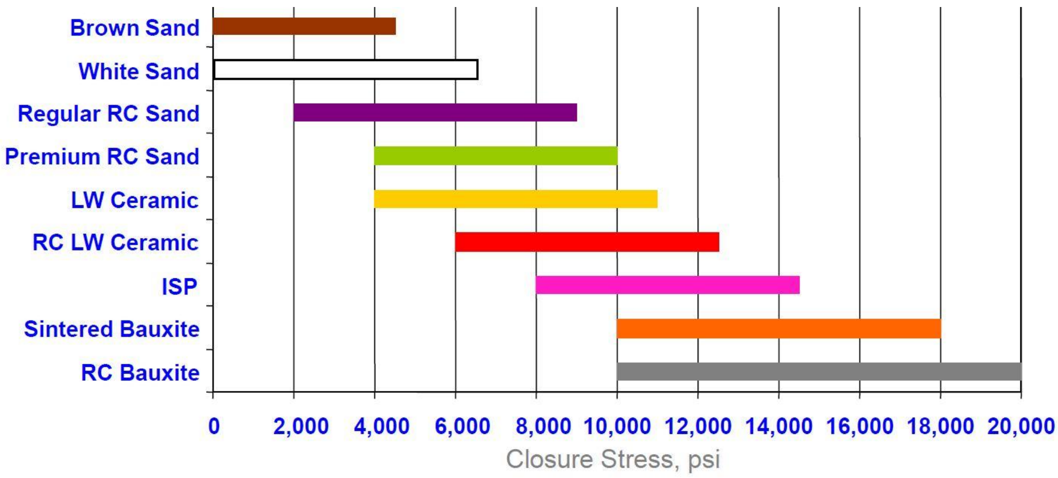


Figure 2.6 – Proppant Application Ranges. Adapted from "Key Considerations for Hydraulic Fracturing of Gas Shales," by LaFollete, R., 2010.

bauxite ,and resin-coated bauxite accordingly. According to this graph, resin-coated bauxite has the highest range which is from 10000 to 20000 psi. The trend of closure stress ranges show that resin-coating will increase the value of closure stress for all types of proppant.

2.5.3 Propped Fracture Conductivity

The fracture conductivity is a relationship of final average fracture width with permeability of proppant-packed fracture (Cholet, 2008). The final average fracture width is directly proportional to permeability of proppant-packed fracture. The fracture conductivity (*FC*) is given as follows;

$$FC = \bar{w}_f k_f \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where

$\bar{w}_f$ is final average fracture width

k_f is permeability of proppant-packed fracture

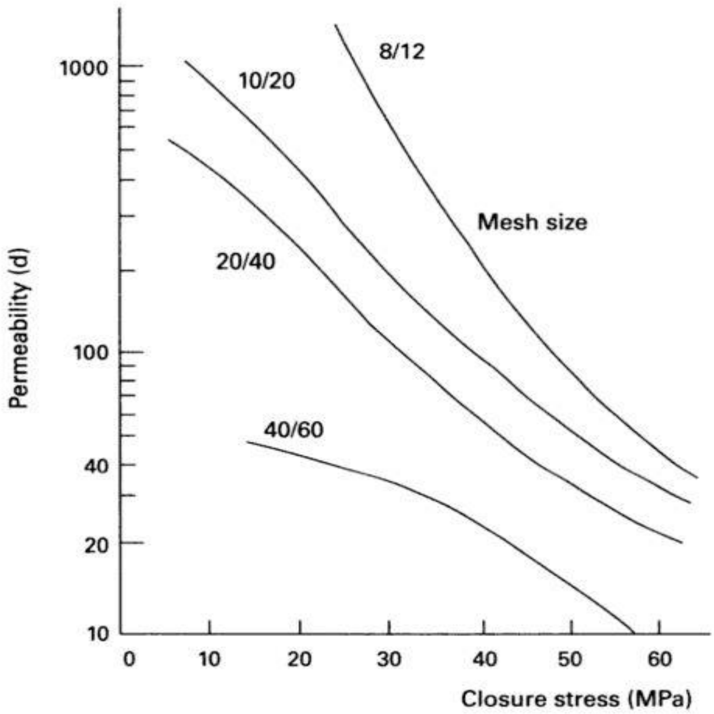


Figure 2.7 – Graph of Permeability (darcy) VS Closure Stress (Mpa). Adapted from "*Well Production Practical Handbook*," by H.Cholet. (2008).

Figure 2.7 shows the permeability of various sand sizes as a function of closure stress. The largest proppant, 8/12 mesh size, gives the highest value of permeability at the same closure stress and follows by 10/20 , 20/40 and 40/60 mesh size accordingly. This figure illustrates that the larger of proppant size will give the higher permeability value. The larger proppant provides greater permeability because larger proppants creates larger open areas for the fluid to flow. Though larger proppant will has higher value of permeability but it might be more difficult to transport it in place.

2.6 TYPES OF RESIN FOR COATING

There are several types of resin for manufacturing coating. The widely used rasins are acrylics, alkyds, epoxies, polyester, polyurethanes, and vinyls. Various forms of resins is supplied including high-solids, waterborne, solvent-containing, and powder coating.

The most commonly use to coat proppants are epoxy or phenolic (B. Dewprashad et al, 1993). The former is a mixture of epoxide resin and amine hardener or crooslinker. Usually, phenolic resins combine between novalac resin and hexamethylenetetramine as crooslinker.

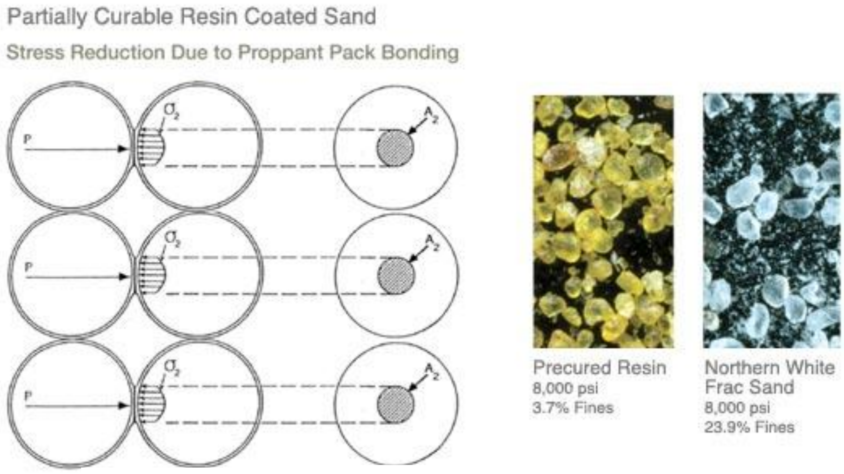
2.7 TYPES OF RESIN COATED SAND

Generally, there are two (2) main types of resin-coated sand;

1) Curable
2) Precured

2.7.1 Curable

Curable resin-coated sand is required time at downhole temperature to cure the thermosetting resin. The advantage of curable to precured resin-coated proppants is that it allows the individual proppant grains to bond together into a uniform pack and leads to the greater ability to reduce amount of fines generation. It is also and preventing flowback of proppant (Hexion, 2010)



$\sigma_2 = P/A_2$ σ=stress on surface of grain

P= grain-to-grain load

$\sigma_2 << \sigma_1$ A = area over which P acts

Figure 2.8 – Stress Reduction Due to Proppant Pack Bonding. Adapted from “Consideration for Fracturing with Resin Coated Proppant,” by Hexion 2010

Figure 2.9 show that the uniform pack of grain that bond together will secure the broken grain and reduces the amount of loose fine.

The curable resin-coated proppant also reduces the embedment effect in the formation which will maintain the fracture width throughout the well life.

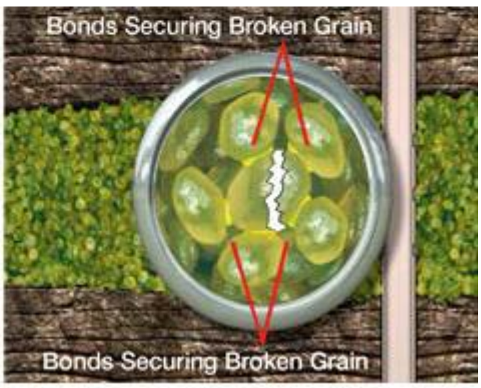


Figure 2.9 – Curable Resin Coated Sand Bonding. Adapted from “Consideration for Fracturing with Resin Coated Proppant,” by Hexion 2010.

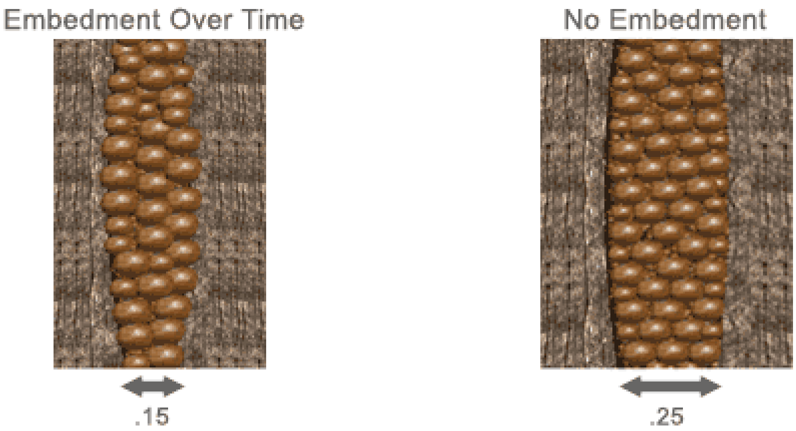


Figure 2.10 – Embedment Effect in the Formation. Adapted from “Consideration for Fracturing with Resin Coated Proppant,” by Hexion 2010.

2.7.2 Precured

Precured resin-coated sand is older technology and does not have to rely on downhole condition to set the resin. The coating on the sand grains is fully cured to give additional strength of individual grains (P. Percival, 2011). It is also designed to have the ability to reduce fines but not preventing flowback of proppant.

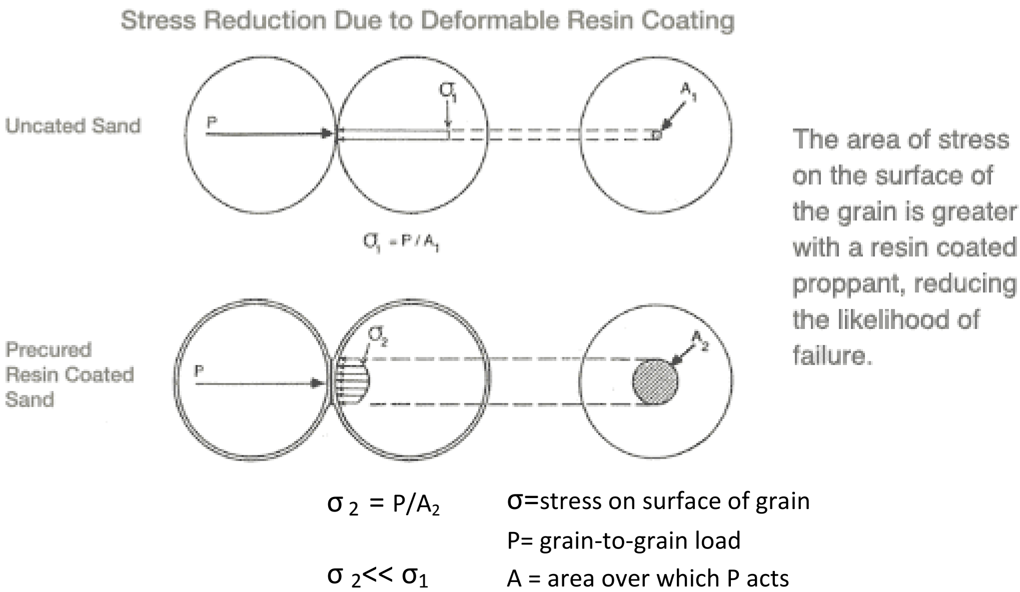


Figure 2.11 – Stress Reduction Due to Deformable Resin Coating. Adapted from “Consideration for Fracturing with Resin Coated Proppant,” by Hexion 2010

2.8 CURABLE RESIN-COATED PROPPANTS IN SAND CONTROL APPLICATION

Plastic materials have been used for sand control application since 1945 (Wrightman, G.G. and Buckley, S.E., 1945). In 1975, curable phenolic-based resin-coated proppant was patented. The curable resin-coated proppants are commonly used in sand control application such as hydraulic fracturing or gravel packing.

The main applications of resin-coated proppant are as following;

1) Increase fracture conductivity
2) Stop fines particle of the formation from migrating into the wellbore
3) Maintain long-term fracture permeability
4) Prevent flow back of proppants.

2.9 EFFECT OF FRACTURING AND RESERVOIR FLUIDS ON UNCONFINED COMPRESSIVE STRENGTH (UCS) OF PROPPANT PLUGS

The unconfined compressive strength of resin coated proppant plugs was used to estimate the effect of fracturing and downhole fluids on proppant pack strength under uniaxial loading (Barmatov, 2008). The preparation of proppant plugs under simulated downhole conditions of stress, temperature and fracturing fluids used a standard curing cell . All samples were cured under a closure pressure of 1300 psi for 1 hour and 100 degree celcius.

Four different sample were produced. Series#1 was saturated with brine and use as reference value. Series #2 and #3 contain cross-linked polymeric gel. Series #2 is low pH but series #3 is high pH. Unlike previous samples, series #4 is prepared on high pH borate cross-linker without polymer.

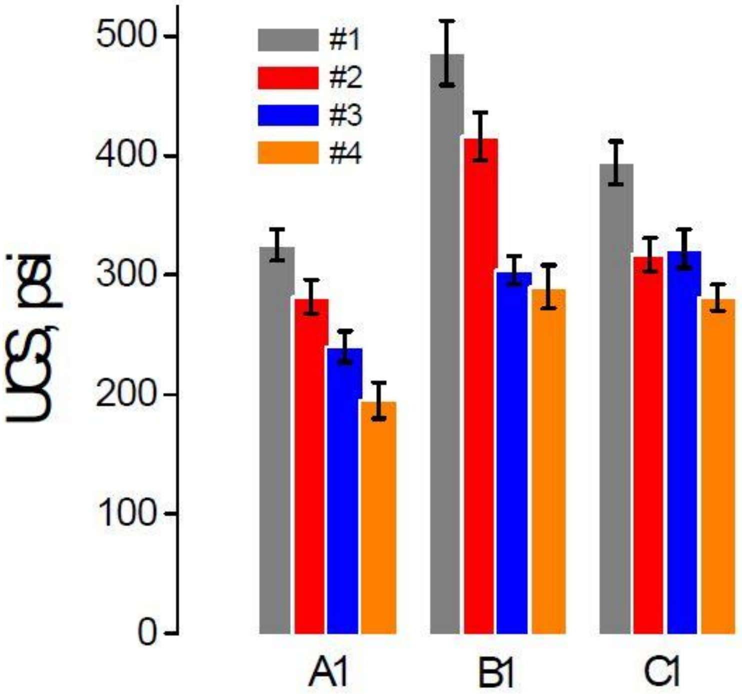


Figure 2.12 ─ Unconfined compressive strength for RCP samples A1, B1 and C1 prepared in various fluid 1-4. Adapted from "Setting the Standard for Resin Coated Proppant Test," by Barmatov, E, et al. 2008.

Figure 2.12 demonstrates the unconfined compressive strength test results for resin coated proppant A1, B1, C1 cured in the presence of different fluids. The proppant prepared in brine has unconfined compressive strength increases in the following sequence B1>C1>A1. For those that cured with polymetric fluid, They show the lower strength than the reference value. Additionally, the more pH value of polymeric slurry is the weaker of unconfined compressive strength.

From the examination of resin coated proppant. It seems like there are two (2) main factors influencing pack strength. They include the effect of saturation media on grain-to-grain bond strength and the amount of resin coating on the proppant. The reduction of resin content leads to reduction in pack strength. In the same of manner of influence of high-pH media, pack strength consistently decrease while the pH increase.

CHAPTER 3

METHODOLOGY

The project methodology will be divided into 2 phases which are FYP I and FYP II as follows:

3.1 FYP I

FYP I consists of 2 parts of implementations which are preliminary study and pre-experimental work.

3.1.1 Preliminary Study

This part will be focused on the project planning and literature review including types of proppants, types of resins, comparison of characteristic of proppant, resin coated methods, curable resin coated proppant for sand control application, current studies, and also previous experiment of resin-coated sand that has been done**.** The Main interest of the research will be the method of improving the strength and stability of sand consolidation with resin to prevent the production of fines particle from the formation and the flow back of the proppant.

3.1.2 Pre-experimental work

The pre-experimental work is actually referred to resin-coated sample preparation. There are 7 samples which are different in percentage of resin concentration to be prepared as following;

(1) 5% of resin
(2) 10% or resin
(3) 15% of resin
(4) 20% of resin
(5) 30% of resin
(6) 40% of resin
(7) 50% of resin

Table 3.1 – Parameter used in Resin Coated Sand Sample Preparation

Source of Sand	Terengganu Sand
Sieve Size	30/70 mesh size (0.2261-0.6 mm)
Amount of Resin (%)	5,10,15,20,30,40,50
Amount of Sand	420 grams
Required Equipment	Mould, Mixer, Oven
Portion Between Resin & Hardnener	50/50
Minimum Cure Time	24 hours
Cure Temperature	120 degree celcius

The parameters of resin coated sand is shown in table 3.1. The estimated time to prepare 1 sample is around 2-3 hours not including cure time (24 hours).

3.2 FYP II

FYP II consists of 2 phases of implementations which are experimental work and discussion and conclusion. The experiment will be conducted using Uniaxial Compressive Strength Triaxial Compression Test, Mercury Pressure Porosimetry machine and continue the further experimental work with investigation of solid production of resin coated in sand control application by using High Pressure High Temperature Cell Test with 7 types of samples that has been prepared previously.

Figure 3.1 shows the process flow throughout the whole project work. It includes preliminary study, experimental setup, pre-experimental work, experiment, analysis of results, discussion of analysis and report writing.

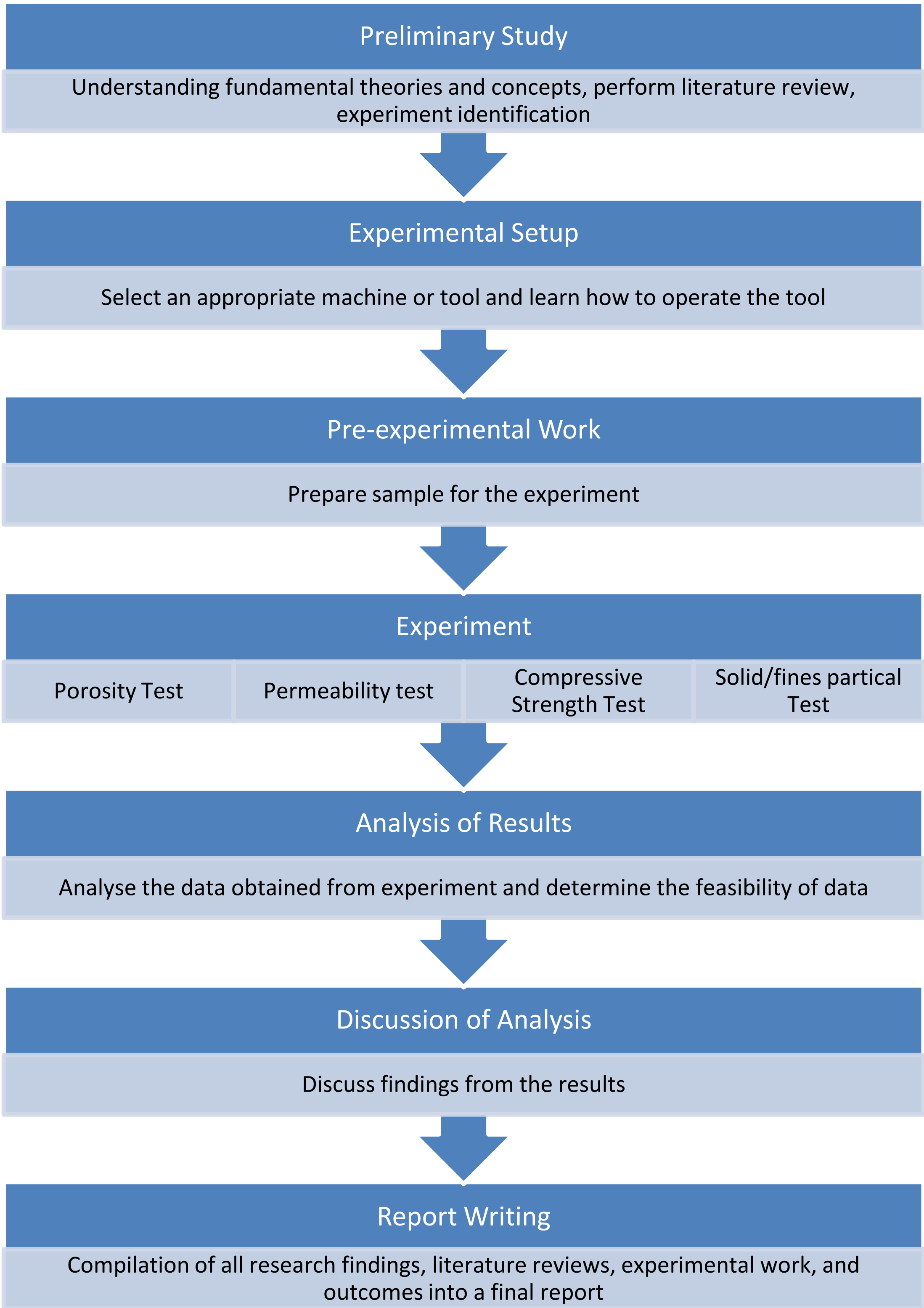


Figure 3.1 — Process Flow of the Project

3.3 PROJECT TIMELINE

Table 3.2 – Final Year Project I (May 2012) proposed activities timeline.

Activities in FYP I	WEEK NO.																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Selection of Project Topic															Study Week	Final Examination Week	
Preliminary Research Work																	
Submission of Extended Proposal																	
Proposal Defense																	
Continue with Project Work																	
Submission of Interim Draft Report																	
Submission of Interim Report																	

Table 3.3 – Final Year Project II (September 2012) proposed activities

Activities in FYP II	WEEK NO.																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Continue with Project Work															Study Week	Final Examination Week	
Submission of Progress Report																	
Preparation of Report Writing; Discussion, Conclusion, and Recommendations																	
Pre-EDX																	
Submission of Draft Report																	
Submission of Disseration (Soft Bound)																	
Submission of Technical Paper																	
Oral Presentation																	
Submission of Dissertation (Hard Bound)																	

3.4 TOOLS REQUIRED

There are 4 main tools involves in this project which are Uniaxial Compressive Strength Triaxial Compression Test, Mercury Pressure Porosimetry machine, PoroPerm, and High Pressure High Temperature Cell Test.

Figure 3.2 – Tools Required (Porosimeter, Compression Test, and Mould). Taken from UTP laboratory at block 14.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 ANALYSIS OF RESIN COATED PROPPANT

This section demonstrates the enhancement of local silica sand with resin coating and analysis of coating methods. The purpose of this experiment is to achieve the optimum method in coating the local silica sand. The results in this chapter include the effect of different portion of coating in silica sand in term of unconfined compressive strength, the effect of resin concentration in coating silica sand in term of unconfined compressive strength, permeability and porosity, and the production of fine particles in gravel packing application.

Figure 4.1 shows the resin coated samples in different resin concentration prepared for experiment mentioned in section 3.2. By investigate the physical appearance of all samples, it is clearly seen that the higher concentration of resin is the darker of their physical appearances.

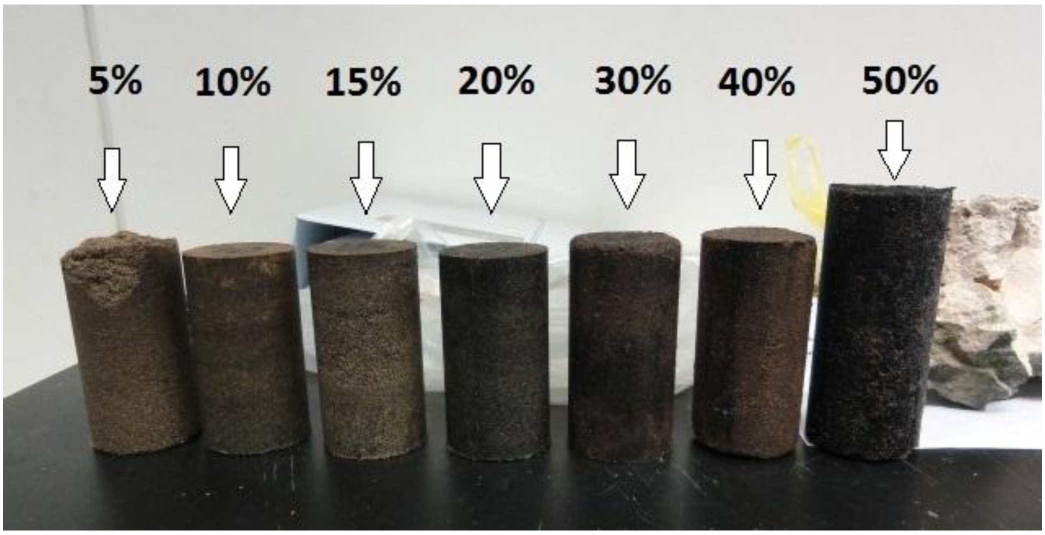


Figure 4.1 – Resin Coated Samples in Different Resin Concentration (5% to 50%)

4.1.1 Effect of Different Portion of Coating Silica Sand

This experiment consists of two different portions of silica sand to formed resin coated silica sand. The strength mechanism of resin coated silica sand can be affected by a portion of silica sand when mixing. A first portion of silica sand contain at least partially coated with resin and wherein the second portion of silica is free from resin.

Both portion then will mixed together to formed slurry and consolidated as resin coated silica sand pack. Table 4.1 shows the effect of different portion of coating silica sand in terms of unconfined compressive strength.

Table 4.1: Effect of Different Portion of Coating Silica Sand.

Sample	Portion of Coating Sand (First to Second)	Unconfined Compressive strength (PSI)
1	100-0	1967
2	25-75	3583
3	50-50	4614
4	75-25	2765

Figure 4.2 shows the summary of unconfined compressive strength versus different sample portions that is shown in table 4.1. The results of 20% resin concentration of all samples were compared with reported data of 3% resin concentration (Nyugen et al., 2007).

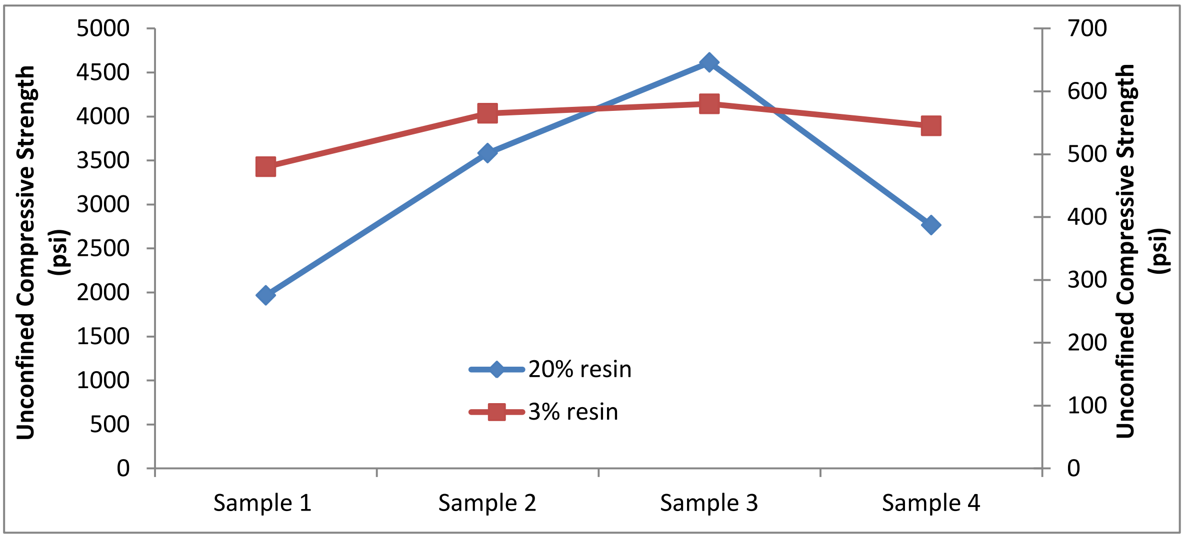


Figure 4.2 — Summary of Unconfined Compressive Strength vs. Different Sample Portions

Traditionally, resin coated silica sand is blending all silica sand together with the resin at the same time as in sample 1 (Nyugen et al., 2007). According to figure 4.2, it is obviously seen that when the portion of silica sand is mixed, the unconfined compressive strength of the compacted silica sand is higher than traditional method. Sample 3 presents the highest value of compressive strength for 20% resin concentration as same as 3% resin concentration which are at 4614 psi and 580 psi. The value of compressive strength for 20% resin higher than 3% resin due to the quantity of resin that increase the strength of consolidated pack. The pattern of experimental results at 20% resin concentration is similar to the reported data which is 3% resin concentration.

4.1.2 The Effect of Different Resin Concentration of Coating Silica Sand

4.1.2.1. Unconfined Compressive Strength

Figure 4.3 shows the cubic samples prepared for unconfined compressive strength test. Figure 4.4 shows the coating of the sample after the coated sand was cured. The bonding between grains, illustrated by the footprints at the contact points, helps establish the consolidation strength for the proppant pack to withstand stress load. SEM pictures illustrate the footprints and bonding between sand grains after subjected to unconfined compressive strength measurement. The consolidation strength corresponds proportionally with the resin concentration on the proppant.

Figure 4.3: Cubic Sample of Different Resin Concentration

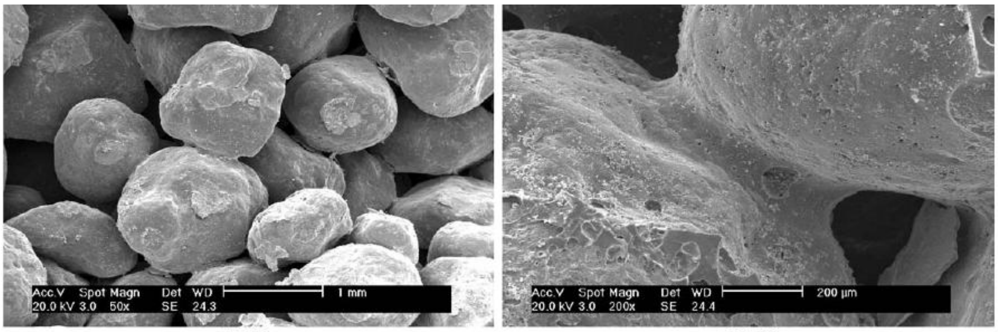


Figure 4.4 –SEM of resin coated that is cured at 230°F for 24 hours

The consolidation strength of the resin silica sand depends on the resin concentration, cure time and cure temperature. Conventional method of coating silica sand by resin is normally in the range of 3% to 5% by weight of silica (Nyugen et al., 2004). However, the present invention, the amount of resin that used to coat the proppant is at least 3% to 50% by weight of silica sand (Daparo D., Perez E., Saravia C., Nguyen P.D., Bonapace J.C., 2009). The desired outcome of resin coated sand is to achieve high strength with less amount of resin because it will reduce the total cost of sand control. The investigation is mainly focused on the effect of different resin concentration where the cure time and temperature were constant at 24 hour at 120°C.

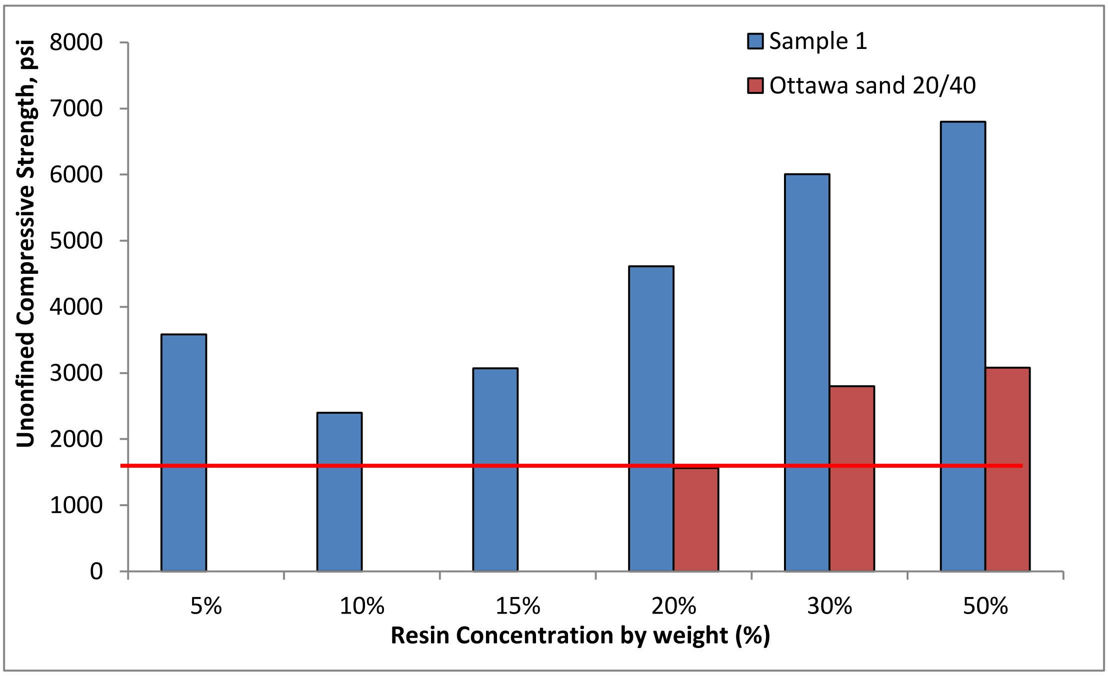


Figure 4.5 ─ Compressive strength with different resin concentration.

Figure 4.5 shows compressive strength with different resin concentration. Obviously, resin coated silica sand of 50% resin concentration has the highest unconfined compressive strength which is at 6800 psi. The following 30% and 20% resin concentration are 6008 psi and 4614 psi respectively. Furthermore, the results were compared with reported data of Ottawa Frac sand 20/40 (Dewprashad B., 1996). All samples of resin coated silica sand show higher value of unconfined compressive strength than Ottawa sand by about 53% to 66% variations. Ottawa sand 20/40 has the lowest unconfined compressive strength at 1562 psi. Both resin coated silica sand and Ottawa sand 20/40 show the increment in unconfined compressive strength when the resin concentration increases. The reason is the resin will coat around each grain of sand and reacts with one another, allowing the grains to bond. The higher of resin concentrations, the stronger grain-to-grain bond of the sand will be.

All Samples of resin coated silica sand meet the specification of consolidation strength at 2000 psi (Nyuyen et al., 2004). Villesca concluded that high strength consolidated pack could be achieved using a relatively small amount of consolidating material (Villesca J. et al., 2010). Thus, the optimum values of resin concentration ranges are from 25% to 40% of resin concentration. The concentration of resin is actually depended variously on the type of job, cure time and cure temperature. Resin coating allows the individual proppant grains to bond together into a uniform pack and leads to the greater ability to reduce amount of fines generation (Hexion, 2010). The bonding between grain to grain keep the grain from shifting, improved proppant pack integrity, enhanced fracture flow capacity by keeps the fractures propped completely open and increased long-term production of the well.

4.1.2.2 Porosity and Permeability

Figure 4.6 shows the summary of permeability and porosity of resin coated silica sand in different resin concentration from 5% to 50%. It illustrates the reduction in the permeability and porosity after sand pack due to the increase in concentration of resin. Resin coating can improve the strength of silica sand and provide good permeability and porosity of consolidated pack. However, the permeability and porosity are decreasing accordingly to the higher resin concentration. The permeability of the resin coated silica sand varies from 224 md to 379 md for 5% to 50% respectively. The porosity of the resin coated silica sand also varies from 15% to 38% for 5% to 50% respectively. The resin coating creates a layer around the silica and prevents water from reacting with the proppant grain surface.

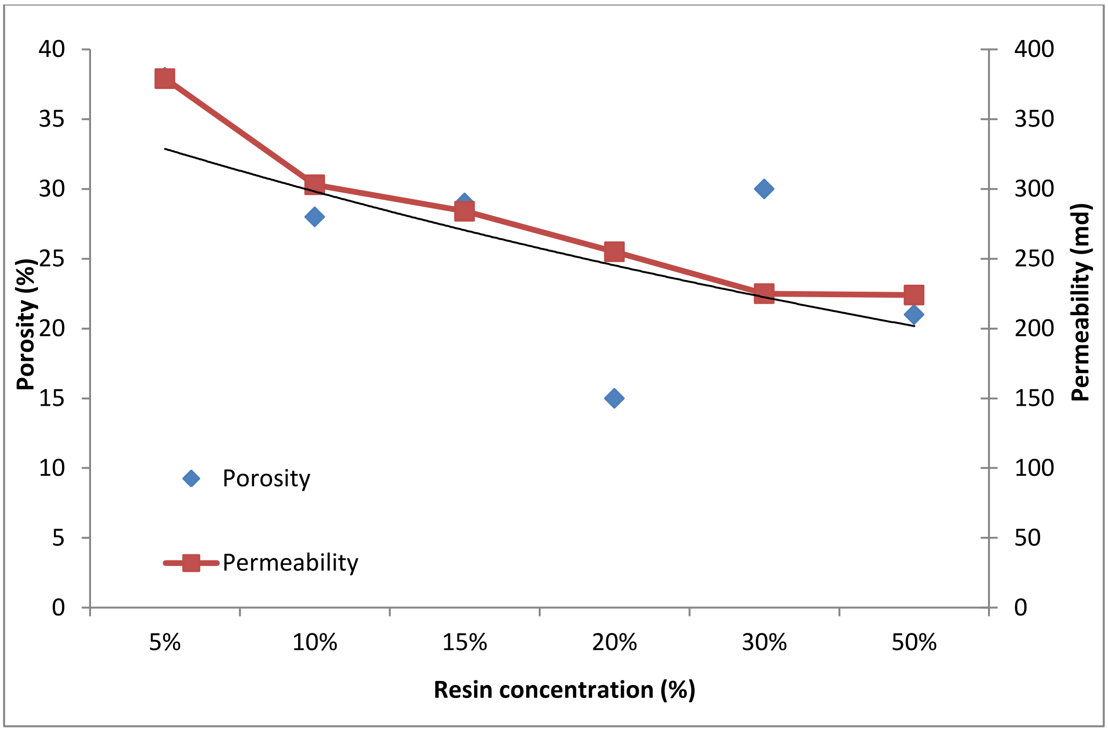


Figure 4.6 ─ Summary of Permeability and Porosity of Resin Coated Silica Sand in Different Resin Concentration

4.1.2.3. Summary of Resin Coated Silica Sand

Figure 4.7 shows the comparison of unconfined compressive strength and permeability versus resin concentration of resin coated silica sand. The unconfined compressive strength will increase directly-proportionally with resin concentration. Unlike the unconfined compressive strength, permeability decrease as the resin concentration increase. Thus, figure 4.7 illustrates that unconfined compressive strength is inversely proportional to permeability.

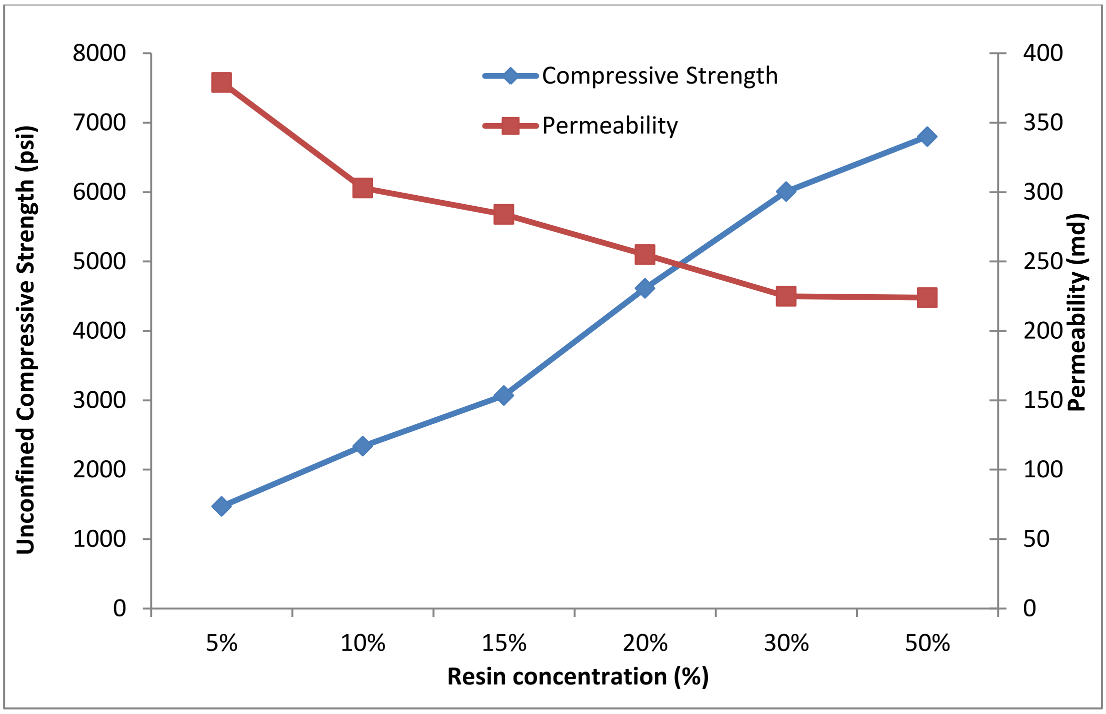


Figure 4.7 — Unconfined Compressive Strength and Permeability vs. Resin Concentration

4.1.3 Effect of Resin Coated in Solid Production in Gravel Packing Application

Resin coated silica sand is prepared with different resin concentration and tested under gravel packing application by High Temperature High Pressure vessel. Figure 4.8 shows the comparison between the pure sand gravel pack and resin coated silica sand gravel pack. The deposited solid production in sand gravel pack is significantly lesser than one in resin coated silica sand pack, it is due to the fine particle from slurry invaded into and entered through the gravel pack. In resin coated gravel pack, only small amount of the fine particle is present after gravel pack test.

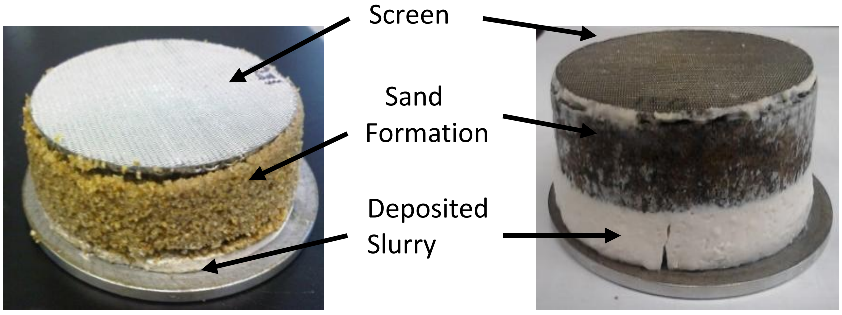


Figure 4.8 — Comparison between sand gravel pack and resin coated gravel pack.

The fines from slurry will mobilized with minimum amount of flow through the gravel pack (Tiffin, 1998). In this experiment, the maximum acceptable value of solid production is recommended to be 0.12 pounds of produced formation sand per square foot of screen inflow area in unit of lbs/ft (Hodge, Constien, Skidmore, 2002). Solid production is reduced in resin coated sand pack because the pore spaces inside the pack will trap fine particle. The resin coating will keep the fines from migrating through the proppant pack and reduces the amount of solid production (Terracina, 2010).

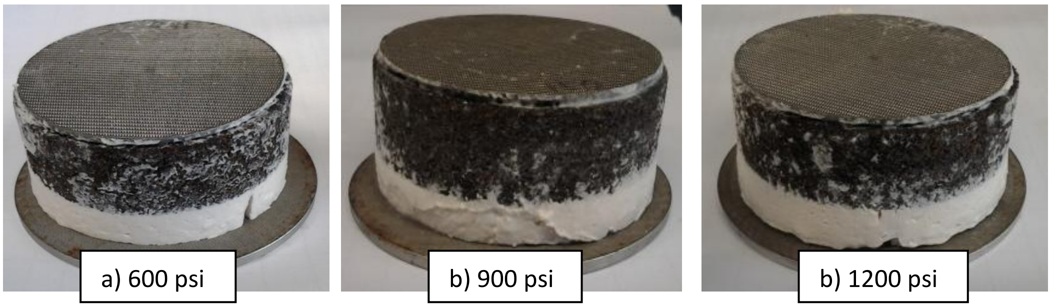


Figure 4.9 ─ 15% of resin coated with different pressure in gravel packing application.

Figure 4.10 shows the solid production of different resin concentration and closure stress. All samples meet the requirement of less than 0.12 lbs/ft^2 of solid production. Different resin concentration and closure stress will affect the solid production. In term of average solid production, the higher closure stress is the lower of solid production. Sample with 5 % resin concentration show the highest of solid production where 20% resin shows the lower solid production. This is because, the migration of fine particle into the gravel pack was minimal and very little particle was collected on the downstream filter.

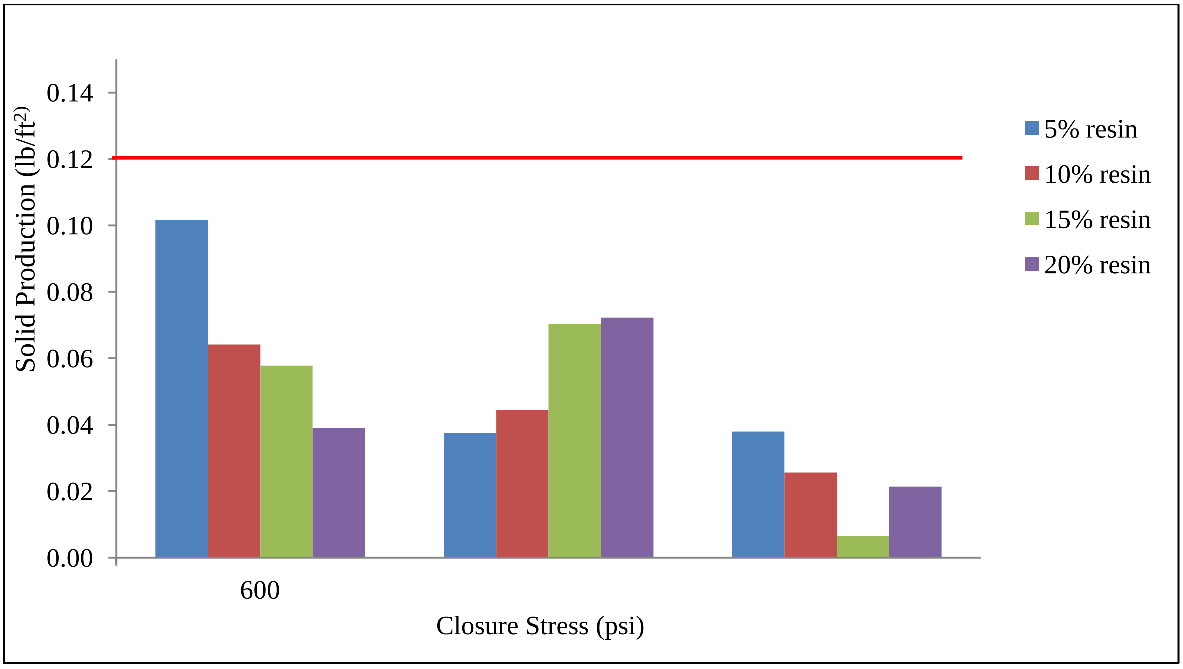


Figure 4.10 ─ Solid Production of different % resin coated and closure stress (psi).

Figure 4.11 show the comparison of solid production in resin coated silica sand and pure sand (Sample 1). Sample 1 produced more than 0.12 lbs/ft^2 of solid production and did not meet the requirement. It illustrates that the resin coated silica sand can reduce a significant amount of solid particle comparing to pure sand without resin coating.

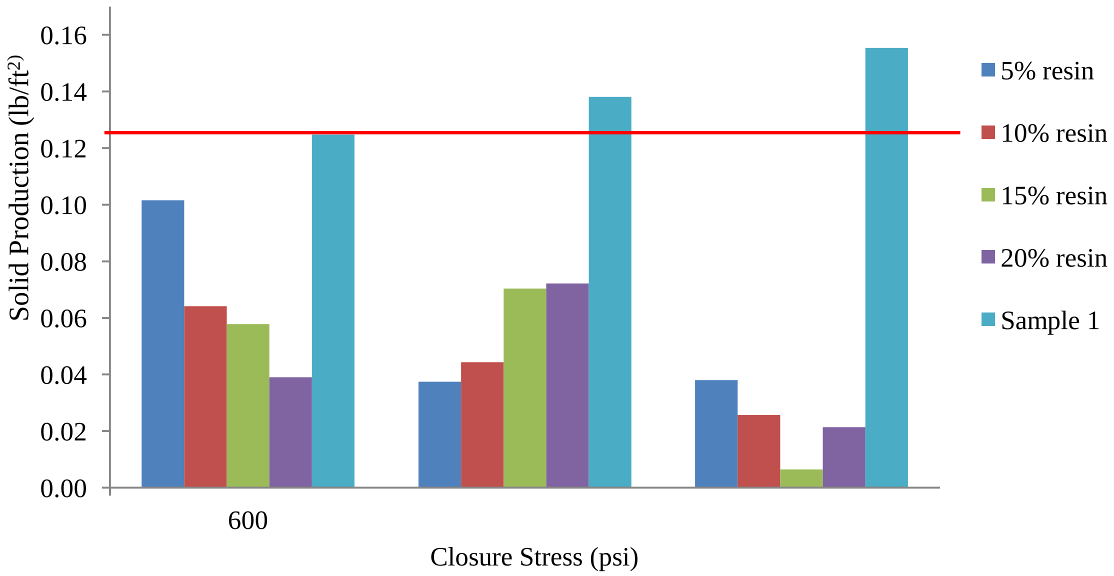


Figure 4.11 ─ Comparison of solid production of different % resin with 30/80 sand (Sample 1).

CHAPTER 5

CONCLUSIONS & RECOMMENDATIONS

It's important to determine the properties and performance of proppant using in sand control application in order to ensure the effectiveness and efficiency of the application applied. Porosity, permeability, compressive strength and solid/fines production are the most general information to test properties and performance of proppant. Moreover, these properties and performance can be affected by many factors such as temperature and pressure of formation.

The study of resin coated local silica sand for sand control application has been successfully conducted for range of samples in different resin concentration from 5% to 50% by weight of silica sand. The objectives of the study are fully achieved.

Resin concentration shows the significant role in the change of physical data and performance of all samples. Even though resin coating reduces the permeability and porosity of sand pack, it greatly increases the strength. All samples of resin coated silica sand meet the standard requirement for gravel pack application investigated in the present study. Therefore, the resin coated local silica sand might be commercially used as proppant in sand control application i.e. gravel packing.

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