Characterization of Local Sands for Possible Use as Proppant

by

Nor Emie Akmal binti Suhaimi

Dissertation submitted in partial fulfillment of
the requirement for the
Bachelor of Engineering (Hons)
(Mechanical Engineering)

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the Mechanical Engineering Program
Universiti Teknologi PETRONAS in partial fulfillment of the requirement for the
Bachelor of Engineering (Hons)(Mechanical Engineering)

Approved by,

AP Dr. Ismail Mohd Saaid

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
November 2008

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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ABSTRACT

This paper presents results on literature and experimental works on Malaysia local sands for the possible use as proppant. Proppant is a granular substance that is pumped into the formation by the fracturing fluid and helps keep the cracks open after a fracture treatment. In Malaysia, proppant used during the hydraulic fracturing are imported from foreign countries such as United States and Canada. This situation may lead to the increase of the well stimulation cost.

This project is to study characteristics of various types of local sands for the possible source of proppant. The study focuses on characterizing and data gathering using several available testing and in accordance with American Petroleum Institute (API) standards. Sand samples taken from several locations were subjected to several testing and analyses such as particle size distribution, crush resistance, density and porosity determination, mineralogy analysis, photomicrograph and permeability test to determine their special characteristics. These experiments involved major equipments like Scanning Electron Micrograph, X-Ray Diffraction, X-Ray Fluorescence, Auto Pallet machine, MAZAK CNC Integrex – III 5X and Ultrapycnometer 1000 Version 2.2. All the experiments followed closely the requirements set by American Petroleum Institute. However, some procedures were modified to suit the condition of equipments.

The results obtained from the present study are then compared with the existing characteristics of sand based proppant in the market. Even though the local sands cannot surpass the typical sand based proppant at certain characteristics, they do show promising results and meet some of the API- RP 56 requirements. Several recommendations are included in this report for improvement.

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ABBREVIATIONS

API American Petroleum Institute

ASTM American Standard Measurement

CNC Computer Numerical Controlled

PTTC Petroleum Transfer Technology Council

RC Resin Coated

SEM Scanning Electron Microscopy

SPE Society of Petroleum Engineer

UTP Universiti Teknologi PETRONAS

XRD X-Ray Diffraction

XRF X-Ray Fluorescence

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND STUDY

Thousands of wells per year have been stimulated by hydraulic fracturing technique since its first commercial introduction in 1949 due to its popularity in high success ratio (SPE, 1990). Hydraulic fracturing requires a propping agent, called "proppant" to maintain the crack from closing.

SPE also reported that the best proppant have to be combined with the fluid, good design plan and the right equipment for worthwhile well stimulation. A good proppant selection will determine how successful the stimulation treatment can be. Still, it is also largely dependent on the money invested since better characteristics of proppant come with higher price.

Generally made from sand, ceramic particle or bauxite, proppant is usually follow a certain standards set by the American Petroleum Institute (API). The standards recommend several numbers of practices in order to control the proppant quality to be used in hydraulic fracturing operations.

Currently, proppant is commercially produced outside Malaysia, especially in United States and Canada. This situation exposes the well stimulation cost to risk of unsecured supply and fluctuation in the exchange rate. Locally produced proppant, as alternative, could overcome these problems. Up till today, there is no local proppant supplier and manufacturer in Malaysia.

In proppant industry, natural based proppant is made of high purity silica sand because of its physical properties. In Malaysia, silica sand plays a big role in the glass-making and local construction industry (Kwan, 2006).

1.2 PROBLEM STATEMENT

Currently, oilfields developers in Malaysia are experiencing expensive well stimulation cost with minimum of USD 20 million (Rach, 2008). One of the main items that play a major role in hydraulic fracturing and the most popular well stimulation process is proppant. In current Malaysia's oil and gas industry scenario, proppant is imported from various foreign countries around the world. This situation may be one of the reasons that contribute to the increased cost in well stimulation. Hence, it is hoped that the problem can be reduced by adding another alternative by producing local proppant. The application of local sands as the proppant may boost the Malaysia economic progress especially in sand industry and reduce the well stimulation cost as it will offer cheaper proppant than existing ones. So far, there is no studies have been conducted on local sands for the use as proppant. Hence, this project is meant to give a better insight about the characteristics of local sands for the possible use as proppant. However, a lot of studies need to be done in order to produce proppant that is competitive with current proppant products in market.

1.3 OBJECTIVES

Objectives of this project are:

1. To characterize local sands for possible use as proppant.
2. To identify various techniques for proppant characterization.
3. To compare local sand characteristics with existing proppant in market.
4. To perform proppant tests on selected local sands.

1.4 SCOPE OF WORKS

Generally, this project will be divided into several stages. In order to achieve the objectives, this project will be done according to time frame and planned schedule. Besides that, literature review is done to provide sufficient insight into the proppant and local sands. Several laboratory testing are also planned based on the information obtained from the literature review and later, the results obtained will be compared to the reference material. The scope of the study will also focus on the characterization of various local sands using several equipments available in UTP. Details on the experiments and equipments will be described in the later part of this report.

CHAPTER 2

LITERATURE REVIEW AND THEORY

2.1 PROPPANT IN HYDRAULIC FRACTURING

U.S Patent 4522731 defines hydraulic fracturing as well stimulation technique that is designed to increase the productivity of a well by creating highly conductive fractures or channels in the producing formation surrounding the well.

It involves two processes. First, fluid is injected into the well at a sufficient rate and pressure to rupture the formation thereby creating a crack or fracture in the reservoir rock. There after a particulate material called proppant is placed into the formation to "prop" open the fracture. Proppant is a granular substance that is carried into the formation by the fracturing fluid and helps keep the cracks open after a fracture treatment (Baker Hughes, 2008). Appendix 1 shows the process of hydraulic fracturing.

In order for well stimulation to occur, the propping agent must have sufficient mechanical strength to resist the closure stresses exerted by the earth. Insufficient strength of proppant to resist the earth's closure stresses may result of proppant damage and thereby reducing the permeability of the propped fracture.

Aside from that, proppant must also be inexpensive since large volumes of proppant are needed in a well stimulation treatment. A well for single hydraulic fracturing might require around 100, 000 to 500 000 lb of proppant (Rach, 2008).

2.2 SAND BASED PROPPANT OR FRAC SAND

Proppants come in various types; natural sand, ceramic particles, bauxite, lightweight and coated proppant are among the variety with each of them has their individual characteristics (Yew, 1997). This project is mainly focused on **natural sand based proppant.**

Despite all the significant amount of discussion and competitive wrangling in today's fracturing market over proppants, still, various types of sand remains as favourite for proppant used in hydraulic fracturing since its first introduced (Halliburton, 2008).

In general, sand based proppant or frac sand is used at net closure stresses below 6,000 psig and man-made proppants used at higher closure stresses. Proppant must adhere to strong rules and requirements by the American Petroleum Institute (API).

Halliburton in their website further describes that in current market there are two classifications of natural sand based proppant in fracturing treatments; "brown" sand and "white" sand.

API defines brown sand as grade "D" sand. This sand fits certain roundness and other several criteria that meet the "D" classification. White sand is usually known by more specific names like Ottawa and Jordan as well as names given by the supplier. White sand is classified by API as grade "E" sand and it provides the high chemical purity and good crush resistance.

Below are the examples of images of natural proppants that are currently available in market.

Figure 2.1: Example of Natural Sand Based Proppants

(Source: www.halliburton.com/public/pe/contents/Brochures/Web/H03562.pdf)

Ottawa and Brady sands represent approximately 90% of hydraulic fracturing sand used in the petroleum industry (Doundarov, 2008).

2.3 RELATIONSHIP BETWEEN PROPPANT SELECTION AND WELL DEPTH

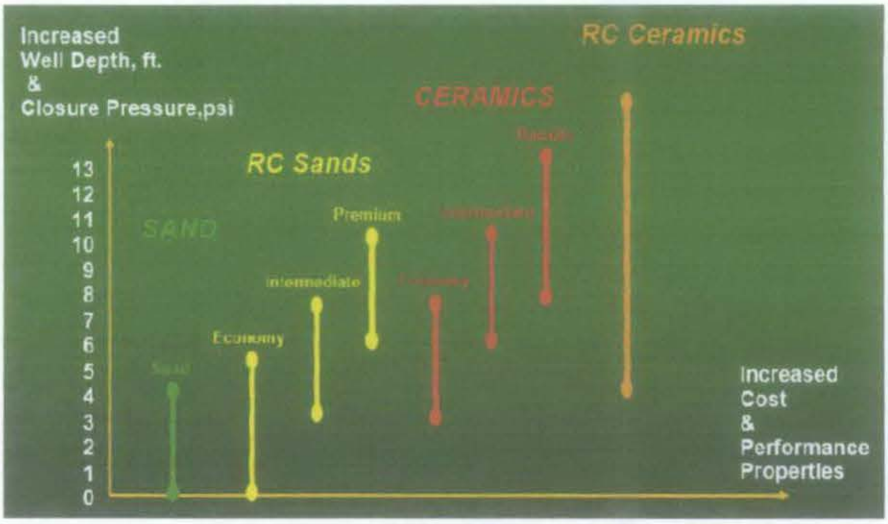


Figure 2.2: Relationship between Proppant Selection and Well Depth

(Source: www.garfield-county.com/module)

Figure 2.2 shows the relationship of proppant, well depth, closure stress, cost, and performance properties (Holcomb, 2006). Deeper wells experience high closure stress and need high performances that are obviously more expensive. Sand proppant with the lowest cost and properties is suitable for shallow well while RC ceramics; high performance man-made proppants are meant for deeper well.

2.4 CURRENT MARKET SCENARIO

Many different materials; either natural or synthetic are being used to prop open the hydraulic fracturing in oil and gas oils and increase the productivity (Yew, 1997).

According to Rach, Nina (2008), sand proppants comprise 83% of the total proppant market but now the competition is getting higher with the increased demand of ceramic proppants. Analysts from the Freedonia Group reported that the market for well-stimulation materials in the US will increase 7.7 % per year through 2008. Proppant will represent about 39% from the well stimulation market .Some analysts even said that "proppant will remain the largest segment and grow the fastest" at 9.5% per year, to reach $550 million by 2008 (Rach, 2008).

This shows that proppant manufacturing and supply is a fast growing industry. As operators are searching for ways to increase production from the existing wells, exploring tight reservoirs and drilling deeper well, they will increasingly turn to hydraulic fracturing that will be fuelling the market for proppant demands (Rach, 2008).

2.5 MAIN CHARACTERISTICS OF PROPPANT

2.5.1 Roundness and Sphericity

Proppants often described in term of roundness and sphericity (Kazi, 2007).

According to CarboCeramics (2008) with reference to API RP 56, **roundness** is a measure of the relative sharpness of the grain corner while **sphericity** is the measure of how closely a particle to a shape of a sphere. Roundness and sphericity often described based on the shape of the grain.

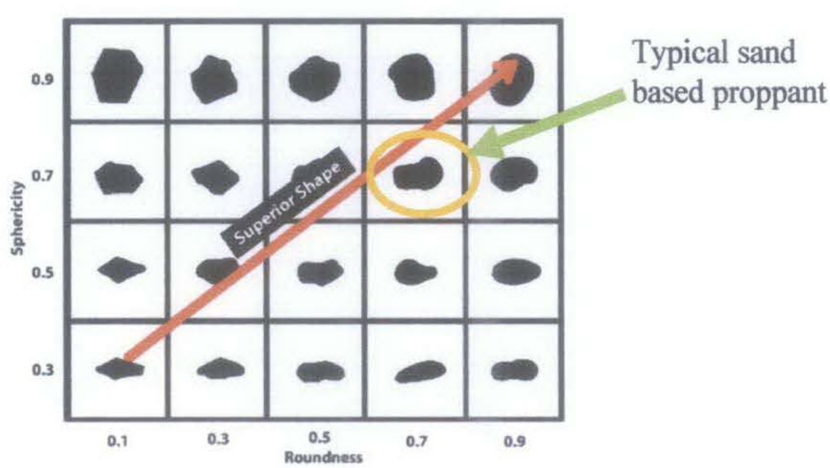


Figure 2.3: Krumbein Roundness and Sphericity Chart

(Source: www.carboceramics.com)

Figure 2.3 shows the Krumbein Roundness and Sphericity Chart that is commonly used in the oil and gas industry to determine the roundness and sphericity of proppant. Higher value of sphericity and roundness indicates higher quality of proppant (CarboCeramics, 2008). Usual sand proppant has typical values of 0.7 for both sphericity and roundness (Vincent, 2004). Improved roundness and sphericity will enable greater porosity and have fine production at higher closure stress as shown in Figure 2.4.

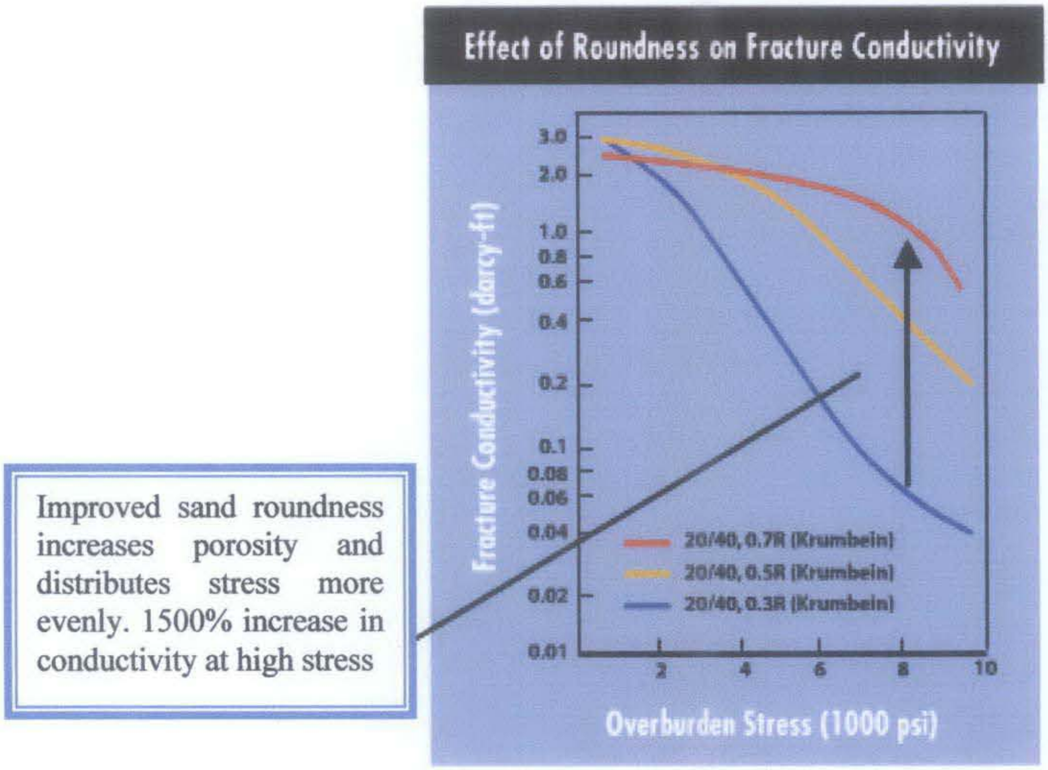


Figure 2.4: Effect of Roundness on Fracture Conductivity

(Source: www.carboceramics.com (Taken from Economides, Nolte: Reservoir Stimulation Monograph, after Steanson, et. al, 1979))

Researchers in 1970s have showed the importance of proppant shape upon fracture conductivity (Steanson *et al.*, 1979). Fracture conductivity is directly related to the permeability. At closure stresses below 2000psi, angular proppant shape provides adequate permeability compare with rounder sand grains. However, as the pressure increases, angular sand grain is more vulnerable to point loading and may lead to severe proppant damage (CarboCeramics, 2008). Rounder sand shows more promising result when it comes to higher closure stresses.

2.6.2 Proppant Size and Uniformity (Distribution, Sieve)

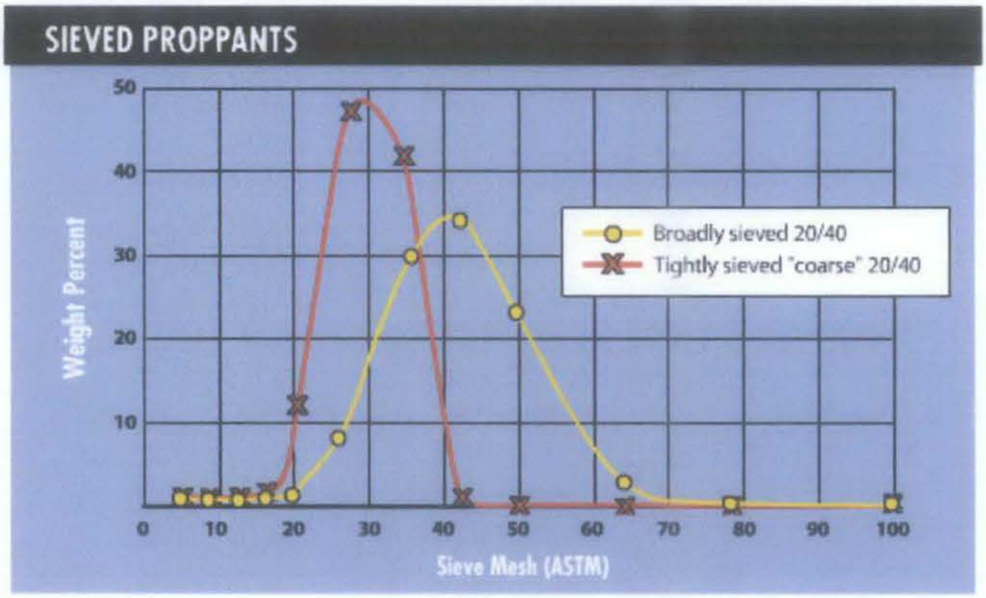


Figure 2.5: Particle Size Distribution

(Source: www.carboceramics.com)

Figure 2.5 shows the example of the particle size distribution. The arrow indicates the sieved proppant in range of 20-40 according to US Mesh size. Higher number of sieve mesh represents smaller diameter of proppant. Tightly sieved proppants represent a uniform proppant size with highly superior flow capacity and porosity. Coarse distribution at the other hand represent large diameter of proppant. Table 2.1 is the ASTM sieve series that is frequently used by the oil and gas industry (CarboCeramics, 2008).

Table 2.1: ASTM Sieve Series

(Source: www.carboceramics.com)

U.S Mesh	Sieve Opening	
	(in)	(mm)
2.5	0.3150	8.0000
3	0.2650	6.7300
3.5	0.2230	5.6600
4	0.1870	4.7600
5	0.1570	4.0000
6	0.1320	3.3600
7	0.1110	2.8300
8	0.0937	2.3800
10	0.0787	2.0000
12	0.0661	1.6800
14	0.0555	1.4100
16	0.0469	1.1900
18	0.0394	1.0000
20	0.0280	0.7100
30	0.0232	0.5890
35	0.0197	0.5000
40	0.0165	0.4200

The larger number of the mesh represents the smaller number of sieve opening.

2.6.3 Grain Strength

If a proppant is not strong enough to withstand closure stress of fracture, it will crush and permeability will be reduced greatly. Also, as reservoir pressure is reduced by fluid production, the closure stress will increase. Therefore, it is important that proppant strength be selected for the stress that will be present during the later life of the well.

2.6.4 Grain Size

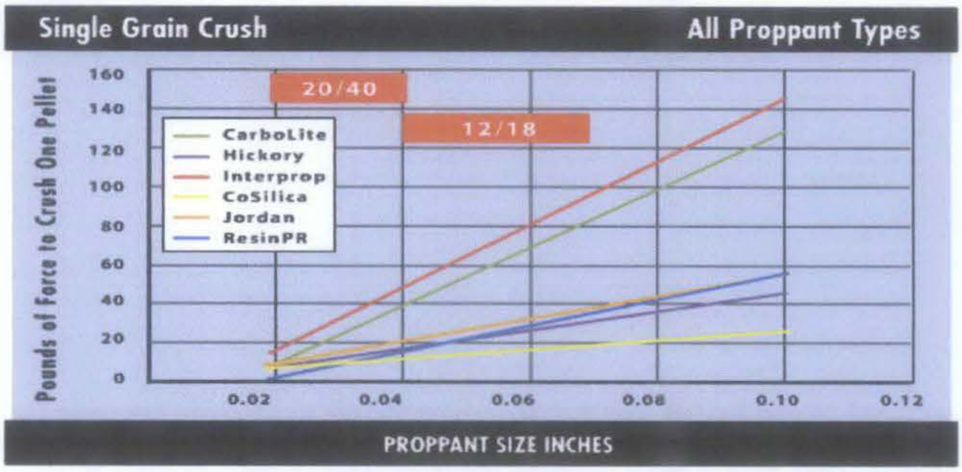
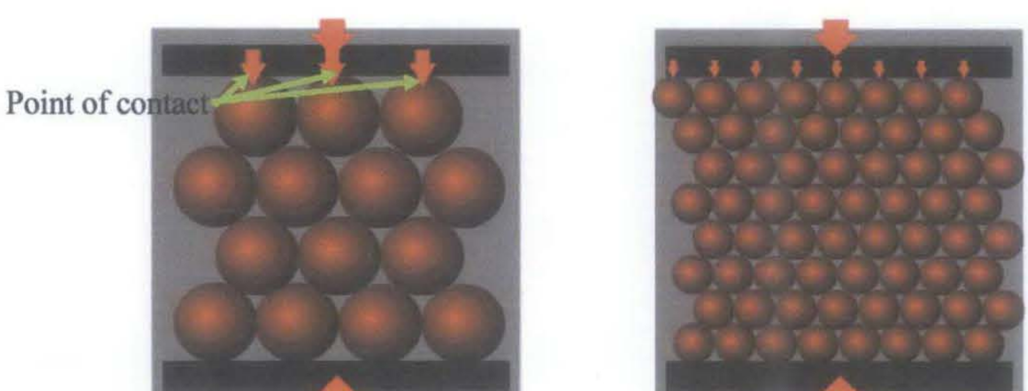


Figure 2.6: Single Grain Crush for All Proppant Types

(Source: www.carboceramics.com)

Based on figure above, regardless of the types of the proppant, larger size of proppant has greater individual strength if compare with the smaller ones. However, in higher closure stresses, effect of the particle size on permeability is reduced due to increased crushing of the larger proppant. Figure 2.7 will give a greater view about the reason.

Stress Stress



Stress Stress

Figure 2.7: Closure Stress Distribution for Different Sizes of Proppant

Figure 2.7 indicates that smaller proppant grains distribute closure stress over a greater number of contact points. It takes longer time for the smaller grains to crush compare with the larger grains. So, large-sized proppant is only significant for shallow wells that have low closure stress. However, as the stress increases, smaller grain-sized proppant is the better option.

2.6.5 Permeability and Porosity

Permeability is a measure of the ability of a porous media, in this case is sand to transmit fluids. Permeability is an appropriate criterion for extremely low velocity flow (CarboCeramics, 2008). Darcy's Law is only applicable for laminar flow that has lower Reynolds' number.

Darcy's Law:

$$q = \frac{kA}{\mu}\frac{dP}{dr} \quad \text{..........................} \quad (1.1)$$

Where,

A=area of cross-section, q= flow rate, k=permeability, P= pressure and μ=viscosity

Porosity is the measure of sand volume which is not occupied by solid particles. Porosity is affected by the uniformity of the particles. Rounder particles have higher porosity if compare with the angular ones.

According to US Petroleum Technology Transfer Council (PTTC) in their newsletter on 12 February 2008, permeability will reduce up to 60% with only 20% reduction of porosity. It is important to select the suitable proppants since porosity degrades with time due to proppant damage and fines production. PTTC also mentioned that larger proppants have higher rate of degradation.

2.7 AMERICAN PETROLEUM INSTITUTE RECOMMENDED PRACTICE (API – RP) 56

API recommended practices for measuring the properties of the proppant used in hydraulic fracturing are being followed by most of proppant suppliers in oil and gas industry to generate specification of their products to show the products reliability and quality performance. For sand based proppant, API – RP 56 is the recommended standard followed by most proppant suppliers. It consists of several criteria as mentioned by CarboCeramics and PanTerra in their website which are:

- Procedures recommended to obtain representative sample
  - It is recommended by API that sampling to be done at source-of-supply.
- Sample handling and storage
  - Importance of following the API practices during the proppant sampling and storage.
- Recommended sieve analyses
  - Implementation of the procedures recommended by the standard to evaluate the grain size of sand or proppant.
- Sphericity and roundness determination
  - Sphericity is a measure of how close sand grains approach the shape of a sphere. Roundness is a measure of the relative sharpness of grain corners or of grain curvature.
- Acid solubility
  - Indication of the amount of undesirable contaminants (carbonates, iron oxides, etc.) present in the sample.
- Turbidity measurement
  - Determination of the clay and soft particle content of the sand.
- Crush resistance testing
  - The crush resistance test is to measure the amount of produced fines under stress applied by the guidelines of the procedure.
- Mineralogical analyses
  - Determination of mineral contained in the proppant.

However, for this study some procedures are modified to suit the condition of the available equipments.

2.8 POSSIBILITY OF PRODUCING LOCAL SAND BASED PROPPANT

Dominant component of sand is quartz, which is composed of silica (SiO_2). However, it also contains other components like aluminium, feldspar and iron-bearing minerals. Silica sand or industrial sand constitutes high silica content and this sand is used for purposes other than construction.

Usually, the usage of industrial sand depends on several characteristics such as grain size, uniformity and strength. For oil and gas industry, silica sand can be used as proppant. At certain roundness and sphericity, it can be used to maximize permeability and porosity. Silica's hardness and its overall structural integrity can resist high pressures present in wells up to 2,450 meters deep (Kamar Syah Ariff, 2004). Also, its chemical purity can resist chemical attack at the reservoir condition.

According to Malaysian Geology website, in Malaysia, silica sand is mainly deposited in Johor beaches and several places in Selangor and Perak. Also, there is 54 million tonnes of high quality silica sand estimated reserve in Sarawak.

Malaysia Mineral and Geoscience Department (JMG) reported in their official website that typical high quality unprocessed local silica sand contains 97% to 99.9% of SiO_2; depends on its place of deposition. Local silica sand is able to replace imported raw material as it constitutes comparable quality with the imported ones. However, local silica sand is usually produced for glassmaking industry and construction with no evidence of any local proppant producer or supplier.

Appendix 2 shows the production of mineral commodities in Malaysia from year 2002 until year 2006. Malaysia produced around 512, 277 metric tonnes of silica sands (Kwan, 2006) which most of the production is mean for export and glassmaking industry. It is a good indication that Malaysia has abundant resource of silica sand which shows promising future to produce local silica sand as proppant.

2.9 SUMMARY OF LITERATURE REVIEW

Proppant is widely used in hydraulic fracturing; a well stimulation process means to increase the well production. Even after the introduction of ceramic proppant, frac sand; natural sand based proppant is still the world's largest demand. Most of the frac sand in market is high-graded silica sand that passed the minimum requirements set by the API standards for examples in term of grain size, sphericity, roundness and crush resistance. In Malaysia, silica sand is deposited in several places in Peninsular Malaysia and Sarawak. However, most of the silica sand produced is for export and glassmaking industry. So far, there is no local proppant supplier. Therefore, a final year project entitled "Characteristics of Local Sand for Possible Use as Proppant" is conducted to study the potential of local sand as proppant. This project will give benefit, not only to oil and gas industry, but also to local silica sand industry by utilizing local minerals.

CHAPTER 3

METHODOLOGY

3.1 PROJECT FLOW

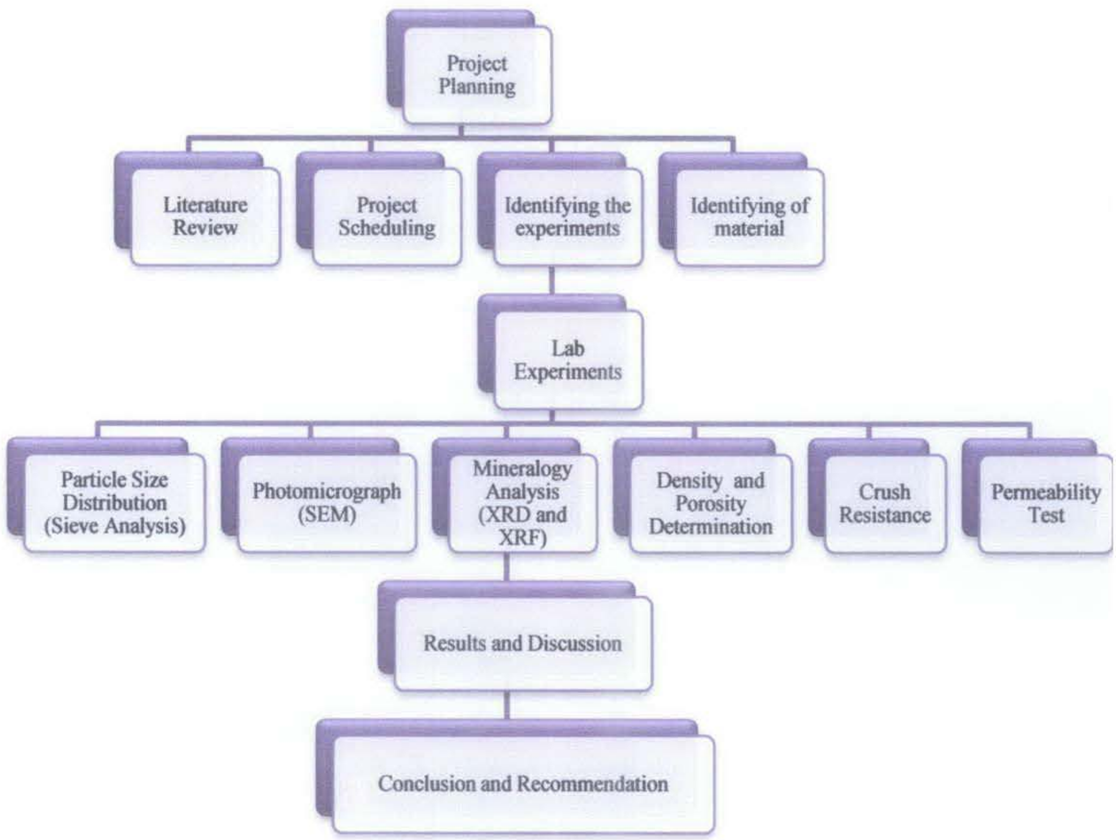


Figure 3.1: Project Flow Chart

Project timeline and execution plan for experiments are attached in Appendix 3.

3.2 MATERIALS

Several sand samples are taken from different places for this project. Below are the details:

Table 3.1: Types of Sand Samples

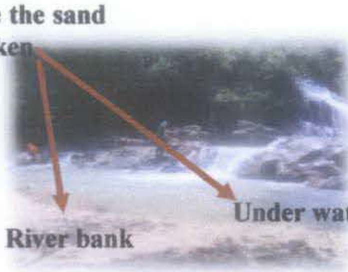
No.	Types of sand	Descriptions	Initial Observation
1	Mine Sand	A sand sample was taken from abandoned mine in front of UTP  	• White in colour • Homogenous
2	Silica Sand	A sand sample from silica sand mine located in Taman Maju, Tronoh  	• White in colour • Homogenous
3	a) River Sand (Under Water) b) River Sand (Bank)	Samples were taken from Lubuk Timah Waterfall (20 minutes drive from Gopeng) from 2 different locations: • From the river (underwater) • Near the river bank  	• Brown in colour • Heterogenous • River sand (bank) is coarser than river sand (under water).
4	River Sand (Supplier)	A sand sample from sand supplier in Tronoh *(Available sizes: -20/+40, -16/+30 US Mesh size)*	• Brown in colour • Heterogenous

Figure 3.2: Examples of Sand Samples

3.3 EXPERIMENTS

3.3.1 Particle Size Distribution (Sieve Distribution Analysis)

This experiment is to determine the particle size distribution of sand particles.

Equipment/Apparatus: Mechanical sieve shaker, drying oven, test sieves of different sizes (3.35 mm, 2.00 mm, 1.18 mm, 0.60 mm, 0.425 mm, 0.3 mm, 0.212 mm and 0.15 mm), tray, sieve brush, electronic balances and scoop.

Procedures:

- Oven dried sample is weighted (2kg per experiment).
- 8 numbers of test sieves are stacked on the mechanical shaker with the largest size test sieve appropriate to the maximum size of material present at the

bottom of the stack followed by the smaller size test sieves and a receiver at the bottom of the stack.

- The sample is placed on the top sieve and the sieve is covered with a lid.
- The test sieves are agitated on the mechanical sieve shaker for 5 minutes.
- The amounts retained on each of the test sieves are calculated.

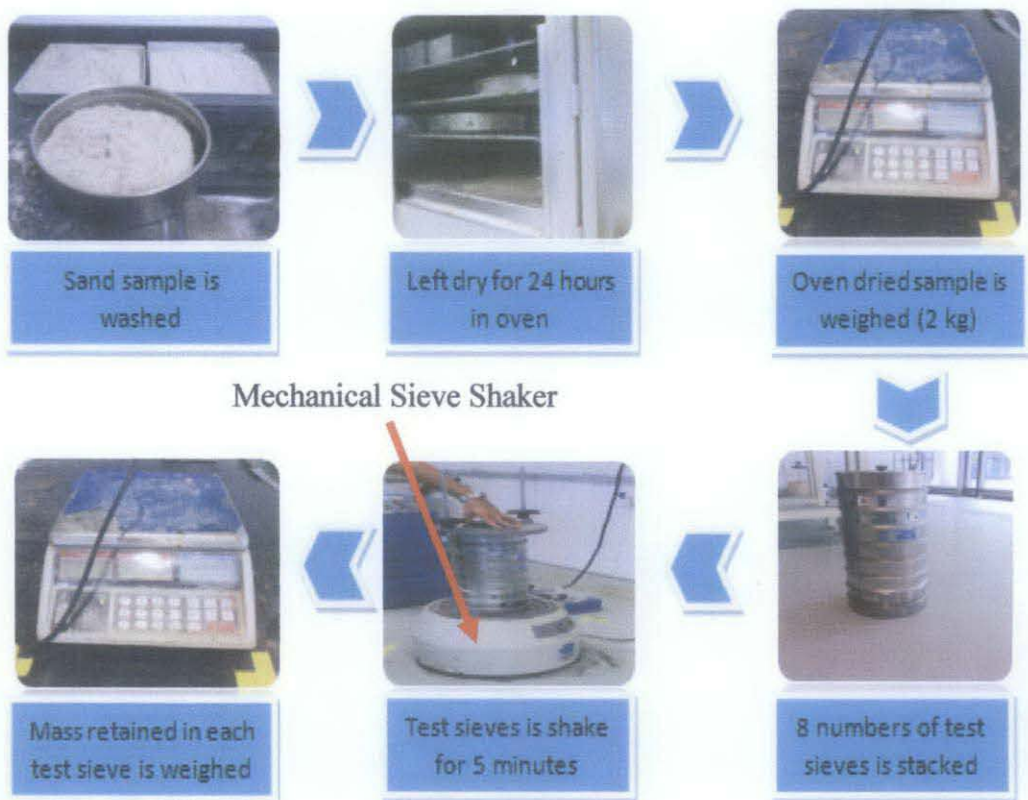


Figure 3.3: Particle Size Distribution Experimental Procedures

All the samples need to be oven-dried for at least 24 hours to eliminate all the moisture that may contribute to error during the sieving process. The sand sample provided by supplier in Tronoh is already sorted out. So, this testing is no longer needed for the sample.

3.3.2 Photomicrograph for Sphericity and Roundness Determination

This experiment is to determine the degree of roundness and sphericity of the samples.

Equipment/Apparatus: Scanning Electron Microscopy (SEM).

Figure 3.4: Scanning Electron Microscopy

The results are then compared with the Krumbein Roundness and Sphericity Chart (refer to Appendix 4) to determine the degree of roundness and sphericity.

3.3.3 Density Determination

3.3.3.1 True Density Determination

This experiment is to determine the true density of the sand samples.

Equipment/Apparatus: Ultrapycnometer 1000 Version 2.2 and electronic balance.

Figure 3.5: Ultrapycnometer 1000 Version 2.2

Description: During the setup, weight of the sample and number of runs need to be entered. All samples are run for 5 times for more accurate and precise results. The results are automatically calculated.

3.3.3.2 Bulk Density Determination

The bulk density of the samples is determined using the graduated cylinder method.

Equipment/Apparatus: Electronic balance and graduated cylinder.

Procedure:

- Sand sample is added to about 1 ml of a 10ml graduated cylinder.
- The sample is compacted by tapping the cylinder base on the palm of hand.
- 1 ml of sample is added again and compacted as above.
- The sample level as volume in cc (1ml = 1 cc) is recorded.
- The sample is weighted and recorded.
- The above steps are repeated for 3 times for each sample.
- Average value and bulk density for each sample are calculated using Equation 3.1.

$$\textbf{\textit{Bulk Density}} = \frac{\textit{Weight of dry sample(g)}}{\textit{Volume of dry sample (cc)}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.1)$$

3.3.4 Porosity Determination

This experiment is to determine the porosity of the sand samples.

Description: Using the same results of previous experiments of particle density and bulk density, porosity of the sands are measured using below equation:

$$\%\,\textbf{\textit{Porosity}} = \left(1 - \frac{\textit{Bulk Density}}{\textit{Particle Density}}\right) x\ 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots (3.2)$$

3.3.5 Mineralogy Analysis

3.3.5.1 X- Ray Fluorescence (XRF): Elemental Analysis

This experiment is to determine the mineralogy of the sand samples.

Equipment/Apparatus: X- Ray Fluorescence, compaction machine and grinder.

Description: XRF is used for elemental analysis of many samples. Omega Physics in their website mentions that XRF has advantage as it is non-destructive, multi-elemental, fast and economical if compare to other competitive techniques, such as Atomic Absorption Spectroscopy (AAS), Inductively Coupled Plasma Spectroscopy (ICPS) and Neutron Activation Analysis (NAA). For information, the samples need to be compacted in pallet before the analysis can be conducted.

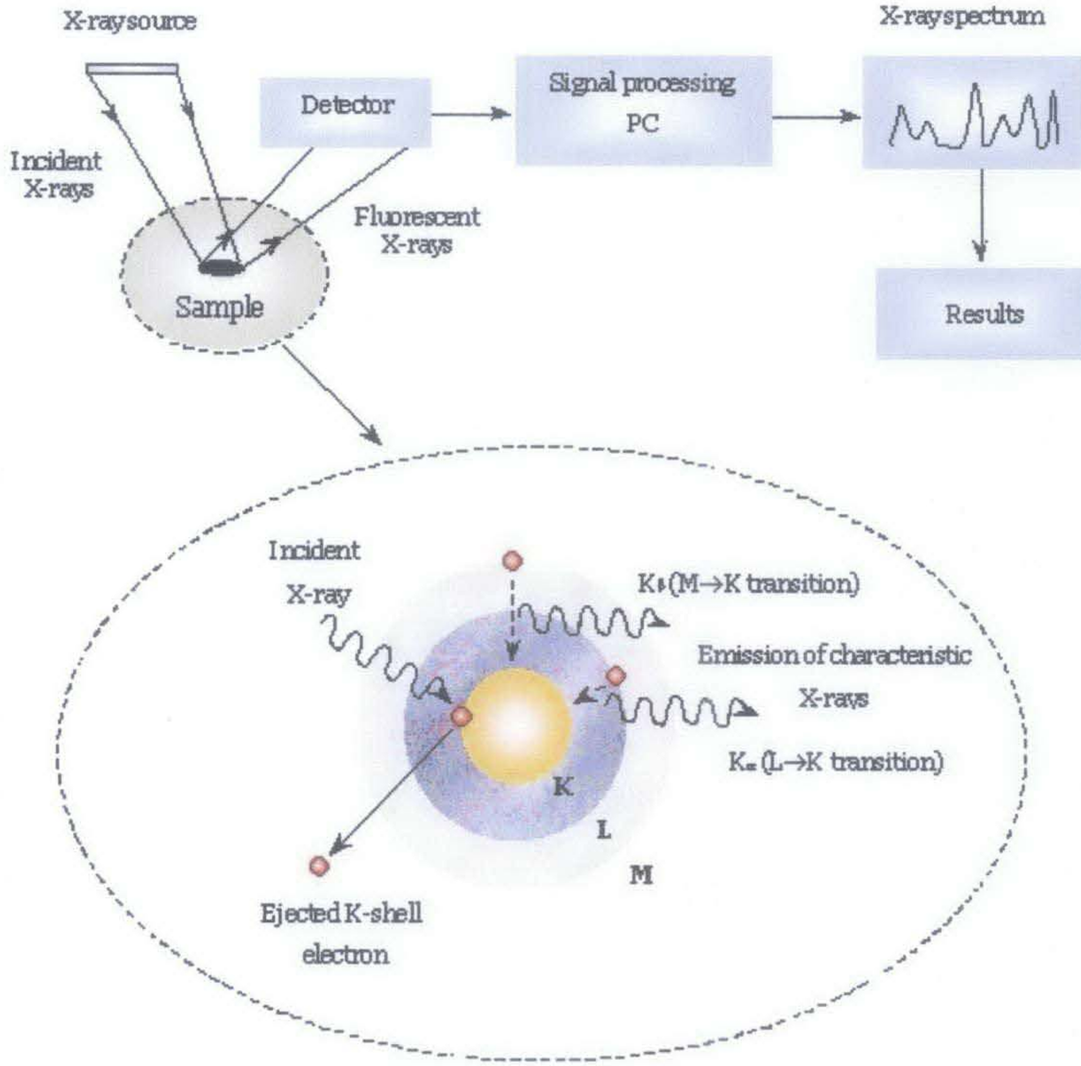


Figure 3.6: Basic Principle of XRF

(Source: http://omega.physics.uoi.gr/xrf/english/the_xrf_technique.htm)

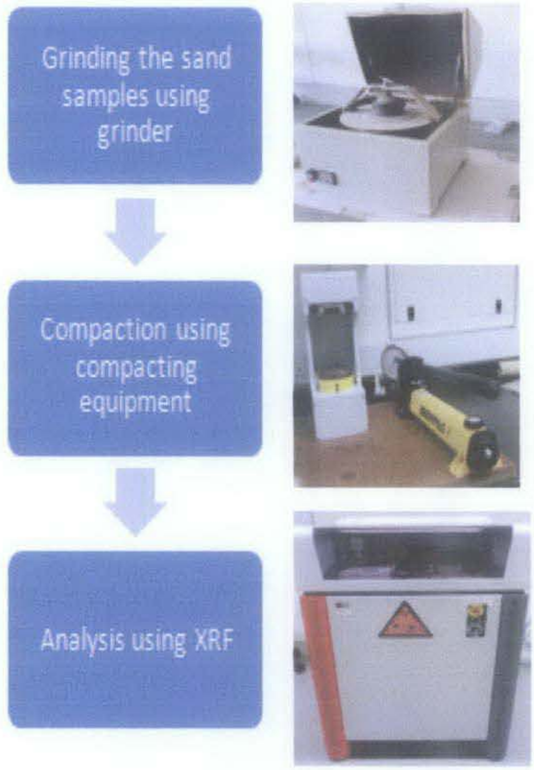


Figure 3.7: Process Flow for XRF Elemental Analysis Sample Preparation

3.3.5.2 X-Ray Diffraction Analysis

This experiment is to trace the presence of silica dioxide, SiO_2 in the samples.

Equipment/Apparatus: X-ray Powder Diffraction (XRD) and grinder.

Description: X-ray powder diffraction (XRD) is a rapid analytical technique primarily used for phase identification of a crystalline material. For this project, the XRD is used mainly to trace the presence of silica in the sample to confirm the XRF results. XRD only requires minimal amount in the powder form. Like XRF, the sand need to be grinded into powder first before the analysis can be conducted.

3.3.6 Crush Resistance Determination

API procedures for measuring proppant crush involve loading a pre-set volume of proppant into a **crush cell** that has a floating piston. When placed in a crush press the piston applies a direct load onto the proppant grains.

3.3.6.1 Crush Cell Manufacturing

Equipment/Apparatus: MAZAK Integrex 200-III 5x CNC Lathe machine.

Description: A special crush cell is designed for the crush resistance testing. MAZAK Integrex 200-III 5x CNC Lathe machine is used for better accuracy and precision if compare with the conventional CNC Lathe machine.

Figure 3.8: Mazak Integrex 200 – III 5X

The crush cell is divided into three main parts which are the plunger, mould and base and is made using steel. Detail design of the crush cell components are attached in Appendix 5.

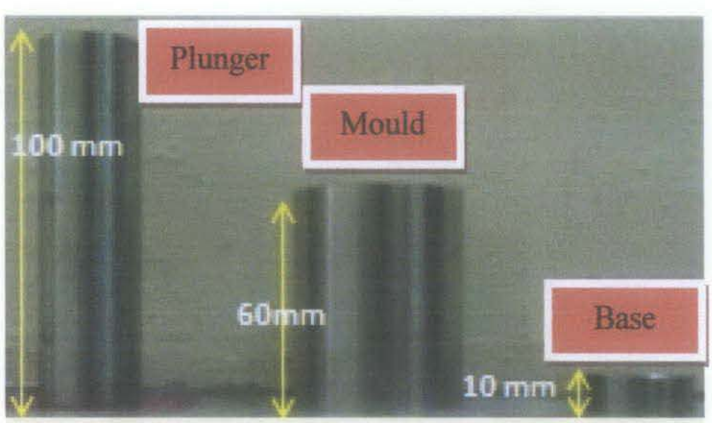


Figure 3.9: Front view of crush cell components

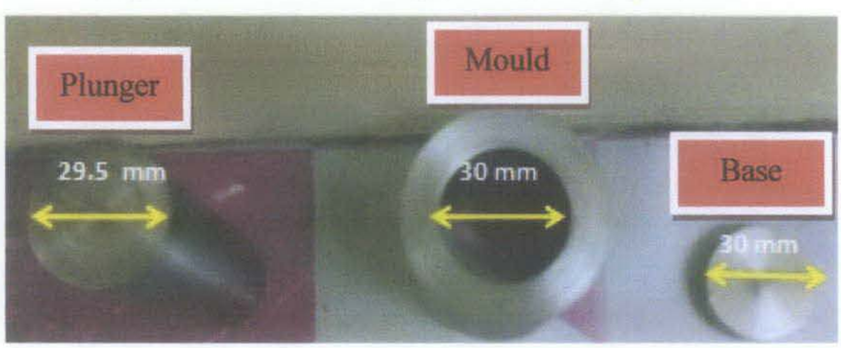


Figure 3.10: Top view of crush cell components

3.3.6.2 Crush Resistance Testing

This experiment is to determine the crush percentage of the sand samples under specified stress.

Equipment/Apparatus: Auto Pallet Press machine and automatic balance.

Description: 4 lb/ft^2 or equal to 1.95g/cm^2 of proppant is loaded into the crush cell, holding the required stress for 2 minutes, and then measuring the weight percentage of crushed material that falls below the lower mesh size. 2 different sizes of sand particles are used (-20/+40 and -16/+30 US mesh sizes) at 5 different stress level; 1000 psi, 2000 psi, 3000 psi , 4000 psi and 5000 psi.

Procedures:

- Proppant is sieved within the specified range (e.g. -20/+40).
- Crush cell is filled to a concentration of 1.95g/cm2 of cell.
- A uniform loading rate is applied to the cell to reach the desired stress level
- The stress is held for 2 minutes before released.
- Material is sieved again as mentioned above.
- The amount of the crushed material is calculated as percent weight of proppant smaller than specified range.

API size specifications allow up to 10% of the material outside the given range.

Figure 3.11: Auto Pallet Press Machine

3.3.7 Constant Head Permeability Testing

This experiment is to determine the coefficient of permeability of sand samples using Constant Head Method.

Equipment/Apparatus: Permeameter cell, reservoir tank, manometer set, filter, measuring cylinder, thermometer and stop watch.

Description: Permeability of sand is a measure of its capacity to allow flow of liquid; in this case water through the pore spaces between solid particles. The degree of permeability is determined by applying a hydraulic pressure gradient in sample of saturated sand and measure the consequent flow. The coefficient permeability is expressed as a velocity. The flow of water for this experiment using constant head permeameter is laminar. The volume of water passing through the sand sample in a known time is measured, and the hydraulic gradient is measured using the manometer tubes.

Procedures:

- The internal diameter of the permeameter cell is measured.
- The distance between each manometer gland and the next along the same line is measured.
- Apparatus is assembled as Figure 3.13.
- The length of sample is measured and recorded.
- Control valve is closed.
- The supply valve is opened. At the same time, the manometer tube pinch cocks is opened one by one ensure that no air is trapped in the flexible tubing as water flows into the manometer tubes.
- The control valve at the base of the permeameter cell is opened to produce flow. The manometer measurements are taken once the water levels are stable.
- Measuring cylinder of suitable capacity is placed under the outlet of the discharge reservoir and the timer is started simultaneously.
- The time is recorded once the water reaches the desired level of the measuring cylinder.
- Temperature of the water in the discharge reservoir is measured.
- Experiment is repeated for 4 times for more accurate results.

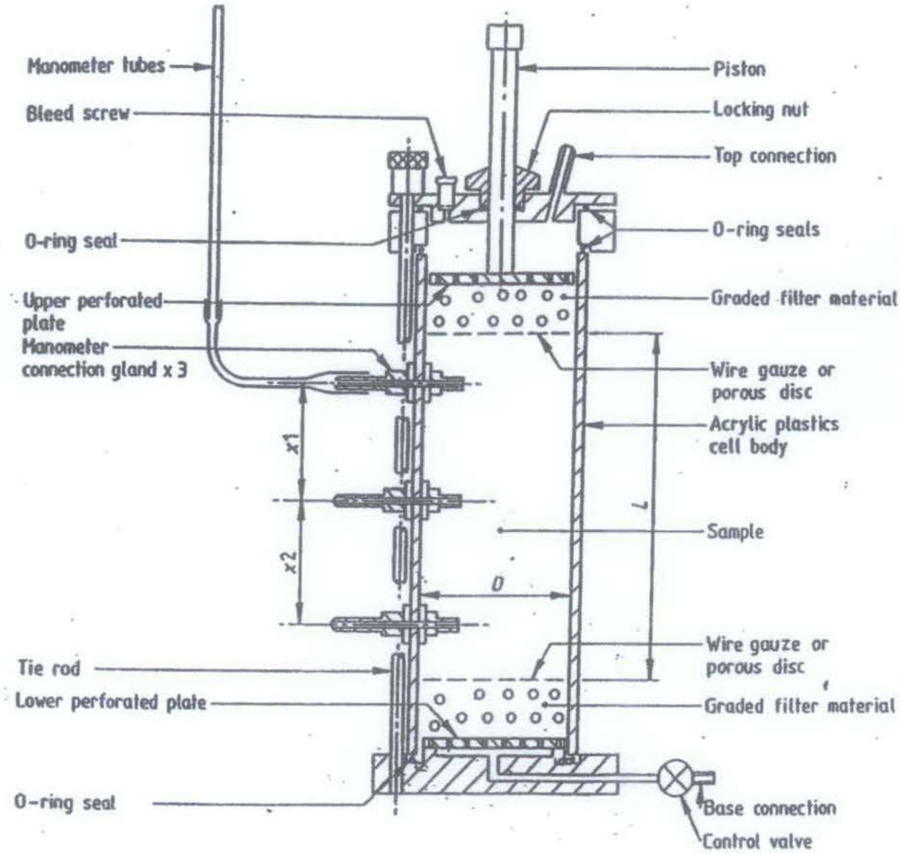


Figure 3.12: Permeameter Cell

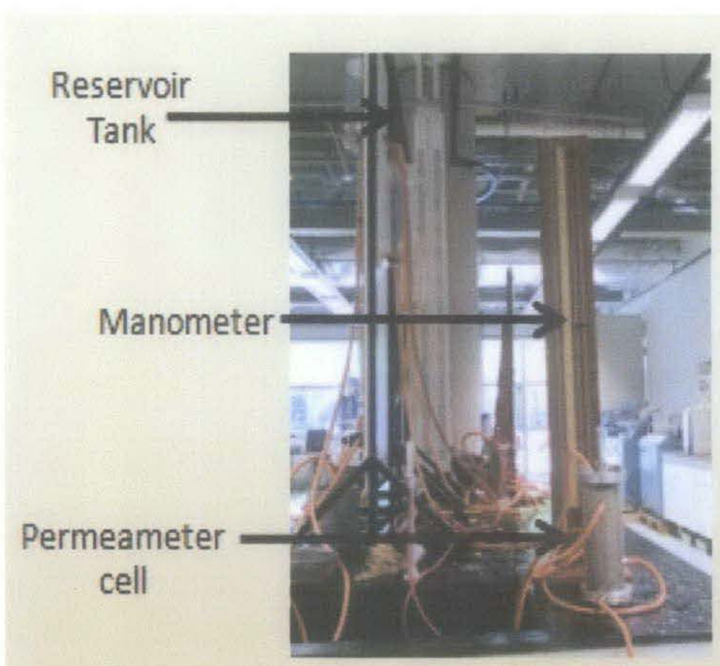


Figure 3.13: Apparatus Arrangement for Constant Head Permeability Testing

CHAPTER 4

RESULTS AND DISCUSSION

4.1 PARTICLE SIZE DISTRIBUTION (SIEVE ANALYSIS)

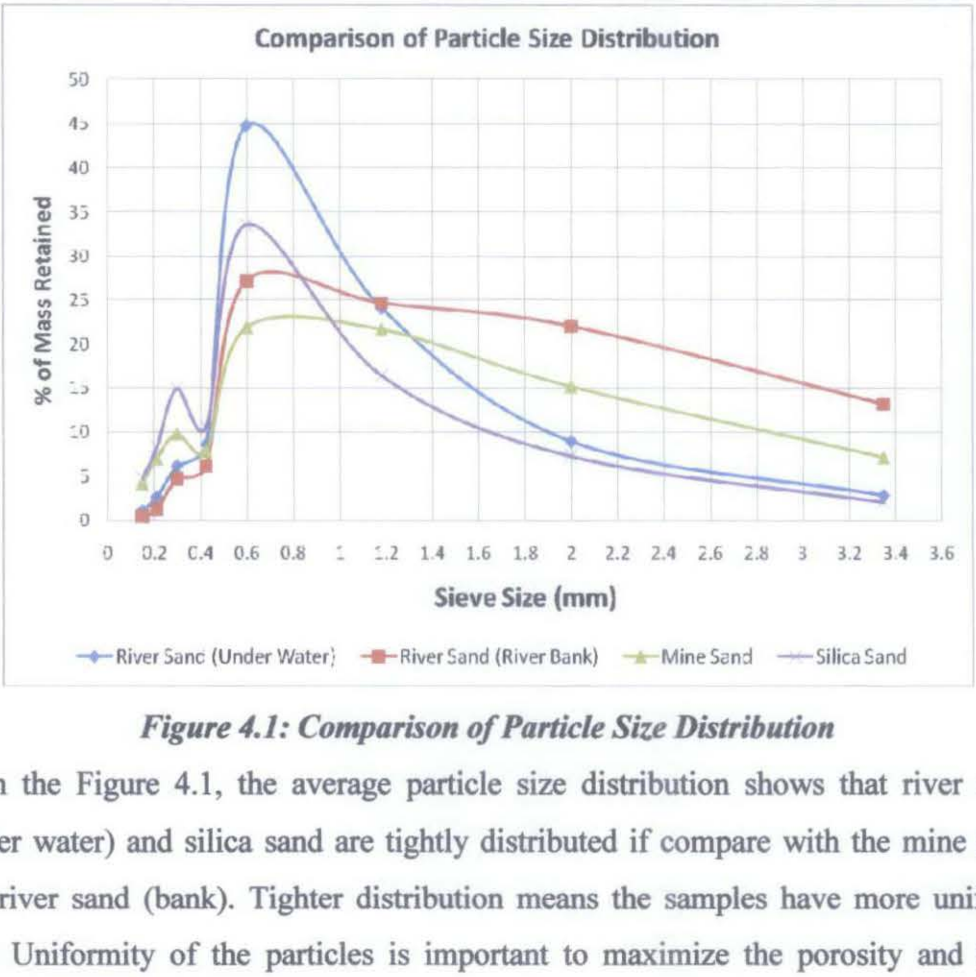


Figure 4.1: Comparison of Particle Size Distribution

From the Figure 4.1, the average particle size distribution shows that river sand (under water) and silica sand are tightly distributed if compare with the mine sand and river sand (bank). Tighter distribution means the samples have more uniform size. Uniformity of the particles is important to maximize the porosity and flow capacity of the samples.

However, unlike this project where the samples were taken from the sites without any initial sorting, in real industry application, the supplier will usually sort out the sand according to the size required. Only after that, the sands size distribution will be tested according to API specification for quality control. API specification requires a minimum of 90% of the tested sample should fall between the designated sieve sizes. Details of results are attached in Appendix 6.

4.2 TRUE AND BULK DENSITY

4.2.1Results of the True Density and Bulk Density

Table 4.1 shows the true density and the bulk density for each sand samples. True density is the mass per unit volume of sand particles while bulk density describes mass of sand particles that fills a unit volume, and includes both sand and porosity void volume (CarboCeramics, 2008). Details of results are attached in Appendix 7.

Table 4.1: Density of Sand Samples

Sand Samples	True Density (g/cc)	Bulk Density (g/cc)
1. Mine Sand	2.689	1.345
2. Silica Sand	2.7568	1.378
3. River Sand (Under Water)	2.859	1.430
4. River Sand (Bank)	2.8681	1.434
5. River Sand (Supplier)	2.7825	1.391

Mine sand has the lowest value of both true density (2.689 g/cc) and bulk density (1.345g/cc). Both properties are measured without closure stress, so the bulk density will increase substantially if the proppants crush or if pack rearrangement results in loss of porosity.

Bulk density for local sand samples is then compared with available sand based proppant in market, Ottawa Sand and Brady Sand. Brady sand and Ottawa sand are the typical sand based proppant that are used in hydraulic fracturing.

Table 4.2: Comparison of Bulk Density between Local Sands and Typical Sand Based Proppant

(Data for Ottawa and Brady Sands are taken from: www.halliburton.com/public/pe/contents/Brochures/Web/H03562.pdf)

Sand Samples	Bulk Density (g/cc)
1. Mine Sand	1.345
2. Silica Sand	1.378
3. River Sand (Under Water)	1.430
4. River Sand (Bank)	1.434
5. River Sand (Supplier)	1.391
6. Ottawa Sand	**1.54**
7. Brady Sand	**1.57**

Based on the Table 4.2, local sands constitute lower bulk density if compare with Ottawa sand and Brady sand. Even though proppant is typically purchased by mass, the benefit of a proppant is based on its volume.

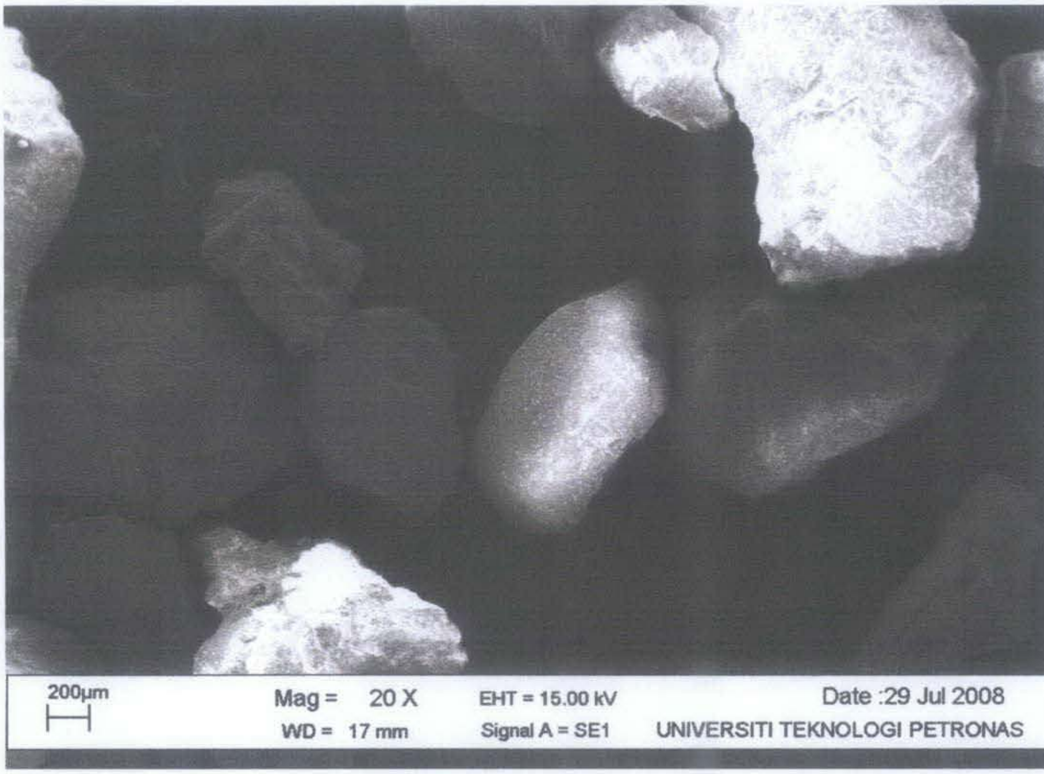
For example, it is apparent that a fracture containing 100 000 pounds of local mine sand will occupy more volume than a fracture containing 100 000 pounds of Ottawa sand. For typical hydraulic fracturing that are allowed the fracture to close on the proppant, the density of the proppant will significantly impact the achieved fracture width (CarboCeramics, 2008). Fracture width will be narrower with denser proppant.

4.3 SCANNING ELECTRON MICROSCOPY (SEM) ANALYSIS

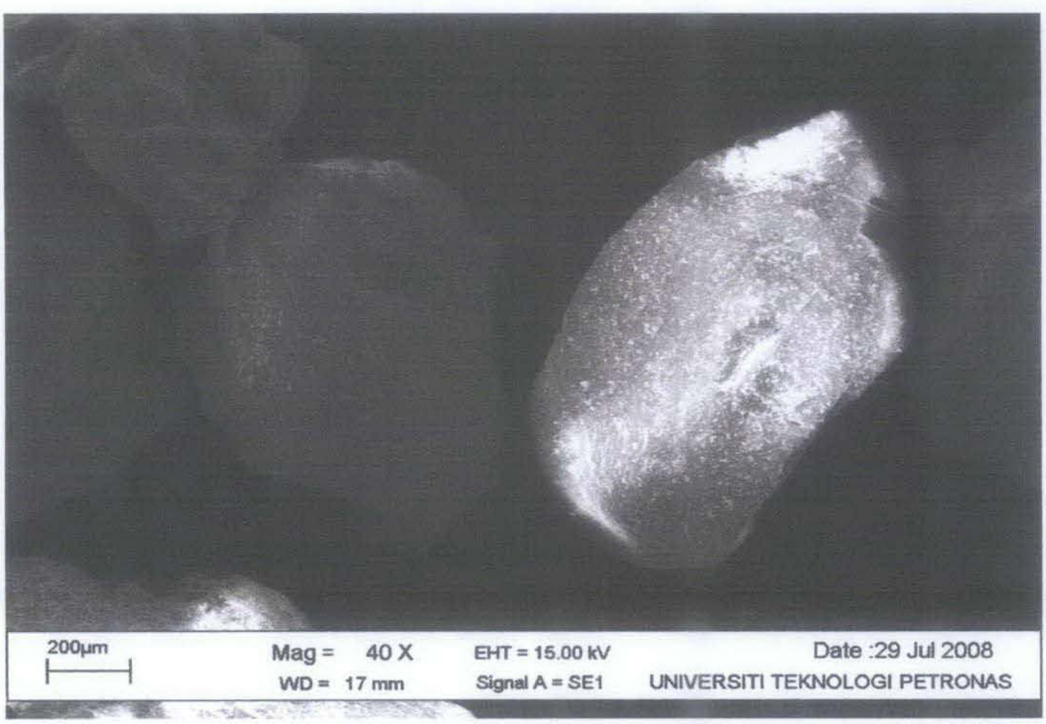
Table 4.3: Photomicrograph

1. Mine Sand

a) Mag: 20x

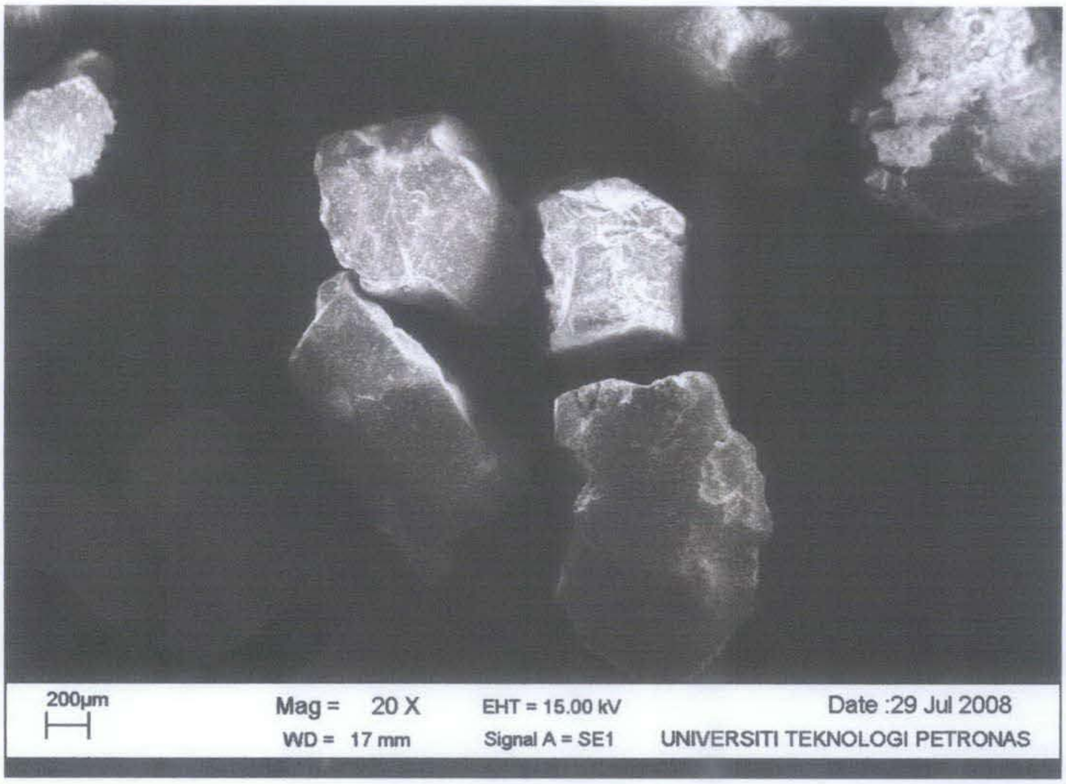


b) Mag: 40x

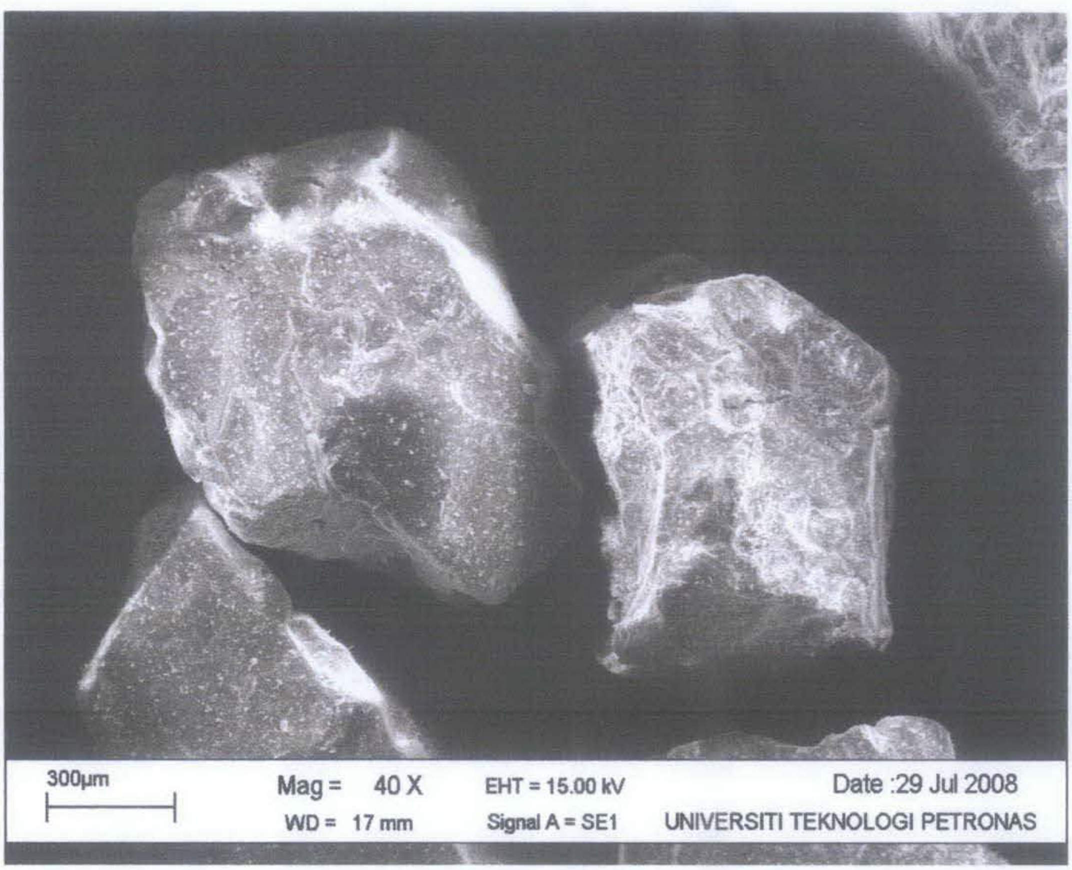


2. Silica Sand

a) Mag: 20x

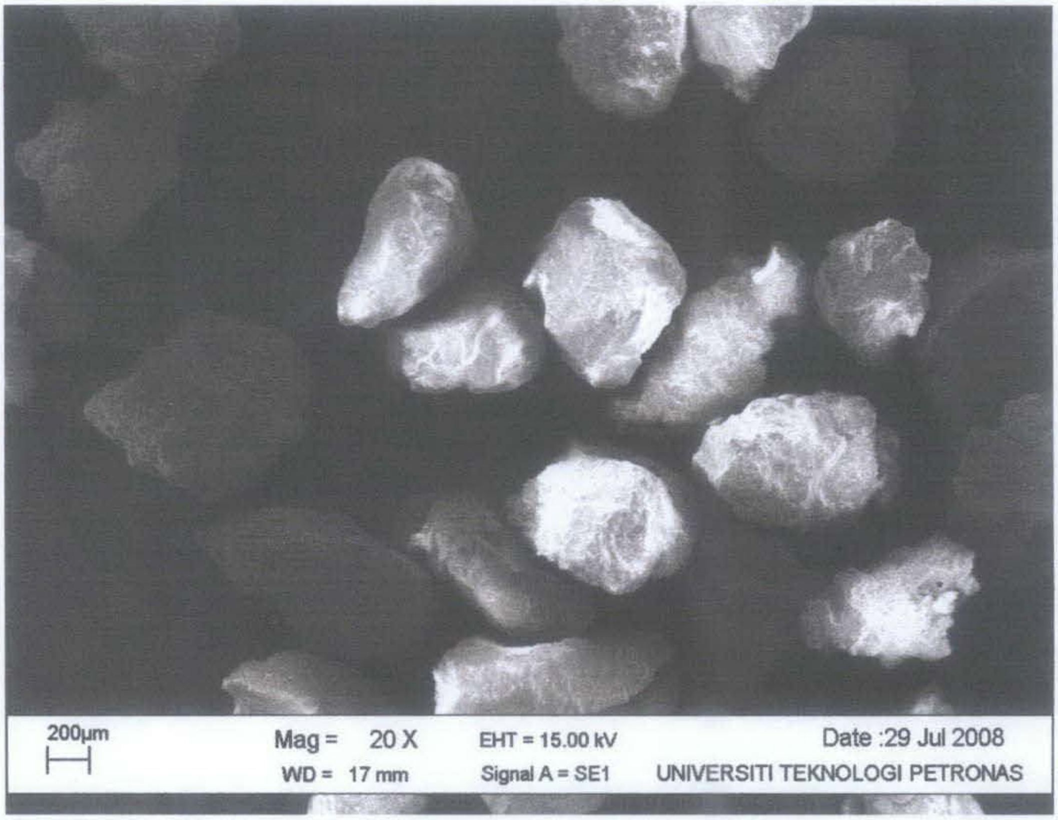


b) Mag: 40x

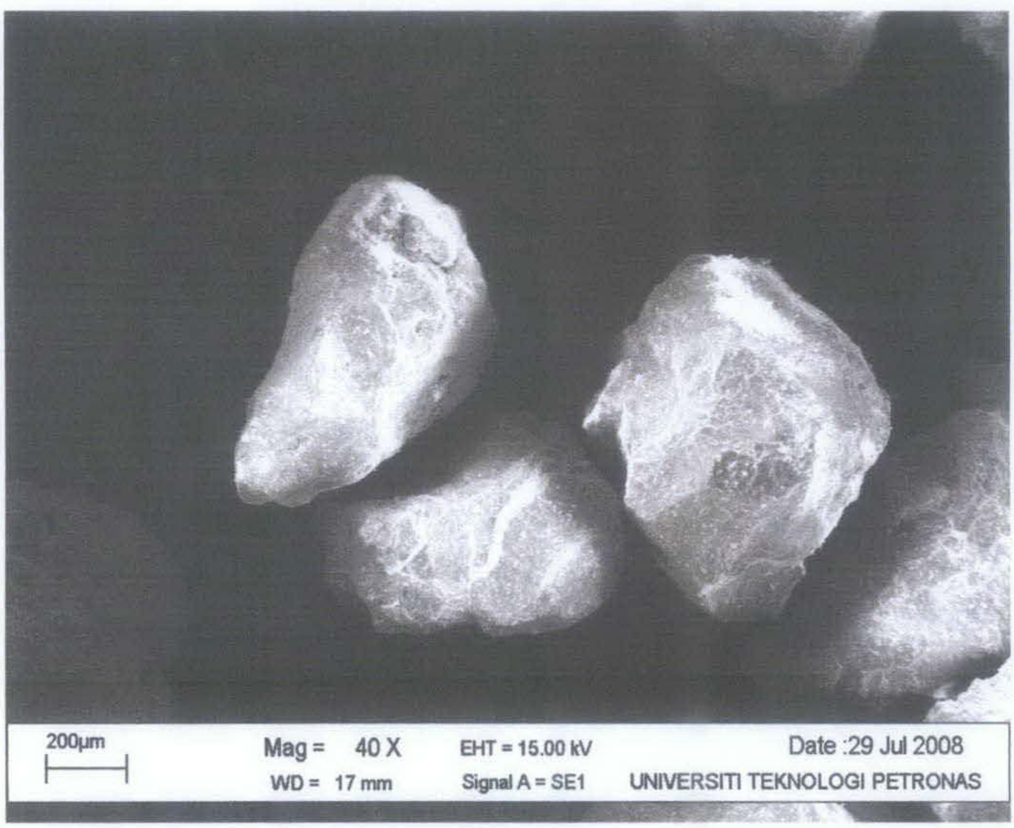


3. River Sand (Under Water)

a) Mag: 20x

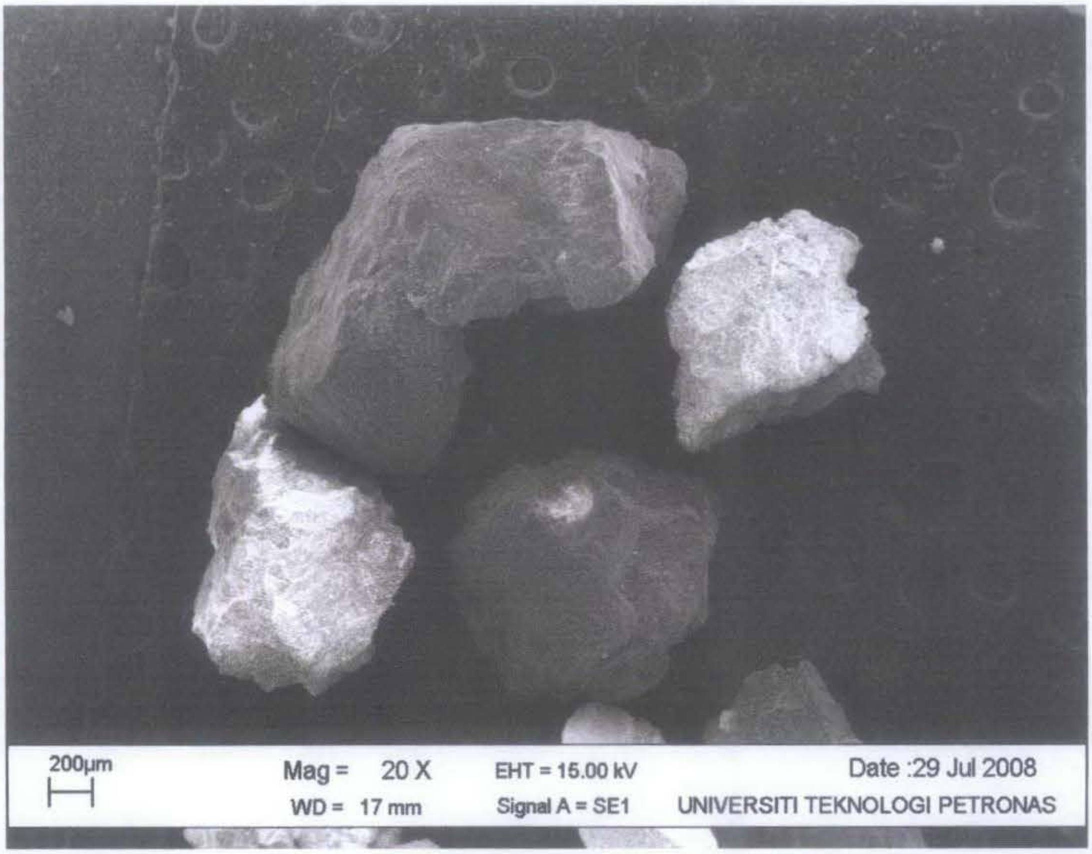


b) Mag: 40x

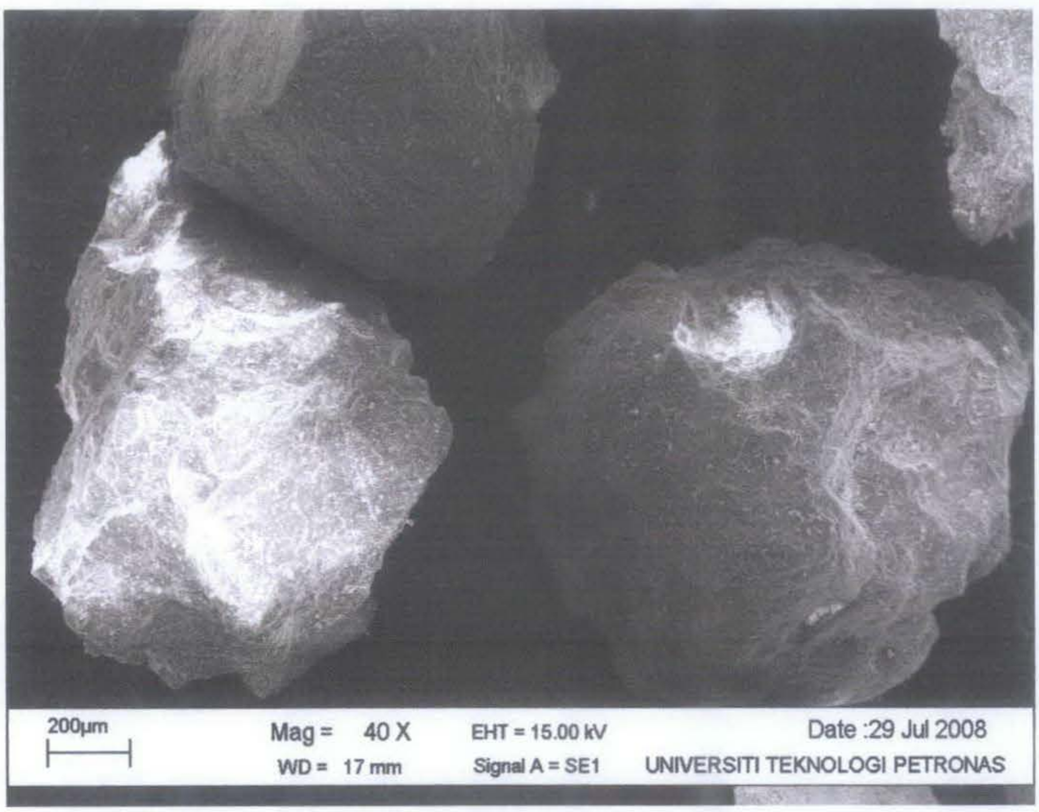


4. River Sand (Bank)

a) Mag: 20x



b) Mag: 40x



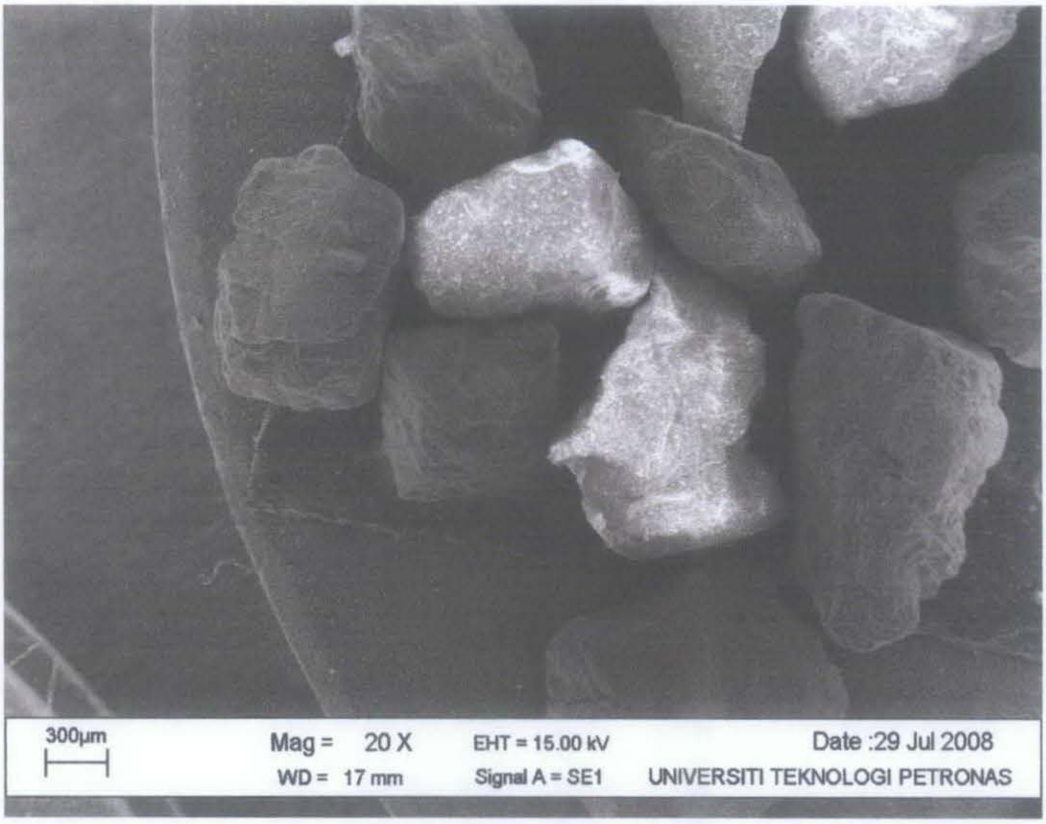
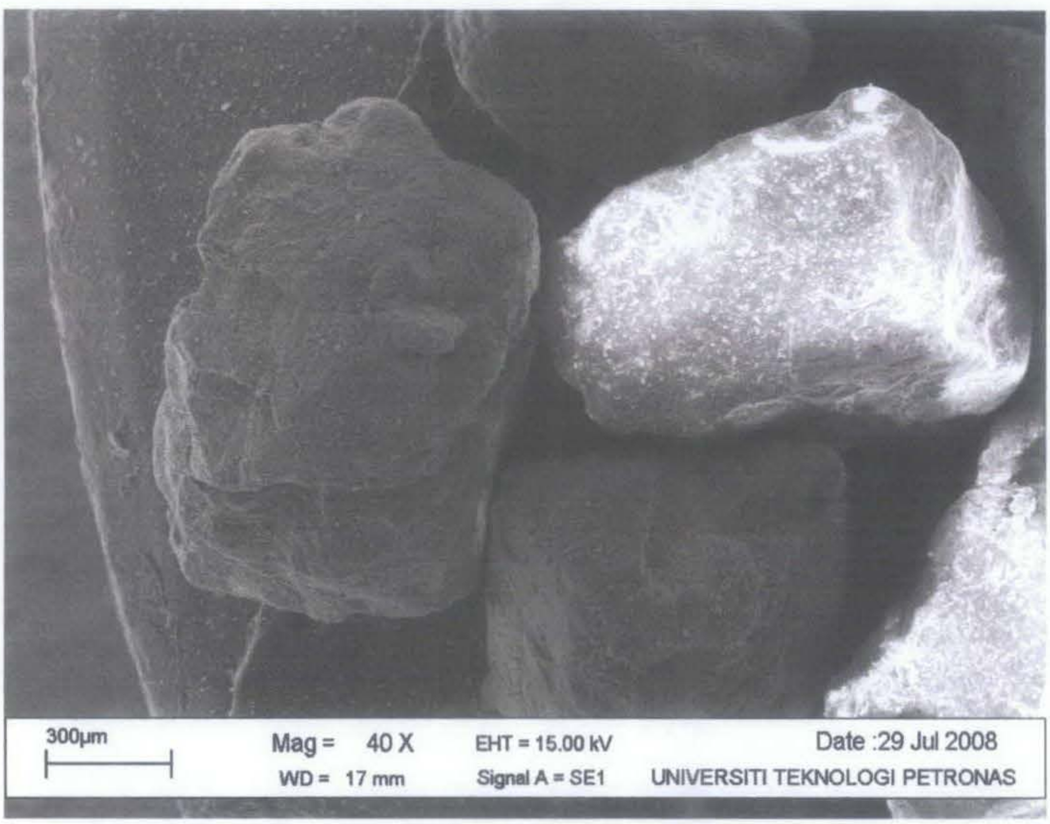
5. River Sand (Supplier)
a) Mag: 20x

b) Mag: 40x


Table 4.3 shows the photomicrograph of different sand samples using Scanning Electron Micrograph (SEM) with magnifying of 20x and 40x. From this photomicrograph, sphericity and the roundness of the sand particles can be determined and then to be compared with Krumbein Roundness and Sphericity Chart (refer to Appendix 4). Below are the details:

Table 4.4: Roundness and Sphericity Value of Sands

Sand Samples	Roundness (R)	Sphericity (S)
1. Mine Sand	0.5	0.7
2. Silica Sand	0.5	0.7
3. River Sand (Under Water)	0.7	0.5
4. River Sand (Bank)	0.5	0.7
5. River Sand (Supplier)	0.5	0.7

Roundness and sphericity are important properties because they impact the porosity and permeability. Typical sand proppant has typical values of 0.7 for both roundness and sphericity. As shown in Table 4.4, the sand samples do not meet the desired values. However, at low closure stress, the roundness and the sphericity of the sand particles are not really that significant. As earlier mentioned in literature review (refer to 2.5.1 Roundness and Sphericity), angular shape proppant also gives adequate permeability at closure stress lower than 2000 psi.

The roundness and sphericity of local sands are compared with the typical sand based proppant in market which are Ottawa and Brady sands. Table 4.5 shows the details.

Table 4.5: *Comparison of Sphericity and Roundness between Local Sands and Typical Sand Based Proppant*

(Data for Ottawa and Brady Sands are taken from: www.halliburton.com/public/pe/contents/Brochures/Web/H03562.pdf)

Sand Samples	Roundness (R)	Sphericity (S)
1. Mine Sand	0.5	0.7
2. Silica Sand	0.5	0.7
3. River Sand (Under Water)	0.7	0.5
4. River Sand (River Bank)	0.5	0.7
5. River Sand (From Supplier)	0.5	0.7
6. Ottawa Sand	**0.8**	**0.8**
7. Brady Sand	**0.8**	**0.8**

Based on table above, Ottawa and Brady sands have the highest value of roundness and sphericity (0.8 RS). This enable Ottawa and Brady sands to have better porosity and permeability after the stress is applied compare to other sand samples. Also, the rounder particles will distribute load better and have less crush and fines production at higher closure stress.

4.4 POROSITY

Table 4.6: Porosity

Sand Samples	Particle Density (g/cc)	Bulk density (g/cc)	Porosity (%)
1. Mine Sand	2.689	1.345	50
2. Silica Sand	2.7568	1.378	50
3. River Sand (Under Water)	2.859	1.430	50
4. River Sand (Bank)	2.8681	1.434	50
5. River Sand (Supplier)	2.7825	1.391	50

Porosity is calculated by applying the density data into the percentage of porosity calculation (Equation 3.2). As shown in the results; all the samples have the same percentage of porosity.

Porosity is mainly affected by the uniformity of the sand size and shape. So, since the sand samples used in this experiment are at the same size (-20/+40 US Mesh) and sphericity and roundness value are in the same range, the porosity for all samples are the same. API RP – 56 does not specify any requirement in regards to porosity for natural sand based proppant.

4.5 MINERALOGY DETERMINATION

4.5.1 XRF Elemental Analysis

Table 4.7: Chemical Composition of Sand Samples

Contents (Weight %)	Sand Samples				
	Mine Sand	Silica Sand	River Sand (Under Water)	River Sand (Bank)	River Sand (Supplier)
SiO_2	**98.7000**	**97.8000**	**89.8000**	**89.8000**	**88.9000**
Al_2O_3	0.3720	0.7230	6.8800	5.4900	3.8400
K_2O	0.0518	0.1780	1.7500	2.2700	4.4100
Cr_2O_3	0.0849	0.1130	0.0045	0.1080	0.2060
Fe_2O_3	0.5230	0.7630	1.0000	1.5500	1.7500
CuO	nil	0.0040	nil	nil	0.0148
ZrO_2	0.0209	0.0286	0.0253	0.0166	nil
CaO	nil	nil	0.0277	0.0302	0.1700
Na_2O	nil	nil	0.1730	0.1380	0.2980
MgO	nil	nil	0.1090	0.0845	nil
TiO_2	nil	nil	0.1070	0.2440	nil
MnO	nil	nil	nil	0.0225	nil
Rb_2O	nil	nil	0.0402	0.0490	nil
Y_2O_3	nil	nil	nil	0.0041	nil

Table 4.7 shows the chemical composition of the all the sand samples. This result gives a better insight about the purity of the samples. Higher percentage of silica content indicates higher quality of sands (Malaysia Mineral and Geoscience Department, 2008). Silica sand and mine sand have the lowest number of chemical compositions if compare with the other three river sand samples. Meanwhile, for silica dioxide (SiO_2) content, mine sand has the highest percentage with 98.7%.

For sand to be used as industrial sand, it must contain at least 95% of SiO_2 (Kamal Shah Ariff, 2004). As reported by Malaysia Mineral and Geoscience Department in their website, typical high quality of unprocessed local sand contains 97% to 99.9% of SiO_2. Based on the statements, only silica sand and mine sand can be categorized as high quality sand (SiO_2 content between 97% to 99.9%) and can be used as the

4.5.2.3 River Sand (Under Water)

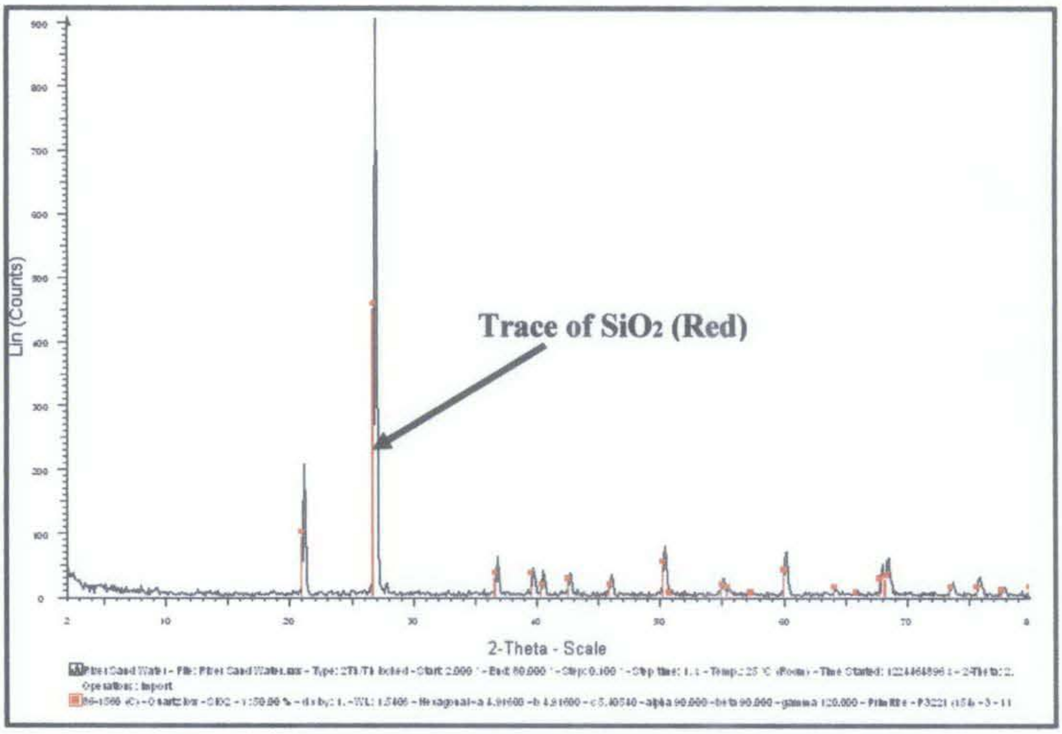


Figure 4.4: XRD Analysis of River Sand (Under Water)

4.5.2.4 River Sand (Bank)

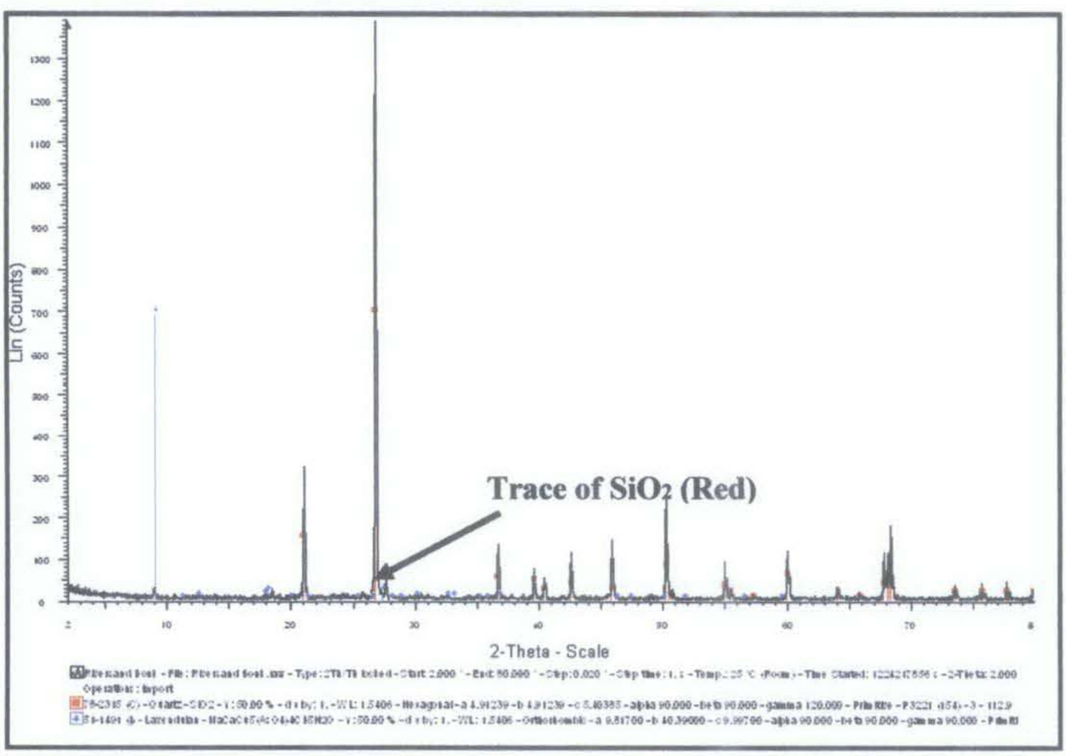


Figure 4.5: XRD Analysis of River Sand (Bank)

4.5.2.5 River Sand (Supplier)

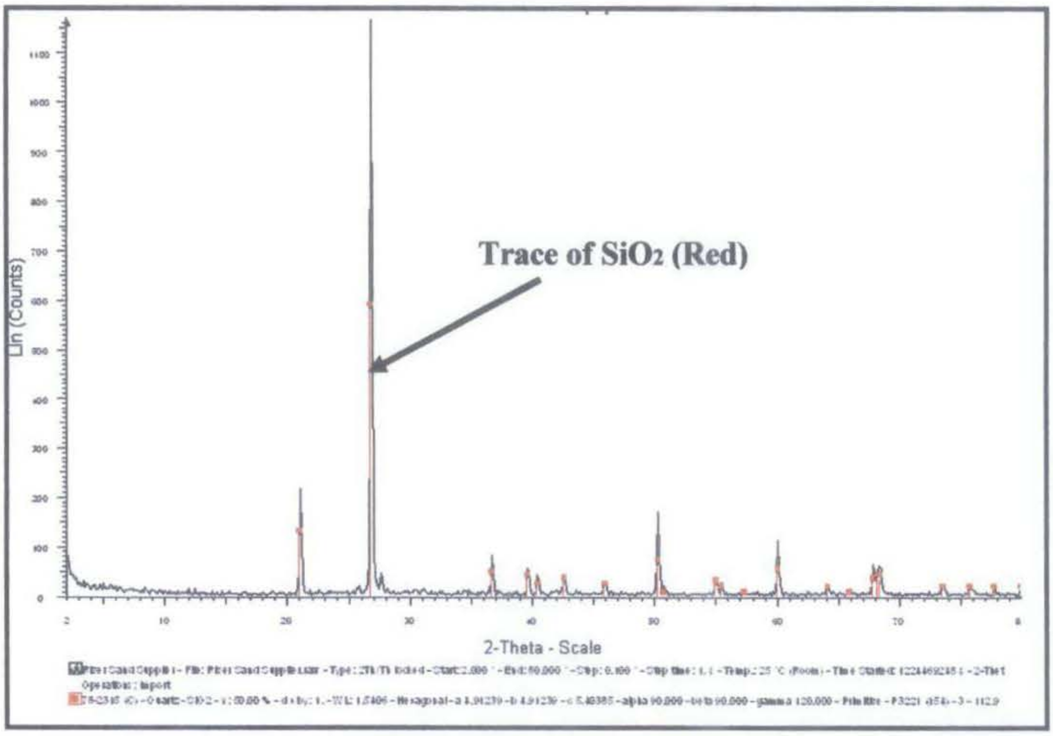


Figure 4.6: XRD Analysis of River Sand (Supplier)

Based on the XRD results, SiO_2 is the dominant component in all the sand samples.

4.5.3 Summary of XRF and XRD results

Table 4.8: Summary of XRF and XRD Results

Sand Samples	Percentage of SiO_2 (XRF) (%)	Trace of SiO_2 (XRD)
1. Mine Sand	98.7	Yes
2. Silica Sand	97.8	Yes
3. River Sand (Under Water)	89.8	Yes
4. River Sand (Bank)	89.8	Yes
5. River Sand (Supplier)	88.9	Yes

4.5.2.5 River Sand (Supplier)

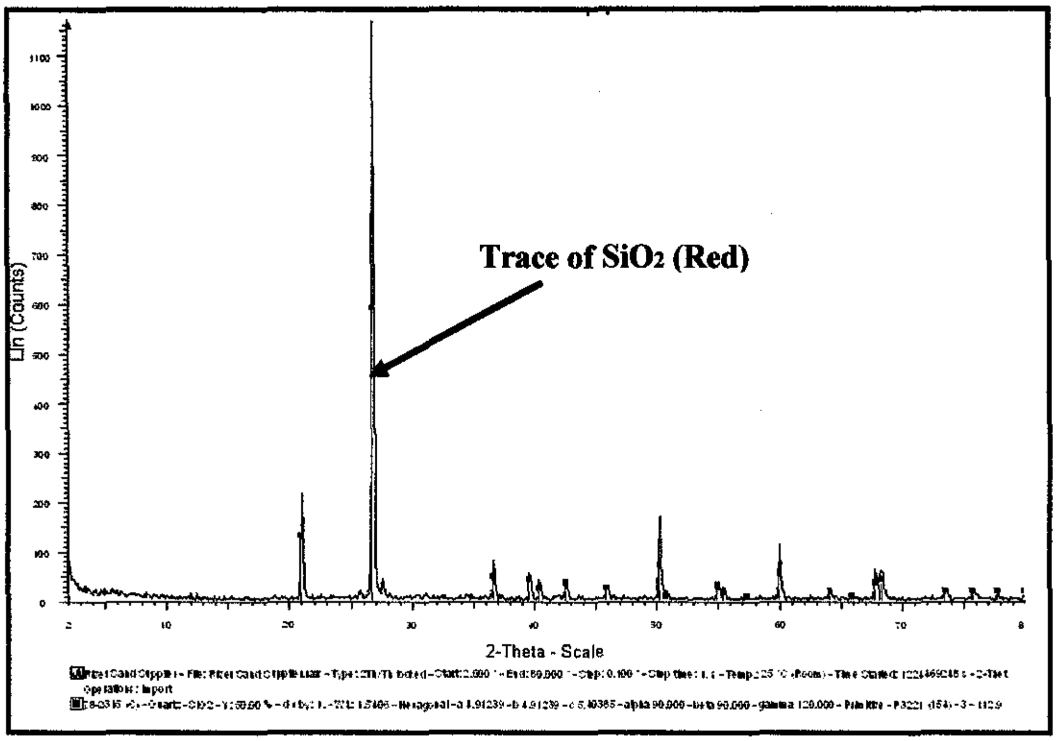


Figure 4.6: XRD Analysis of River Sand (Supplier)

Based on the XRD results, SiO_2 is the dominant component in all the sand samples.

4.5.3 Summary of XRF and XRD results

Table 4.8: Summary of XRF and XRD Results

Sand Samples	Percentage of SiO_2 (XRF) (%)	Trace of SiO_2 (XRD)
1. Mine Sand	98.7	Yes
2. Silica Sand	97.8	Yes
3. River Sand (Under Water)	89.8	Yes
4. River Sand (Bank)	89.8	Yes
5. River Sand (Supplier)	88.9	Yes

4.6 CRUSH RESISTANCE

4.6.1 Crush Resistance Results and Discussion

Table 4.9: Percentage of Crush of Sand Samples of Different Sizes at Different Stress Level

Crush Stress Level (psi)	% Weight of crush									
	Mine Sand		Silica Sand		River Sand (Under Water)		River Sand (Bank)		River Sand (Supplier)	
	20/40	16/30	20/40	16/30	20/40	16/30	20/40	16/30	20/40	16/30
1000	1.67	1.67	7.18	9.00	13.35	16.83	10.95	6.24	23.58	17.77
2000	10.45	14.94	22.42	20.31	30.33	25.03	24.74	23.29	24.38	28.00
3000	18.72	23.07	30.98	31.63	36.78	30.25	30.11	30.54	26.63	32.57
4000	27.28	29.31	32.43	36.13	38.81	31.41	36.20	33.66	38.02	36.42
5000	30.40	35.19	38.45	38.67	41.13	38.45	39.61	37.29	40.55	49.04

API only allows maximum of 10% of weight crush. Based on above results, only mine sand and silica sand meet the requirement for both sand particles sizes; -20/+40 and -16/+30 at 1000 psi. While for river sand (bank), only the -20/+40 sand size meet the requirement at the lowest crush stress. However, all samples failed to meet the requirement for the closure stress larger than 1000 psi.

As mentioned before, percentage of weight crush is related to the shape of the grain where angular grains tend to crush easier than the rounder ones. Since all samples are more angular if compare with available proppant in market, they tend to crush easily even at the lowest closure stress of 1000 psi.

This experiment also highlighted the different of crush percentage for different sizes. It is proven that larger proppant particles will crush easier if compare with smaller sized proppant. For example, at 1000 psi, -20/+40 silica sand has lower crush percentage if compare with -16/+30 silica sand.

Table 4.10: Comparison of Crush Resistance between Local Sands with Typical Sand Based Proppants at 2000psi, 3000psi and 4000psi for 20/40 and 16/30 US Mesh Size Sands

(Data for Ottawa and Brady Sands are taken from: www.halliburton.com/public/pe/contents/Brochures/Web/H03562.pdf)

Crush Stress Level (psi)	% Weight of crush													
	Mine Sand		Silica Sand		River Sand (Under Water)		River Sand (Bank)		River Sand (Supplier)		Ottawa Sand		Brady Sand	
	20/40	16/30	20/40	16/30	20/40	16/30	20/40	16/30	20/40	16/30	20/40	16/30	20/40	16/30
2000	10.45	14.94	22.42	20.31	30.33	25.03	24.74	23.29	24.38	28.00	nil	nil	nil	nil
3000	18.72	23.07	30.98	31.63	36.78	30.25	30.11	30.54	26.63	32.57	nil	3.95	nil	3.32
4000	27.28	29.31	32.43	36.13	38.81	31.41	36.20	33.66	38.02	36.42	1.82	7.55	11.00	nil

Table 4.10 shows the comparison of crush resistance between local sand and typical sand based proppants. Based on the comparison, it clearly indicates that Ottawa sand and Brady sand; 2 most common sand based proppant used in hydraulic fracturing have better crush resistance. It is due to their high roundness and sphericity values. Also, Ottawa sand and Brady sand are well known by many proppant suppliers as highest quality fracturing sand with high purity (Halliburton, 2008).

It seems that the sample purity also affected the crush resistance. For example, mine sand that contains 98.7% SiO_2, has the lowest crush resistance percentage among the local sand.

4.7 CONSTANT HEAD PERMEABILITY TEST

Table 4.11: Co-efficient Permeability of Sand Samples

Sample	Mine Sand			Silica Sand			River Sand (Under Water)			River Sand (Bank)			River Sand (Supplier)		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Permeability,k (m/s)	5.17	5.93	4.84	5.47	4.76	6.09	6.45	6.46	6.48	6.43	6.66	7.29	6.75	6.97	7.78
Average k (m/s)	5.31			5.44			6.46			6.80			7.17		

Based on above result, river sand (supplier) has the highest permeability coefficient with value of 7.17 m/s. However, according to constant head permeability laboratory manual of Civil Engineering Department, Universiti Teknologi PETRONAS with reference to BS 1337 Part 2:1990; this experiment is only suitable for medium having coefficients of permeability in the range 10^{-2} to 10^{-5} m/s. Moreover, no closure stress is applied during the experiment. The results might not be reliable due to these reasons.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

Proppant, the main material used in hydraulic fracturing is becoming more popular in current oil and gas industry. Apparently, there appears to be no local proppant supplier or manufacturer in Malaysia. In line with one of the National Industrial Mineral policy; to enhance Malaysia's competitiveness advantage in a global market for mineral commodities and their value added products, this project gives a new prospect to Malaysia's sand industry and adds another option for proppant selection for oil and gas companies.

Proppant is characterized based on its physical properties and chemical composition. Several experiments have been conducted to analyse the local sands characteristics in order to determine the possibility of producing local sands as proppant. Based on the experiment results, below are the conclusions:

- Among the samples, only mine sand and silica show good potential in every test that has been conducted.
- Both mine sand and silica sand meet the minimum requirement of SiO_2 content of 95%. Mine sand contains 98.7% of SiO_2 and silica sand with 97.8%.
- For crush resistance, only mine sand and silica sand produced less than 10% of crushed particles at the closure stress of 1000 psi.
    - **Percentage of crush for -20/+40 US Mesh size**

Mine sand: 1.67% wt

Silica sand: 7.18% wt

- **Percentage of crush for -16/+30 US Mesh size**

  Mine sand: 1.67% wt

  Silica sand: 9.00% wt

However, for the closure stress larger than 1000 psi, no samples met the API specifications that only allow maximum 10% of weight crush.

- For sphericity and roundness, all samples have almost the same range of values which are 0.5-0.7 RS.
- Mine sand has the lowest density among all the samples.
- Permeability test conducted during this project is not suitable to measure permeability of proppant.
- Comparing all local sands samples used in this project with Ottawa and Brady sand indicates the sphericity, roundness and crush resistance need to be improved before they can be used as proppant.

5.2 RECOMMENDATIONS

This report has provided a basic insight of proppant characteristics and several of experimental setups. Below are recommendations for improvement:

5.2.1 To coat the sand with resin for improved characteristics

By coating sand with resin, the particles will have better roundness and sphericity. Also, it will have better resistance at high closure stress and improve the hydrocarbon flow. Furthermore, resin-coated sand can reduce the proppant flow back problem that can cause the fracture to close and reduce the permeability.

According to Sinclair *et al.* (2007) typical resins that are used during the coating process are epoxy, furan, phenolic resins or combinations of such resin. This process is also known as "hot coat" process.

First, the particulate substrate is heated to a desired temperature (e.g. about 400^{o}F to about 450^{o}F) and then the resin is added to the hot particulate substrate. Sinclair *et al.* (2007) suggested that the desired temperature is preferably above the melting point of the resin.

5.2.2 To conduct short-term and long-term conductivity test

Apart from crush resistance, conductivity is one of the most desirable proppant characteristic. This test will give better insight on the local sand performance as proppant. However, this testing can not be conducted in UTP due to equipment unavailability.

5.2.3 To conduct acid solubility test

This test is important as it reveals the presence of any contaminant. This test is not conducted during this project due to lack of information on the procedure.

5.2.4 To purchase API – RP 56: Recommended Practices for Testing Sand Used in Hydraulic Fracturing

This API standard provides complete guidelines in testing the frac sand.

5.2.5 To characterize more local sands

It is suggested to characterize more local sands especially industrial sands used in glass making industry. It is well-known that the sand used in glass making industry constitutes high chemical purity that is able to resist corrosive attack.

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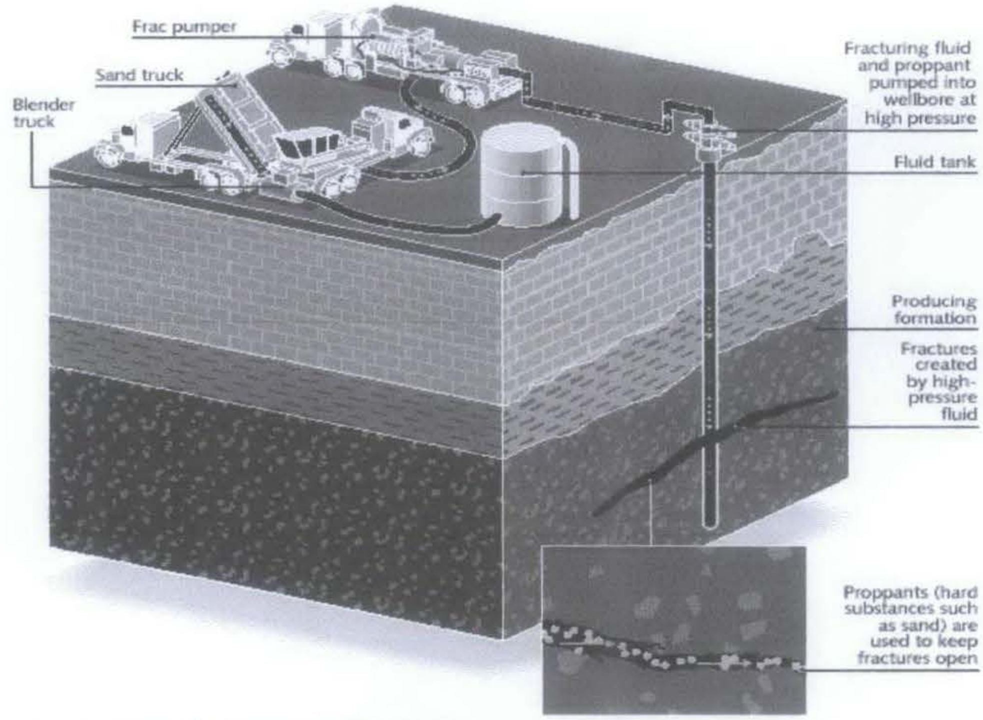
APPENDIX

APPENDIX 1

HYDRAULIC FRACTURING



High-pressure fluid creates cracks extending 300 metres or more into the producing formation. Sand props open the cracks, which are typically five to ten metres high but only two to six millimetres wide.

(Source: Petroleum Communication Foundation, *Our Petroleum Challenge*, Canadian Centre for Energy Information, 1999)

APPENDIX 2

MALAYSIA OF PRODUCTION OF MINERAL COMMODITIES

(metric tons unless otherwise specified)

Commodity[2]		2002	2003	2004	2005	2006
METALS						
Aluminum, bauxite, gross weight		39,975	5,732	2,040	4,735	91,806
Gold, mine output, Au content[3]	kilograms	4,289	4,739	4,221	4,250	3,497
Iron and steel:						
Iron ore, gross weight		404,350	596,612	663,732	949,605	667,082
Pig iron, direct-reduced iron and hot-briquetted iron	thousand metric tons	1,061	1,600	1,710	1,349	1,540
Steel, crude	do.	4,722	3,960	5,698	5,296	5,500 [e]
Lead metal, secondary[e]		40,000	40,000	40,000	40,000	42,000
Niobium (columbium)-tantalum metals, struverite, gross weight		2,298	2,619	121	552	93
Rare-earth metals, monazite, gross weight		441	795	1,683	320	894
Silver, mine output, Ag content[3]	kilograms	--	--	364	401	410
Tin:						
Mine output, Sn content		4,215	3,359	2,745	2,857	2,398
Metal, smelter		30,887	18,250	33,914	36,924	22,850
Titanium:						
Ilmenite concentrate, gross weight		106,046	95,148	61,471	38,196	45,649
Dioxide[e]		56,000	56,000	56,000	56,000	56,000
Zirconium, zircon concentrate, gross weight		5,292	3,456	6,886	4,954	1,690
INDUSTRIAL MINERALS						
Barite		3,082	--	--	--	910
Cement, hydraulic	thousand metric tons	14,336	17,243	15,692	17,860	17,860
Clays and earth materials	do.	23,092	23,909	24,221	28,757	23,921
Clays, kaolin		323,916	425,942	326,928	494,511	341,223
Feldspar		30,819	42,662	79,220	117,180 [r]	142,358
Mica		3,669	3,609	3,544	4,542	5,152
Nitrogen, N content of ammonia		847,900	909,500	842,500	920,000 [r, e]	950,000 [e]
Sand and gravel	thousand metric tons	19,574	17,955	18,371	17,072	25,225
Silica sand, peninsular Malaysia and Sarawak		447,398	533,617	631,402	531,891	512,277
Stone:						
Aggregate	thousand metric tons	84,934	85,142	51,236	62,761 [r]	79,912
Dolomite		--	--	27,500	38,500	37,702
Limestone	thousand metric tons	27,450	33,397	31,598	30,868	33,471
MINERAL FUELS AND RELATED MATERIALS						
Coal		352,513	172,820	389,176	789,356	901,801
Gas, natural:[4]						
Gross	million cubic meters	56,843 [r]	60,941 [r]	63,165 [r]	70,471 [r]	70,191
Net[5]	do.	48,317 [r]	51,800 [r]	53,691 [r]	59,901 [r]	59,663
Liquefied natural gas	thousand metric tons	15,007	17,311	20,729	21,948	21,948
Petroleum:[4]						
Crude and condensate	thousand 42-gallon barrels	254,770	269,370	279,009	267,720	255,425
Refinery products[4, 6]	do.	186,000 [r]	200,000 [r]	225,000 [r]	218,000 [r]	208,000

[e]Estimated; estimated data are rounded to no more than three significant digits; may not add to totals shown. [r]Revised. -- Zero.

[1]Table includes data available through September 29, 2007.

[2]In addition to the commodities listed, a variety of crude construction materials, which include clays and stone, fertilizers, and salt, is produced but not reported, and information is inadequate to make reliable estimates of output.

[3]Includes byproduct from tin mines in peninsular Malaysia and gold mines in peninsular Malaysia and the State of Sarawak.

[4]Includes production from peninsular Malaysia and the States of Sabah and Sarawak.

[5]Gross less volume of reinjected and flared.

[6]Includes liquefied petroleum gas, naphthas, and lubricants.

Sources: Ministry of Primary Industry, Minerals and Geoscience Department (Kuala Lumpur), Malaysian Minerals Yearbook 2005; U.S. Geological Survey Minerals Questionnaire, 2006; and Southeast Asia Iron and Steel Institute, Steel Statistical Yearbook, 2005.

APPENDIX 3: PROJECT TIMELINE AND EXECUTION PLAN

1) PROJECT TIMELINE

Semester 1

PROJECT TIMELINE FOR SEMESTER 1																
NO	DETAIL/WEEK	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	PROJECT TOPIC SELECTION															
2	PRELIMINARY RESEARCH WORK															
3	SUBMISSION OF PRELIMINARY REPORT				●											
4	PROJECT WORK CONTINUES															
	a) Literature review on proppant and its usage in hydraulic fracturing															
	b) Checking on Equipment Availability															
5	SUBMISSION OF PROGRESS REPORT								●							
6	SEMINAR (COMPULSORY)															
7	PROJECT WORK CONTINUES															
	a) Literature review on sand															
	a) Collecting sands sample															
	b) Lab Testing Planning															
8	SUBMISSION OF INTERIM REPORT															●
9	ORAL PRESENTATION															●

● Suggested milestone

Process

Semester 2

PROJECT TIMELINE FOR SEMESTER 2																			
NO	DETAIL/WEEK	SEM BREAK	1	2	3	4	5	6	7	8	9	10	11	12	13	14	SW	EW
1	PROJECT WORK CONTINUES	░	░	░	░													
	a) Particle Size Distribution	░	░	░	░													
	b) Density and Porosity Determination	░	░	░	░													
	c) X-Ray Fluorescence (XRF)	░	░	░	░													
2	SUBMISSION OF PROGRESS REPORT 1						●											
3	PROJECT WORK CONTINUES					░	░	░	░									
	a) Manufacturing of Crush Cell using CNC Machine					░	░	░	░									
	b) Scanning Electron Micrograph (SEM)					░	░	░	░									
4	SUBMISSION OF PROGRESS REPORT 2										●							
5	PROJECT WORK CONTINUES									░	░	░						
	a) Crush Testing									░	░	░						
	b) Permeability Test									░	░	░						
6	SEMINAR (COMPULSORY)										░	░	░					
7	PROJECT WORK CONTINUES											░	░	░	░	░		
	a) X-Ray Diffraction (XRD)											░	░	░	░	░		
8	POSTER EXHIBITION													●				
9	SUBMISSION OF DISSERTATION (SOFT BOUND)																●	
10	ORAL PRESENTATION																	●
11	SUBMISSION OF DISSERTATION (HARD BOUND)																	●

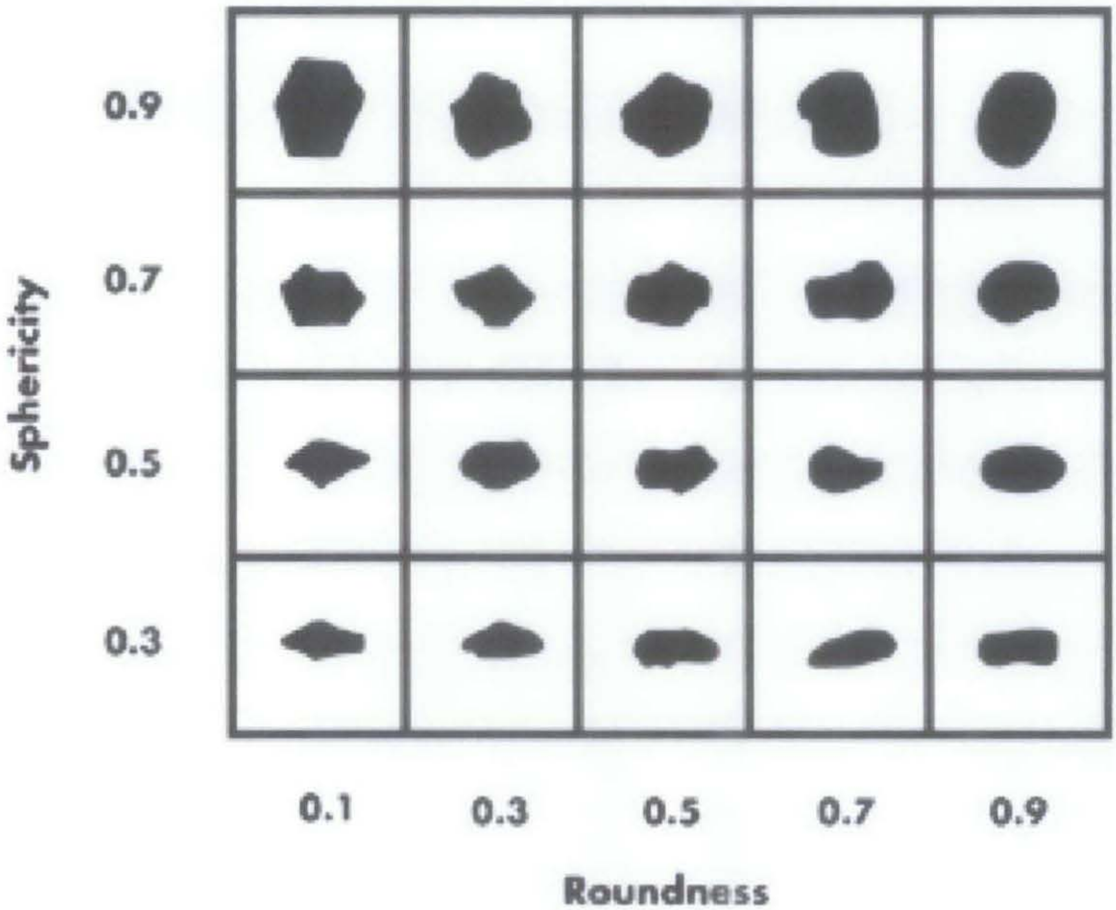
● Suggested milestone
░ Process
SW Study Week
EW Exam Week

2) FYP EXECUTION PLAN (EXPERIMENTAL)

FYP EXECUTION PLAN (EXPERIMENTAL)				Progress			Problems Encountered/ Remarks		
No	Experiment	Equipments / Methods	Purposes	30%	70%	100%	Arising Matters	Reasons	Actions Taken
1	Sieve Analysis	Sieve shaker	Size distribution						
2	Photomicrograph	Scanning Electron Micrograph	Sphericity and roundness of sand determination						
3	Density Determination (True Density and Bulk Density)	a) Ultrapycnometer	True/Particle density determination						
		b) Graduate Cylinder Method	Bulk Density determination						
4	Elemental Analysis	X- Ray Fluorescence (XRF)	Mineralogy determination						
	a) Grinding	Grinder	To grind sand to become powder for compaction						
	b) Compaction	Compaction equipment	To compact the sand for XRF analysis				Samples are failed during the 1st run	The sand compacts are crushed during the XRF analysis	Request for 2nd run (Provide more samples)
5	Crush Testing	Crush Test Equipment	Crush resistance determination				Remarks: Experiment are done using 20/40 and 16/30 sands		
	a) Crush cell manufacturing	CNC Lathe Machine: Mazak Integrex 200 III 5x, Conventional Lathe	To manufacture crush cell with exact precision				1) Modification of design	Specified size of boring tool is not available	Change in design to match the boring tool design
							2) Delay in manufacture	1) CNC Machine system is infected by virus	Consult technician about the equipment status
6	Permeability	Permeability apparatus setup	To determine the permeability of the sand				Equipment only set up for constant pressure head	Equipment setup, more on civil work	Proceed, since no other equipment available in UTP
7	Porosity	Ultrapycnometer, cylinder method	To measure the porosity of the sand				Remarks: Porosity can be determined using bulk density and particle density data: **%Porosity = [1- (Bulk density/Particle density)]x100%**		

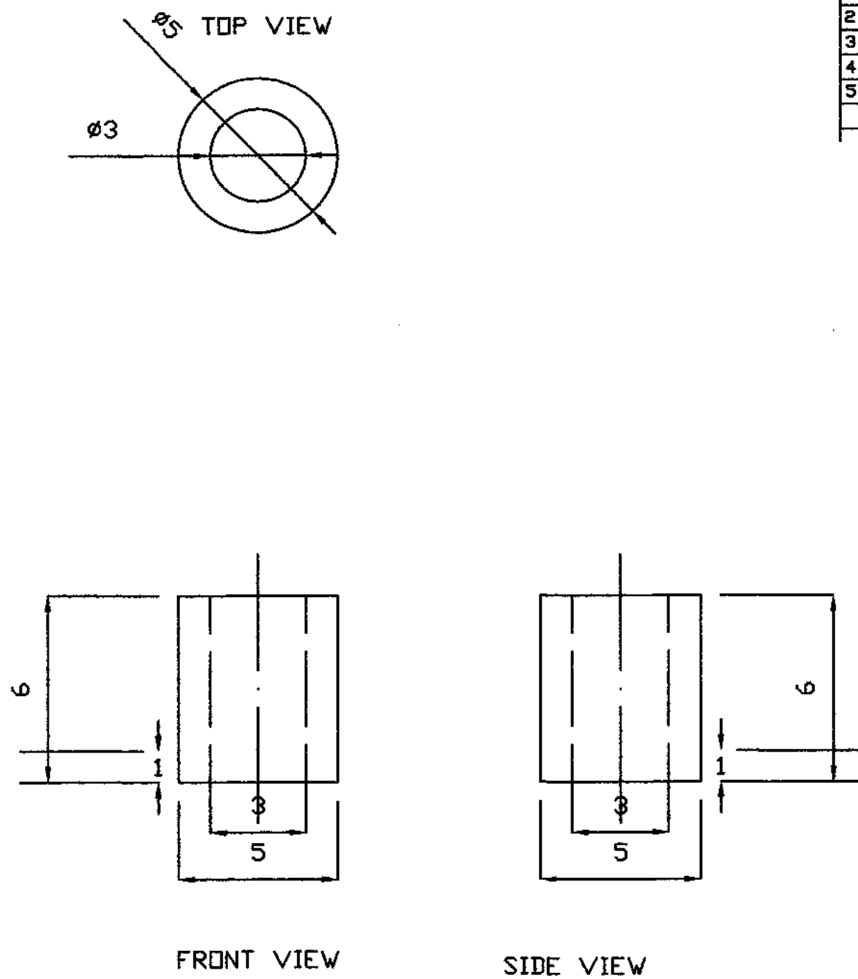
APPENDIX 4

KRUMBEIN ROUNDNESS AND SPHERICITY CHART



(Source: www.carboceramics.com)

APPENDIX 5



No	Bill of Material	
1		
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3		
4		
5		

Note
1) All measurement in cm unit.
2) Detail measurement is shown in the next drawing.

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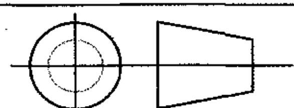
MOULD
Top, Front and Side View



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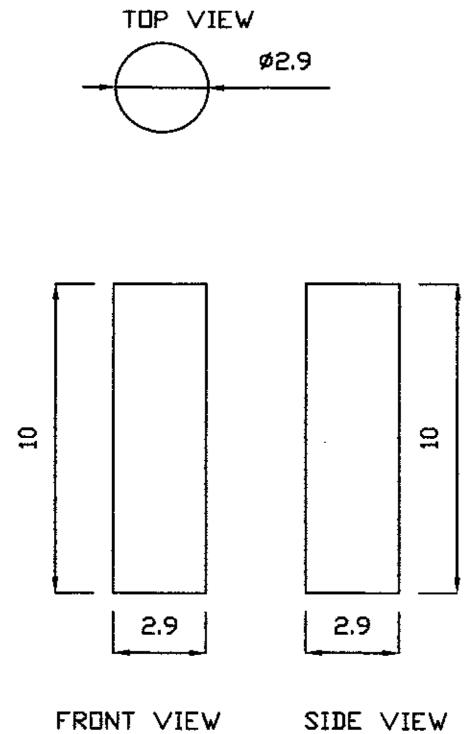

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Note
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2) Detail measurement is shown in the next drawing.

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PLUNGER
Top, Front and Side View

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6372
MECHANICAL ENG DEPT

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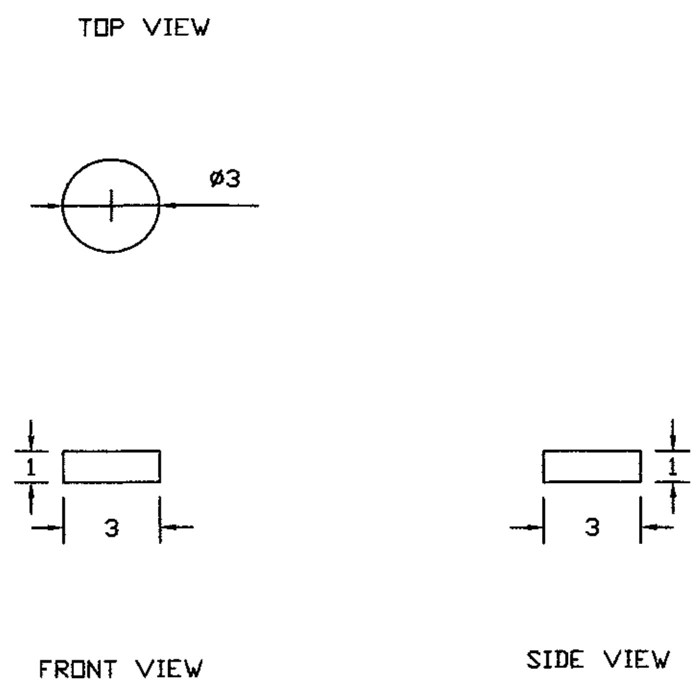

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Note
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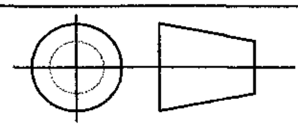
BASE
Top, Front and Side View



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Checked Date	Revision REV 1	Sheet MD-01

APPENDIX 6

PARTICLE SIZE DISTRIBUTION (SIEVE DISTRIBUTION)

1) TEMPLATE FOR EXPERIMENT

Sieve size(mm)	Tray (kg)	Initial Dry Mass: 2.0 kg			Initial Dry Mass: 2.0 kg			%Average
		T1 (kg)	Act. Mass retained (T1 - tray) kg	% of Mass Retained (%T1)	T2 (kg)	Act. Mass retained (T2 - tray) kg	% of Mass Retained (%T2)	
3.35								
2								
1.18								
0.6								
0.425								
0.3								
0.212								
0.15								
Pan								
Total								

2) SUMMARY OF RESULTS

Sieve Size (mm)	% of Mass Retained											
	Mine Sand			Silica Sand			River Sand (Under Water)			River Sand (Bank)		
	Trial 1	Trial 2	Average	Trial 1	Trial 2	Average	Trial 1	Trial 2	Average	Trial 1	Trial 2	Average
3.350	7.100	6.150	6.625	1.950	2.250	2.100	2.900	2.850	2.875	11.950	14.450	13.200
2.000	14.350	14.550	14.450	6.850	7.650	7.250	8.850	9.050	8.950	22.100	22.050	22.075
1.180	20.350	22.300	21.325	15.600	17.200	16.400	24.900	23.350	24.125	25.150	24.300	24.725
0.600	21.450	23.350	22.400	29.750	37.400	33.575	45.650	43.950	44.800	28.550	26.050	27.300
0.425	8.500	6.800	7.650	13.200	8.000	10.600	8.100	9.150	8.625	6.250	6.000	6.125
0.300	9.550	11.050	10.300	16.150	13.700	14.925	5.850	6.500	6.175	4.650	4.700	4.675
0.212	8.250	6.050	7.150	9.900	6.650	8.275	2.400	2.950	2.675	1.050	1.500	1.275
0.150	4.250	4.250	4.250	5.400	4.100	4.750	0.950	1.400	1.175	0.250	0.600	0.425
Pan	6.200	5.500	5.850	1.200	3.050	2.125	0.400	0.800	0.600	0.050	0.350	0.200
Total	**100.000**	**100.000**	**100.000**	**100.000**	**100.000**	**100.000**	**100.000**	**100.000**	**100.000**	**100.000**	**100.000**	**100.000**

APPENDIX 7

DENSITY

1) TRUE DENSITY (ULTRAPYCNOMETER)

Mine Sand

```
                 QUANTACHROME CORPORATION
             Ultrapycnometer 1000 Version 2.2
                     Analysis Report

Sample & User Parameters              Analysis Parameters

Sample ID: MI (Mine Sand)             Cell Size: Small
Weight: 4.6200 grams                  V added - Small: 12.4554 cc
Analysis Temperature: 32.7 degC       V cell: 20.9726 cc
                                      Target Pressure: 19.0 psi
Date: 07-17-08                        Equilibrium Time: Auto
Time: 11:01:18                        Flow Purge: 1:00 min.
User ID: EMIE                         Maximum Runs: 5
                                      Number of Runs Averaged: 5

                         Results

Deviation Requested: 0.005 %          Deviation Achieved: +/- 0.1709
Average Volume: 1.7181 cc             Std. Dev. : 0.0065 cc
Average Density: 2.6890 g/cc          Std. Dev. : 0.0101 g/cc
Coefficient of Variation: 0.3767 %

                       Tabular Data

       RUN        VOLUME (cc)     DENSITY (g/cc)

        1           1.7117          2.6990
        2           1.7106          2.7008
        3           1.7173          2.6903
        4           1.7240          2.6798
        5           1.7269          2.6754
```

Silica Sand

```
                 QUANTACHROME CORPORATION
             Ultrapycnometer 1000 Version 2.2
                     Analysis Report

Sample & User Parameters              Analysis Parameters

Sample ID: SI (Silica Sand)           Cell Size: Small
Weight: 3.7350 grams                  V added - Small: 12.4554 cc
Analysis Temperature: 32.6 degC       V cell: 20.9726 cc
                                      Target Pressure: 19.0 psi
Date: 07-17-08                        Equilibrium Time: Auto
Time: 10:40:18                        Flow Purge: 1:00 min.
User ID: EMIE                         Maximum Runs: 5
                                      Number of Runs Averaged: 5

                         Results

Deviation Requested: 0.005 %          Deviation Achieved: +/- 0.2323
Average Volume: 1.3568 cc             Std. Dev. : 0.0083 cc
Average Density: 2.7528 g/cc          Std. Dev. : 0.0167 g/cc
Coefficient of Variation: 0.6108 %

                       Tabular Data

       RUN        VOLUME (cc)     DENSITY (g/cc)

        1           1.3487          2.7693
        2           1.3496          2.7675
        3           1.3575          2.7514
        4           1.3562          2.7539
        5           1.3718          2.7227
```

River Sand (Under Water)

QUANTACHROME CORPORATION
Ultrapycnometer 1000 Version 2.2
Analysis Report

Sample & User Parameters

Sample ID: RW (River Sand, Water)
Weight: 3.5700 grams
Analysis Temperature: 32.8 degC

Date: 07-17-08
Time: 11:22:29
User ID: EMIE

Analysis Parameters

Cell Size: Small
V added - Small: 12.4554 cc
V cell: 20.9726 cc
Target Pressure: 19.0 psi
Equilibrium Time: Auto
Flow Purge: 1:00 min.
Maximum Runs: 5
Number of Runs Averaged: 5

Results

Deviation Requested: 0.005 %
Average Volume: 1.2487 cc
Average Density: 2.8590 g/cc
Coefficient of Variation: 0.7058 %

Deviation Achieved: +/- 0.2893
Std. Dev. : 0.0088 cc
Std. Dev. : 0.0201 g/cc

Tabular Data

RUN	VOLUME (cc)	DENSITY (g/cc)
1	1.2423	2.8738
2	1.2371	2.8858
3	1.2486	2.8592
4	1.2527	2.8498
5	1.2627	2.8273

River Sand (Bank)

QUANTACHROME CORPORATION
Ultrapycnometer 1000 Version 2.2
Analysis Report

Sample & User Parameters

Sample ID: RB (River Sand, Bank)
Weight: 3.6200 grams
Analysis Temperature: 33.0 degC

Date: 07-17-08
Time: 11:44:39
User ID: EMIE

Analysis Parameters

Cell Size: Small
V added - Small: 12.4554 cc
V cell: 20.9726 cc
Target Pressure: 19.0 psi
Equilibrium Time: Auto
Flow Purge: 1:00 min.
Maximum Runs: 5
Number of Runs Averaged: 5

Results

Deviation Requested: 0.005 %
Average Volume: 1.2621 cc
Average Density: 2.8681 g/cc
Coefficient of Variation: 0.4853 %

Deviation Achieved: +/- 0.1957
Std. Dev. : 0.0061 cc
Std. Dev. : 0.0139 g/cc

Tabular Data

RUN	VOLUME (cc)	DENSITY (g/cc)
1	1.2600	2.8730
2	1.2519	2.8916
3	1.2632	2.8657
4	1.2651	2.8613
5	1.2704	2.8495

River Sand (Supplier)

QUANTACHROME CORPORATION
Ultrapycnometer 1000 Version 2.2
Analysis Report

Sample & User Parameters

Sample ID: RS (River Sand Supplier)
Weight: 3.3500 grams
Analysis Temperature: 33.1 degC

Date: 07-17-08
Time: 12:06:10
User ID: EMIE

Analysis Parameters

Cell Size: Small
V added - Small: 12.4554 cc
V cell: 20.9726 cc
Target Pressure: 19.0 psi
Equilibrium Time: Auto
Flow Purge: 1:00 min.
Maximum Runs: 5
Number of Runs Averaged: 5

Results

Deviation Requested: 0.005 %
Average Volume: 1.2040 cc
Average Density: 2.7825 g/cc
Coefficient of Variation: 0.4752 %

Deviation Achieved: +/- 0.1865
Std. Dev. : 0.0057 cc
Std. Dev. : 0.0132 g/cc

Tabular Data

RUN	VOLUME (cc)	DENSITY (g/cc)
1	1.2012	2.7888
2	1.1956	2.8020
3	1.2038	2.7827
4	1.2062	2.7773
5	1.2130	2.7618

Summary of True Density

Sand Samples	Weight (gram)	Average Volume (cc)	Average Density (g/cc)
River Sand (From Supplier)	3.350	1.2040	2.7825
River Sand (Under Water)	3.570	1.2487	2.8590
River Sand (River Bank)	3.620	1.2621	2.8681
Mine Sand	4.620	1.7181	2.6890
Silica Sand	3.735	1.3568	2.7568

2) BULK DENSITY

Calculation

$$Bulk\ Density = \frac{Weight\ of\ dry\ sample(g)}{Volume\ of\ dry\ sample\ (cc)}$$

Example:

$$Bulk\ Density = \frac{2.77g}{2cc} = \frac{1.385g}{cc}$$

Summary of Results

Sand Sample	Volume(cc)	Weight (g)	Density (g/cc)
Mine Sand	2	2.750	1.375
		2.750	1.375
		2.760	1.380
	Average	**2.753**	**1.377**
Silica sand	2	2.780	1.390
		2.760	1.380
		2.770	1.385
	Average	**2.770**	**1.385**
River Sand (Under Water)	2	2.610	1.305
		2.590	1.295
		2.610	1.305
	Average	**2.603**	**1.302**
River Sand (Bank)	2	2.460	1.230
		2.460	1.230
		2.490	1.245
	Average	**2.470**	**1.235**
River Sand (Supplier)	2	2.670	1.335
		2.670	1.335
		2.660	1.330
	Average	**2.667**	**1.333**