The Impact of Sand Erosion in Gas Export Pipelines

by

Muhammad Sukry Azizi bin Wardi
14880

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Universiti Teknologi PETRONAS
Bandar Seri Iskandar
31750 Tronoh
Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Petroleum Engineering Programme
Universiti Teknologi PETRONAS
in partial fulfilment of the requirement for the
BACHELOR OF ENGINEERING (Hons)
(PETROLEUM)

Approved by,

____

(Mrs Noor Ilyana Ismail)

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
January 2015

CERTIFICATION OF ORIGINALITY

This is to clarify 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.

MUHAMMAD SUKRY AZIZI BIN WARDI

ABSTRACT

One of the common problems in oil and gas industry is sand erosion. Fine sand was believed to cause insignificant erosion damage. It was believed that fine sand cause insignificant erosion damage. The aims of this study are to explore and investigate sand erosion due to particle size, sand flow rate, air velocity, impact angle and distance between nozzle and pipe which cause erosion in gas pipelines by measuring the thickness loss of pipe. This study is the lab based study. The different sizes sand, carbon steel plates, air blower and mixing chamber are used in the experiment. The experiment has three stages. The first stage is sand and metal plate sampling. The sand is characterized into two different sizes, coarse sand and fines by using dry sieving method. The metal plates are polished and then several images of surface before experiment are captured. These images are categorised as untreated sample. Then, second stage is the erosion experiment which the concept is almost same with "sand blasting" concept and each experiment are run for 3 hours with different parameters. Last stage is the most important part. The surfaces of eroded metals are analysed using Scanning Electron Microscope (SEM) and Universal Scanning Probe Microscope (USPM). The images captured using SEM show how the different parameters cause the erosion in gas pipeline physically. Energy Dispersive Spectrum (EDS) by SEM are used to analyse the change of composition in eroded surface. Then, the metals are analysed using USPM to determine the thickness loss overtime. Several outcomes are obtained. The experiments show higher the particle size, sand flow rate, air velocity give more erosion on metal surface. When the distance between nozzle and plate is closed, the thickness loss overtime is higher, and impact angle at 90^0 cause higher erosion compare to 45^0.

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TABLE OF CONTENTS

CERTIFICATION OF APPROVAL ii

CERTIFICATION OF ORIGINALITY ii

ABSTRACT iv

ACKNOWLEDGEMENT v

TABLE OF CONTENTS vi

LIST OF FIGURES ix

LIST OF TABLES xi

CHAPTER 1: INTRODUCTION

1.1 Background of study 1

1.2 Problem statement 3

1.3 Objectives 3

1.4 Scope of study 3

CHAPTER 2: LITERATURE REVIEW

2.1 Sand Production 4

- 2.1.1 Factors that lead to sand production 5
  - 2.1.1.1 Inherent rock strength 5
  - 2.1.1.2 Degree of consolidation 6
  - 2.1.1.3 Production rate 6
  - 2.1.1.4 Reduction of pore pressure 7
- 2.1.2 Effects of sand production 7
  - 2.1.2.1 Accumulation in Surface Equipment and Downhole . 7
  - 2.1.2.2 Erosion of down choke and surface equipment . 8
  - 2.1.2.3 Collapse of the formation 9

2.2 Sand control 9
2.2.1 Chemical Method – Resin Injection 9
2.2.2 Mechanical Method 11
2.2.2.1 Screen or Slotted Liner with Gravel Pack . . 11
2.2.2.2 Slotted Liner or Screen without Gravel Pack . . 13
2.3 Sand Management 14
2.3.1 Sand Settling 15
2.3.2 Sand Monitoring System 16
2.3.3 Sand Erosion 17
2.3.3.1 Particle size 19
2.3.3.2 Particle shape 20
2.4 Dry Sieving Method 21
2.5 Scanning Electron Microscope (SEM) 23
2.6 Universal Scanning Probe Microscope (USPM) . . . 25

CHAPTER 3: METHODOLOGY

3.1 Project activities 26
3.2 Project flow chart 27
3.3 Gantt charts 28
3.4 Key Milestones 30
3.5 Experiment methodology 31
3.5.1 Dry Sieving Method 31
3.5.2 Erosion Test 33
3.5.3 Scanning Electron Microscope (SEM) . . . 35
3.5.4 Universal Scanning Probe Microscope (USPM) . . 36

CHAPTER 4: RESULT & DISCUSSION

4.1 Sampling 37
4.1.1 Mine Sand 37
4.1.2 S45C Carbon Steel Plate 39

4.2 Scanning Electron Microscope 40
4.2.1 Particle Size 41
4.2.2 Air Velocity 43
4.2.3 Sand Flow Rate 44
4.2.4 Distance between Nozzle and Target Surface . . 45
4.2.5 Impact Angle 47
4.3 Universal Scanning Probe Microscope 48
4.3.1 Untreated Sample 49
4.3.2 Treated Sample 51

CHAPTER 5: CONCLUSION 53

CHAPTER 6: RECOMMENDATIONS 54

REFERENCES 55

LIST OF FIGURES

Figure 1 Fines erosion that cause failure of eductor in a North Sea . . 2
Figure 2 Choke valve erosion and sand in HP-A swivel . . . 8
Figure 3 Distinct stages for sand consolidation process . . . 10
Figure 4 Resin-coated sand 11
Figure 5 Different types of gravel pack completion 12
Figure 6 Side view of a cased hole gravel pack 12
Figure 7 Classification of grain shape 20
Figure 8 Dry sieving facilities. 21
Figure 9 A typical SEM instrument 23
Figure 10 Overview of the main types of Scanning Probe Microscope types 25
Figure 11 Key milestones for Final Year Project 27
Figure 12 Equipment used for Dry Sieving Method 31
Figure 13 Dry Sieving Method for sand sampling 32
Figure 14 Schematic of the Erosion Test Facility 33
Figure 15 Experiment Setup 34
Figure 16 Scanning Electron Microscope (SEM) 35
Figure 17 Scanning Electron Microscope (SEM) Machine . . . 36
Figure 18 Universal Scanning Probe Microscope (USPM) Machine . 36
Figure 19 Different sizes of sand collected using dry sieving test . . 37
Figure 20-A 45µm sand size 38
Figure 20-B 150µm sand size 38
Figure 21-A Pointed region for EDS (mine sand) 38
Figure 21-B EDS result of mine sand 38
Figure 22-A Pointed region for EDS (S45C carbon steel) . . . 39
Figure 22-B EDS result of S45C carbon steel. 39
Figure 23-A SEM on untreated sample 40
Figure 23-B Surface of treated sample by naked eye 40
Figure 24-A Eroded surface by 150µm san 41

Figure 24-B Eroded surface by 45µm sand 41
Figure 25-A Eroded surface due to air velocity at 20 m/s . . . 43
Figure 25-B Eroded surface due to air velocity at 22 m/s. . . . 43
Figure 26-A Eroded surface due to sand flow rate at 1 kg/hr. . . 44
Figure 26-B Eroded surface due to sand flow rate at 1.5 kg/hr. . . 44
Figure 27-A Eroded surface due to 5 cm 45
Figure 27-B Eroded surface due to 10 cm 45
Figure 28-A Eroded surface at 45^0 angles 47
Figure 28-B Eroded surface at 90^0 angles 47
Figure 29-A Pointed region for EDS (treated sample) . . . 48
Figure 29-B EDS result of after erosion test (treated sample) . . 48
Figure 30-A 3D image of untreated sample in nm 49
Figure 30-B Top view of untreated sample in nm 49
Figure 30-C Surface thickness of untreated sample in nm . . . 49
Figure 30-D 3D image of untreated sample in degree . . . 50
Figure 30-E Top view of untreated sample in degree . . . 50
Figure 30-F Surface thickness of untreated sample in degree . . 50
Figure 31-A 3D image of treated sample in nm 51
Figure 31-B Top view of treated sample in nm 51
Figure 31-C Surface thickness of treated sample in nm . . . 51
Figure 31-D 3D image of treated sample in degree 51
Figure 31-E Top view of treated sample in degree 51
Figure 31-F Surface thickness of treated sample in degree . . . 51

LIST OF TABLES

Table 1 Experimental observation of coarse and fine sand erosion . . 19
Table 2 Standard Sieve Opening 22
Table 3 Final Year Project I Gantt chart 28
Table 4 Final Year Project II Gantt chart 29
Table 5 EDS composition result for mine sand 39
Table 6 EDS composition result for S45C carbon steel . . . 40
Table 7 EDS composition result for S45C carbon steel after experiment . 48

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Based on Macmillan Dictionary, the meaning of erosion is “the process by which the rock or land surface begins to disappear due to the damage of wind, water, ice, gas etc.” Levy (1995) defines erosion as “the material loss from the metal surfaces that being impacted by a flowing fluid which carries tiny, solid particles with a sequence of mechanical actions”. The relation between these definitions is actually referring to the erosion of metals by various damaging mechanisms.

In this topic, the study will be focusing on the erosion of gas export pipelines caused by sand production. The main objective is to investigate how sand particle damage or erode the flowlines. There are a few parameters may affect the erosion of the metal which are air velocity, sand flow rate, impact angle as well as the distance between impact target and nozzle. This erosion refers to flowlines wear due to solid particles impact carried by the fluid stream flowing through it. Fines, which is very small sized sand often may find its way into the piping components of onshore, offshore and subsea facilities which then causing erosion/wear of pipelines/flowlines.

As stated earlier, this phenomenon concentrates on the physical behaviour that occurs when small, solid particles strike surface that are chemically inactive or are undergoing simultaneous oxidation. This behaviour is affected by the characteristics of the target materials and the impacting particles, as well as by the conditions under which the surface degradation is occurring (for examples flow velocity and direction, temperature, gas composition, and the quality of particles in the flowing gas stream).

There were many cases where leaking accident happen due to the erosion of metals, caused by coarse sand and fines in the oil and gas industries. Some cases resulting in fatality due to the leaking of high-pressured natural gas from production flowlines which leading to explosion.

There are several evidences show that there are severe erosion damage caused by fine sand under certain conditions. For example, Figure 1 shows the failure of educator due to fines erosion.

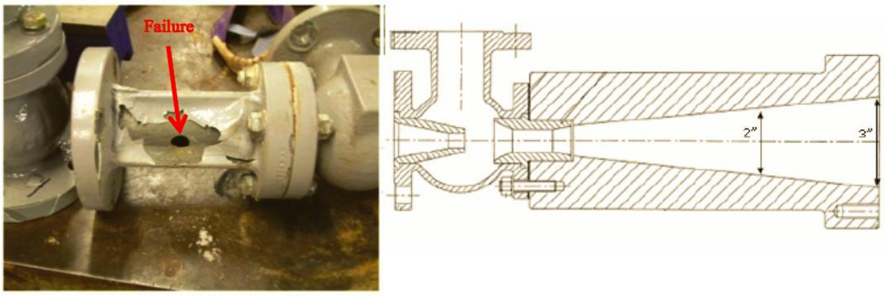


Figure 1 Fines erosion that cause failure of eductor in a North Sea

Many people believe that fines (less than 50-75 microns) only cause insignificant erosion damage due to its particle size. However, fines can escape through most sand screens which make them almost inevitable in oil and gas production and cause severe damage at location that coarse sand are not anticipated. Above figure is the example of erosion due to fine. It was believed that fine sand cause insignificant erosion damage. But evidence from industry proves that the statement is not true.

Therefore, then main objective of this study is intended to study the impacts of sand erosion in gas pipelines.

1.2 Problem Statement

Zhang et al. (2012) stated that one of the common problems in oil and gas industry is sand erosion. Produced oil and gas usually contain sand which normally filtered downhole and monitored at various critical locations in the pipelines and flowlines. However, the amount and size of the sand that can be filtered are limited. Fine sand was believed to cause insignificant erosion damage. However, fines can escape through most sand screens which make them almost inevitable in oil and gas production. It was believed that fine sand cause insignificant erosion damage. But evidence from industry proves that the statement is not true.

Therefore, the main objective of this project is to investigate the impact of sand erosion in gas pipelines. It is known that erosion rate is higher in gas flow with solids than liquid flow with solids.

1.3 Objectives

The aims of this study are to explore and investigate factors that cause sand erosion and to examine the effects of particle size, sand flow rate, air velocity, impact angle and distance between nozzle and pipe on sand erosion on pipe surfaces by measuring the thickness loss overtime.

1.4 Scope of Study

This project will involve study on the coarse sand and fines properties. The parameters in this study are particle size, sand flow rate, air velocity, impact angle and distance between nozzle and target surface. For particle size, this study will focus on coarse sand and fines. For sand flow rate, air velocity, impact angle as well as distance between nozzle and target surface, this study will focus on different value of the parameters so that the effect of different value of each parameter can be determined.

CHAPTER 2

LITERATURE REVIEW

2.1 Sand Production

Being known as one of the toughest hydrocarbon extraction related problem to solve, producing sand from wells is a major problem faced by oil and gas producers, all over the world for decades. Mohammed, Lesor, Aribo and Umeleuma (2012) state that sanding or sand production means production of formation sand alongside the formation fluids which are water, oil as well as gas due to unconsolidated nature of the formation. Many of operational problems experienced by the oil companies are caused by the production of sand during oil and gas production.

This sanding process has essentially no economic value. Most of the project budgets for oil and gas extraction are spent on equipment repairs which related to sand production, meanwhile the oil and gas industry lost many of their revenues due to the restricted production of the wells due to sand production annually (Norton & Smith, 1996). On the contrary, sand productions not only reduce recovery rates by plugging wells, but also erode the equipment and settle in surface vessels. It is costly to control the formation damage which usually involves either slowing the production rate or sand-consolidation or using gravel packing techniques. As a result, sand production is a global. Areas of main problems include the Canada, Niger Delta, U.S. Gulf Coast, Trinidad, Indonesia, Venezuela, and Canada. At least some problems are informed in all areas of the world where oil and gas are produced.

Mohammed, Lesor, Aribo and Umeleuma classify sand production into three categories which are transient, continuous, and catastrophic. Transient sanding usually encountered during clean-up after perforation or acidizing. During transient stage, sand production will decline with time. Next is continuous sand production which occurs during production from the unconsolidated sandstone reservoir that has no sand control equipment. Sand production will be observed for this case throughout the life of the well. Catastrophic sanding occurs when a high rate of sand influx causes the well to die and/or choked. This type of sand production occurs when the reservoir fluids are excessively produced and this is the worst case of sand production.

2.1.1 Factors that lead to sand production

There are several factors which responsible for the production of sand in the oil and gas industry. Factors controlling the onset of mechanical rock include naturally existing earth stress, inherent rock strength as well as additional stress caused by drilling or production.

2.1.1.1 Inherent Rock Strength

Sand production is initiated when the formation stress exceed the strength of the formation (Carlson, Gurley, King, Price-Smith & Walter, 2002; Oyeneyin, Macleod, Oluyemi, & Onukwu, 2005). The derived formation strength mainly from the natural material that cements sand grains, but cohesive forces also hold together the sand grains resulting from residual water (immovable formation water). There are many factors that cause the stress on formation sand grains which are tectonic actions, pore-pressures, overburden pressures, stress changes from drilling, and drag forces on production fluids,. In some cases, pressure that have declined to the extent that the overburden which being supported mainly by the vertical component of inter grain stress rather than by the pore pressure cause the onset of sand production occurs late in the life of a field (Appah, 2001). This may allow the sand grains to move due to the shearing of the cementing material and hence be produce into wellbore or, below a certain pore pressure, the point stress between the sand grains exceeds their fracture strength and the grans collapses causing the instability and onset of sand production.

2.1.1.2 Degree of Consolidation

Dees (1993) stated that the poorly consolidated reservoirs usually have rocks which relatively young in geologic age, and are unconsolidated because natural processes have not cemented the rock grains together by mineral deposition which result many reservoirs are susceptible to sand production. The degree of consolidation refers to the compressive strength of the formation that shows how strong the bond between the sand grains of the formation is. A high compressive strength of the formation means that the individual sands grains are bonded together strongly and are properly consolidated. This also shows that sand production normally happens when producing hydrocarbon form poorly consolidated sandstone formations. A poorly consolidated sandstone formation is said to have the compressive strength of less than 1,000 psi (King et al., 2003). The unconsolidated sands are loose and are susceptible to be produced into wellbore and to the surface unlike consolidated sands that are carried by fluid drag forces.

2.1.1.3 Production rate

The rate at which the formation is produced can lead to sand production in well. Every reservoir has a threshold pressure, which is the pressure at which a well will produce sand free. However, engineer tends to ignore the threshold pressure so as to produce at a maximum since this threshold pressure is below economic producing rate. Due to this, sand is produced. According to Samsuri, Sim and Tan (2003), during the production of oil and gas, the fluids create forces inside the formation that are to exceed the compressive strength of the formation. These forces are the pressure differential and frictional drag forces. This shows that there is a critical flow rate to which the wells must be producing at or below to ensure that the forces created do not exceed the formation compressive strength.

2.1.1.4 Reduction of pore pressure

Pore pressure is one of the forces that support the weight of the overlying rock. When producing, the pressure in the formation depletes, thus decreasing some of the pressure that is supporting the rock. The resulting low amount of pressure causes a huge amount of stress on the formation rock and after a certain amount of time, the sand grains start to break loose from the rock (Abbas, Nasr-El-Din & BaTaweel, 2002). These grains are then produced together with the flowing formation fluids into the oil well. Further reduction in the pore pressure will result in the compaction of the formation rock and lastly, will cause surface subsidence. When the wellbore pressure is small compared to the reservoir pressure, this will lead to high rate of fluid flow from the reservoir into the wellbore. The high viscosity fluid that flows with high velocity from the reservoir into the wellbore may be produced with the reservoir sand.

2.1.2 Effects of sand production

In the petroleum industry, sand production with the oil and gas from sand prone formation creates a number of potentially dangerous and costly problems. Some of the damage caused by sand production are discussed below.

2.1.2.1 Accumulation in Surface Equipment and Downhole

Some of the surface equipment used in hydrocarbon production are powerful enough to produce velocity that can even carry sand grains up the tubing. Due to this, the sand grains produced might be trapped in the separator and production pipeline. Sand cleaning needs to be done when a huge amount of sand is trapped in the areas mentioned before to ensure the production of the well is not interrupted.

Operating time will be lost if restoration of production is required since the well operation must be stopped, the disassembling of the equipment, and removal of the sand manually (Norton et al., 1996). These will result in increasing maintenance cost as well as revenue lost due to lost in production time.

Sinclair et al. (1978) have mentioned in their study that the producing velocity of the sand doesn’t have to be high to affect the downhole equipment. The sand that couldn’t be carried to the surface will accumulate and fill the bottom of the casing and may bridge off in the tubing. After a while, the sand will start to cover the producing interval and will cause a decrease in the production rate of hydrocarbon.

Eventually, the sand will cover up the whole producing interval and completely stops the production of hydrocarbon. Well clean-up and production restoration then needs to be done to the oil well before resuming production.

2.1.2.2 Erosion of down choke and surface equipment

Erosion of the equipment due to sand production is mainly cause by the sand being produced together with the formation fluids flowing at high velocity in highly productive wells. This leads to regular replacement of the equipment which are damaged by the flowing sands. Loss of the equipment could happen if the erosion is too severe or if the erosion occurs for a long period of time and potentially creates serious safety and environmental problem.

Figure 2: Choke valve erosion (left), sand in HP-A swivel (right) (Loong, Goo, & Rawlins, 2014)

2.1.2.3 Collapse of the formation

In normal oil and gas production, it is possible to obtain a huge amount of sand together with the produced fluid. The formation will suffer a hole or a void space in its body with the production of sand at a greater rate and the hole will continue to expand if the sand productions continue for a certain amount of time (Van Pollen & Malone, 1959). As time passed and the empty space grew larger and larger, the layers of formation on top of the hole will collapse due to insufficient support from the materials at the bottom formation layers.

2.2 Sand Control

It is necessary to employ "sand control" methods in the poorly consolidated reservoir wells. According to Dees (1992) and Hugh and Ramos (1995), mechanical or chemical methods are the group of methods/techniques that is being used to control sand in formations producing sand.

2.2.1 Chemical Method – Resin Injection

The application of various sand consolidation methods have been made to avoid or constrain sand movement with the fluids produced from hydrocarbon-bearing earth formations. Using resin-coated particulate solids to pack the formation, using a bonding resin to wet the unconsolidated sand, and forming a screen by placing resin-treated sand between the loose sand in the formation and the well bore are the types of chemical methods (Talaghat, Esmaeilzabeh & Mowla, 2009).

Vary degrees of success have met by applying these methods. A dispersion sand consolidation mixture is one in which a consolidating fluid contains of a hydrocarbon carrier, a resin or a resin-forming mixture dispersed in it together with a quantity of particulate solids. The resin consolidation processes have been classified in various ways which are minimum preparation time at well site, low injection pressure, short cure time before restoring well to production, high compressive strength of resulting matrix, good resistance to deterioration from well fluids and commonly used treating fluids and high retained permeability. Several types of resins are presently used in the sand control art which are epoxy resins, polyester resins, phenol–formaldehyde resins, urea–formaldehyde resins, furan resins, phenolic resins, epoxy resins, urethane resins and mixtures of such resins (Appah, 2001; Akpabio, 1994).

These chemicals create a stable permeable matrix, consolidated grains around casing by binding rock particles together. However, pre-flush using clay stabilizer is often used since the effectiveness of consolidation process can be hindered by clay concentration. The consolidation process relies on a process comprising of four distinct stages (Mohammed, Lesor, Aribo & Umeleuma, 2012).

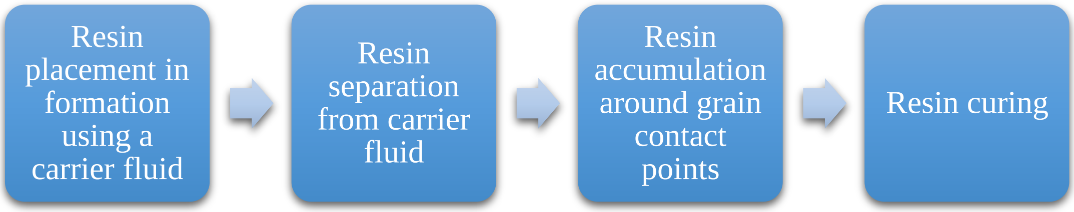


Figure 3: Distinct stages for sand consolidation process

Polymerization of resins is caused by catalysts or curing agents. Sand consolidation with resins has been practiced for many years. Resins are forced into the formations by high pressures instantaneously applied when perforations are formed in the casing of wells or when pressures are released from tubing in wells.

Dees (2003) state that the chemical methods have several important advantages over mechanical methods, but the high cost of the resins and the difficulties in obtaining sufficiently uniform injection of chemicals have limited application to relatively short intervals of perforations. The hardenable resin on the deposited particulate solids caused or permitted to harden whereby a consolidated permeable particulate solid pack is formed between the well bore and loose or incompetent sand in the formation.

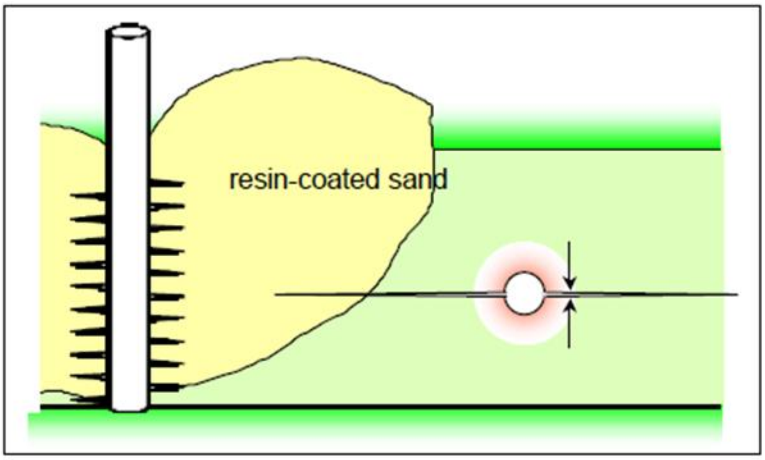


Figure 4: Resin-coated sand (Kuncoro, Ulumuddin & Palar, 2001)

2.2.2. Mechanical Methods

Setting up a physical barrier to the sand movement, this still allows for the passage of reservoir fluids effect the mechanical exclusion of sand. The formation sand cannot pass through the pore throats of the gravel when the barrier takes the form of a screen surrounded by fine gravel, which is sized. Therefore, the sand mechanical exclusion is based upon the relationship between the size of the formation sand, the gravel, and the screen slot widths. The examples for mechanical sand controls are stand-alone scree, wire wrapped screen, expandable sand screen, frac pack, slotted liner and gravel packing.

2.2.2.1 Screen or Slotted Liner with Gravel Pack

The main idea behind gravel packing with screen is the formation of sand bridges when large sand grains are being retained by the larger sand grains in the screen and from there, the sand bridge consist of larger sand grains will become the retainer for smaller sand grains and the whole process will repeat itself forming smaller sand bridges as we go deeper into the formation. The larger sand grains mentioned before are known as the gravel pack sand. According to King et al. (2003), the gravel pack is designed to hold sand grains that are about 5 to 6 times bigger compared to the size of the sand grain in the formation. This layer of larger grains forms a filter with very high permeability at the downhole that enables the flow of hydrocarbon from the formation into the well but blocks the smaller grains from entering the well and being produced together with the hydrocarbon. The stability of the sand bridges formed is considered high as the tight packing of the gravel in between the formation and the screen stops the shifting and resorting of the formation sand ensuring the strength of the sand bridges (Hall et al., 1970). Screen with gravel pack can be used for a wide range of production processes if it is planned and implemented properly, as the performance of the gravel pack will remain pretty much the same under every possible producing conditions. There are two types of gravel packing with screens; as shown below:

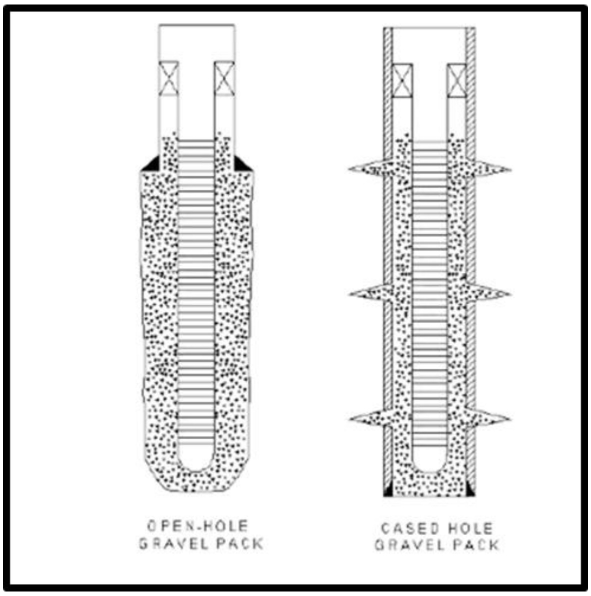


Figure 5: Different types of Gravel Pack Completion (OilWiki)

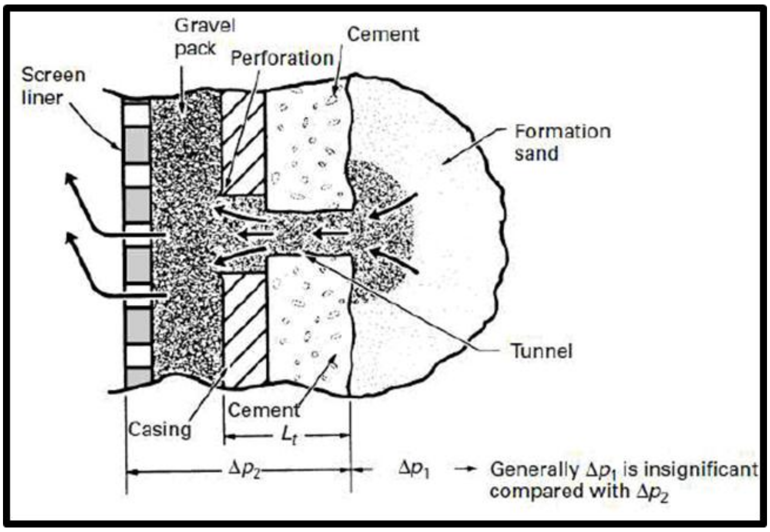


Figure 6: Side View of a Cased Hole Gravel Pack Completion (OilWiki)

Besides screen, this method can also be used with slotted liner. Slotted liner has the same function as a screen in the hole that is forming the final layer of filter for the producing fluid as well as keeping the gravel pack in place, making sure that the gravel pack does not flow together with the produced fluids. Hall et al. (1970) mentioned that the gravel pack is designed in such a way that all the void spaces in the annulus between the screen and the formation is filled with the large-sized sand grains as this ensures that the gravel pack produces the best result in filtering small grains. Sinclair et al. (1978) and Samsuri et al. (2003) both agree that one type of challenge that is faced by cased hole gravel pack is achieving full packing of the gravel pack sand as this can be easily achieved for open hole gravel pack completion. Despite the high cost in implementing the gravel pack to an oil well, it is the preferred method compared to other methods as it is still the most reliable sand control technique available today.

2.2.2.2 Slotted Liner or Screen without Gravel Pack

Gravel packing is not necessary equipment for controlling sand production. It is a known fact that slotted liners and screens have the ability to handle the production of sand without the use of gravel packing in the well completion. But, the formation must have a well-sorted structure and consists of clean, large-sized sand grains to use this type of completion. It is a mistake to be using only slotted liners or screens for other types of formation because the well will only be producing for a very short amount of time before the produced sand starts to clog the liners/screens until no more fluids can pass through the slot (Oliviera et al., 2014).

As used with gravel packing, the screens or slotted liners work the same way when they are being used as a stand-alone. The flowing sand particles will form bridges in the holes of the wire screens much like the sand bridges formed in between the large sand grains in the gravel packing as the screens are being put across the producing formation interval. The concept to sand bridging is that the grains will only bridge in a slot if it has a width that does not go beyond the diameter of two sand grains (Hall et al., 1970). Much like the theory mentioned before, the sand grains will only form a bridge across a hole if the diameter of the hole is not more than the diameter of three sand particles.

The diameter of the slots and the holes in the screens are designed to be the same size as the larger 10% sand grain level of the formation. This is to ensure that the produced sand which is larger in size compared to normal formation sand grains will be stopped at the slots or screens, and help in forming sand bridges to stop the normal-sized and small-sized sand grains form flowing together with the producing fluids (Hall et al., 1970). Due to the unstable state of the bridges formed, they will collapse after a certain time, whenever the well is experiencing shut in or a change in the production rate.

2.3 Sand Management

Fields that have a relatively low formation strength (<1000 psi) may cause the sand production to be inevitable. Sand production will be prevented by installation of downhole sand exclusion systems such as gravel packs and screens at the early life of the field. However, most of the wells from various reservoirs will not produce sand when first brought to production; but produce sand at some later point in the life of wells (Salama, 2000).

In such a case, the operator has several options:

- From day one, complete the wells with downhole sand exclusion systems,
- When sand production begins, recomplete the well by set up sand elimination systems; or
- Do not set up downhole sand elimination systems and design the facilities to manage sand production for handling sand if sand is produced.
- Do sand production management.

Salama said that usually the last option, sand production management will be chosen in various cases because the risk of loss of production is increased due to downhole sand exclusion systems or plugging and mechanical can be damaged when recomplete the wells.

Under sand production management, there are three technical issues that are needed to be addressed in order to maintain the integrity of the production facility under sand production conditions as well as to maximize reservoir production. The technical issues are sand settling, sand monitoring, and sand erosion.

2.3.1 Sand Settling

Solid particles in the fluid can form a bed on the bottom of the line at below some minimum flow velocity in a horizontal pipeline. Partial or complete blockage of flow lines, trapping of pigs, and enhanced pipe bottom corrosion can occurs due to deposition of the solids. Pigging or increasing the flow velocity above the sand settling flow rate can easily remove the small amounts of sand in a pipeline. However, the large quantities of sand that are deposited in a pipeline are difficult to remove and time-consuming.

Depending on the fluid flow rate, there are four main patterns of sand transport in horizontal pipelines (Angelsen, Kvernvold, Lingelem & Olsen, 1989). The sand changes pattern from moving bed to stationary sand bed and from dispersed to scouring and when the flow velocity decreases. A stationary sand bed is a stable bed with immobile sand particles at the bottom. When a stable bed height is reached, the particles in the top then transported downstream which will increase the sand bed length. Increase of the fluid velocity then breaks up the bed into characteristic slow-moving sand dunes with sand particles transported from the back to the front of the dunes. After that, further increase of flow velocity cause the scouring of the sand along the bottom of the pipe to occur with most particles moving along the pipe wall further. In the gas phase and in the liquid phase in multi-phase flow pipes, the sand becomes dispersed when flow velocity increases further.

Any change between these patterns which depends on the service conditions may be considered to be critical. Transition between scouring and dispersed for slurry transport is considered critical if want to evade excessive wear to the bottom of the pipe. In this case, the minimum velocity is needed to retain solid particles suspended in the flow, and thus evade their drop-out. Therefore, this minimum velocity is the sand settling velocity. Flow rate of sand settling is the transition between scouring and moving dunes (i.e., sand is moving along the pipe even it is on the bottom of the pipe) for oil and gas transport. The velocity to disperse the sand would be higher than the flow velocity at this condition, i.e., to make sure all the sand is in suspension. Since the settling velocity is the transition between sand settling and sand transport, therefore the settling velocities and the transports are almost the same. This is not true for cases when the bottom sand layer has been static for some time. Higher flow rate will be required to initiate the movement of such a layer because sand tends, with time, become more firmed and more adherent to itself and to the pipe surface. This level of flow rate increase is not well recognized.

Therefore, it is suggested that under conditions of sand production, the times of shutdown and production below the sand settling flow rate should be kept to the smallest. Moreover, when the flow rate is increased, precaution must be taken to avoid sudden transport of huge quantities of sand if the flow lines are operated for a long period of time under conditions below the sand settling flow rate.

2.3.2 Sand Monitoring System

Whatever sand exclusion method that are adapted cannot be guaranteed will work indefinitely. As a result, monitoring the sand content of the produced fluids is essential so that wells can be shut-in when the sand start producing before subsurface or surface equipment becomes blocked or damaged. Batch, probe or downhole sand detection are the methods of monitoring sand production.

The cheapest method of sand monitoring is the batch monitoring system. It involves periodically taking a sample of produced fluid from the well head, filtering out and washing the sand, drying it and weighing it (Allen & Allan, 1982; Suman, Ellis & Suyder, 1983). Unfortunately, the random nature of sand production, particularly if the well is slugging or on intermitted pump cause the batch sand monitoring to be inaccurate. However, better accuracy may be obtained if a greater weight of sand is collected over a longer sampling period after passing a known quantity of produced fluid through a filter. However, the probe monitoring leads to a greater accuracy than periodic observation since it involves a continual monitoring.

Sand probes may be used to monitor and record the quantity of sand produced or to shut in a well (Suman, Ellis & Suyder, 1983). These probes can be piezo-electric probe or sonic probe or mechanical probe.

Furthermore, the downhole sand detection uses a system known as SANFLOG to detect sand influx in single liquid phase wells or a wet or dry gas wells. The system can also be used as a listening device operating on audio signals between 0.3 and 10 KHz (Sarnuri, Sim & Tan, 2003). The operator can use the tool to listen for flow from producing interval while simultaneously recording sand impacts due to this dual capability. The operator may elect to selectively treating the specific zone if only part of the producing formation is contributing to sand production.

2.3.3 Sand Erosion

According to Subramani, Rhyne and Vedapuri (2014), erosion refers to wear of pipeline material due to impact of solid particles carried by the fluid stream flowing through it. Sand control has become increasingly significant at high-rate wells with sand become extra prominent.

According to Salama, erosion due to sand is different if compared to erosion in sand-free systems. Salama also stated that, erosion rate for sand-free system only related to two parameters which are flow velocity and mixture density. However, sand erosion is motivated by several factors including sand characteristics (concentration, impact angle, impact velocity, shape/sharpness, number of particles hitting the surface, size distribution, hardness, and density), and material properties (hardness and microstructure), fluid characteristics (density, composition, flow rate, and viscosity), and component geometry (choke, tee, bend, and joint).

Sand erosion as a result of sand production is a main concern. This is because; sand erosion can causes loss of pipe wall thickness that can lead to expensive failures and production lost. Although cost of sand production is very low, it still can give impact to erosive failure at high production velocities. Previous studies indicated that when the produced fluid is a liquid, exchange of momentum between sand particles and liquid lessens the impact velocity of sand particles, resting in small or no erosion at all. However, current erosion data does not cover the range of materials and flow conditions happened in high flow rate oil wells (Russell, Shirazi & Macrae, 2004).

There is an extensive database that can be used to calculate erosion rates of different materials. These data can be presented using the following equation:

$$Er = A{V^n}_p F(\alpha)$$

Where;

Er is an erosion rate measured as the ratio between the mass of metal loss and the mass of sand hitting the target material. The sand concentration, flow conditions, and the geometry of the component influence the target material hit by amount of sand hitting.

A and *n* are depends on material properties which experimentally determined constants. n can be as high as 6 for brittle materials and the value of n is in the range 2–3 for ductile materials.

Vp is the impact velocity of the sand particle on the metal surface.

F (a) is function that depends on the impact angle and the value varies between 0 and 1. The target material ductile/brittle behaviour also influences the function. The value of *F (α)* is a maximum for ductile materials such as as ceramics at 90º and for steel at impact angles of 20º to 40º.

The prediction of proper values of particle impact angle, α, and velocity, *Vp*, whose values depend on: pipe geometry (elbow, tee, choke, etc.), pipe diameter, sand density, sand particle diameter, fluid density, and fluid viscosity are the most difficult parts in calculating erosion rate. One can account for these factors in predicting particle impact angle and velocity through the use of particle tracking simulation models.

Numerous factors that can cause the sand erosion such as solid loading, velocity of fluid, particle shape, particle size, impact angle of pipeline, the diameter of pipeline as well as type of carrier fluid. However, factors that are focused in this study are only the particle shape and also particle size.

2.3.3.1 Particle size

Subramani, Rhyne and Vedapuri mentioned about the important asset integrity concern that needs to be addressed for old and new oil and gas pipelines. The concern here is about the solid particle erosion due to coarse and fine sand. Fine sand often find its way into onshore and offshore components as well as subsea facilities and cause erosion and subsequent pipelines integrity issues. Fine sand can cause much more severe erosion and happen in locations that cannot be anticipated by large particles. Jordan (1998) found that when impacting solids size were reduced (from coarse to fine), there were also changes of mechanism of pipe material erosion which from brittle (impact) to ductile (sourcing or abrasive) erosion.

This study will use different sizes of sand which are coarse (150µm) and fines (45µm). The objective of using different particle size is to compare the degree of damage caused by coarse and fines on metal plates.

Table 1: Test condition and experimental observation of coarse and fine sand erosion (Clark (1990) and Jordan (1998))

Particle size (µm)		Erosion rate (x 10^9 m/s)
Minimum	Maximum	
150	180	15.5
106	150	10.3
75	106	5.8
53	75	2.8
<1	53	0.8

2.3.3.2 Particle shape

Sand particle shapes have a significant influence on the sand production performance. According to Edward (2013), shape can be expressed in the mean of angularity and sphericity. Edward also stated that sand grains differ from well-rounded toward rounded, sub-rounded, sub-angular, angular and very angular. Sphericity is often used to measure how close a particle is to a perfect sphere (Cheel, R., 2005). The angularity of sand can be predicted by visual examination with a low power microscope and then to compare it with published charts, as shown in FIGURE 7.

Subramani, Rhyne and Vedapuri stated that erosion caused by fines usually negligible due to low momentum of fines. However, Russell, Shirazi, and Macrae successfully indicate that small and sharp particles (about 25 µm) can cause severe erosion in single-phase carrier (liquid or gas) system. These fines cause the erosion is almost same with larger particles (150-300 µm) and not directly proportional to their mass. Furthermore, even the size and mass of particles were same, but rounded particles significantly less erosive than sharp particles and at critical hardness value, the mass lost by erosion raised sharply (Clark, 1991).

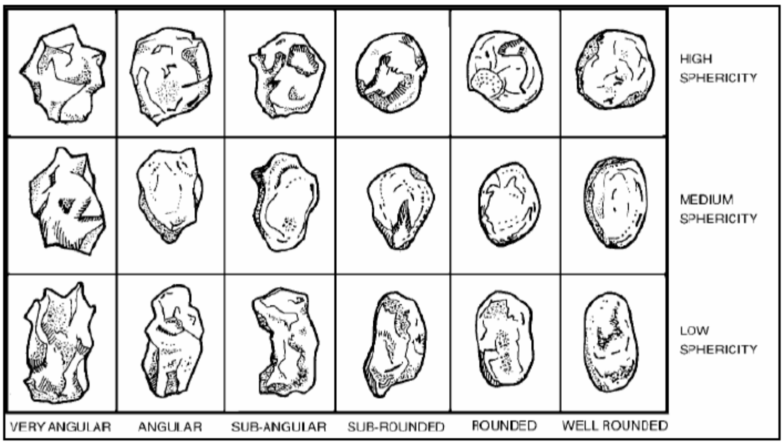


Figure 7: Classification of Grain Shape (Turkeli, A., 2012)

2.4 Dry Sieving Method

Figure 8: Dry Sieving Facility. (W.S Tyler, 2008)

Sieve method analysis is a common method implementation on a formation sand sample to define grain / particle size distribution for sand control applications. The analysis is done by using a series of mesh having gradually smaller screen sizes. The formation sample is placed on the top of the mesh series and it will seeps through the screens until it faces the screen which has smaller openings than the size of the grains.

Amila (2011) mentioned that by using dry sieving method, preparation the formation sample is done by removing the fines, then, drying the remaining samples in oven. The sample is powdered using a mortar and grinder, if necessary, to ensure individual grains are filtered rather than conglomerate grains. The formation sample then is placed in the sieving apparatus. Mechanical vibration is used to assist the particles in seeping through and on to the various mesh screens. The weight of the formation sample retained on each screens can be calculate by deducting the weight of the mesh before and after the process. Table above provides a reference for mesh size versus sieve opening.

Accurate gravel packing information can be gathered if the analysed data from the sieve analysis is precise. Hence, the formation sample that will use for sieve analysis must be actual represent of the formation itself. Bashir, A. (2007) stated that a sample should be taken within the formation or at every lithology change possibly in every 2 to 3 ft.

Table 2: Standard Sieve Opening (Bashir, A., 2007)

U.S. Series Mesh Size	**Sieve Opening (mm)**	**U.S. Series Mesh Size**	**Sieve Opening (mm)**
2.5	8.000	35	0.5000
3.0	6.73.	40	0.420
3.5	5.660	45	0.351
4.0	4.760	50	0.297
5	4.000	60	0.250
6	3.360	70	0.210
7	2.630	90	0.177
8	2.380	100	0.149
10	2.000	120	0.124
12	1.680	140	0.104
14	1.410	170	0.088
16	1.190	200	0.074
18	1.000	230	0.062
20	0.840	270	0.053
25	0.710	325	0.044
30	0.589	400	0.037

2.5 Scanning Electron Microscope (SEM)

Figure 9: A typical SEM instrument. (Geochemical Instrumentation and Analysis)

The scanning electron microscope (SEM) uses a focused beam of high-energy electrons to generate a variety of signals at the surface of solid specimens. The signals that derive from electron-sample interactions reveal information about the sample including external morphology (texture), chemical composition, and crystalline structure and orientation of materials making up the sample. In most applications, data are collected over a selected area of the surface of the sample, and a 2-dimensional image is generated that displays spatial variations in these properties. Areas ranging from approximately 1 cm to 5 microns in width can be imaged in a scanning mode using conventional SEM techniques (magnification ranging from 20X to approximately 30,000X, spatial resolution of 50 to 100 nm). The SEM is also capable of performing analyses of selected point locations on the sample; this approach is especially useful in qualitatively or semi-quantitatively determining chemical compositions (using Energy-Dispersive X-Ray Spectroscopy (EDS)), crystalline structure, and crystal orientations (using Electron Backscatter Diffraction (EBSD)). The design and function of the SEM is very similar to the Electron probe micro-analyser (EPMA) and considerable overlap in capabilities exists between the two instruments.

Accelerated electrons in an SEM carry significant amounts of kinetic energy, and this energy is dissipated as a variety of signals produced by electron-sample interactions when the incident electrons are decelerated in the solid sample. These signals include secondary electrons (that produce SEM images), backscattered electrons, diffracted backscattered electrons (EBSD that are used to determine crystal structures and orientations of minerals), photons (characteristic X-rays that are used for elemental analysis and continuum X-rays), visible light (cathodoluminescence–CL), and heat. Secondary electrons and backscattered electrons are commonly used for imaging samples: secondary electrons are most valuable for showing morphology and topography on samples and backscattered electrons are most valuable for illustrating contrasts in composition in multiphase samples (i.e. for rapid phase discrimination). X-ray generation is produced by inelastic collisions of the incident electrons with electrons in discrete orbitals (shells) of atoms in the sample. As the excited electrons return to lower energy states, they yield X-rays that are of a fixed wavelength (that is related to the difference in energy levels of electrons in different shells for a given element). Thus, characteristic X-rays are produced for each element in a mineral that is "excited" by the electron beam. SEM analysis is considered to be "non-destructive"; that is, x-rays generated by electron interactions do not lead to volume loss of the sample, so it is possible to analyse the same materials repeatedly.

2.6 Universal Scanning Probe Microscope (USPM)

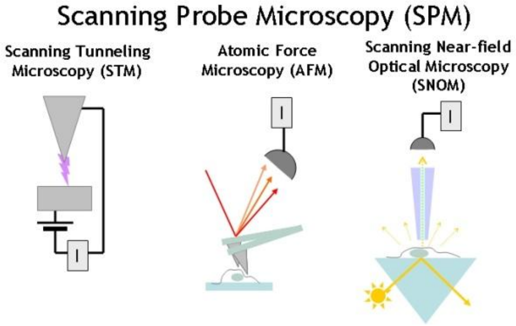


Figure 10: Overview of the main types of Scanning Probe Microscope types. (http://en.wikibooks.org/wiki/Nanotechnology/Scanning_probe_microscopy)

Scanning probe microscopes (SPM) is a branch of microscopy that creates images of surfaces using a physical probe that scans a specimen. An image of the surface is obtained by mechanically moving the probe in a raster scan of the specimen, line by line, and recording the probe-surface interaction as a function of position. Scanning probe microscopes allow scientists to image characterize and even manipulate material structures at exceedingly small scales including features of atomic proportions.

Scanning probe microscopy covers the methods where a sharp tip is scanned over a surface in a raster pattern and the interaction with the surface is recorded in each pixel to form an image of the interaction. There are a multitude of methods and interactions in SPM. Broadly speaking, there are three main categories:

- In scanning tunnelling microscopy (STM), one uses an atomically sharp metallic tip and records the minute tunnelling current between the tip and the surface, when the tip is hovering so close to the surface that electrons can move between the surface and the tip.
- In Atomic force microscopy (AFM), a cantilever with a sharp tip - somewhat like the needle of an old record player - is scanned over the surface and the topography or surface softness can be recorded.
- In Scanning near-field optical microscopy (SNOM) a probe with a smaller aperture is scanned over the surface collecting the light coming from regions much smaller than the wavelength of the light used.

CHAPTER 3

METHADOLOGY

3.1 Project Activities

Below are the project activities for this study.

Problem Statement and Objectives

- Identify the purpose of conducting the project

Literature Review

- Reading and collecting information as much as possible from different sources regarding the project

Experiment Methadology and Analysis

- Deciding the experimental method, materials, and procedures needed to conduct this project

Data Gathering and Analysis

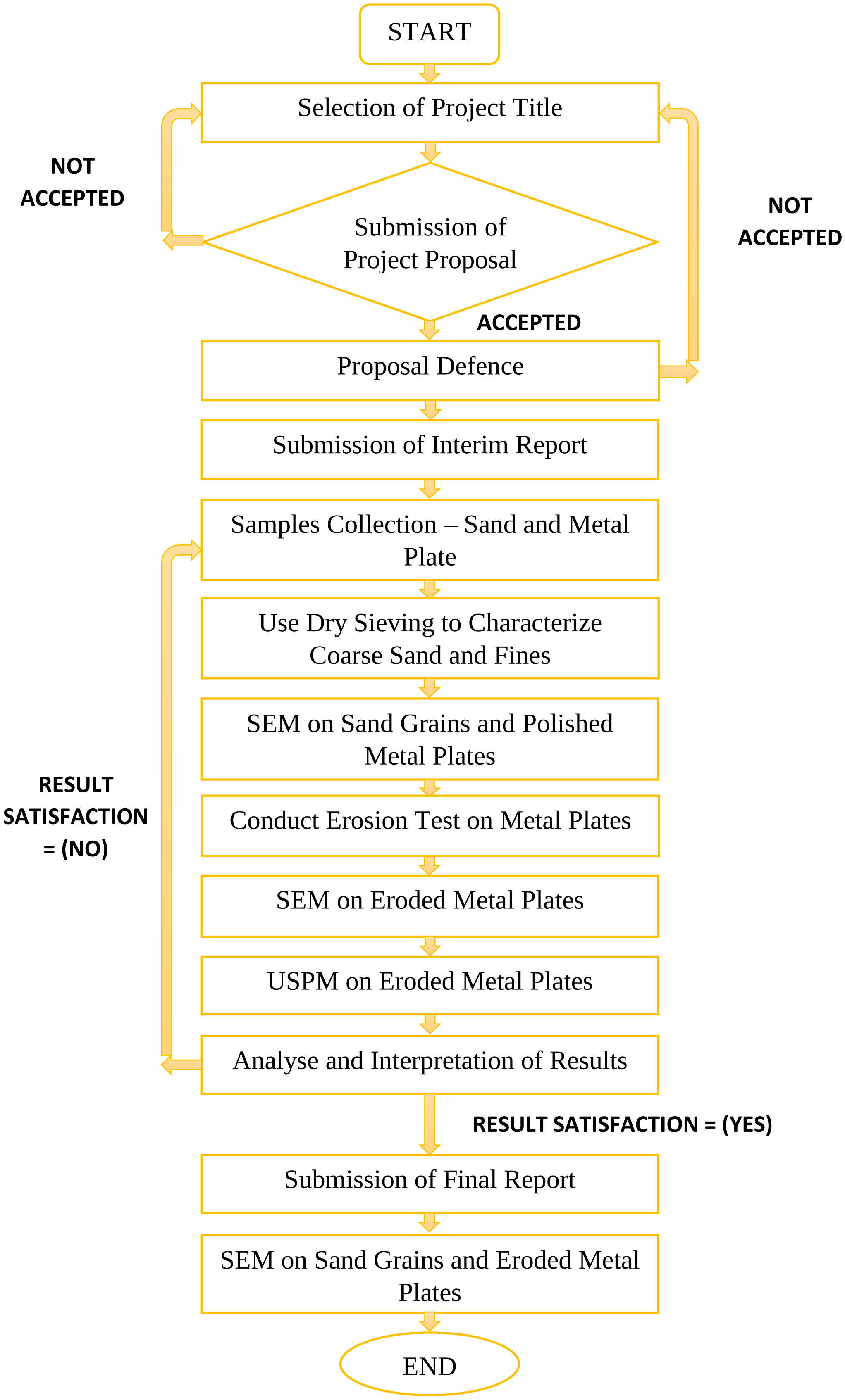
- The data(s) of experiment is collected and interpreted critically
- Result will be analysed and discussed

Documentation and Reporting

- All findings in this experiment will be documented and reported
- Conclusion and recommendation will be made by the end of the study

3.2 Project Flow Chart

Below is the project flow chart for this study.



3.3: Gantt charts

Table 3 Final Year Project I Gantt chart

No	Detail	Week													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Project Title Selection	🟥	🟥												
2	Primary Research Work and Proposal Preparation		🟥	🟥	🟥	🟥									
3	Extended Presentation Submission						🟩	🟩							
4	Presentation of Proposal Defence								🟥	🟥					
5	Project work continues – to improve on all necessary elements										🟥	🟥	🟥		
6	Interim Draft Report Submission													🟩	
7	Interim Report Submission														🟩

🟥 Process	🟩 Suggested Milestone

Table 4: Final Year Project II Gantt chart

No	Detail	Week														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Project Work Continues	🟥	🟥	🟥	🟥	🟥	🟥	🟥								
2	Progress Report Submission							🟩								
3	Project Work Continues								🟥	🟥	🟥	🟥	🟥			
4	Pre-SEDEX									🟩						
5	Draft Final Report Submission											🟩				
6	Dissertation Submission (Soft Bound)												🟩			
7	Technical Paper Submission												🟩			
8	Viva													🟩		
9	Project Dissertation Submission (Hard Bound)															🟩

🟥 Process	🟩 Suggested Milestone

3.4 Key Milestones

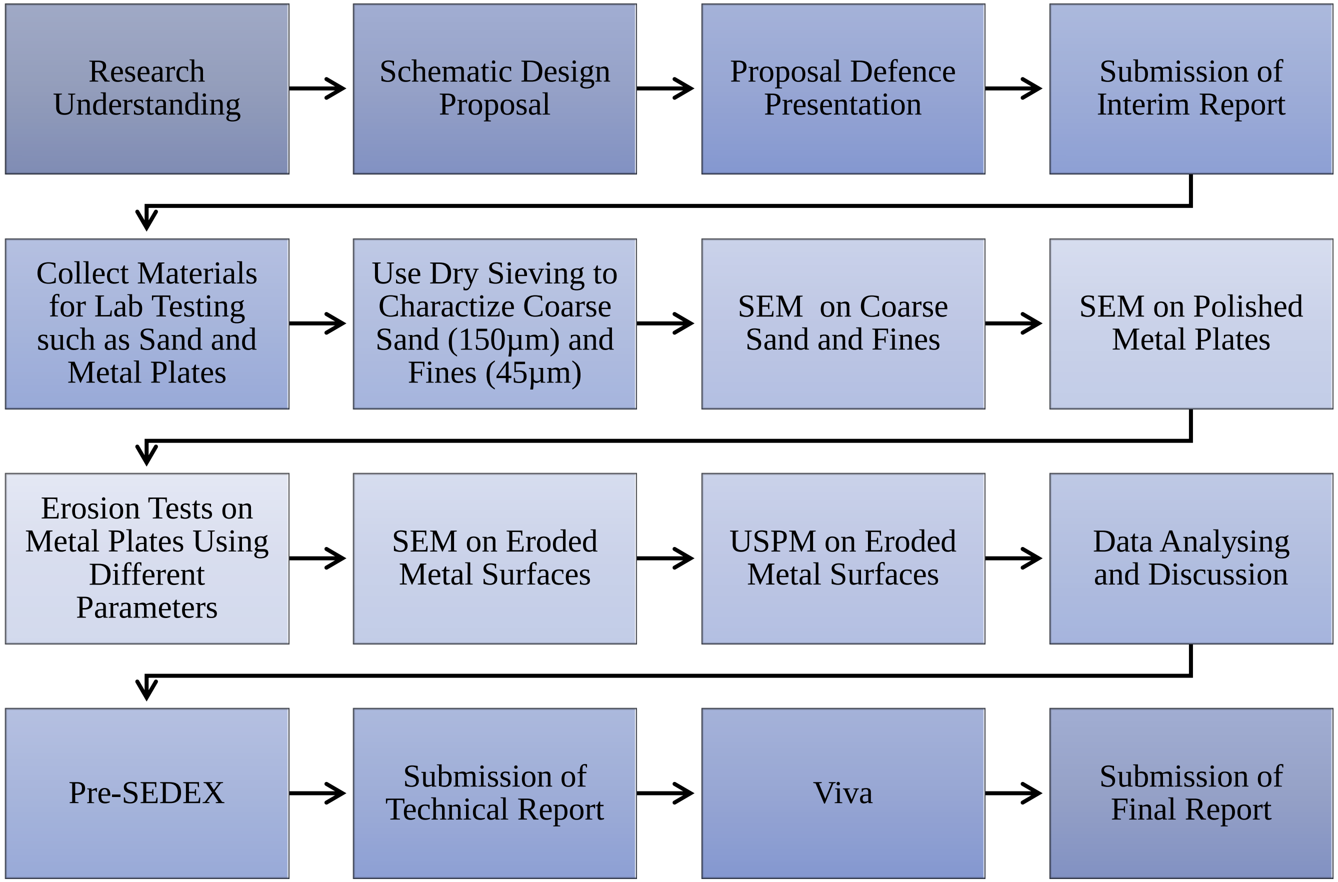


Figure 11: Key Milestone for Final Year Project

3.5 Experiment Methodology

The study is experiment based. Therefore, the study will be done in lab to gain data from the experiment. All lab activities that are conducted are at room conditions which are pressure at 1 atm and temperature 24^{0}C.

3.5.1 Dry Sieving Method

Dry sieving method is used to characterise the sand particles. Sieve analysis is classic laboratory work implementation on a formation sand sample to determine grain / particle size distribution for sand control applications. The analysis is done by using a series of mesh having gradually smaller screen sizes. The formation sample is placed on the top of the mesh series and it will seeps through the screens until it faces the screen which has smaller openings than the size of the grains. This method will used to obtain coarse sand (150µm) and fines (45µm) for the experiment.

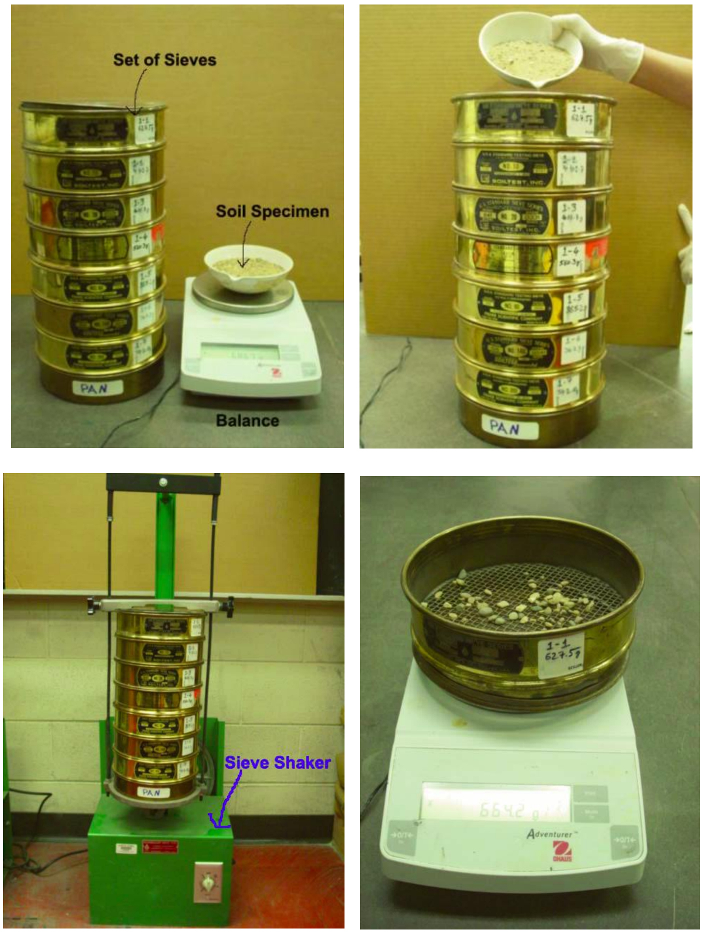


Figure 12: Equipment Used for Dry Sieving Method

Experiment Procedures:

1. Check whether all the sieves are clean, and assemble them in the ascending order of sieve numbers.
2. Arrange the sieve test accordingly as shown below, starting with lid and end with pan:
   Lid → 2.36mm → 2.00mm → 1.18mm → 600µm → 425µm → 300µm → 212µm → 150µm → 63µm →45µm → pan.
3. Carefully pour the sand sample into the top sieve and put the cap over it.

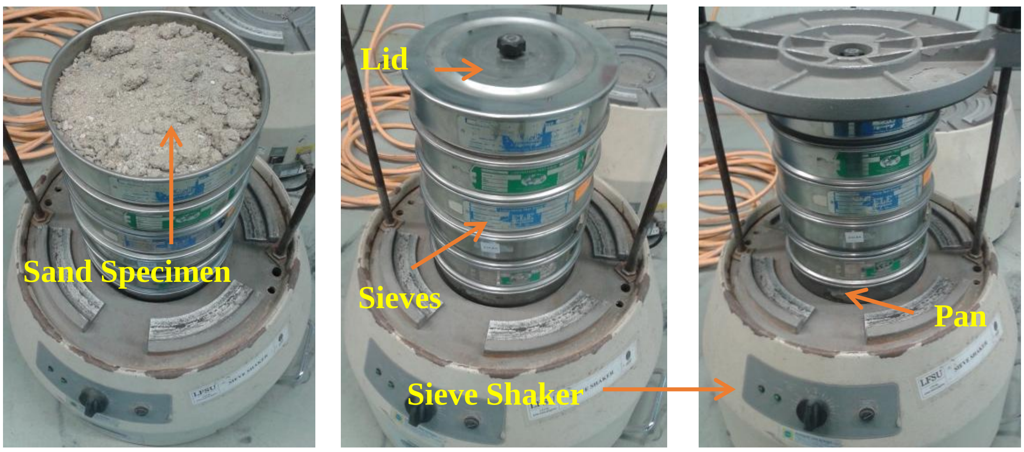


Figure 13: Dry Sieving Method for Sand Sampling

4. Put the sieve stack in the sieve shaker and shake for 15 minutes.
5. Remove the stack from shaker and collect the sand sample accordingly.

3.5.2 Erosion Test

Materials and equipment used are:

1. Sand

   Sand type will be sandstone, a clastic sedimentary rock of sand-size particles which used as an erosion agent for flowlines erosion. Berea sandstone or other types will be used to present the sand production in reservoir.
2. Carbon steel plate

   The plate is used as erosion sample for representing the inner surface of production flowlines that will be eroded by fine sand during reservoir production.
3. Air blower

   The purpose of this equipment is to generate air pressure and velocity of air and sand system in production flowlines. The blower can supply air about 21 kPa, at speed of 2800 r/min and the maximum flux is 120 m^3/h.
4. Mixing chamber (Venturi)

   Venturi is the chamber for mixing air from air blower and sand from sand feeding system.

Experiment setup:

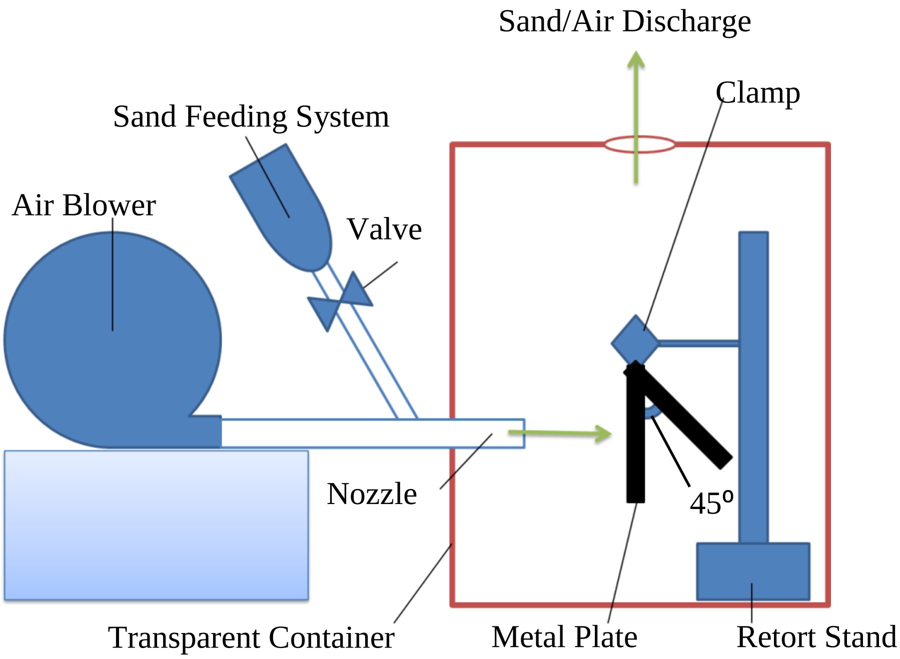


Figure 14: Schematic of the erosion test facility

Experiment Procedure:

1. Polish the metal plate and capture several images of the polished surface using SEM.
2. Record the initial weight of the metal plate.
3. Use retort stand to clamp the metal plate perpendicularly to nozzle.
4. Switch on the air blower and then carefully pour the 150 µm sand sample into sand feeding system.
5. Open sand feeding system valve and run the experiment for 3 hours.
6. Close the sand feeding system valve and switch off the air blower.
7. Record the weight of eroded metal plate.
8. Repeat step 2 until 7 using different parameters:
   a. Sand size.
   b. Impact angle.
   c. Air velocity.
   d. Sand flow rate.
   e. Distance between nozzle and metal plate.

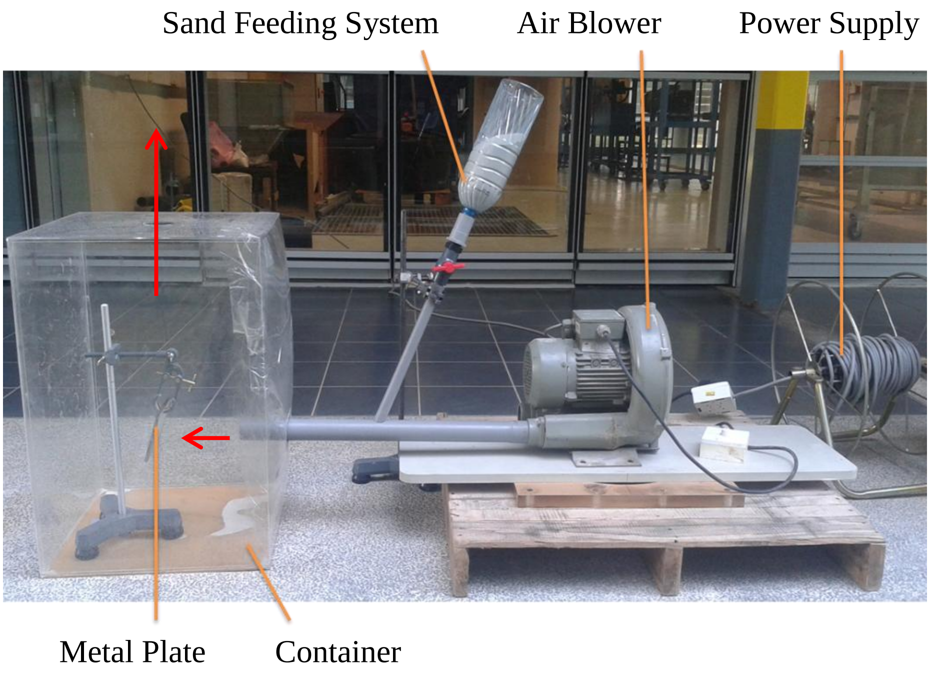


Figure 15: Experiment Setup

3.5.3 Scanning Electron Microscope (SEM)

SEM is a type of electron microscope that produces images of a sample by scanning it with a focused beam of electrons. The several purposes of using SEM which are;

1. To measure the size of the sand particle.
2. To view the shape of the sand particle.
3. To measure the cross-section of erosion on metal plate as well as to estimate the depth of penetration due to sand erosion.
4. To identify the compositions of sand grains and metal plates using Energy Dispersive Spectrum (EDS).

Figure 16 is the image of schematic diagram of SEM – shows how the machine technically work to capture the image of surface of samples as well as to analyse the composition of the sample surface. Figure 15 is the image of the SEM used for this study.

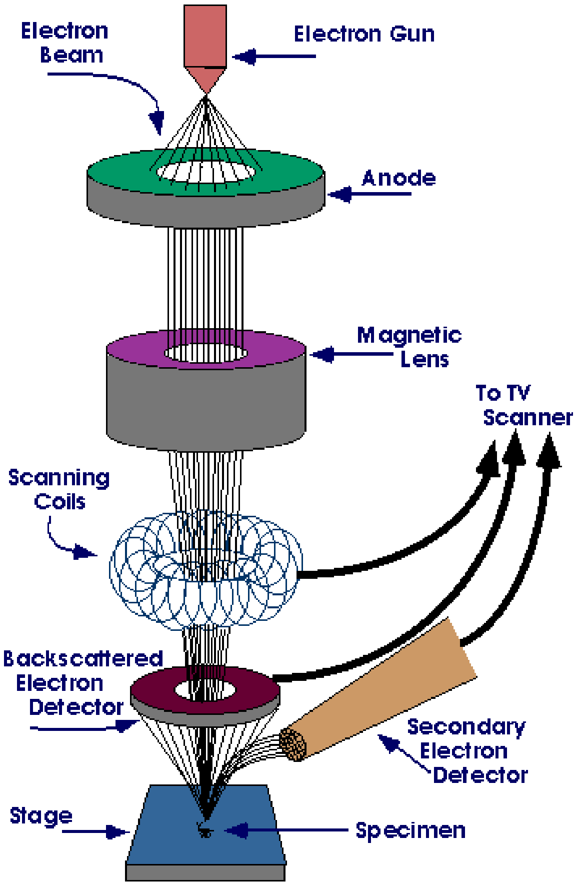


Figure 16: Scanning Electron Microscope (SEM).

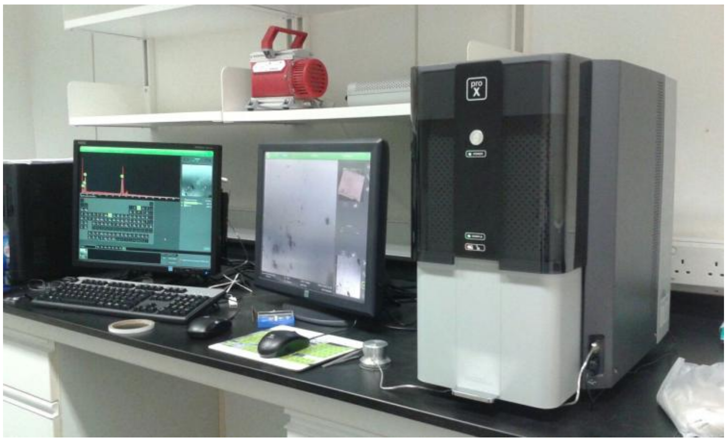


Figure 17: Image of Scanning Electron Microscope (SEM) Machine

3.5.4 Universal Scanning Probe Microscope (USPM)

Scanning probe microscopes (SPM) is a branch of microscopy that creates images of surfaces using a physical probe that scans a specimen. An image of the surface is obtained by mechanically moving the probe in a raster scan of the specimen, line by line, and recording the probe-surface interaction as a function of position. Scanning probe microscopes allow scientists to image characterize and even manipulate material structures at exceedingly small scales including features of atomic proportions. USPM is used to analyse the 3D image of 500nmx500nm surface. Therefore, the thickness loss of metal surface can be obtained using the machine.

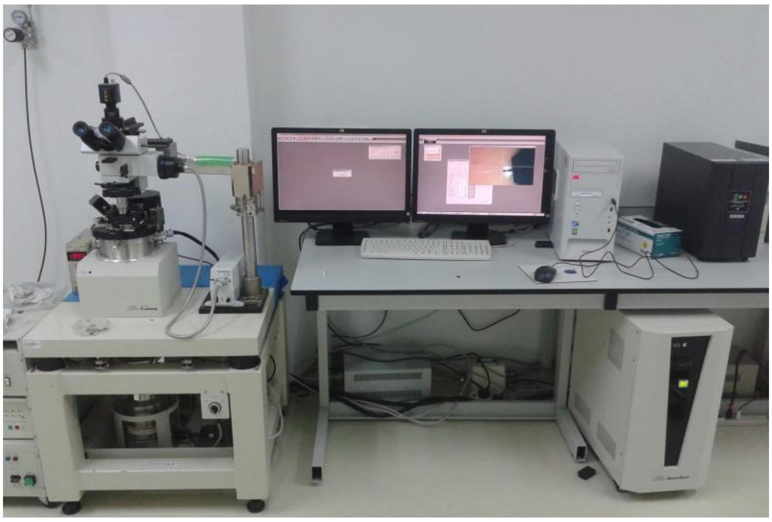


Figure 18: Image of Universal Scanning Probe Microscope (USPM) machine

CHAPTER 4

RESULT AND DISCUSSION

4.1 SAMPLING

4.1.1Mine Sand

Sand type will be sandstone, a clastic sedimentary rock of sand-size particles which used as an erosion agent for flowlines erosion.

Mine sand in Perak, Malaysia has been used in this experiment due to unavailability of Berea sandstone. The sand is dried under sunlight and then sieve using sieve shaker.

The sizes of sand particle used in the experiment are 150 microns and 45 microns. The sand samples are collected using dry sieving test. The sieve test is characterized using these set-ups:

Lid → 1.18mm → 600μm → 425μm → 300μm → 212μm → 150μm → 63μm →45μm → pan.

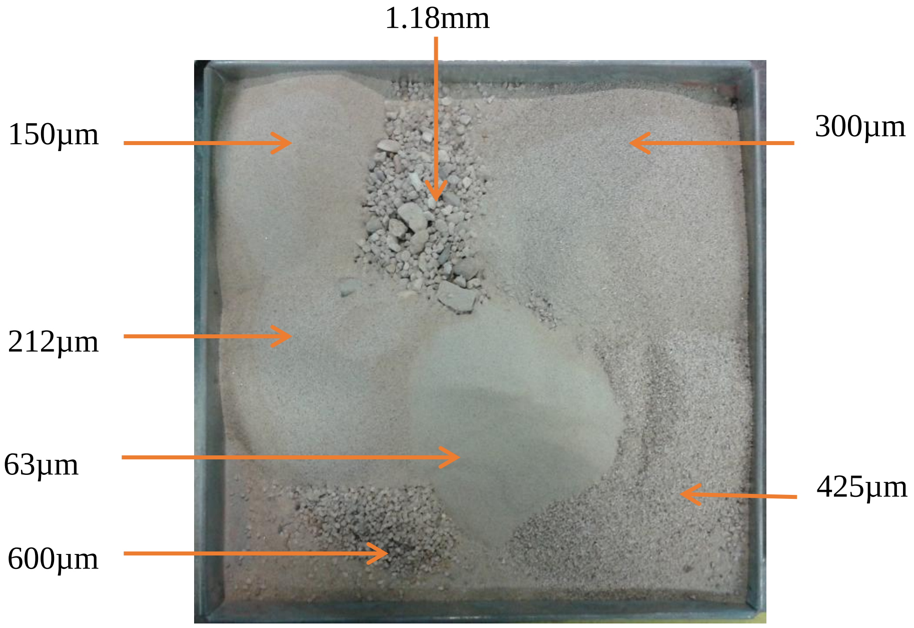


Figure 19: Different sizes of sand collected using dry sieing test

Below are the images of sand grains that captured using SEM. Figure 20-A and Figure 20-B show the size and shape of coarse sand and fines at 500x magnification.

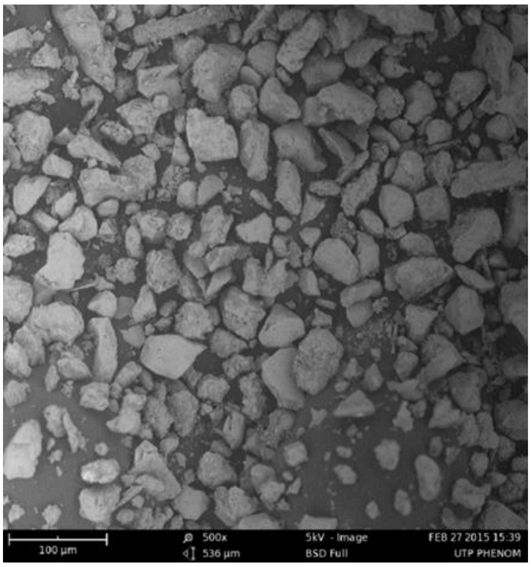


Figure 20-A: 45µm sand size

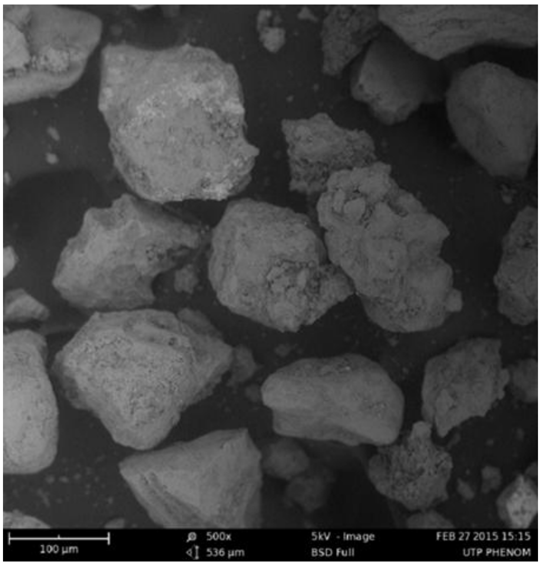


Figure 20-B: 150µm sand size

The images captured show that how the differences between 150µm sand size and 45µm sand size. The images also show the shape of the sand grains which are rounded to angular. The shape is not considered as a parameter for this experiment because it is unable to control the shape of the sand since it is too small to separate between rounded and angular sand grain.

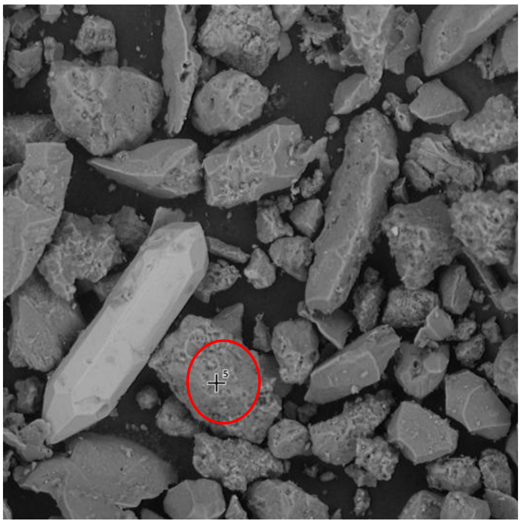


Figure 21-A: Pointed region for EDS

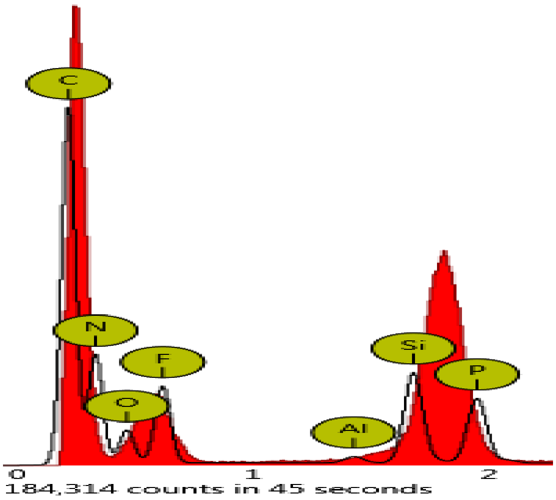


Figure 21-B: EDS result of mine sand

Figure 21-A and Figure 21-B are the image of pointed Energy Dispersive Spectrum (EDS) test and EDS result for mine sand which shows that the composition of mine sand in Perak. The table shows that Perak mine sand contains Aluminium (0.5%), Silicon (31.3%), Phosphorus (4.1 %) as well as Carbon (18.2%). Nitrogen, Oxygen and Fluorine also available is due to surrounding of the material,

Table 5: EDS composition result for mine sand

Element Number	Element Symbol	Element Name	Confidence	Concentration	Error
6	**C**	**Carbon**	**100.0**	**18.2**	**0.5**
7	**N**	**Nitrogen**	**100.0**	**31.3**	**1.0**
14	**Si**	**Silicon**	**100.0**	**4.4**	**1.0**
15	**P**	**Phosphorus**	**100.0**	**4.1**	**1.2**
9	**F**	**Fluorine**	**100.0**	**25.2**	**1.4**
8	**O**	**Oxygen**	**100.0**	**16.2**	**2.2**
13	**Al**	**Aluminium**	**100.0**	**0.5**	**4.4**

4.2.1 S45C - Carbon Steel Plate

Steel plates are used as erosion sample. The plates are representing the inner surface of production flowlines that are eroded during the production. The plates need to be polished first before running the experiment to get the smooth surface and will not affect result of the erosion experiment. EDS result for carbon steel surface before the experiment.

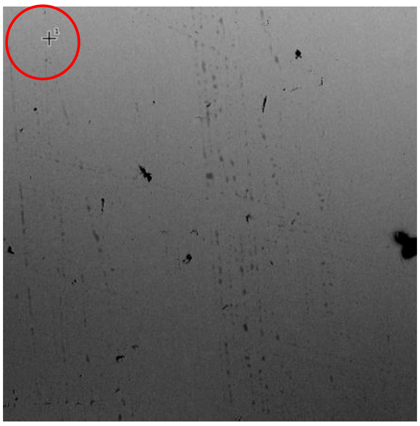


Figure 22-A: Pointed region for EDS

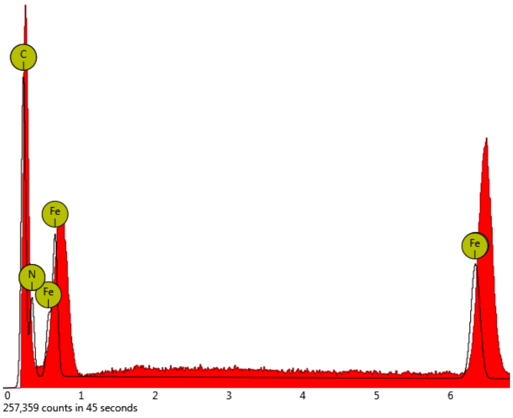


Figure 22-B: EDS result of S45C carbon steel

Table 6 shows that the composition of S45c carbon steel which is Carbon (20.9 %), Ferum (Iron) (42.8 %). Nitrogen is present due to surrounding.

Table 6: EDS composition result for S45C carbon steel

Element Number	**Element Symbol**	**Element Name**	**Confidence**	**Concentration**	**Error**
6	C	Carbon	100.0	20.9	0.8
26	Fe	Iron	100.0	42.8	1.0
7	N	Nitrogen	100.0	36.3	1.7

4.2 SCANNING ELECTRON MICROSCOPE (SEM)

The experiments will be conducted using several tests. The results of pre-experiment and post-experiment will be recorded and analysed.

Figure 23-A is the image of untreated sample surface (SEM of polish metal at 2000x magnification) and Figure 23-B is the treated sample surface (eroded surface after 3 hours erosion test by naked eye).

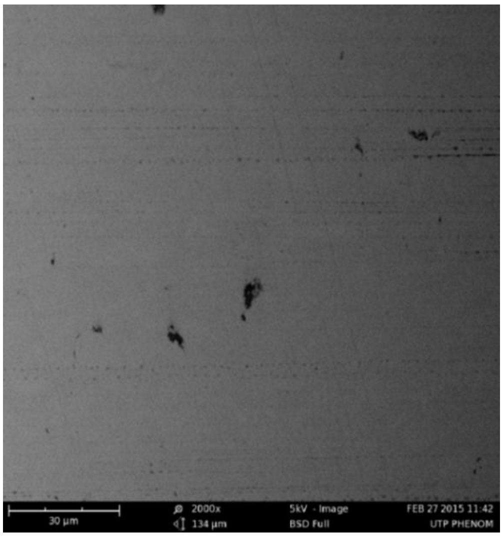


Figure 23-A: SEM on untreated sample at 500x magnification

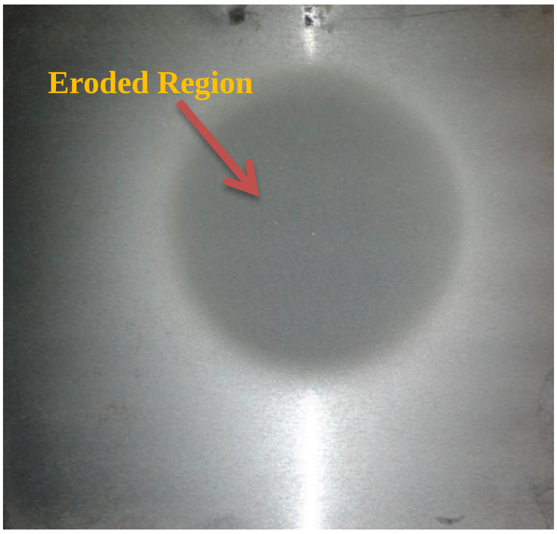


Figure 23-B: Surface of treated sample by naked eye

There experiment have been conducted focusing on the parameters which are particle size, air velocity, sand flow rate, impact angle as well as distance between nozzle and target surface. For each parameter, several experiments conducted using 2 different conditions. The repeatability of the experiments is considered good to obtain the best results.

SEM results of treated sample at 2000x magnifications for each parameter are captured so that comparison can be done with SEM of polished metal (untreated sample) which also al 2000x magnification.

4.2.1 Particle Size

The parameters for this experiment are:

- Sand type: Mine sand
- Sand size: **150µm, 45µm**
- Angle: 90^0
- Sand flow rate: 1 kg/hr.
- Distance: 10cm
- Air Velocity: 20m/s

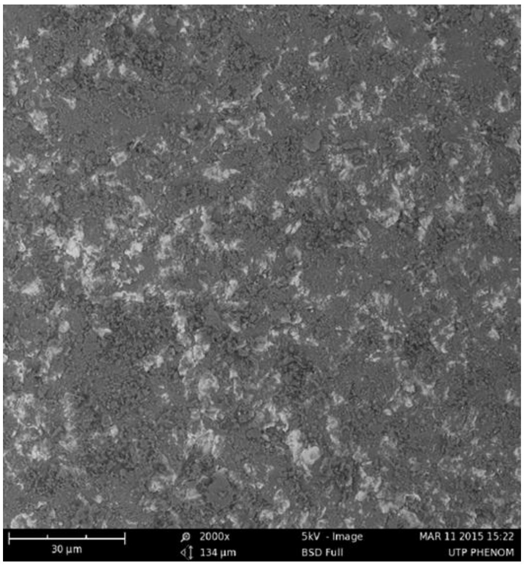


Figure 24-A: Eroded surface by 150µm sand

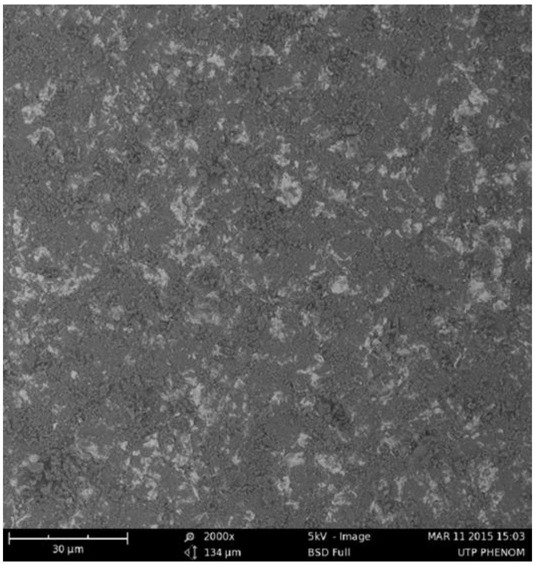


Figure 24-B: Eroded surface by 45µm sand

Figure 24-A and Figure 24-B show that there is a strong relationship between particle size and the damage scar size on the metal surface. Coarse sand (150µm) erodes more compared to fines (45µm).

According to Clark (1990), it has been noted that collision efficiency, η, decreases with decreasing particle size. This is expressed in the collision efficiency of the body (the number of particles impacting unit area of the body in unit time divided by the number of particles in the volume directed at unit area of a target in unit time) having a value less than unity. For a given set of erosion conditions, a decrease in collision efficiency will cause a decrease in erosion rate. Quantitatively, this may be understood in terms of the low inertia of small particles which are not constrained to follow the air as it moves around a body in its path. Therefore, the bigger particle size will have more inertia and momentum as well as will be following air path to impact the metal surface and cause higher erosion in term of penetration on the metal surface. However, the results prove that even fines can cause the erosion on metal surface even the mass of fines is small compared to coarse sand. So, this proves that the fines will cause severe damage especially at places where coarse sand cannot anticipate in a longer time period.

4.2.2 Air Velocity

The experiment parameters are:

- Sand type: Mine sand
- Sand size: 150µm,
- Angle: 90^0
- Sand flow rate: 1 kg/hr.
- Distance: 5cm
- Air Velocity: **20m/s, 22 m/s**

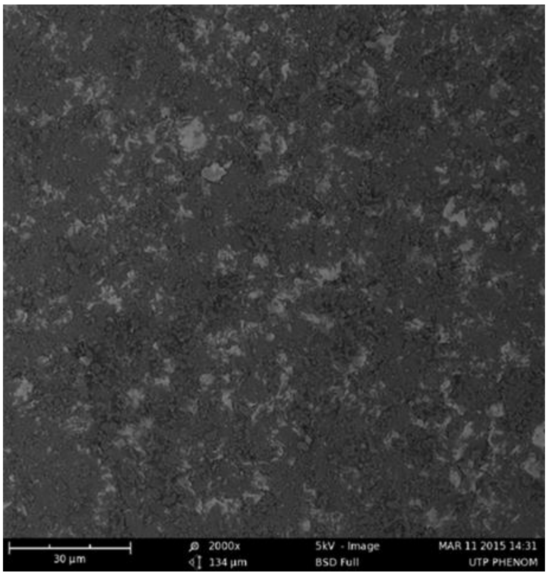


Figure 25-A: Eroded surface due to air velocity at 20 m/s

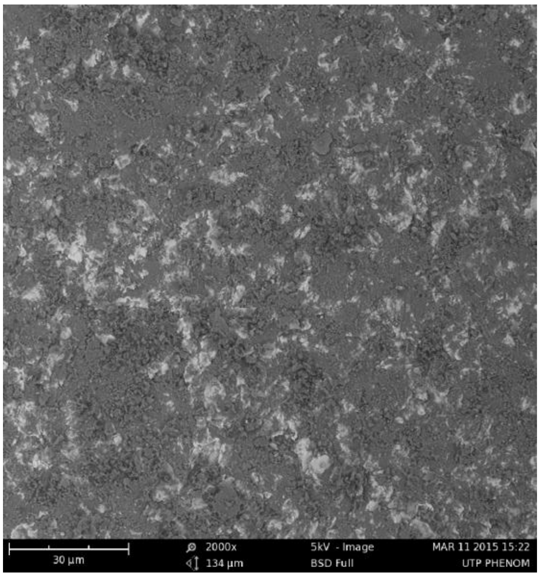


Figure 25-B: Eroded surface due to air velocity at 22 m/s

Figure 25-A and Figure 25-B show that the relationship between air velocity and the erosion on the metal surface. Erosion rate at air velocity at 22 m/s is higher erosion rate than 20 m/s. The difference between these two surfaces is obvious. The velocity is important in supplying the impact energy to sand. So, these results explain that erosion rate is directly proportional to kinetic energy (mV2/2) of unit mass of particles impacting the metal specimen [10]. Certainly the velocity effect is very important since a moderate increase in impact speed may produce a dramatic increase in erosion rate. Therefore, increasing of velocity gives higher erosion of metal surface due to increase of momentum and inertia of the sand particles. The difference of erosion on surface will be much higher is the times for running the experiments are longer.

Increase of air velocity also will constrain more the sand particle, even it is coarser or more fines, to follow the air as it move around in its path. So, this proves that the velocity of the air is very important parameter in affecting the sand erosion since it can increase the inertia and kinetic or impact energy of the sand particles as well as constrain it more in flowing in air path.

4.2.3 Sand flow rate

The experiment parameters are:

- Sand type: Mine sand
- Sand size: 150µm
- Angle: 90^0
- Sand flow rate: **1 kg/hr., 1.5 kg/hr.**
- Distance: 5cm
- Air Velocity: 20m/s

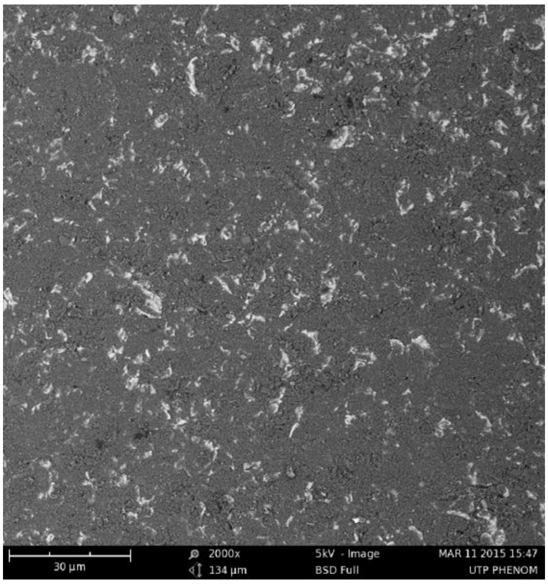


Figure 26-A: Eroded surface due to sand flow rate at 1 kg/hr.

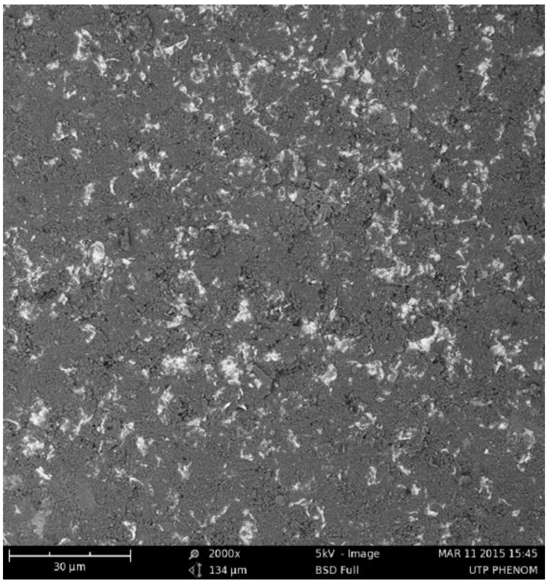


Figure 26-B: Eroded surface due to sand flow rate at 1.5 kg/hr.

Figure 26-A and Figure 26-B show how the sand feeding system affects the results of the erosion on metal surface. The higher rate of sand feed will slightly increase the impact of sand on metal surface. The erosion rate did not greatly increase with the solid loading and it is indicate that particle-particle interference was taking place during the process of impacting sand on metal surfaces and

reducing the ability of all particles to impact the eroding surface. Thus, greatly increase of sand loading will not affect much on the eroded surface due to the particle-particle interference.

Increase of sand feed also effect of air flow which cause the flow becomes less stable due to air-particle interference. This because more sand will flow with air and the air flow decrease a bit, thus will affect the momentum of sand to impact the target surface. However, further increase of sand feed will cause the air flow to be blocked due to sand. So, this is also explained why higher sand production will affect the production rate.

4.2.4 Distance between nozzle and target surface

The experiment parameters are:

- Sand type: Mine sand
- Sand size: 150µm
- Angle: 90^0
- Sand flow rate: 1 kg/hr.
- Distance: **5cm, 10cm**
- Air Velocity: 20m/s

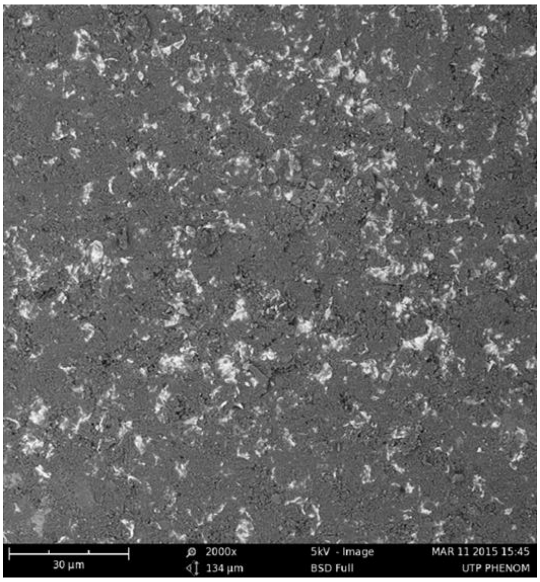


Figure 27-A: Eroded surface due to 5 cm

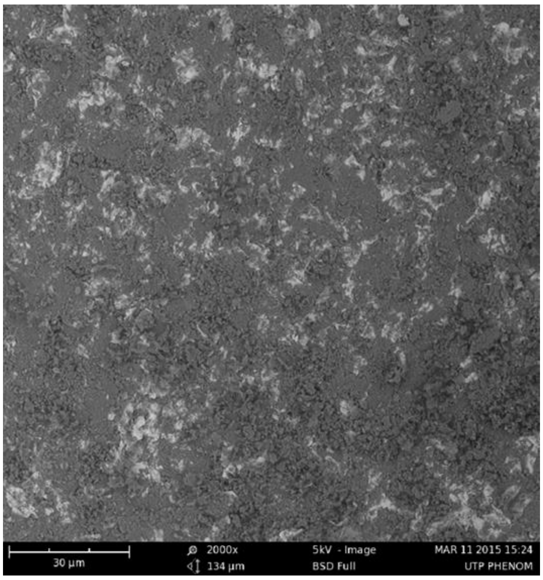


Figure 27-B: Eroded surface due to 10cm

Figure 27-A and Figure 27-B show the effect of distance between nozzle and metal surface. This shows that the short distance will cause the shorter impact time which increase the sand impact in certain period of time in terms of quality. The results also explain that longer distance between nozzle and target surface cause the momentum of particle to drop slightly due to energy loss during the traveling of sand in flowing air generated by air blower pass through nozzle to metal surface. The longer distance also cause the impact region or target on surface bigger. This is because flowing air that carrying sand becomes not stable and will spread at the end of the nozzle outlet, thus increase the impact radius. Therefore, the increase of impact radius due to long distance of air flowing cause the sand are not concentrate to impact the target surface anymore, thus will decrease the momentum @ impact energy of sand.

Compared to 5 cm distance, the air flow still stable when passing through the nozzle, thus the sand will constrained to follow the air during the short distance travel. So, this make the target surface still in same size with nozzle size because there is no or very little increase of impact radius.

4.2.5 Impact angle

The experiment parameters are:

- Sand type: Mine sand
- Sand size: 150µm,
- Angle: **45^0, 90^0**
- Sand flow rate: 1 kg/hr.
- Distance: 5cm
- Air Velocity: 20m/s

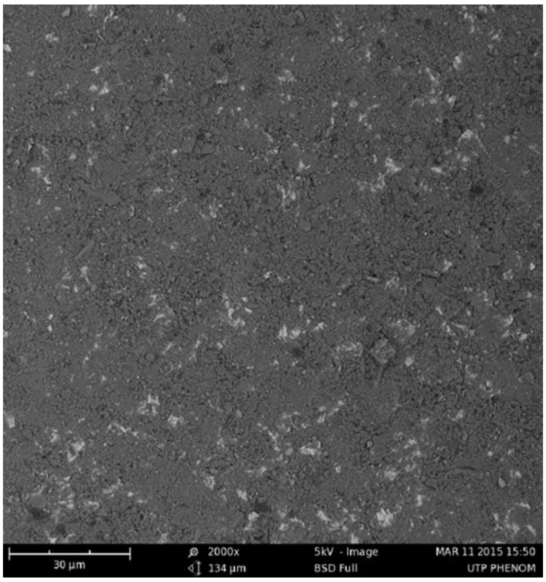


Figure 28-A: Eroded surface at 45^0 angle

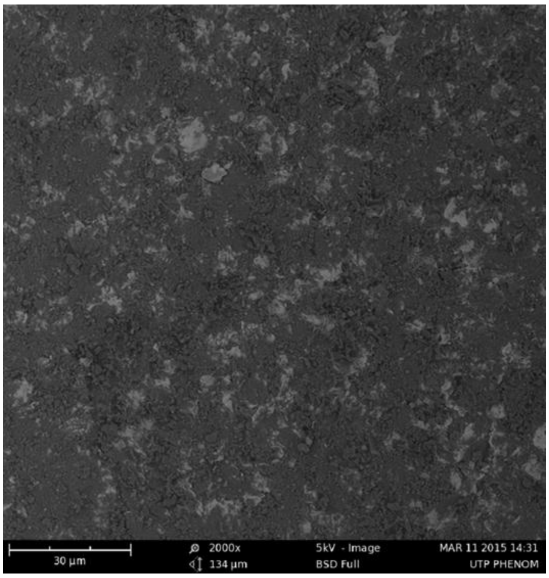


Figure 28-B: Eroded surface at 90^0 angle

Figure 28-A and Figure 28-B show how impact angles at 45^0 and90^0 contribute to erosion rate on metal surface. At 90^0 impact angle, the erosion is the greatest in term of penetration because almost of the sand particles will impact on the metal surface. Small or narrow target surface, plus at perpendicular angle cause the sand to concentrate on eroding the surface which cause better penetrate compared to incline impact angle. This penetration causes the “digging” erosion shape on the small target area.

However, at 45^0 impacts angle, the erosion occurred is also great, but in term of area. This is because the incline plate causes the air to spread to lower region of the target surface. So, the erosion occurred also will spread to lower region of the target surface. This also cause by the sand-sand interference during the eroding the plate. Almost half of the sand particles impact the closest region to nozzle, and the other half will be interfered from impacting the surface and thus flow to lower region surface and erode the surface there. Therefore, this erosion will causes the “cupping” erosion shape on larger target area.

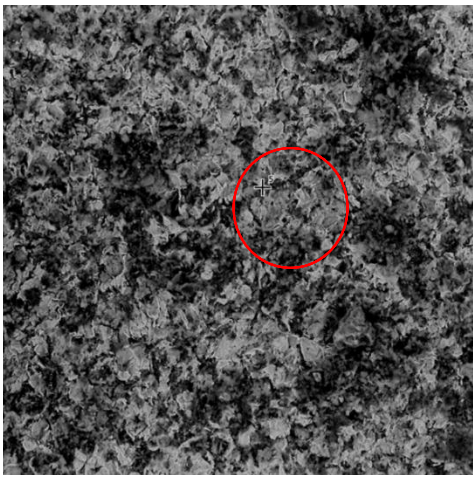


Figure 29-A: Pointed region treated sample for EDS

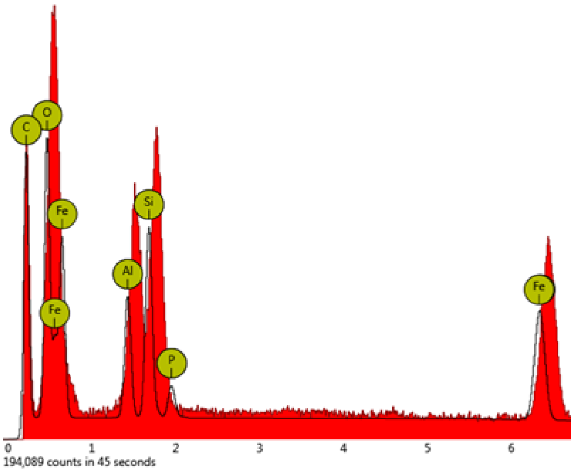


Figure 29-B: EDS result of after erosion test

Table 7: EDS composition result for S45C carbon steel after erosion test

Element Number	**Element Symbol**	**Element Name**	**Confidence**	**Concentration**	**Error**
8	O	Oxygen	100.0	53.8	1.2
6	C	Carbon	100.0	11.7	1.3
14	Si	Silicon	100.0	8.9	1.4
26	Fe	Iron	100.0	16.0	1.5
13	Al	Aluminium	100.0	7.6	1.8
15	P	Phosphorus	100.0	2.0	4.1

The EDS test has been done on plate after erosion experiment and the result shows that there are changes of metal composition after the experiment. This shows that sand that impacted on metal surface cause some of sand is attached to the metal or maybe there is some chemical reaction between sand and the metal which cause the elements from sand transferred to the metal. The compositions change to C, Si, Fe, Al and P from only Fe and C. This also shows that the erosion of metal due to sand causes the changes of composition.

4.3 UNIVERSAL SCANNING PROBE MICROSCOPE (USPM)

The USPM is the last stage of experiment. USPM is used to measure the surface thickness loss. Shown are the results of USPM on surface of untreated sample and treated samples. The area of images is 25 µm x 25 µm. In the images, darker side indicate the bottom of the surface and the lighter side indicate the peak of the surface.

4.3.1 Untreated Sample

The type of analysis of USPM is divided into two (2) types, which are analysis in nanometre (nm) scale and degree (deg) scale. Figure 29-A, Figure 29-B and Figure 29-C are in nm scale and Figure 29-D, Figure 29-E, Figure 28-F are in deg.

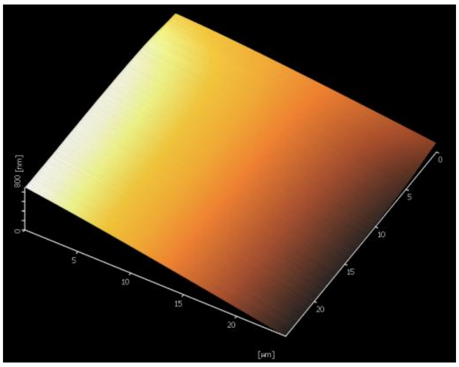


Figure 30-A: 3D image of untreated sample in nm

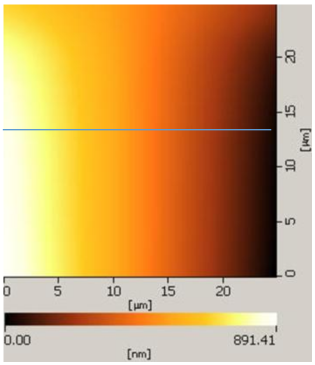


Figure 30-B: Top view of untreated sample in nm

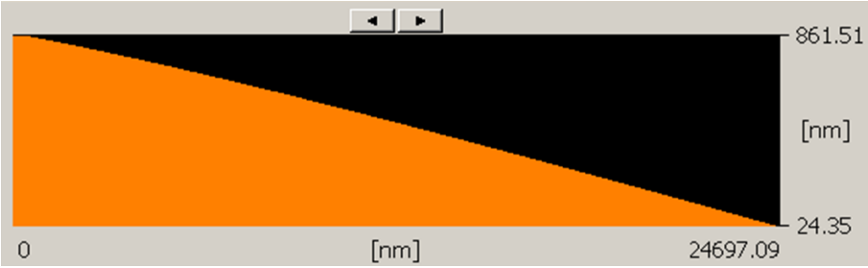


Figure 30-C: Surface thickness of untreated sample in nm

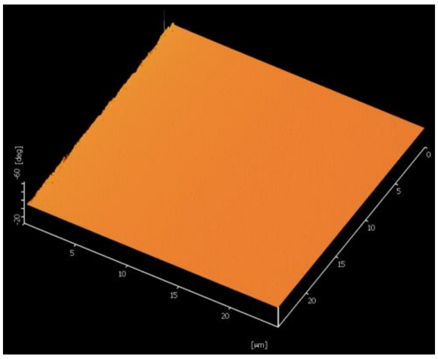


Figure 30-D: 3D image of untreated sample in degree

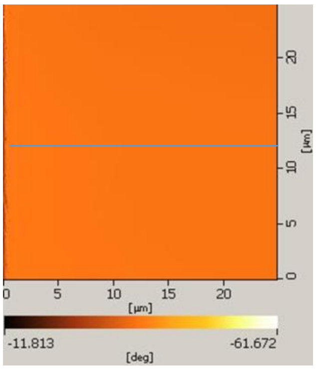


Figure 30-E: Top view of untreated sample in degree

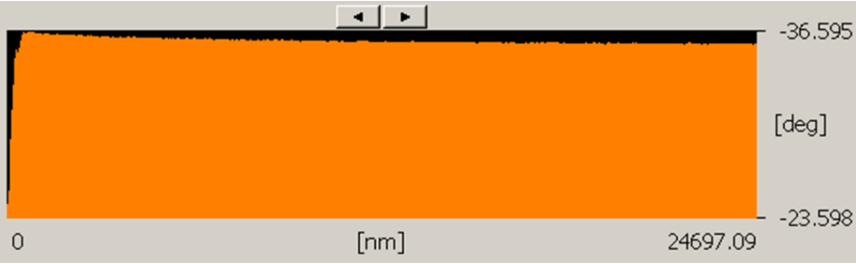


Figure 30-F: Surface thickness of untreated sample in degree

The Figure 29-A show the condition of the untreated sample which is considered have a smooth surface after polished. Figure 29-B is the image of top view of the untreated sample. The colours are from dark to light which is indicate the different level of surface height calculated from lenses of USPM. Figure 29-C is the measure surface thickness of untreated sample from bottom to peak in nm. As shown in the figure, there is a slight different of height from peak to bottom.

$$861.51\ nm\ (peak) - 24.35\ nm\ (bottom) = 837.16\ nm$$

However, the different in height of peak and bottom is about 837.16 nm because of the surface itself which is slightly inclined.

Figure 29-D shows the 3D image of untreated sample in degree. There is no change in degree measurement on the surface. Figure 29-E is the top view of untreated sample in degree measurement. No different is detected in this figure. Figure 29-F is the surface height of untreated sample from bottom to peak in degree. There is some different height of the surface which is very small. The degree reading is decreasing a bit due to small incline of the surface.

4.3.2 Treated Sample

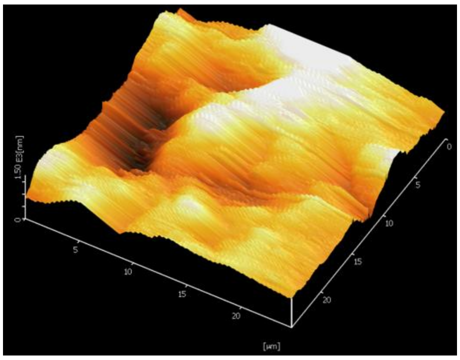


Figure 31-A: 3D image of treated sample in nm

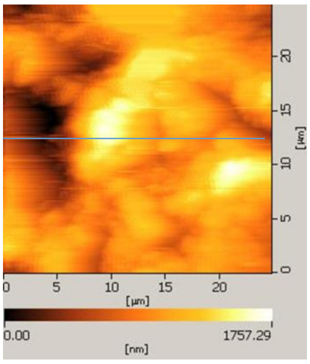


Figure 31-B: Top view of treated sample in nm

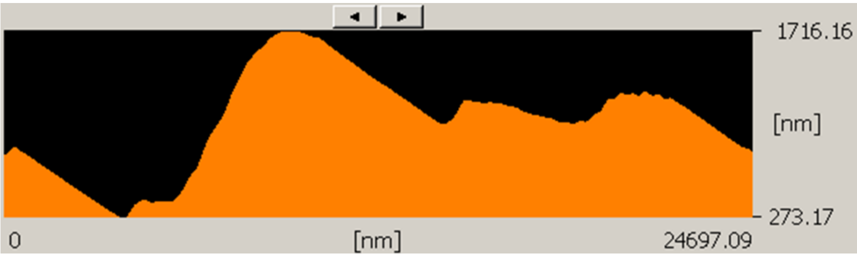


Figure 31-C: Surface thickness of treated sample in nm

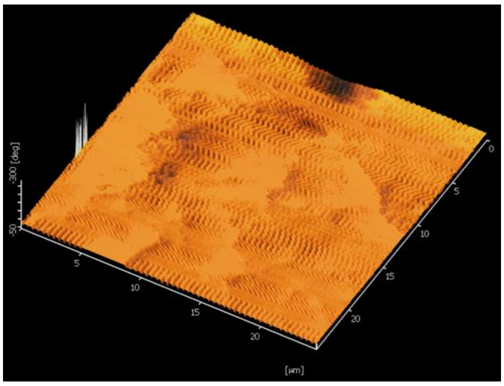


Figure 31-D: 3D image of treated sample in degree

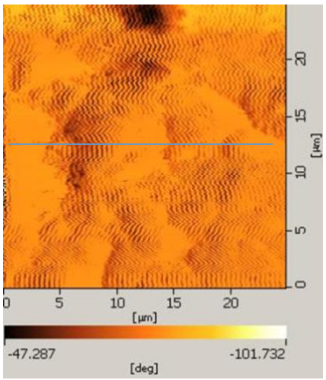


Figure 31-E: Top view of treated sample in degree

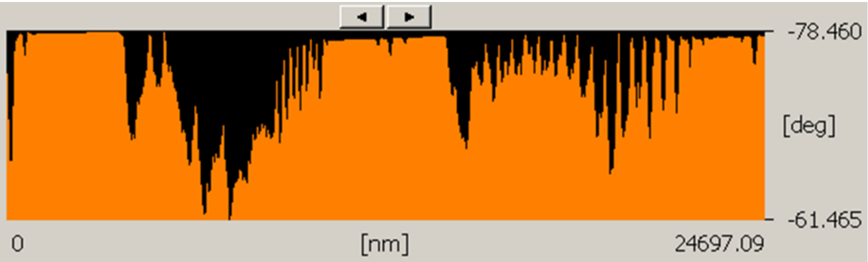


Figure 31-F: Surface thickness of treated sample in degree

The Figure 30-A show the condition of the treated sample which is very different after the experiment conducted. The mountain-like image is produced compared to the surface of untreated sample. This shows how the erosion factors can affect the surface of target metal. This also proves that erosion can occur even the erosion time is very short.

Figure 30-B is the image of top view of the treated sample. There is a very dark region in the image which is proves that it is the place of the highest erosion occurred may be due to the low in strength of the metal at that region. The peak region has lowest erosion because the metal component is stronger than dark side region.

Figure 30-C show the different between peak and bottom is high compared to the untreated sample. The measurement is only covered the blue line in Figure 29-B.

$$1716.16\,nm\ (peak) - 273.17\,nm\ (bottom) = 1442.99\,nm$$

$$\frac{1442.99\,nm}{3\ hours} = 481\,\frac{nm}{hr} = 8.012\,\frac{nm}{min} = 0.134\,\frac{nm}{sec}$$

The calculation shows that how much the rate of erosion can reduce the surface thickness overtime regarding the data obtained from USPM.

Figure 30-D shows the 3D image of treated sample in degree measurement. There are some changes on the whole surface in degree measurement. The colour of bottom and peak shown is same.

Figure 30-E is the top view of treated sample in degree measurement. The darkest region is the highest peak of the surface.

Figure 30-F show the different between peak and bottom high compared to the untreated sample. The result is generated from measurement that only covered on blue line in Figure 29-E. The result shows how the erosion takes place on the surface.

CHAPTER 5

CONCLUSION

The study is done to explore and investigate factors that cause sand erosion and to examine the effects of particle size on erosion rate on pipe surfaces. Experiments will conduct to obtain these data.

Before the experiment, dry sieving method is used to obtain the correct sand sizes which are 45 microns (fines) and 150 microns (coarse sand). After that, the sand samples are categorized into different types. They are used as “erosion agents” in the erosion test. The sand will flow with air and hit metal plate at 45º and 90º impact angles. The experiment will be run for three (3) hours. After that, the eroded plates will be examining using SEM which is used to identify the shape of sand grains as well as to capture image of erosion on metal surface. Besides, it is also used to measure the cross-section of eroded on plates so that the type of erosion can be identified.

As a conclusion, from this experiment study, the initial hypothesises are proved. Larger grain sizes are expected to cause severe erosion on surface of pipework compared to fines. 90^0 impact angles give more erosion in term of penetration and 45^0 impact angles give more erosion in term of area. Increase of sand flow rate will increase the sand erosion, but greatly increase of sand feed causes the decrease of sand erosion. Air velocities also affect the erosion rate, which erosion will increase greatly even moderate increase of air velocity. Short distance between nozzle and target surface increase the sand impact on metal surface.

By identifying all parameters, the prediction of pipeline lifespan can be predicted. Using this data in this study, prediction of erosion overtime can be predicted, thus avoiding severe accidents to be happened.

CHAPTER 6

RECOMMENDATIONS

As for recommendations, hopefully in the future, this study should be continued using different parameters, specimens and conditions. The parameters that can be considered in this study are the shape and sphericity of the sand and the sand strengths according to Mohr’s scales. For the experiment specimens and conditions that can be considered are use of real reservoir sands and fracturing sands, use of real pipelines steel grades that are used in oil and gas industries as well as conduct experiments at real reservoir temperatures and pressures.

This study should also be continued using better equipment such as using air blower with more accurate regulator as use of loop sand discharge system for infinite sand feeding system. Experiment done by machine in high technology lab also can be considered in this study to avoid or minimize the human error during the experiments conducted.

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