CHAPTER 1
INTRODUCTION

1.1 Background of Study

The Onshore Slug Catcher (OSC) was used to receive gas and condensate from offshore, to separate liquid from gas prior sale to Gas Processing Plant (GPP) and to separate condensate prior selling and further process at GPP. The OSC consists of facilities such as separators, compressors, pumps, valves and pipelines. For PETRONAS, the company who run the OSC plant, the reliability factor of the plant is the most important criterion that can sustain productions of the terminal. Maintenance work on certain equipments is considered vital in order to sustain the reliability of the terminal. For OSC terminal, there are some problems related to its condensate pump. The problems occurred due to failures of the mechanical seal that still cannot be resolved at the condensate booster pumps (P-5150, P-5151, P-5155, P-5156).

1.2 Problem Statement

There are many factors that can cause the failures of a pump seals. The factors that can cause the failures to occur depending on the design, operation-wise, type of seals used and maintenance work for the pump itself. In the OSC terminal, the problem lies with the mechanical seal used at the condensate pumps that always leads to the pump failure. Until now, the company still could not figure out the problems with the seal used at the condensate pumps that decrease the reliability of the terminal.

1.3 Objectives

The main objective of the project is:

a) to carry out failure analysis for the failed seal used at the condensate booster pump

1.4 Scope of Study

The project was divided into four phases in order to achieve the objectives. They are:

a) Literature review on the pump design and operation

b) Study on the mechanical seal properties

c) Failure analysis and testing

i. Study on common failures (seals)

ii. Data gathering

1. Mechanical catalog
2. Failures occurred (history)
3. Sampling

iii. Lab or experimentation

1. Visual inspection
2. Experimentation

d) Evaluation and presentation

i. Reports

ii. Seminars

The relevancy of the project as below:

a) to carry out the failure analysis of the pump seal used

b) to assist the operation side of Terengganu Crude Oil Terminal (TCOT) in finding the root cause of existing failures

CHAPTER 2
LITERATURE REVIEW AND THEORY

2.1 The Pump

There are various pump used in OSC terminal. However, the main pump that will be studied thoroughly in this project is basically on condensate booster pumps (P-5150, P-5151, P-5155, P-5156). The function of the pump is to pump the condensates that have being separated from the condensate separator V-5140 to the condensate filter before being send to GPP for further separation and stabilization. In OSC, there are two identical trains, which are train A and train B whereby each of the train consist of two set of condensate booster pump which are: [4]

a) Train A : P-5150 and P-5151
b) Train B : P-5155 and P-5156

For further details, Process Flow Diagram (PFD) of the schematic layout of the specific pump at OSC was attached as APPENDIX I. All the pumps are identical to each other and they are electrical motor driven horizontal centrifugal type of pump. The example picture of the condensate booster pump is shown in the Figure 2.1 below.

Figure 2.1: Condensate booster pump at OSC

2.2 The design and the operation of the pump

The type of pump used at the condensate booster pumps were manufactured by Nuovo Pignone DVS.

2.2.1 Operation-wise

The condensate booster pump used in OSC operates at the minimum flow rate of 360 kl/day or 15 kl/hr. The general specifications of the pump are:

a) Design flow rate : 1250 kl/day or 52.1 kl/hr
b) Each has 1986 kPa differential pressure
c) Design pressure : 15037 kPa
d) Design temperature: -20 to 49 ^{O}C

The automatic mechanism of pump shutdown is critical to the operation of a processing plant. This is because, in certain condition, the pump needs to be shut-off automatically in order to maintain the reliability of the plant and also the pumps itself. If the pressure inside the pump is too low or too high, it can cause the pump to malfunction. Thus, it can also lead to hazardous incident such as fire. The switches feature on each pump such as Temperature Switch High (TSH), Pressure Switch Low (PSL) can triggers the shutdown of the pump and if the level in the separator is low, the Level Switch Low (LSL) will be triggered and both pumps per train will be shutdown. As for the suction pressure, if the pressure is too low (below 6350kpa), the Pressure Alarm Low Low (PALL) will trigger and the pump will be shutdown. However, for the discharge pressure mechanism, if the pressure is above 9500kpa, Pressure Alarm High High (PAHH) will be triggered and vice versa, if the pressure is below the 7400kpa, the Pressure Alarm Low Low (PALL) will be triggered and resulting the shutdown of the pump [4].

For further understanding about the switches used at the condensate booster pump, Process Flow Diagram (PFD) of the schematic layout of the specific pump at OSC was attached as APPENDIX I.

2.3 Maintenance of the pump and seal

Failure to properly address any portion of the mechanical seal chain could result in catastrophic failure, down time, considerable damage and expense, and most importantly personal injury and possible damage to the environment. Hence, maintenance work should be done accordingly in order to prevent from the reliability of the seals depleted. Specific pumping application requirements will determine the complexity of the seal design to achieve optimum performance. Mechanical seal configurations and options are as vast as pump models and designs. By addressing all the application parameters and fluid behavior characteristics will result in long trouble free mechanical seal service and enhanced pump and its process [1]. For the condensate booster pump in OSC, general maintenance work for pump is carried out by the maintenance technicians in the plant for about 2 to 4 times yearly. However, for the seals maintenance, the services are done directly by the technicians or engineers from the contractor company and that is from Flowserve Company. In order to fully inspect the condition of the seal, the seal must first be dismantling from the pump. Then, the seal compartment will be sent to the Kemaman head quarters for further inspection by the seal expert from the company. The full preview of how the service or analysis being carried out from the company was shown in the APPENDIX II.

2.4 Mechanical seal used for the pumps

The mechanical seal used for the condensate pump in OSC is manufactured by the Flowserve Company Sdn. Bhd.

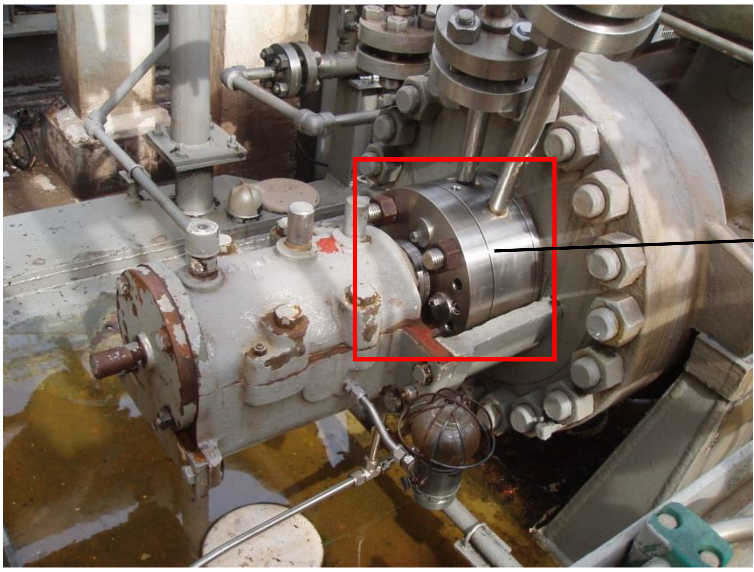


Figure 2.2: Picture of mechanical seal at the condensate booster pump at OSC

The details about the mechanical seal used are:

a) Seal type: DHTW/DHTW
b) Seal Configuration: Dual Pressurized- Back to back cartridge
c) Seal size: 3.000/3.000
d) Material:-
   i. Gland : Tungsten carbide
   ii. Seal Gasket: Fluoroelastomer
   iii. Stationary Face: Carbon
   iv. Rotating Face: Carbon
   v. Coil Spring: Alloy C-276
   vi. O-Ring: Fluoroelastomer
e) Product: H.C Condensate
f) Temp:49^{O}C
g) Specific Gravity:0.730
h) Vapor Pressure:71 Barg
i) Seal Chamber Pressure: 80 Barg
j) Suction Pressure: 70.2 Barg

k) Discharge Pressure: 90 Barg

l) Revolution Per Minute (RPM): 3000 rpm

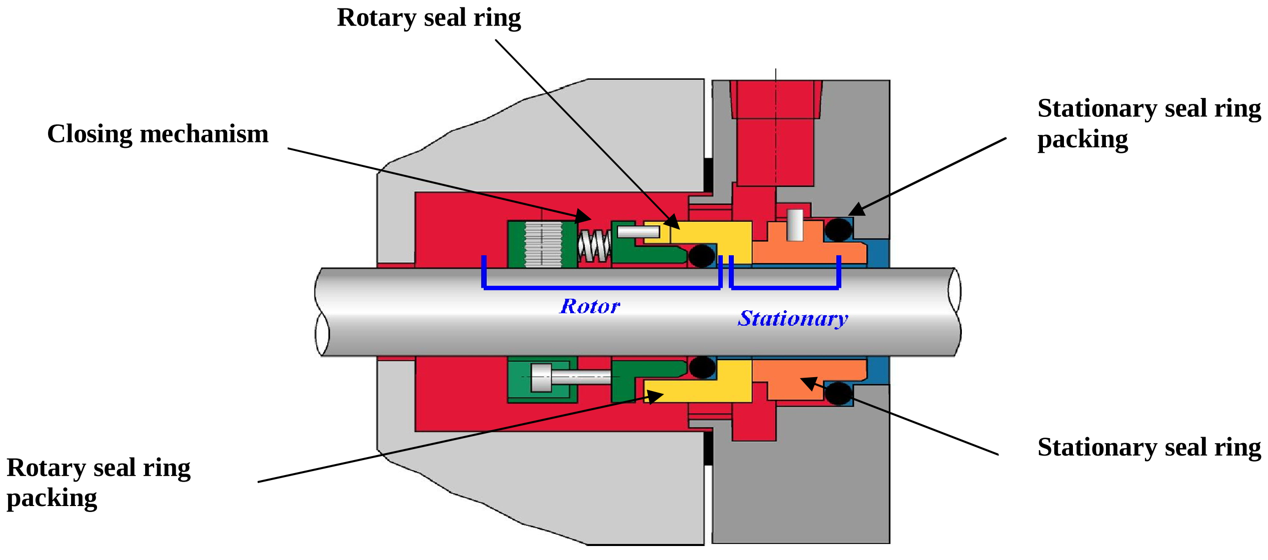
m) API Plan: 53

n) Barrier Liquid: Light Lube Oil

For more detail of the specification, the drawing of the seal was attached at the appendix. (APPENDIX III)

2.4.1 General Design of mechanical seal

Basically, mechanical seal consists primarily of a rotary seal face with a driving mechanism which rotates at the same speed as the pump shaft, a stationary seal face which mates with the rotary and is retained using a gland or in some pump models an integral stuffing box cover, a tension assembly which keeps the rotary face firmly positioned against the stationary face to avoid leakage when the pump is not in operation, and static sealing gasket and elastomers strategically located to complete the seal assembly. In another phrase, the purpose of the seal is to stop the liquid in the pump from leaking between the rotating shaft and the stationary casing. In Figures 2.3 below shows the basic design of mechanical seal which consists of rotary and stationary part.[3]



Figures 2.3: Basic Seal Components [3]

Figures 2.4 and 2.5 shows the inside compartment in a basic mechanical seal for a clearer understanding. [8]

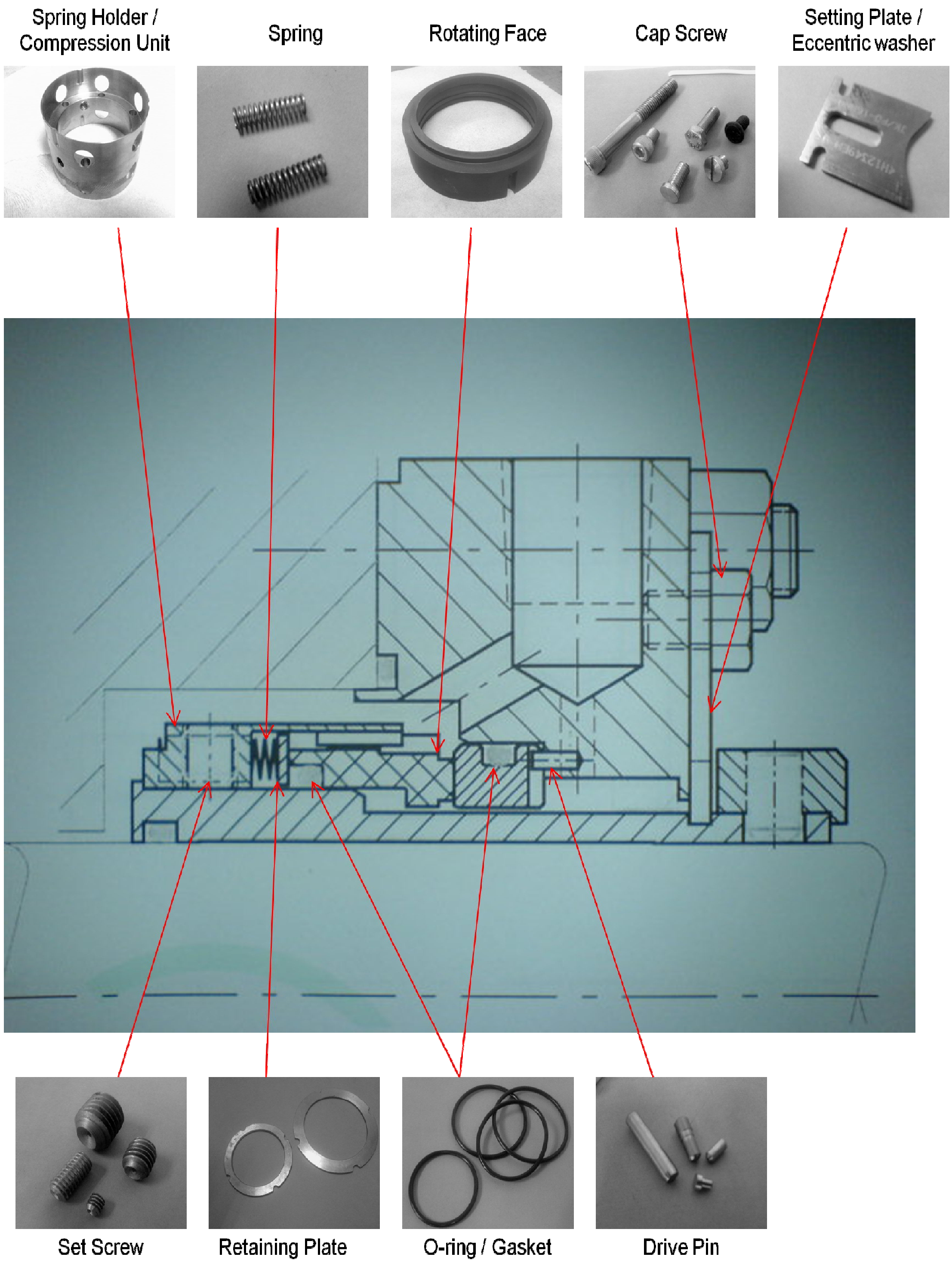


Figure 2.4: Basic compartment in a mechanical seal [8]

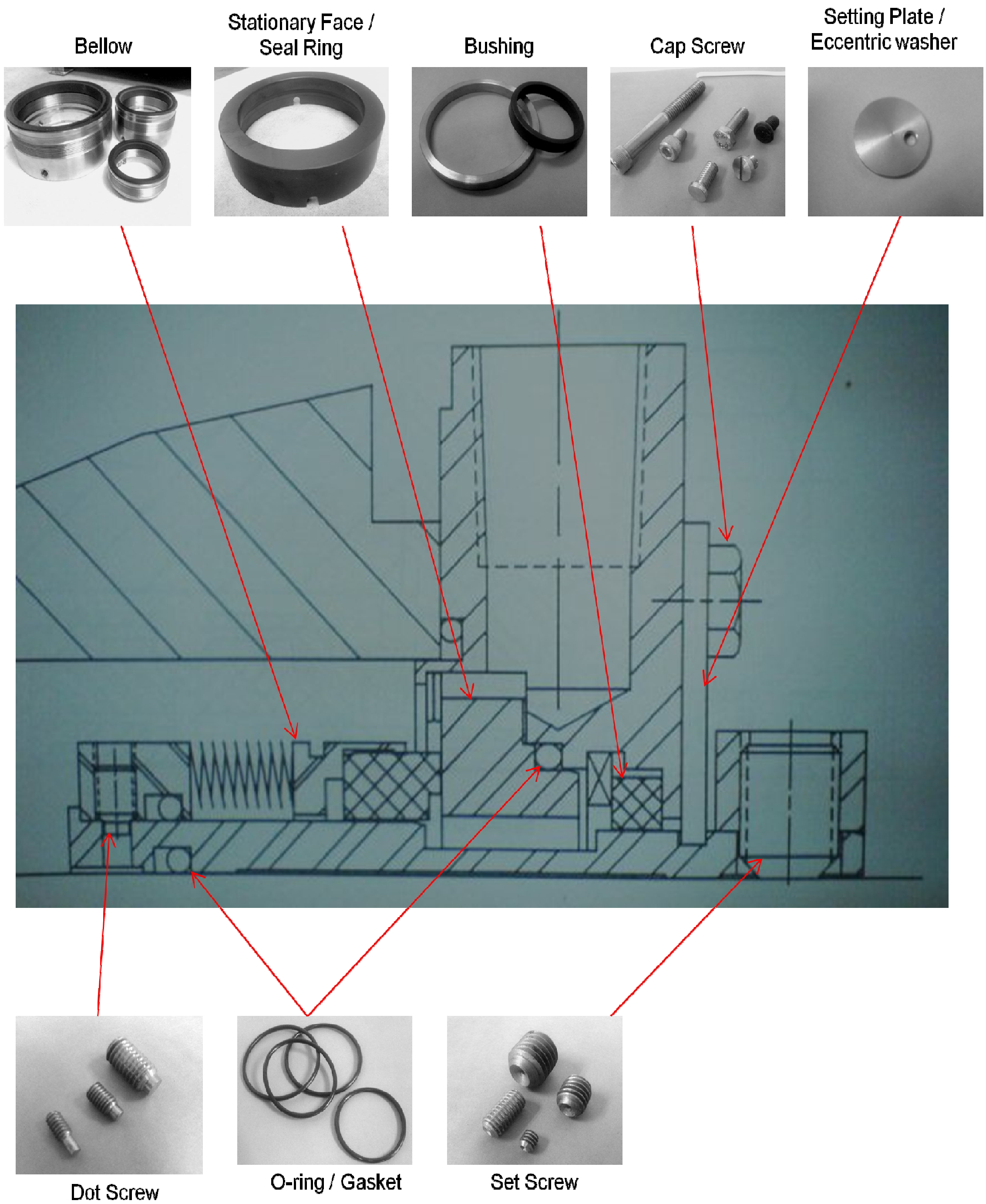


Figure 2.5: Basic compartment in a mechanical seal (continuation) [8]

2.4.2 Factors of selecting seal for pump used

a) Materials

The rotating and stationary sealing faces commonly referred to as primary seal members, are materials selected for their low coefficient of heat and are compatible with the fluid being. Their extremely flat lapped mating surfaces make it extremely difficult for the fluid to escape between them. The fluid does however, forms a thin layer or film between the faces and migrates toward the low pressure side of the faces. It is this boundary layer of fluid which is used and required to cool and lubricate the seal faces. In order to prohibit leakage along the pump shaft through the inside diameter of the rotary and stationary seal faces the mechanical seal assembly uses o-rings, v-rings, wedges and packing. Commonly referred to as secondary sealing members these components of the seal are selected based on fluid compatibility, temperature, elastomeric qualities, and depending on the type and design of the seal they may perform in either a dynamic or static state. Typical values of the coefficient of friction of mechanical seal face material combinations running under dry conditions are given in Table 2.1. [5]

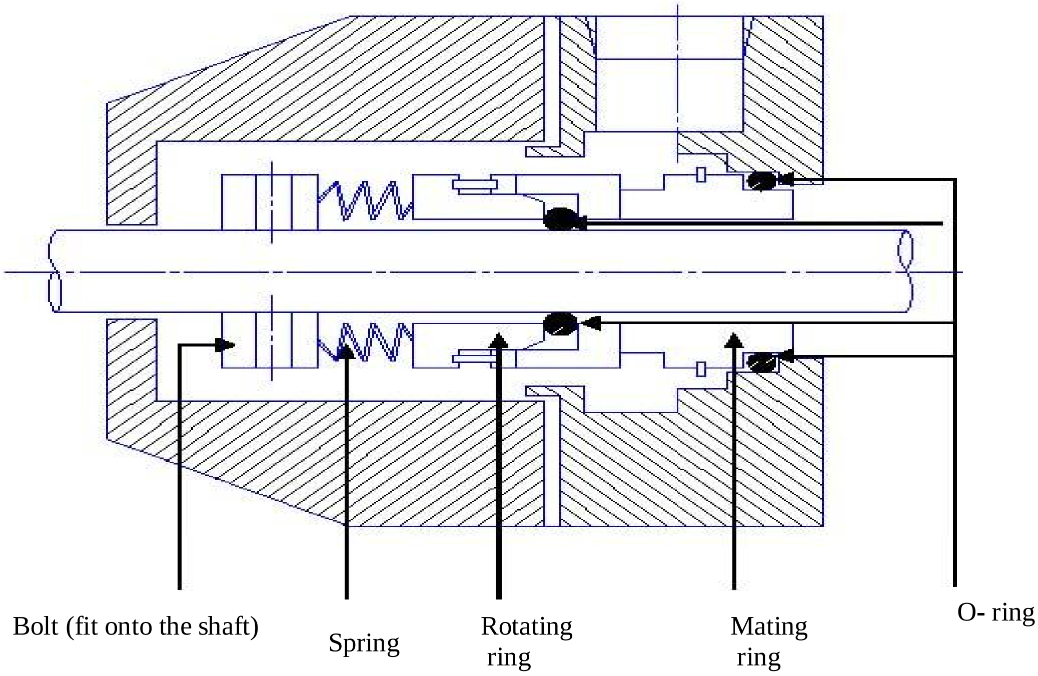
Table 2.1: Typical coefficient of friction for mechanical seal face pairs [5]

Material combination	Friction coefficient (dry)
Metal/PFTE	variable with load and speed
Tungsten carbide/carbon	0.1-0.15
Silicon carbide/carbon	0.1-0.15
Stellite/carbon	0.2-0.25
Tungsten carbide/tungsten carbide	0.2
Silicon carbide/silicon carbide	0.25
Tungsten carbide/silicon carbide	0.2

b) Mechanical Face Seals

The term face indicates that the seal contact is over an area rather than having line of contact or it may indicate that the contact is on the face of housing or a shaft. The term mechanical implies a device rather than soft packing as being the essential characteristic of the seal. Mechanical also implies touching, as well, so as to allow one to distinguish the mechanical seal from a fixed clearance seal.

Often the mechanical face seal is referred to as an end face seal or a radial face seal indicating the form of the sealing surface (Lebeck, 1991). [5]



Figures 2.6: Essential components in mechanical face seal

i. **Primary Ring/ Rotating Ring:** The ring is mounted so as to provide flexibility to allow for small relative axial and angular motion for misalignment between the parts. The primary ring also provides one of the sealing surfaces as shown in Figure 2.6.

ii. **Mating Ring:** The ring is rigidly mounted to the shaft or to the housing but does not rotate. It provides the second sealing surface. This ring works as a surface guided ring.

iii. **Secondary Seal / O-ring:** It allows the primary ring to have axial and angular freedom of motion while retaining the sealing integrity. The secondary seals are the O-rings in the case shown in Figure 2.6.

2.5 Failure modes of the seals

There are some example of common failure modes of the seals and its possible causes in the Table 2.3 shown below. [7]

Table 2.2: Possible Failure mode of the seals and it causes

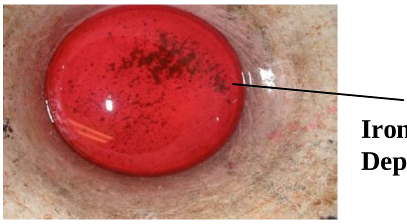
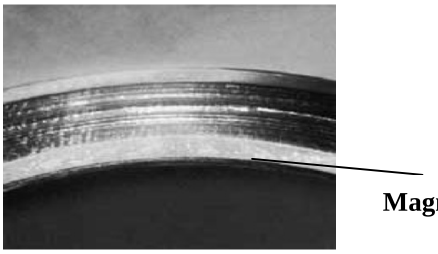
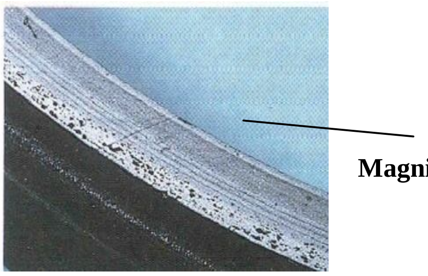
Type of failure	**Possible causes**
a)Excessive Iron Oxide Deposits  Figures 2.7 : Excessive iron deposit at the seal face	
b)Scored or “Record Grooved” Primary Ring or seat insert  Figures 2.8 :Recorded grooved at primary ring	i)Solids or abrasive damage
c)Face Failure - Carbon Blistering  Figures 2.9 :Carbon blistering at the seal face	i)A pitted or blistered carbon face indicates the system fluid had flashed to steam, damaging the carbon face and creating a direct leak path. ii) Overheating of the seal face, either by lack of flush fluid or dry running. Process fluid could also be exceeding temperature limits of the seal.

Table 2.2: Possible Failure mode of the seals and it causes (continued)

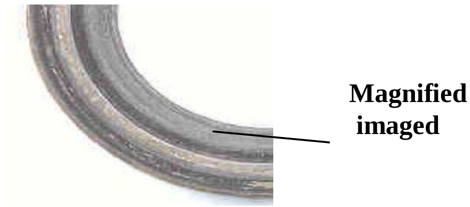
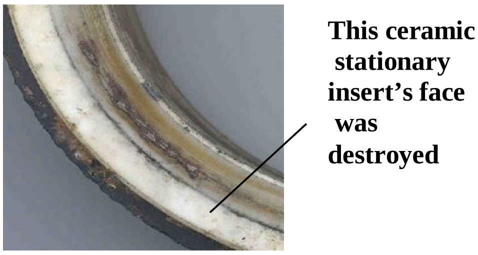
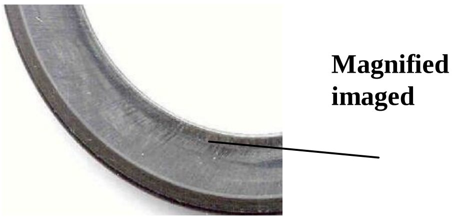
d) Face Failure -Dry Run  Figures 2.10 : Dry run of the seal face	i)This silicon carbide seat insert has a deep wear track worn into the super polished face. A wear track will create a direct leak path. ii) Solids or abrasive damage iii) Dry run damage
e)Face Failure - Metal Fragments in System Fluid  Figures 2.11 :Metal fragment at seal face	i)Metal fragments or filings circulating within system fluid. The fragment attempted to escape to the atmospheric side (Low-pressure and inside diameter) of the ceramic stationary insert. In this case history, the fragments were copper.
f)Face Failures - Incorrect Installation  Figures 2.12 : Result of Incorrect installation of seal	i)This silicon carbide seat insert was installed backwards in the seat bore. Note the rough, partially worn away grind marks on the backside of the seat face. The opposite, polished face is always installed towards the primary ring.
g)Face Failure - Cracked or Fractured Seat Inserts	i)Cracked during installation ii) Thermal Shock due to wet/dry running. iii) Thermal shock caused by extreme system fluid temperature differentials during static or

Table 2.2: Possible Failure mode of the seals and it causes (continued)

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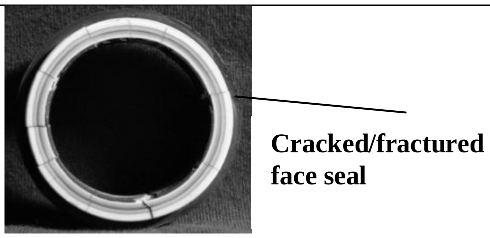

Figures 2.13 : Cracked or fractured seat inserts
</td>
<td>dynamic pump operation.</td>
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<td>
h) Face Failure - Chips on the I.D. of the Seal Faces


Figures 2.14 : Chips formation at the seal faces
</td>
<td>i) A high concentration of solids collected between the carbon I.D. and the pump shaft or sleeve.
ii) Mechanical misalignment, either on seal installation, or within the pump itself.
iii) The pump is operating beyond the recommend.</td>
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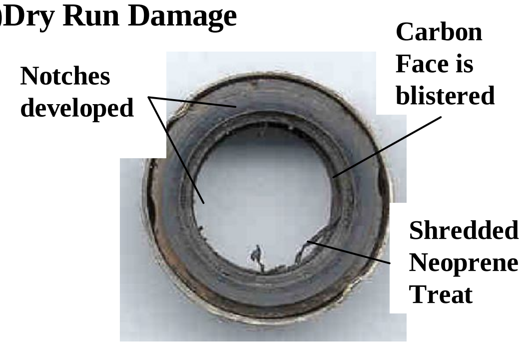
<td>
i)Dry Run Damage


Figures 2.15 : Dry run damages of the seal
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<td>
j)Abnormal wear in the drive system


Figures 2.16 and 2.17 : abnormal wear formed at the drive system of the seal
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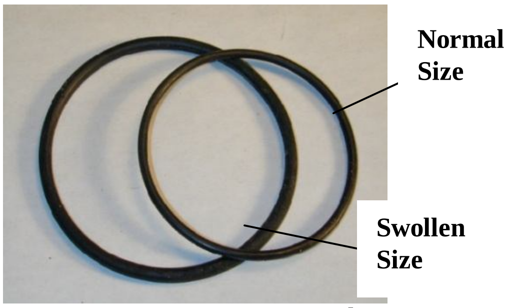
Table 2.2: Possible Failure mode of the seals and it causes (continued)

k)Elastomer Heat Damage  Figures 2.18 :Catastrophic failure of the seal’s elastomer	i) Process fluid temperature to high for the rating of the pump/seal.
l)Chemically Attacked Seal Elastomers  Figures 2.19 : Comparison between normal and swollen elastomers	i)May have come in contact with the elastomers including lubricants used for seal installation, system fluid compatibility, and any chemicals used to flush the system.

2.6 Problem Analysis Methods

2.6.1 Kepner-Tregoe Method of Problem Analysis [9]

This approach is mainly about finding the root cause of the failure based on several criteria before coming out with the possible solutions and recommendation. The visualization of the basic structure of a problem occurring in certain cases is shown in Figure 2.20. There are several techniques that the Kepner-Tregoe method applied. They are:

a) Definition of the problem
b) Description of the problem in four dimensions(The details is shown on the Table 2.4)
   i) Identity
   ii) Location
   iii) Timing
   iv) Magnitude

c) Extraction of key information in the four dimensions to generate possible causes

d) Testing for most probable cause

e) Verification of the true cause

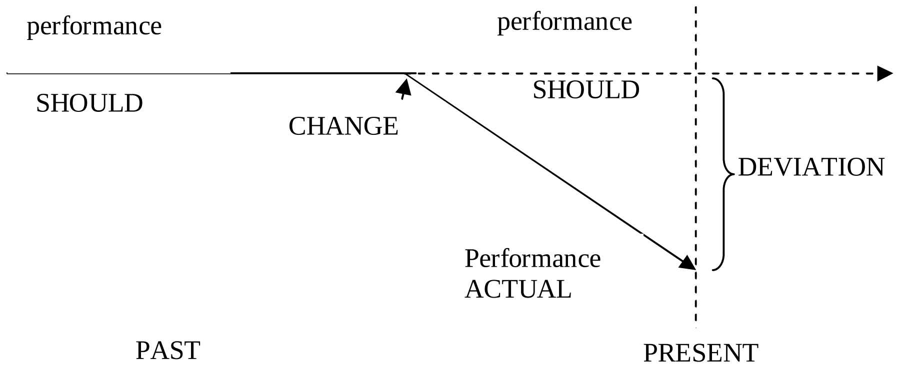


Figure 2.20: Basic Structure of a problem [9]

Table 2.3: Four Dimension Problem Description

Dimension	**Specifying Questions**	**Performance Deviation**	**Closest Logical Comparison**
Identity	What unit? What failure?		
Location	Where the location?		
Timing	When the malfunction was first observed? When it has been observed since? When in the operating cycle of the unit is the malfunction first observed?		
Magnitude	What is the extent of the malfunction? How many affected? How much affected?		

2.7 Testing / Experimentation

2.7.1 Surface Roughness

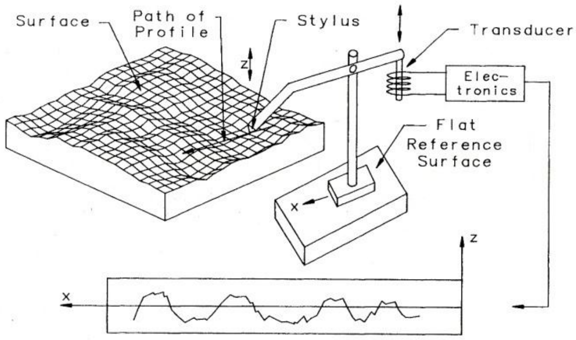


Figure 2.21: Surface profilometer

The height of the surface is commonly measured using a small but finite radius stylus. The fact that such a stylus must have a finite radius does introduce some error into the measurement, particularly if the slope on the surface is steep and the radius is large. The radius of the stylus has been standardized at 10 μm (ANSI/ASME B46.1, 1985). The figure shown that the example of how surface profilometer is being set-up for interpretation.[11]

At the present time, ANSI/ASME B46.1 (1985) specifies that the roughness average, R_a is the preferred way to characterize surface roughness. By definition, given discrete values for the height z,

$$Ra = \frac{1}{N}\sum_{i=1}^{N} |\, zi - z \,| \qquad (2.1)$$

For a given sample length, one can also use the integral definition,

$$Ra = \frac{1}{L}\int_{X=0}^{X=L} |\, zi - z \,| \qquad (2.2)$$

Surface roughness as measured by Ra characterizes only an average of the height of the peaks and depths of the valleys. The nature of the surface, as characterized by the density function and other measures, may well be more important to a specific tribological process than the surface roughness itself. Table 2.4 shows that the typical surface roughness values for several seal surfaces that can be used to evaluate the results.

Table 2.4: Typical Surface Roughness

Material	Mating Material	Condition	Roughness Ra (μm)[2]	Source
WC	carbon	100 h water test	0.05[1]t	Paxton et al (1980)
Al_2O_3	carbon	100 h water test	0.2[1]t	Paxton et al (1980)
SIC	carbon	100 h water test	0.1[1]t	Paxton et al (1980)
6 carbons	–	as lapped	0.58r/0.62t	Lebeck & Young (1981a)
6 carbons	WC	20–100 h water test/ initially lapped	0.46r/0.43t	Lebeck & Young (1981a)
carbon	–	as polished	0.20r/0.28t	Lebeck & Young (1980)
carbon	WC	100 h water test/ initially polished	0.19r/0.13t	Lebeck & Young (1980)
WC	–	as polished	0.10r/0.10t	Lebeck & Young (1980)
WC	carbon	100 h water test/ initially polished	0.04r/0.05t	Lebeck & Young (1980)
carbon	–	as polished	0.08–0.13	Dziedzic (1980)
WC	–	as polished	0.03–0.05	Dziedzic (1980)
siliconized graphite	–	as polished	0.08–0.13	Dziedzic (1980)
SIC	–	as polished	0.03–0.08	Dziedzic (1980)

(1) Estimated based on profile
(2) t – tangential r – radial

2.7.2 Rockwell Hardness Test

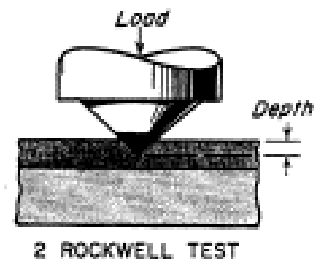


Figure 2.22: Rockwell Test Indentation

The Rockwell scale is a hardness scale based on the indentation hardness of a material. The Rockwell test determines the hardness by measuring the depth of penetration of an indenter under a large load compared to the penetration made by a preload. There are different scales, which are denoted by a single letter, that use different loads or indenters. The result, which is a dimensionless number, is noted by HRX where X is the scale letter. When testing metals, indentation hardness correlates linearly with tensile strength. This important relation permits economically important nondestructive testing of bulk metal deliveries with lightweight, even portable equipment, such as hand-held Rockwell hardness testers [14]. Figure 2.22 shows the Rockwell indentation diagram while Table 2.5 shows various Rockwell Scale that was commonly used in the industry.

Table 2.5: Various Rockwell Scales [10]

Scale	Abbreviation	Load	Indenter	Use
A	HRA	60 kgf	120° diamond cone[†]	Tungsten carbide
B	HRB	100 kgf	1/16 in diameter steel sphere	Aluminium, brass, and soft steels
C	HRC	150 kgf	120° diamond cone	Harder steels
D	HRD	100 kgf	120° diamond cone	
E	HRE	100 kgf	1/8 in diameter steel sphere	
F	HRF	60 kgf	1/16 in diameter steel sphere	
G	HRG	150 kgf	1/16 in diameter steel sphere	

Mechanical seal faces should read at least 60 on the Rockwell "C" scale [13].

CHAPTER 3
METHODOLOGY / PROJECT WORK

3.1 Project Research

This is the most important step in creating the project to achieve the targeted objectives. The first phase of this project is to gain understanding in the current issues and challenges faced related to this project. The first phase involved research on;

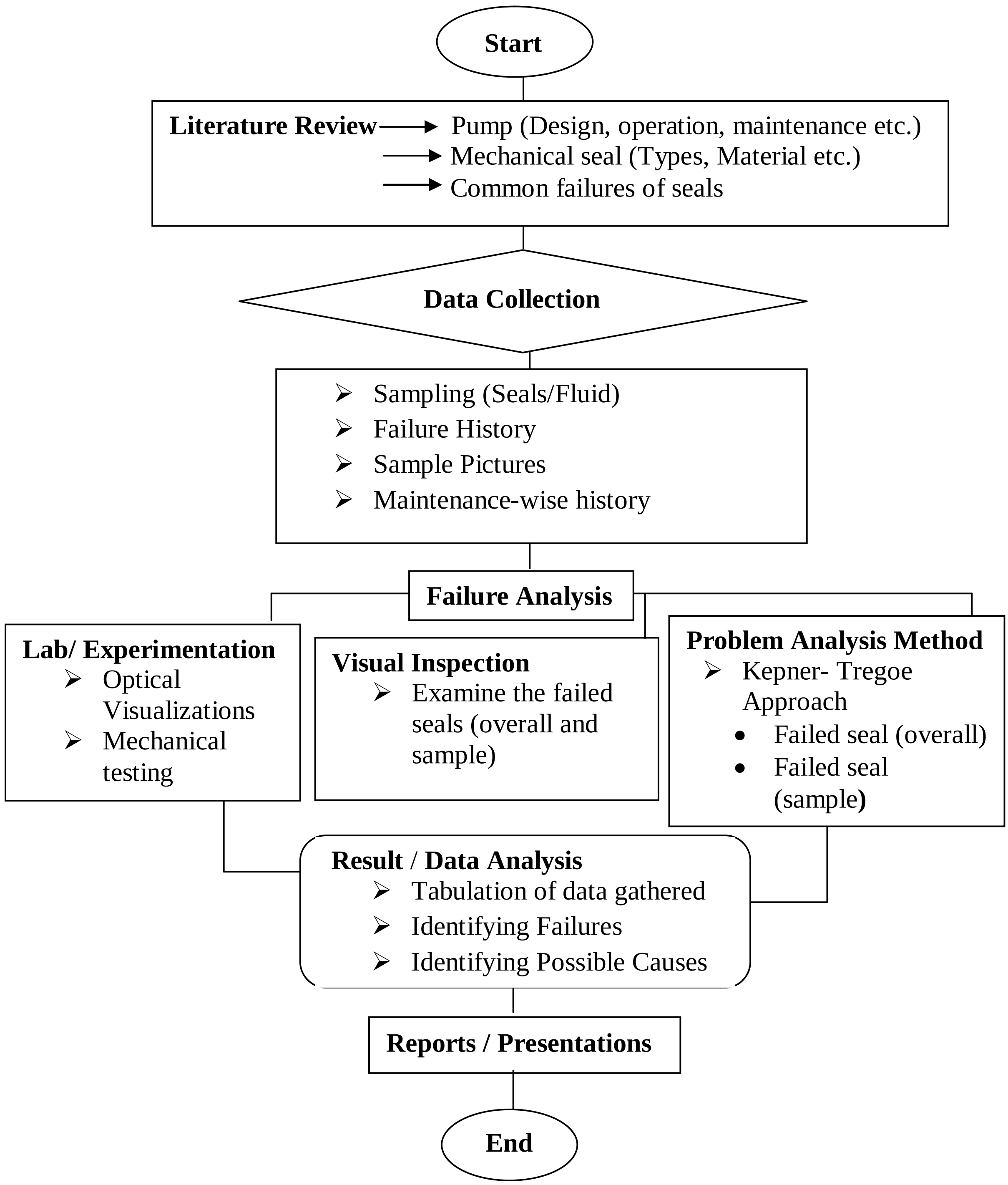
a) The specific pump and seal used
b) Common failures of the seals
c) Testing that can be carried out

3.1.1 Gantt Chart

The Gantt chart of the overall activities of the project during the final year project (FYP II) was shown in the APPENDIX IV.

3.1.2 Overall flow of the project

Figures 3.1 show the simplified flow of the overall project that will be carried out during the first semester of the final year project.



Figures 3.1: Simplified overall flow of the project

3.2 Data gathering/ collection

This step is the most critical part in the project as the data collected can be used as a reference in determining the failure of the seals and can act as a medium of comparison between the actual specification of the pump and seals and the result from the experiment that will be carried out. Some of the important data that must be collected:

a) Mechanical catalog of the pump and seals
b) Sampling (Seals/Fluid)
c) Failure History
d) Sample Pictures
e) Maintenance-wise history

3.3 Project Experiment Methodology

Practical experiments are further divided into few sub-phases which are visual inspection, mechanical testing and metallographic examination.

3.3.1 Visual Inspection

From the pictures taken from the failed samples, the visual examination of the sample can be done and if there are fractures or wears, the types of the failures can be inspected and determined. Plus, some probable causes can be pre-determined from the failures inspected. There are 2 scenarios of the visual inspections. They are:

a) Visual inspection of failed seal (overall), collaborate with Flowserve Company
b) Visual Inspection of failed seal (sample- stationary face seal)

3.3.2 Microstructure Visualization

a) Roughness Test

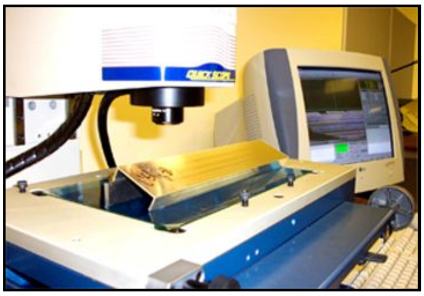


Figure 3.2: Mahr Perthometer Devices

The test is being done by checking the surface roughness by using the Mahr Perthometer. The Mahr Perthometer is a laser based measurement system and as such, is capable of a higher degree of accuracy than stylus type measuring equipment due to some troughs being smaller than the radius of the diamond tip on a stylus system. For the seal experimentation purposes, the length of the specimen is about 10 mm. hence; there are three different measurements that can be taken from the sample that are:

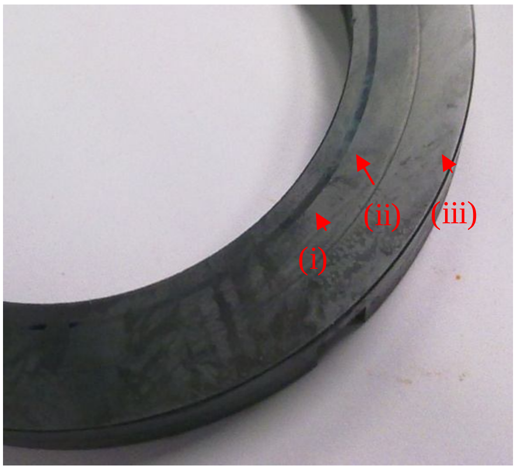


Figure 3.3: Failed stationary face seal (sample)

i) Along the groove line for about 2mm

ii) 5mm distance (intersect along the groove line)

iii) Non-groove area (2mm distance)

Note: The measurement for each profile is being carried out three times at the different location of the face seal

The parameters that can be measured and interpreted are:

i) Roughness average, R_a

ii) Roughness depth, R_z

b) Optical microscope

Optical microscope is used extensively throughout all phases of analysis, from initial inspection through various stages of the processing. Another important consideration with optical microscopy is the ability to capture and enhance any image acquired in the microscope. Digital image capture will provide increased resolution over video capture (at the expanse of file size), while a camera controller with enhancement capabilities (such as contras, brightness, gamma, sharpness, color shift, and annotations) will aid in documenting any observed anomaly. (Cohn & A. Harper, 2005) The picture of the sample is being taken at several locations where the fracture is concentrated. For this visualization, 100X Magnification of the Optical Microscope are being used.

c) Scanning Electron Microscope (SEM)

The most widely used imaging techniques after optical microscopy and is used in most failure analysis laboratories. (Devaney, 1999) In essence, the SEM scans a primary electron beam across the region of interest and detects the emitted and backscattered electrons. All this occurs within the vacuum chamber, thus requiring some sample preparation in contrast to optical microscopy. The output of the detector is imaged as a function of electron beam position on the sample using a display monitor synchronized to the beam scan tare. The high resolution and almost 3-D clarity of the images make SEM one of the best tools for microstructure characterization. (Cohn & A. Harper, 2005) For this visualization, the magnifications of lenses are 500X, 1000X and 5000X magnification.

NOTE: Due to the limited sample, the failure analysis testing is being carried out for the given sample only which is the stationary face seals parts.

3.3.3 Mechanical Testing

Mechanical testing is done to verify that the mechanical properties of the material conform to the standards. There are many types of mechanical testing that can be performed and their procedures can be found in the ASTM mechanical testing standards. The most common method used is hardness testing because of its relative simplicity, low cost, and the fact that for many materials tables exist to relate hardness with yield strength.

a) **Rockwell Hardness Test**

Figure 3.4: Indentec Hardness Testing Machine

The Rockwell Hardness Test presses a steel or diamond hemisphere-conical penetrator against a test specimen and measures the resulting indentation depth as a gage of the specimen hardness. The harder the material, the higher the HR reading will be obtained. In the test, the load of 150kgf is being applied to the specimen as the specimen is a hard material and several measurements were taken at different location of the stationary face seal. The locations are:

i) At the groove area (fractured area)
ii) Non-groove area

The testing was repeated about six times for two different samples in order to get more relevant results.

NOTE: Due to the limited sample, the failure analysis testing is being carried out for the given sample only which is the stationary face seals parts.

CHAPTER 4
RESULTS AND DISCUSSIONS

4.1 Data Gathering, Experimentation and Analysis

4.1.1 Failure history

In figure 4.1 shows the failure history of the mechanical seal at TCOT in 2007. The yellow colour indicates the failure of the seals at the condensate booster pumps (P-5150, P-5151, P-5155, P-5156).

	Tag No	Dwg No	Date In	RQS #	Report Date	Qtn. No.	Qtn. Date	Amount (RM)	Quantity
1	P6100	BWI1853A	17/05/2007	70124	22/05/2007	3953-AJ	21/05/2007	51.615,00	1
2	P290 A	BWI3806	20/05/2007	70125	22/05/2007	3958-AJ	23/05/2007	14.367,40	1
3	P5155 DE	BWI1947 H	12/06/2007	70161	14/06/2007	3983-AJ	12/06/2007	**15.234,30**	1
4	P5155 NDE	BWI1947 H	13/06/2007	70165	LEAK TEST ONLY			**450,00**	1
5	P470 A	S850002-1	14/06/2007	70167	25/06/2007	4001-AJ	21/06/2007	23.209,00	1
6	P5156	BWI1947 H	21/06/2007	70172	25/09/2007	4009-AJ	26/06/2007	**49.220,00**	1
7	P400 B	S04465284 A	18/09/2007	70289	25/09/2007	4162-SZ	24/09/2007	18.845,00	1
8	P5150 NDE	BWI1947 H	17/12/2007	70382	12/12/2007	WARRANTY			
9	P400 A	S0465284 A	18/12/2007	70308		4176-SZ	18/11/2007	480,00	1
10	P5150 DE/NDE	BWI1947 H				PA		**165.087,00**	2
							Total Amount	338.507,70	

Figure 4.1: Failure reports for mechanical seal failure in 2007

Basically from the data, it shows that the mechanical seal used at the condensate booster pumps were frequently failed.

Total cost of the failure is (RM) = 15,234,30 + 450,00 + 49,220,00 +165,087,00

= RM 229,991,30

$$\text{In term of Percentage (\%)} = \frac{\text{Total cost for the seal failure at the condensate booster pump}}{\text{Total cost for the seal failure of the whole plant}} \times 100$$

= (229,991,30 / 338,507,70) x 100

= 68%

From the failure reports of the mechanical seal at TCOT in 2007 only, the cost of repairing the seals at the condensate booster pumps cover about 68% of total amount of services of entire mechanical seals used at the whole plant. Hence, it shows that the reliability of the mechanical seal used at the condensate booster pump is low and further analysis in term of its failure should be carried out to identify the possible causes.

4.1.2 Visual Examination

a) Visual inspection of failed seal (overall), collaborate with Flowserve Company

Table 4.1: Visual Inspection of the failed seal of the condensate booster pump (P-5150, P-5151, P-5155, P-5156)

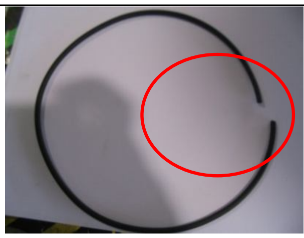
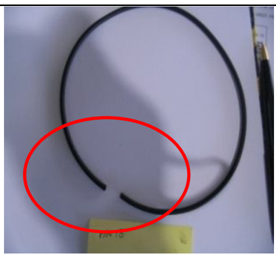
Tag no	**Visual diagram**	**Type of failure**	**Possible causes**
P-5150 NDE	 Figure 4.2: O-ring cut	O-Ring cut	i)Sudden spike of the process pressure during the pressurization of the pump ii)Displacement of o-ring from its original groove (misalignment)
P-5155 DE	 Figure 4.3: Rotating faces broken	Broken body of the outer rotating faces	i)Seal leak at the outer seal face
	 Figure 4.4: Rotating faces chipped out	Outer rotating faces chipped out	i)Internal leakage (Rotating face hitting stationary object) ii)Excessive torque during the start-up procedure iii)Solids or abrasive damage[7]

Table 4.1: Visual Inspection of the failed seal of the condensate booster pump (P-5150, P-5151, P-5155, P-5156, continued)

P-5156 DE	 Figure 4.5: Stationary faces chipped out	Outer stationary face chipping at Inner Dimension	i)Internal leakage (stationary face hitting rotating object) ii)Wobbling and unbalance shaft
	 Figure 4.6: Rotating faces broken at the drive pin	Inner rotating faces have broken at the drive pin	i)Excessive torque during start-up (the inner rotating face broke at the drive pin slot) ii) Thermal Shock due to wet/dry running [7] iii) Thermal shock caused by extreme system fluid temperature differentials during static or dynamic pump operation [7]
	 Figure 4.7: Bushing rubbing with sleeve and chipped off	Bushing was badly rubbing with sleeve and chipped off	i)Wobbling shaft ii)Excessive torque during start-up iii)Solids or abrasive damage [7]
	 Figure 4.8: Stationary face scratch and chipped out ID/OD	Inner stationary face scratch and Inner Dimension/ Outer Dimension chipping	i)Internal leakage ii)Rotating face hitting the stationary object iii)Bearing problem or worn out iv)Wobbling shaft

Table 4.1: Visual Inspection of the failed seal of the condensate booster pump (P-5150, P-5151, P-5155, P-5156, continued)

	 Figure 4.9: Sleeve rubbing with bushing	Sleeve rubbing with bushing	i)Bearing problem or worn out ii)Wobbling shaft
	 Figure 4.10: O-ring was cut	Inner gland O-ring was cut	i)Dynamic movement (axial movement) ii)Vibration iii)Poor lubrication iv)Process fluid temperature to high for the rating of the pump/seal [7]

The possible causes are being pointed out by the experts from the Flowserve Company which are:

a) Mr. Rosli (Senior Service Technician)

b) Mr. Ahmad Shukeri Bin Yong (Senior Service Technician)

c) Jamaludin Marican (Sales & Service Engineer)

b) Visual Inspection of failed seal (sample- stationary face seal)

NOTE: Due to the limited sample, the failure analysis testing is being carried out for the given sample only which is the stationary face seals parts.

Figures 4.11: Pictures of failed sample (stationary face)

Details:

- Part: Stationary face seal
- Material type: Carbon
- No. of sample :1

Based on the picture of the failed seal that have been taken and analyzed, next shown in the Table 4.2 are some of the identified failures of the stationary seal compartment at the failed pump seal (P-5156).

Table 4.2: Visual identification of the failure at the pump seals

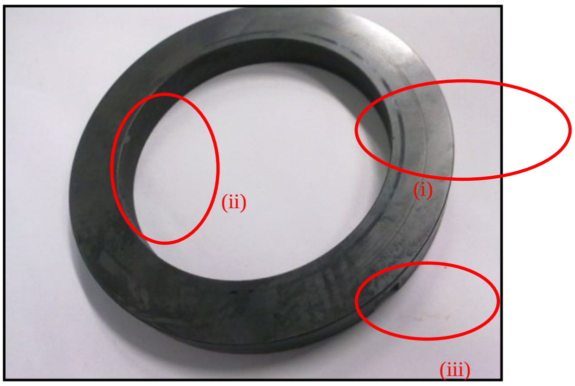


Figure 4.12: Stationary face seal of P-5156

Tag no	**Type of failure**	**Possible causes**
(i)	Grooving along the seal faces	a)Dry running due to insufficient or no liquid between the seal mating faces
(ii) & (iii)	Scratches and chips at ID and OD	a)Mishandling during manufacture, storage, assembly or installation b)Dirt trap between seal faces c)Edge chipping from slamming together during operation when pump cavitates or fluid vaporizes at seal faces d)Excessive shaft run-out e)Excessive shaft deflection f)Misalignment of the seal

4.1.3 Kepner-Tregoe Failure Analysis Approach

a) Failure analysis approach to find root cause (Mechanical Seal)

<u>Deviation Statement: Condensate Booster Pump Failed</u>

Table 4.3: First stage

Dimension	**Specifying Questions**	**Performance Deviation**
Identity	What unit? What failure?	Condensate Booster Pump Mechanical seal failure
Location	Where the location?	Onshore Slug Catcher (OSC) P5151,P5150,P5155,P5156
Timing	When the malfunction was first observed? When it has been observed since? When in the operating cycle of the unit is the malfunction first observed?	Unknown first observed failure During maintenance (yearly/monthly/twice per year)
Magnitude	What is the extent of the malfunction? How many affected? How much affected?	Critical as the cost of replacing the failure part was high The criticality of the pump (increasing) P5151→P5150 →P5155 →P5156

Table 4.4: Second stage

Dimension	**Specifying Questions**	**Performance Deviation**	**Closest Logical Comparison**
Identity	What unit? What failure?	P 5150,P 5155,P 5156 Mechanical seal part failure	Could be but is not (P5151) (No logical comparison)
Location	Where the location?	OSC Specific pump (P 5150,P 5155,P 5156)	Could be but is not (TCOT) Could be but is not observed at the shaft, cooling system, pipeline
Timing	When the malfunction? When it has been observed?	Unknown first observed failure During maintenance (yearly/monthly/twice per year)	Could be but is not observed (early/ during operation) During maintenance by the contractor (Flowserve and Pro Eight)

Table 4.4: Second stage (continued)

Magnitude	What is the extent of the malfunction? How many affected? How much affected?	The criticality of the pump (increasing) P5151→P5150 →P5155 →P5156 Critical as the cost of replacing the failure part was high	Could be but is not (moderate) Different pump have different failures About RM 230k in maintaining the failure part in (2007). Could be high

Table 4.5: Third Stage

Dimension	**Specifying Questions**	**Performance Deviation**	**Closest Logical Comparison**	**What is distinctive about**
Identity	What unit? What failure?	P 5150,P 5155, P 5156 Mechanical seal part failure	Could be but is not (P5151) (No logical comparison)	P 5151 do not have major failure
Location	Where the location?	OSC Specific pump (P 5150,P 5155, P 5156)	Could be but is not (TCOT) Could be but is not observed at the shaft, cooling system, pipeline etc.	P 5155, P5156 are in the same train(Train B)
Timing	When the malfunction ? When it has been observed?	Unknown first observed failure During maintenance (yearly/monthly/ twice per year)	Could be but is not observed (early/ during operation) During maintenance by the contractor (Flowserve and Pro8)	The maintenance team always check the oil level at the pump (Operation-wise problem or maintenance problem)

Table 4.5: Third Stage (continued)

Magnitude	What is the extent of the malfunction How many affected? How much affected?	Critical The criticality of the pump (increasing) P5151→P5150 →P5155 →P5156 Critical as the cost of replacing the failure part was high	Could be but is not (moderate) Different pump have different failures About RM 230k in Maintaining the failure part in (2007). Could be high	P 5150- O-Ring cut P 5155- Rotating face broken and chipped out P-5156- Rotating face broken, Stationary face chipped out ID/OD, Bushing and Sleeve rubbing, Sleeve chipped off, O-Ring cut

Table 4.6: Fourth Stage

Dimension	**Specify-ing Questi-ons**	**Performance Deviation**	**Closest Logical Comparison**	**What is distinctive about**	**Does the distinction suggest a change**
Identity	What unit? What failure?	P 5150,P 5155,P 5156 Mechanical seal part failure	Could be but is not (P5151) (No logical comparison)	P 5151 do not have major failure	P5151 can be used as a reference check
Location	Where the location ?	OSC Specific pump (P 5150,P 5155,P 5156)	Could be but is not TCOT Could be but is not obser-ved at the shaft, cooling system, pipeline etc.	P 5155, P5156 are in the same train(Train B)	Train B can be fully inspected due to Load, Oil, Process, Operation-wise
Timing	When the malfunct ion?	Unknown first observed failure During	Could be but is not observed (early/	The main-tenance team always	Frequent maintenance at the pump and seal Major RCPS

	When it has been obser-ved?	maintenance (yearly/monthly/twice per year)	during operation) During maintenance by the contractor (Flowserve and Pro Eight)	check the oil level at the pump (Operation-wise problem or maintenance problem)	Educate the proper start-up of the equipment (follow OEM specs)
Magnitude	What is the extent of the malfunc-tion? How many affected? How much affected?	Critical The criticality of the pump (increasing) P5151→P5150→P5155→P5156 Critical as the cost of replacing the failure part was high	Could be but is not (moderate) Different pump have different failures About RM 230k in maintaining the failure part in (2007). Could be high	P 5150- O-Ring cut P 5155- Rotating face broken and chipped out P-5156- Rotating face broken, Stationary face chipped out ID/OD, Bushing and Sleeve rubbing, Sleeve chipped off, O-Ring cut	P-5150-Pressure during the process or displacement of the ring from the original groove. P5155- Leakage at the outer seal face, Excessive torque (start-up) P-5156-Leakage at the internal part, shaft problems, excessive torque, start-up procedure, dynamic movement, vibration, poor lubrication etc.

b) Failure analysis approach to find root cause (Failed stationary seal)

Table 4.7: Fourth Stage (Failed stationary seal)

Dimen-sion	**Specify-ing Question**	**Performan-ce Deviation**	**Closest Logical Comparison**	**What is distinctive about**	**Does the distinction suggest a change**
Identity	What unit? What failure?	P 5156 Stationary Face Seal	Could be but is not (P5151)	P 5151 do not have major failure	P5151 can be used as a reference check
Locati-on	Where the location?	OSC Specific pump (P 5156)	Could be but is not TCOT and is not observed at the shaft, cooling system	P 5155, P5156 are in the same train (Train B)	Train B can be fully inspected due to Load, Oil, Process, Operation-wise
Timing	When the malfuncti on? When it has been observed?	Unknown first observed failure During maintenan-ce	Could be but is not observed During maintenance by the contractor (Flowserve and Pro Eight)	The mainte-nance team always check the oil level at the pump (Operation-wise problem or maintenance problem)	Frequent maintenance at the pump and seal Major RCPS Educate the proper start-up of the equipment (follow OEM specs)
Magni-tude	What is the extent of the malfuncti on? How many affected? How much affected?	Can lead to pump failure due to leakage 1 unit Critical as the cost of replacing the failure part was high	Could be but is not (moderate) Different pump have different failures (no stationary face failures)	P 5155- Rotating face broken and chipped out P-5156- Rotating face broken	P5155- Leakage at the outer seal face, Excessive torque (start-up) P-5156-Leakage at the internal part, shaft problems, excessive torque, start-up procedure, dynamic movement, vibration, poor lubrication etc.

4.1.4 Lab work and Experimentation

a) Roughness Test

i) Along the groove line for about 2mm

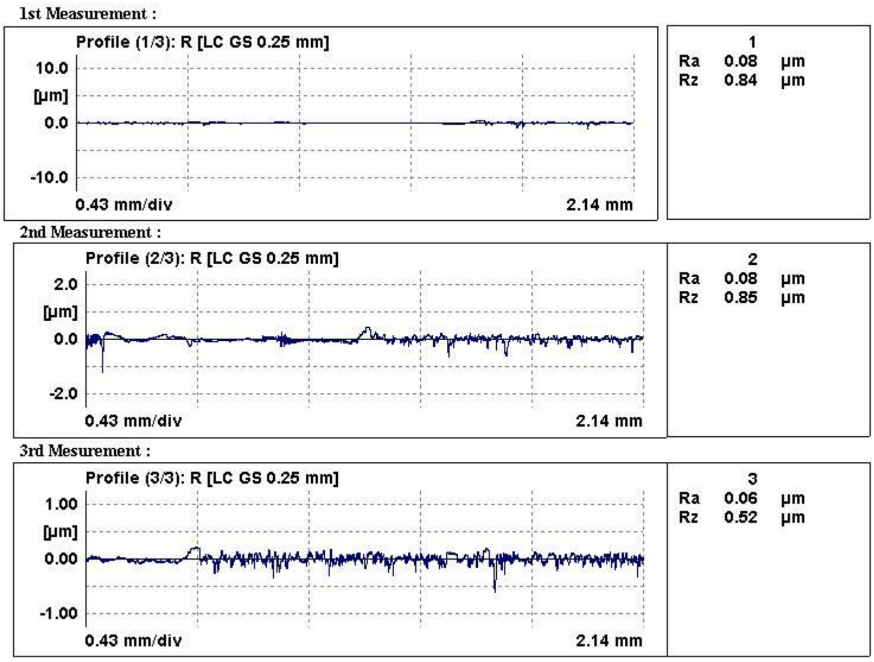


Figure 4.13: Roughness profile of the sample for the first situation

ii) 5mm distance (intersect along the groove line)

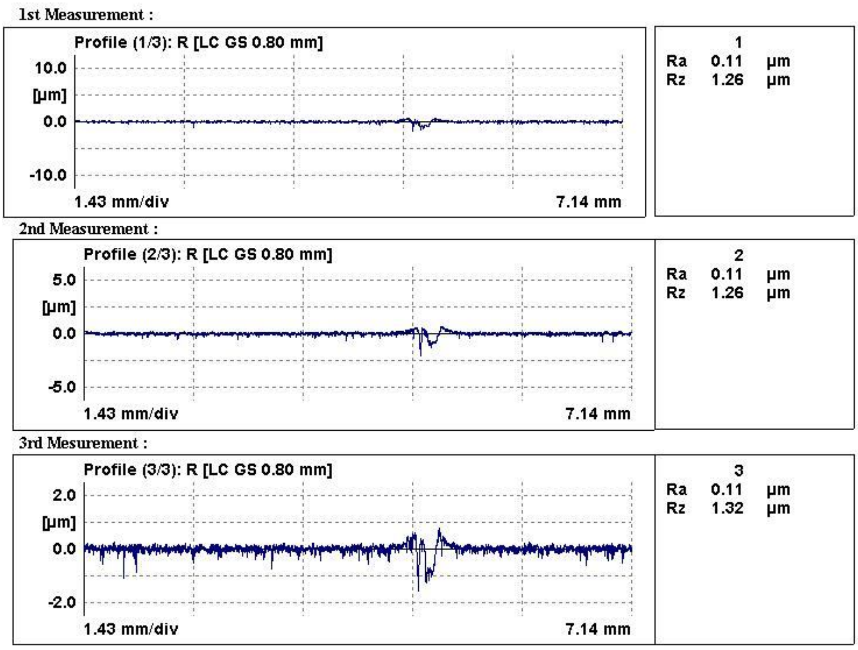


Figure 4.14: Roughness profile of the sample for the second situation

iii) Non-groove area (2mm distance)

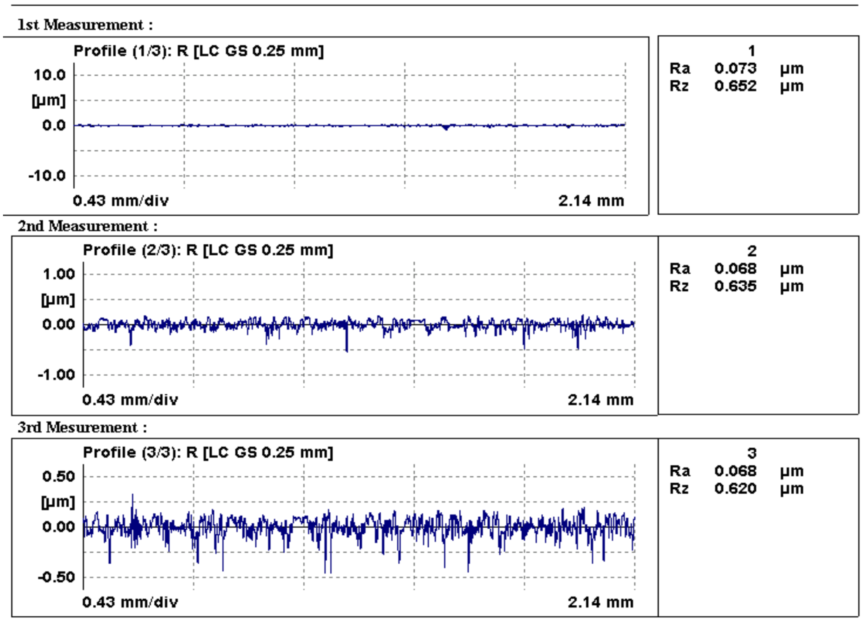


Figure 4.15: Roughness profile of the sample for the third situation

Amplitude parameters characterize the surface based on the vertical deviations of the roughness profile from the mean line. Many of them are closely related to the parameters found in statistics for characterizing population samples. The average roughness, Ra and Rz, average distance between the highest peak and lowest valley in each sampling length, ASME Y14.36M - 1996 Surface Texture Symbols are expressed in units of height. [10]

Table 4.8: Average Reading of the R_a and R_z of different situation

Situation	Average R_a (3 reading) (µm)	Average R_z (3 reading) (µm)
(2mm)-Groove line	0.0733	0.737
(5mm)-Intersect groove line	0.1100	1.280
(2mm)-Non groove line	0.0697	0.636

The reading for Ra from the Table 4.8 shows that for carbon, R_a supposes to be in the range of (0.08-0.13) µm (Dzledzic, 1980). Hence, from the Figure 4.13, the measurement was taken at the groove area (2mm along the face seal) at three different points at the sample. However, the average roughness, R_a of the sample is not constant as it supposes to be and the average reading of R_a is lower than the standard R_a that the seal is suppose to have. The deviation is about 8.38% from its minimum standard of R_a reading. It is the same for the reading of its roughness depth, R_z, where the differences at the groove and non groove part are not balanced. Hence, it can imply or proved that the seal is not well-balanced when it is being used (misalignment). The problems might caused by the seal, operating pump or human error while installing the seal to the pumps.

For the situation as shown in Figure 4.14 (5mm along the face seal), for the R_a reading, it shows that the R_a reading is in the range of the standard roughness which is 0.11 μm. However, for the R_z reading, the difference in height between the highest and lowest peak clearly shows that there are some failure occur at the face seal as the reading is quite high which is 1.28 μm. Hence, it is can clearly determined that there were recorded groove at the face seal.

At the non groove areas (2mm along the face seal) as shown in the Figure 4.15, the Ra reading of the Ra is well below the minimum standard reading for Ra which is 0.0697 μm. It does imply that the seal faces are no longer in proper dimension as it supposes to be. This may lead to seal failure that was caused by the sealing face failures.

Table 4.9: Probable causes from surface roughness test

Type of Failure: Face Failure- Groove along the stationary face seal
<u>Probable causes that can be determined:</u> a) Dirt trap between seal faces b) Excessive shaft run-out c) Excessive shaft deflection d) Misalignment of the seal e) Solids or abrasive damage f) Dry running

b)Optical microscope

The visualization was taken at various places on the surface of the stationary face seal in order to inspect the microstructure of the failed seal in details with the aid of 100X Magnification lens. In Table 4.10 below shows the pictures (Figure 4.16-4.20) as well as identified failure and the description of it.

Table 4.10: Optical visualization of the failed sample (stationary face)

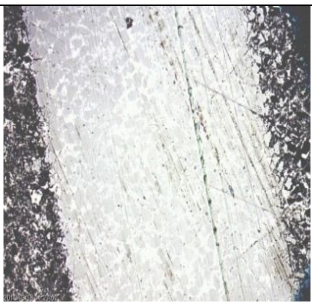
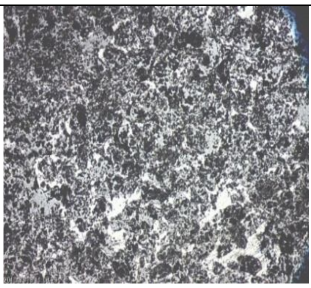
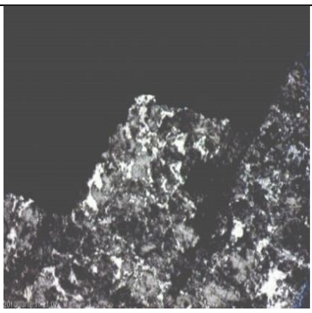
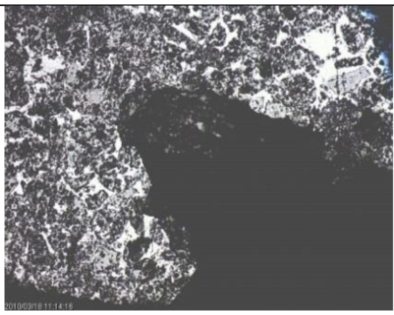
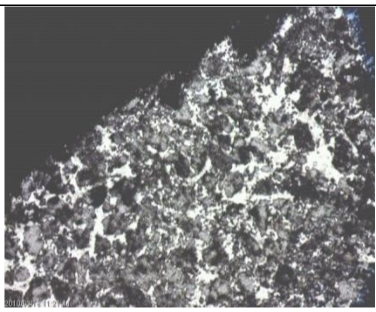
Pictures/images	Type of Failure	Description
 **Figure 4.16:Picture 1**	**Grooving and scratch**	-there are changes on the microstructure of the material -the thickness of the face seal was changed -there is recorded lines at the face seal -it may lead to face failure (leakage)
 **Figure 4.17:Picture 2**	**No Failure**	-the microstructure is still in good condition where the atoms are still bond with each other
 **Figure 4.18:Picture 3**	**Edge Chipping at OD (Outer dimension)**	-there are changes at the microstructure of the material -the strength of the material may be depleted -there are fracture line that can be seen where it may be the weak point of the material -it may lead to face failure (leakage)

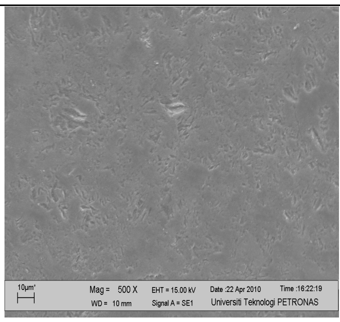
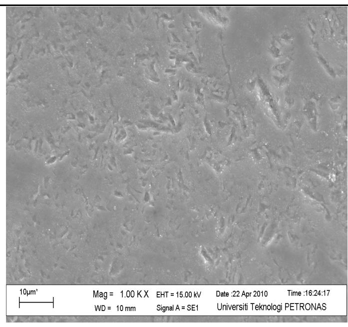
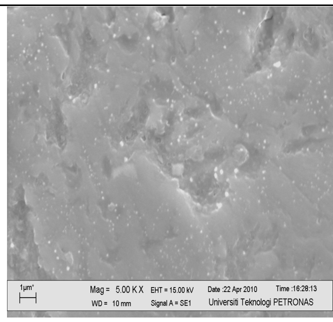
Table 4.10: Optical visualization of the failed sample (stationary face,continued)

 **Figure 4.19:Picture 4**	**Edge Chipping at ID (Inner Dimension)**	-there are changes at the microstructure of the material -the strength of the material may be depleted -it may lead to face failure (leakage)
 **Figure 4.20:Picture 5**	**No failure**	-the microstructure is still in good condition where the atoms are still bond with each other -the edge of the seal is still in good condition

c) Scanning Electron Microscope

The visualization is being carried out using four different magnifications of lenses which are 500X, 1000X, 3000X and 5000X. This visualization shows the microstructure pattern of the stationary face seal (carbon type) in detail as shown in Table 4.11.

Table 4.11: Different Magnification pictures of the failed seal

Magnification: 500X	Magnification: 1000X	Magnification: 5000X
 **Figure 4.21:500X Magnification**	 **Figure 4.22:1000X Magnification**	 **Figure 4.23:5000X Magnification**

Basically, the SEM magnification profile can be used in differentiating the microstructure profile of the seal accurately. However, due to limited sources that can be the comparative profile that can be used in determine the profile changes, the discussion of the result still can be improved in the future analysis. In addition, material composition analysis can also be carried out using the SEM application. This experiment can determine the different percentage of material composition in ones material.

c) Hardness testing

HRC (Rockwell Hardness Scale C) with applied load of 150 kgf (Maximum load as the sample is a very hard material/steel)

Table 4.12: Hardness Testing Measurement

Samples / Readings	Non-groove		Groove area	
	Sample 1 (HRC)	**Sample 2 (HRC)**	**Sample 1 (HRC)**	**Sample 2 (HRC)**
1	46.1	55.6	28.4	45.7
2	48.3	59.5	16.6	34.5
3	41.1	46.5	35.0	32.1
4	44.6	45.6	26.6	18.9
5	54.3	55.3	30.4	25.6
6	45.7	61.0	38.0	41.8
Average	**46.7**	**53.9**	**29.2**	**33.1**

Example of calculation on decrease in performance,

Note: 60 HRC is the minimum hardness reading for mechanical seal faces. [11]

For Sample 1,

% of Decrease in performance = ((60-46.7)/60) X 100%

= 22.17%

Same steps is being used to find the other sample % of decrease in performance and the result are mainly 10.17% for Sample 2 (non-groove), 51.33% for Sample 1 (groove) and 44.83% for Sample 2 (groove). Mechanical seal faces should read at least 60 on the Rockwell "C" scale [11]. Hence, it is proven that the seal faces can no longer withstand higher stress or load applied as the average reading for all the samples shown in the Table 4.12 proved that. Plus, it is proven also that, at the recorded groove area, the stress average that the material can withstand is way much lower from what it was supposed to be operated. (<60 HRC) Hence, it can be said that the seal may fail due to the decrements of the hardness of the material. Plus, it may also lead to pump leakage problems.

Table 4.13: Possible causes from hardness test

Type of Failure: Face Failure- Groove along the stationary face seal **: Face Failure-Scratch and chipping at the stationary seal**
Probable causes that can be determined: a) Misalignment of the seal b) Excessive shaft run-out c) Excessive shaft deflection d) Mishandling during manufacture, storage, assembly or installation

CHAPTER 5
CONCLUSIONS AND RECOMMENDATIONS

The most effective way of sustaining the reliability of the production in the terminal is by maintaining all the process equipments properly and efficiently. Thus, it will increase the life span of the equipments and maintain the production rate of the terminal in longer periods. In conclusion, the project has reached its objective which is to carry out failure analysis for the failed seal used at the condensate booster pump. Paradoxically, the overall failure analysis cannot be carried out to all of the failed seal due to limited sample that is being given to the author. However, the initial visual inspection of the other parts of failed seal have being carried out jointly with the Flowserve company, the company who is in charge with maintaining the mechanical seal for TCOT and OSC terminal.

The results are shown in the Chapter 4 where the failure and probable causes of the seal is being identified. In addition, Kepner-Tregoe Problem Analysis Approach is also being used in the project to identify the root cause of the failures. There are several important areas shown in the approach which are definition of the problem, description of the problem in four dimensions, extraction of key information in the four dimensions to generate possible causes, verification of the true cause and identify testing for most probable cause. The results were also shown in Chapter 4.

For the sample failed seal which is stationary face seal, there are several failure analysis approach being carried out which are visual inspection, Kepner-Tregoe Problem Analysis Approach, Lab and Experimentation. There are various possible causes that can be generated from all the failure analysis approach stated before and the most probable causes that can be identified are shown in Table 5.1. This is mostly base on the visual inspection probable causes which is being supported by the results gathered from the experimentation that have being carried out. The experimentations that have being carried out are Roughness test, Visual Examination using Optical Microscope and Scanning Electron Microscope (SEM) and Hardness Testing.

Table 5.1: Possible causes from various failure analysis approach

Type of Failure: Face Failure- Groove along the stationary face seal : Face Failure-Scratch and chipping at the stationary seal
Probable causes that can be determined: a) Misalignment of the seal b) Dirt trap between seal faces c) Solids or abrasive damage d) Excessive shaft run-out e) Excessive shaft deflection f) Dry running of the seal g) Mishandling during manufacture, storage, assembly or installation

Recommendations to company (PETRONAS Carigali):

From the possible causes that have been determined, there are some recommendations that can be given to the company in order to counter act the failures and causes. They are:

a) Check the alignment of the equipment
b) Carry out the 5 point check by the pump operator as per OEM specification
c) Check the bearing of the pump that may cause the shaft to wobble or deflection
d) Always follow the equipment start-up procedure before starting up the equipment as per OEM specification
e) Dry run may be caused by poor lubrication. Hence, checking the pump suction flows, filters and blockage /restriction of circulation line can be done
f) Change the material of the primary and secondary seal

Recommendations to universities:

1. The analysis can be more efficient if all the failed seals can be brought to the universities for further experimentation.
2. The author suggests that the experiment or testing of failed seal should be conducted jointly by the contractors and the company for better understanding of the failures. In this case, the author can represent the company in joining the contractors in conducting the experiment.

3. Mechanical seal is also an important part of in a pump. In this case, the author suggests that the universities should purchase one or more mechanical seals as a learning medium for the students. Plus, it can also be used for the laboratory work and also for testing and experimentation.

For future work of the project, it is better for the failure analysis if there are more samples that can be analyzed and inspected. In conclusion, this study and research will help the company in analyzing the current problems of the mechanical seal of condensate pump in OSC terminal and perhaps, proper solutions can be achieved via the studies, research, and various failure analysis approaches.