MAINTENANCE STRATEGY DEPLOYMENT OF HVAC SEMI HERMETIC COMPRESSOR USING FAILURE MODE EFFECT ANALYSIS PROCESS (FMEA) METHOD

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BACHELOR OF MECHANICAL ENGINEERING TECHNOLOGY (AUTOMOTIVE TECHNOLOGY) WITH HONOURS

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A thesis submitted
in fulfillment of the requirements for the degree of
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DECLARATION

I declare that this Choose an item. entitled “Maintenance Strategy Deployment Of Hvac Semi Hermetic Compressor Using Failure Mode Effect Analysis Process (Fmea) Method” is the result of my own research except as cited in the references. The Choose an item. has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature :

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Date : 11th January 2023

APPROVAL

I hereby declare that I have checked this thesis and in my opinion, this thesis is adequate in terms of scope and quality for the award of the Bachelor of Mechanical Engineering Technology (Automotive Technology) with Honours.

Signature	:	Fuad Ghani
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Date	:	11th January 2023

DEDICATION

I am dedicating this thesis to my parents Ibrahim Bin Mamat and Rosnani Binti Mat who give their full support through my ups and down and also to all my housemate that always there help builds my motivation up and cheer me up when i felt lost. Also, a big thanks to my project supervisor Ts. Dr. Ahmad Fuad bin Ab. Ghani and Ir. Mohd Azhar bin Shah Rizam for the guidance throughout completing this thesis and to all other UTeM lecturers. Without their dedication in teaching, I wouldn’t reach until this far. Lastly, to my all-good friends, classmates and teammates through bittersweet four years’ journey. Thank you I appreciate all the support and good vibe through the process.

ABSTRACT

Heating, Ventilation, Air Conditioning (HVAC) is a system keeps people healthy by filteringclean indoor air that and maintained the humidity levels at optimal comfort levels. The failure of the compressor results in the breakdown of the entire system. Multi criteria decision making (MCDM) focused with constructing and addressing multi criteria decisionsand planning issues on to failure that occur on the compressor. In this reports, Failure ModeEffect Analysis (FMEA) was applied in order to identify the most significant failure mode using the Risk Priority Number (RPN) score. Then, the highest risk priority number score was compared between the compressor used in oil and gas platform in Terengganu with other failure occur in other wide industry application. The information identified of compressor was gathered on the maintenance reports HVAC Experts Sdn. Bhd. As a recommendation, Risk Based condition maintenance is suggested as it reduce the risk according from higher likelihood breakdown to lowest and are cost-saving.

Keyword: Semi- hermetic compressor, Hermetic compressor, FMEA Method, RPN score

ABSTRAK

Pemanasan, Pengudaraan, Penyaman Udara (HVAC) ialah sistem memastikan orang ramai sihat dengan menapis udara dalaman yang bersih dan mengekalkan tahap kelembapan padatahap keselesaan optimum. Kegagalan pemampat mengakibatkan kerosakan keseluruhan sistem. Pembuatan keputusan pelbagai kriteria (MCDM) tertumpu dengan membina dan menangani keputusan pelbagai kriteria dan merancang isu kepada kegagalan yang berlaku pada pemampat. Dalam laporan ini, Analisis Kesan Mod Kegagalan (FMEA) telah digunakan untuk mengenal pasti mod kegagalan yang paling ketara menggunakan skor Nombor Keutamaan Risiko (RPN). Kemudian, skor nombor keutamaan risiko tertinggi dibandingkan antara pemampat yang digunakan dalam platform minyak dan gas di Terengganu dengan kegagalan lain berlaku dalam aplikasi industri yang luas. Maklumat yang dikenal pasti mengenai pemampat telah dikumpul pada laporan penyelenggaraan HVAC Experts Sdn. Bhd. Sebagai cadangan, penyelenggaraan keadaan Berdasarkan Risiko dicadangkan kerana ia mengurangkan risiko mengikut pecahan kemungkinan lebih tinggi kepada terendah dan menjimatkan kos.

Kata kunci: Pemampat separa hermetik, Pemampat hermetik, analisis FMEA, skor RPN

ACKNOWLEDGEMENTS

In the Name of Allah, the Most Gracious, the Most Merciful

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LIST OF SYMBOLS AND ABBREVIATIONS

FMEA	-	Failure Mode Effect Analysis
HVAC	-	Heating Ventilation and Air Conditioning
Sdn Bhd	-	Sendirian Berhad
RPN	-	Risk Priority Number
FMEA	-	Failure Mode Effect Analysis
HVAC	-	Heating Ventilation and Air Conditioning
	-	
	-	

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Background

HVAC stand for Heating Ventilation and Air Conditioning or in the simple way system that are used to keep people warm and cool in both residential and commercial facilities. It is known as heating, ventilation, and air conditioning, and it keeps people cool and comfortable in places like Malaysia, where the weather is typically hot and humid. Because the systems utilized free-moving air particles in both residential and commercial buildings, they keep people healthy by filtering clean indoor air and maintaining humidity levels at appropriate comfort levels. The heating and air conditioning system is one of the most complex and comprehensive systems in a structure, and if one component fails, it can damage the entire system. The primary function of air conditioning is to decrease extreme temperatures. There is also a technique of eliminating heat and moisture from the interior of a closed space to improve the comfort of the atmosphere indoors. Furthermore, there is a process known as ventilation, which gets its source from fresh outside air intake and exchanges it to replenish oxygen while removing undesirables including foul odors, carbon dioxide, and excessive wetness. The air returns for ventilation, ducting, electrical elements, compressor, condenser, expansion valve, outside unit, and blower are just a few of the components that keep the system running.

Before, there are many gaps between the ventilation process into the building caused from the open and closed door system. But nowadays, the modern construction tightly focused on the sealed so ventilation process can be improving. After the outdoor air is 12 brought in the HVAC system itself will works to filter the air, remove dirt, excessive moisture, dust and other particles to keeps people inside breathes clean air. When the process is done, the air will direct into the space provided such as home living rooms, cars, classes, laboratory and factories. So taking care from the earlier stage is crucial and support as mentioned by researchers (Haberschill et al., n.d.) in designing the system, it crucial to study and investigate the performance of each component as there are wide variety of operating circumstances also the interactions between the component in the system. It is to prevent excessive failure, experimenting to determine performance may costly and be time consuming.

An air conditioner that has undergone an air conditioning system check is critical for improving efficiency, lowering energy consumption, operating expenses, and lowering carbon emissions. Building owners, operators, engineers, managers, and others who are responsible for the overall functioning of the system have legal obligations and responsibilities in the operation and maintenance of air conditioning systems. That system's ability to generate healthy and comfortable environments must be monitored and maintained on a regular basis. Routine inspections and maintenance must highlight the system's capacity to offer healthy and comfortable conditions for building occupants while minimizing refrigerant gas leaks.

Compressor is like the heart to the HVAC system. The failure of the compressor results in the entire system failing. It's usually the root of a lot of system issues. Based on the maintenance report, the key component of the system was identified, and Failure Mode Effect Analysis (FMEA) was used to determine the most significant failure mode impacting parameter first. The FMEA examines numerous failure modes and their effects on the system, then assesses the severity of the failure based on failure rate and failure effect incidence (Jomde et al., 2017). The analytical data should be updated because it will assist the system in the long run. By overcoming the failure via analysis, the facility's overall operating and maintenance costs will be reduced, and the system's performance will be enhanced. The FMEA approach was adopted in accordance with the American Bureau of Shipping (ABS) standard, which was incorporated by Act of the Legislature of the State of New York in 1862 and modified in 2015.

As part of this report, the performance of HVAC support system maintenance reports produced by HVAC experts Sdn.Bhd, such as blower compressor, and refrigerant data in industrial facilities, has been compiled into this report to study the failure mode through Failure Mode Effect Analysis (FMEA) analysis. The file database, which was generated from 2015 to 2020, was used to identify possible failure mechanisms and unfavourable scenarios that may damage the system. As a result, throughout the system's existence, maintenance of each component is necessary. Significantly, new HVAC systems are more expensive than current HVAC systems owing to compliance with safety laws and industry standards. The oil and gas platform's HVAC system was scheduled for maintenance as per usual practise (Preventive maintenance, Corrective maintenance, and Risk-based inspection). While running a maintenance plan, these would be frequent possibilities for the maintenance department.

1.2 Problem Statement

Semi hermetic compressor is known as sealed type compressor. Semi hermetic screw compressors are often used in marine refrigeration, residential structures, petrochemical, pharmaceutical, and chemical operations, industrial refrigeration, and high temperature ammonia heat pumps. Failures in the oil and gas industry can have a wide variety of ramifications, hurting both business and safety. As a result, evaluating failures is crucial in order to prevent them from happening again. The majority of compressor failures are caused by system defects that must be rectified to prevent recurrent problems. During a field inspection of a failed compressor, symptoms of system problems are usually detected. The system's ability to offer healthy and comfortable conditions for building occupants while lowering energy consumption should be the emphasis of the inspection and maintenance routine.

The failure mode of the compressor was investigated in this study for the HVAC support system. One of the components that keeps the HVAC system operating is the compressor. When the compressor fails, the entire system fails, according to Jomde et al. 2017. Corrective and preventative maintenance are two types of maintenance that are currently in use. It has a high price tag. Semi hermetic and hermetic compressors are widely utilized in a variety of applications; they are designed to provide cost-effective maintenance while maintaining optimal compressor performance.

1.3 Research Objective

The main aim of this research is to find integrity assessment to be applied of HVAC support system. The following are the objectives of this research:

a) To perform Failure Mode and Effect Analysis (FMEA) and formulate solution on maintenance strategy.

b) To analyze and access problem, potentially dangerous situations, addressing gaps and improving safety, environmental performance of semi hermetic compressor.

1.4 Scope of Research

The scope of this research are as follows:

- The FMEA method was applied limited to an offshore perspective.
- The analysis to ensure that the failure often happen in mechanical, electrical and piping.

- Mainly focused on the semi hermetic compressor.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Energy efficiency is recognized as a key strategy in today's modern society to address growing issues such as rising electricity costs, utility costs, unexpected and high costs of equipment repairs, climate change, and energy crisis. However, without proper commissioning and installation, it can harm and have an impact on building management. Due to unexpected increases in energy costs over time, many companies around the world have been forced to save energy in their buildings in order to reduce operating costs. This has also led to the creation of green companies, as many existing commercial buildings are built with low carbon emission features. Because of the improvements, the building's environmental performance is improved. However, currently, energy efficiency in commercial buildings may be achieved by redeveloping the building's heating, ventilation, and air conditioning (HVAC) system to be more energy efficient.

Compressors are one of the HVAC/R support systems. Compressor, condenser, expansion valve, and evaporator are also included in the basic HVAC system. There are several types of compressors listed in the business. Semi-hermetic refrigeration compressors are a common type of compressor because of its benefits, which include steady operation, dependability, high efficiency, and a compact structure.

2.2 Background of Heating Ventilation Air-Conditioning (HVAC)

HVAC are stand for Heating Ventilation and Air Conditioning. Refrigeration "R" is sometimes added, resulting in "HVACR." The technique of managing the temperature of a constrained space to satisfy the demands of the people or goods within it is referred to as HVAC. HVAC systems are in charge of not just heating and cooling, but also maintaining indoor air quality (IAQ). In the winter, the air is heated, and in the summer, the air is cooled. In HVAC systems, thermodynamics, fluid mechanics, and heat transport are all employed. These fields are all utilized in different HVAC components. Indoor air quality (IAQ) refers to the air quality inside a building or structure as it relates to the health and safety of its occupants. IAQ is affected by gas inclusion or contamination, as well as uncontrolled mass and energy transmission. Heating, cooling, and air conditioning systems are used in a range of applications, including houses, buildings, industries, automobiles, aquariums, and more. The use of HVAC systems is becoming increasingly widespread, and more study is being done in this area. While the field of application expands, the HVAC sector grows. A heating and cooling system, as well as interior temperature control, is simply a collection of many pieces of equipment that are all connected. HVAC systems employ mechanical and electrical components to provide comfort to building/space occupants or to maintain items, products, or anything else placed in space.

HVAC cooling systems can be coupled with HVAC heating systems or placed separately, depending on the HVAC design. HVAC systems keep machinery running on a large scale by regulating the temperature of the space/hall/room where they are placed. HVAC water chillers have become vital in any industry for a multitude of reasons. In the backdrop of the HVAC system, a water chiller produces chilled water, which is subsequently cycled throughout the building or area and up to cooling coils in air handling units. Blowers circulate air over cooling coils, which is then disseminated throughout the room or building for comfort or to preserve goods/items, as required by HVAC design. Air is delivered by supply ducts, while return air is collected via return ducts in air handling systems. Energy is provided by chilled water and cooling water pumps to keep the chilled and cooling water circulating. HVAC Valves are also put at various points in pipe to make HVAC system maintenance easier or to manage the system. Heating the air can be accomplished using an HVAC heat pump, a hot water generator, or a furnace. During the winter, certain industrial chillers can also be used as heaters. In the heating mode, heated coils take the place of cooling coils. The cost of an

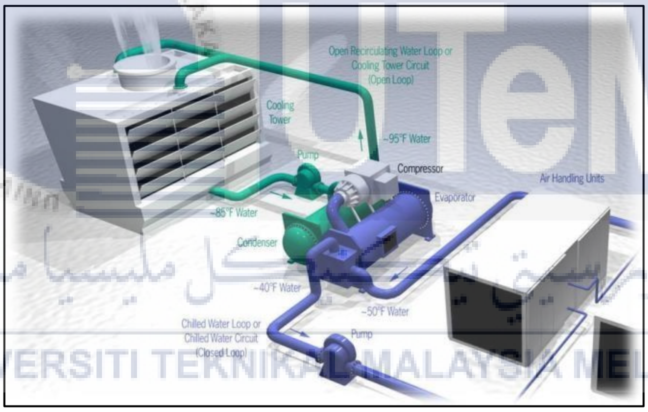


Figure 2-1 Basic System of HVAC

HVAC system varies depending on the use, as does the cost of heating and cooling an area or environment.

Heating and air conditioning split systems, hybrids, ductless mini splits, and packaged systems are the four types of HVAC systems. HVAC systems rely on the distribution system to provide the right amount of air at the right time while preserving perfect environmental conditions. The refrigerant type and delivery method, such as air handling equipment, fan coils, air ducts, and water pipelines, all affect the distribution system.

2.3 Basic Refrigerant Cycle

A refrigeration cycle's function is to absorb and reject heat. The refrigeration cycle, also known as a heat pump cycle, is a means of transporting heat away from a cooling region. A compression and expansion cycle is used to control the pressure of the operating refrigerant.

The cycle list as shown below:

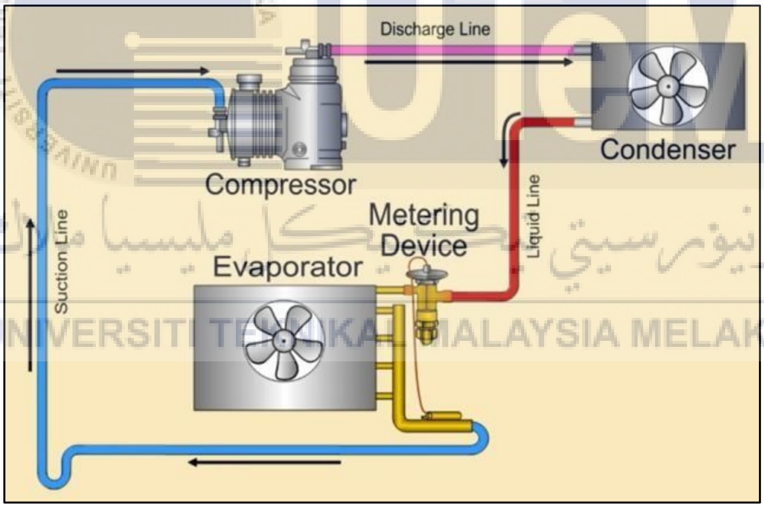


Figure 2-2 Basic Refrigerant Cycle

2.3.1 Compressor

The compressor is the air conditioner's true heart. The refrigerant enters the compressor as a low-pressure, low-temperature gas and exits as a high-pressure, high-temperature gas. A split air conditioning system is the most common type of central air conditioning system found in most houses. The compressor is housed in the outside unit. Its duty is to circulate and apply energy to the refrigerant necessary for heat exchange via the coils of the interior and outdoor units. The compressor is powered by a motor that is similar in design to a cylinder and piston motor. The gaseous refrigerant is compressed by the compressor, which raises its temperature and converts it to a high-pressure gas. The refrigerant is forced through a line to the outdoor coil, where it releases its heat and condenses into a liquid due to the high pressure.

2.3.2 Condenser

The condenser, commonly known as the condenser coil, is one of two types of heat exchangers in a simple refrigeration loop. From the compressor, this component gets vaporised, high-temperature, high-pressure refrigerant. The heated refrigerant vapour gas vapour is cooled in the condenser until it condenses into a saturated liquid state. A condenser (or AC condenser) is the part of an air conditioner or heat pump that releases or absorbs heat depending on the season. Both split air conditioner and heat pump condensers have the same basic components. The condenser cabinet houses the condenser coil, a compressor, a fan, and various controls. The condenser coil might be made of copper tubing with aluminium fins or all aluminium tubing to transfer heat fast. The condenser fan is a crucial component that helps with heat transmission by pumping air over the coil. The compressor is the system's heart since it compresses the refrigerant and pumps it to a coil as a hot gas. The hot gas is pushed straight to the evaporator coil in heat pumps to create heat.

2.3.3 Expansion Valve

These components come in a number of styles. Fixed orifices, thermostatic or thermal expansion valves, and more sophisticated electronic expansion valves are all common. The job of the expansion device in a system, regardless of configuration, is to induce a pressure decrease when the refrigerant exits the condenser. Some of the refrigerant will boil fast as a result of the pressure decrease, resulting in a two-phase mixture. Flashing is a quick phase shift that helps the evaporator, the next piece of equipment in the circuit, do its function. Thermal expansion valves are occasionally referred to as "metering devices," but this word can also apply to any other device, such as a capillary tube or a pressure-controlled valve, that discharges liquid refrigerant into the low-pressure part but is unaffected by temperature.

2.3.4 Evaporator

The evaporator is the second heat exchanger in a common refrigeration circuit, and it, like the condenser, is called after its principal purpose. It serves as the "business end" of a refrigeration cycle because it does what we expect air conditioning to do: absorb heat. The air is cooled by the refrigerant absorbing heat from the location in question when it enters the evaporator as a low-temperature, low-pressure liquid and a fan blows air through the evaporator's fins. After that, the refrigerant is returned to the compressor, where the cycle repeats all over again.

2.4 Research gap

This research analyzes a review of the study in the maintenance area of HVAC components support system in general, with the study focused on the HVAC maintenance reports at a selected firm, the findings of which may be used as a reference and applied to other companies. Those working in maintenance in the sector frequently struggle with prioritizing maintenance concerns in order to build an appropriate approach. One of the way used to prioritize the concern is through the FMEA approach. The FMEA approach is used to trace the effect of each failure mode in the reciprocating compressor until the cause is discovered, allowing the appropriate remedial action to be decided (Qosim, n.d.).

Table 2-1 Research gap

No	**Authors**	**Year**	**Study method**	**Topic/ focus**	**Description**	**Gap**
1	Amit Jomde etal.	2017	FMECA (Failure Mode Effects and Criticality Analysis)	FMECA on linear compressor	Applied FMECA on linear compressor. Studied effect of the failure mode of refrigerator powers in the vapor compression refrigeration system(VCSR).	Different type of compressor. Duration of the maintenance should be applying not clear.

2.	Qosim,n.d.	2017	RCFA (Root Cause Failure Analysis) & FMEA (Failure Mode and Effect Analysis)	The goal of this researchis to uncover problems that cause failures in compressor performance	The effect of each failure mode in a reciprocating compressor is tracked in order to decide remedial action. So that maintenance costs and improvements can be reduced.	Piston Compressor PK60-150. Different type of compressor not semi hermetic compressor. Author expects using Taguchi analysis as verification comparison.
3.	Dwianda	2021	FMEA	FMEA of Pneumatic SystemofCNC Milling Machine	FMEA method to define priority failure for pneumatic system in CNC milling machine.	Applied preventive maintenance instead of corrective maintenance and the journal applied FMEAon CNC Milling Machine. Also, repair action isnot assigned to each failure

						mode.
4.	Dilbagh Panchalet al.	2018	Fuzzy FMEA and GRA (Grey Relation Analysis)	Carry out risk analysis for clean and sustainable urea fertilizer manufacturing.	To provide a framework based on fuzzy methodological techniques for carrying out risk analysis on a real industrial system of a urea fertilizer business in northern India.	The Fuzzy FMEA method applied in centrifugal compressor. Compressor application not HVAC system. Subsystem different from HVAC system.
5.	Fengyua n Jiang & Dong, 2020	2020	Nonlinear finite element analysis, quantitative analysis	The elements that contribute to the risk of falling debris on offshore pipelines were investigated.	The effects of relevant parameters on failure risk are investigated, including seabed flexibility, burialdepth, acceptable criteria, and fundamental variable sensitivity.	No mentioned type of maintenance should be applied; the risk is not prioritized clearly. The method uses show lower percentage of failure risk.
6.	Pisut Koomsap & Thuangporn Charoen-	2016	FMEA	Customer dissatisfaction using improved	Customer complaint been included into new risk	A research that demonstrates the

	chokdilok, 2016.			customer oriented in FMEA.	assessment technique using Kano model to determine customer perceive failure mode the customer oriented RPN was created and compared to traditional approaches.	effectiveness of a certain strategy. However, more research and testing are necessary before using customer-oriented FMEA in other sectors, as the outcomes would differ from standard FMEA.
7.	J. Mateus, et al.	2019	FMEA	Finding of the fundamental reason resulted in the crankshaft collapsing of turbo diesel engine.	Explain the crankshaft failure mode and its mechanical processes, fractographic, metallographic and numeric analyses carried out.	The study show combined FMEA with numerical analyses helps finding the real reason of the collapsing but through estimation of the researcher.

8.	Bassetto& Hernandez	2007	FMEA	Refrigeration system reciprocating compressors	Using bathtub curve to define reliability distributions for refrigeration semi hermetic compressor for failure rate and then applied FMEA to the failure mode based on 600 reports of occurrence of failures.	This study stated that the design and operation of such compressor have significant impact on the behaviour of reliability metrics. Mentioned maintenance could help maintaining the life cycle but no maintenance action is suggested in the research.

2.5 Type of Compressors

2.5.1 Scroll Compressor

Scroll compressors are positive displacement compressors used in household and commercial air conditioning, refrigeration, and heat pump applications. These compressors have a mechanical compressing element that accepts gas on the periphery and releases it in the center. This element is made up of two identical spiral-shaped metallic pieces (scrolls). One scroll remains stationary, while the other moves in an orbital pattern, causing gas to migrate from the scroll's periphery to its inside. Throughout the migration, the gas chambers' capacity is gradually reduced. As a result, the gas's pressure and temperature increase. The main irreversibility in scroll compressors is commonly thought to be leakage between chambers with different pressures. Heat transport within the compressor has an impact on thermodynamic efficiency. The temperature profile throughout the scroll wraps and the gas temperature inside the suction pockets (suction temperature), which is higher than the input temperature owing to refrigerant contact with hot compressor parts, are critical for heat transfer characterization. Many authors have developed models to predict suction temperature in scroll compressors, which are typically used in combination with numerical compression simulations.

When it comes to heat transfer during the compression process, the gas temperature rise and scroll temperature profile may be focused on. According to most studies, a linear temperature profile in relation to the scroll involute angle is a reasonable assumption.

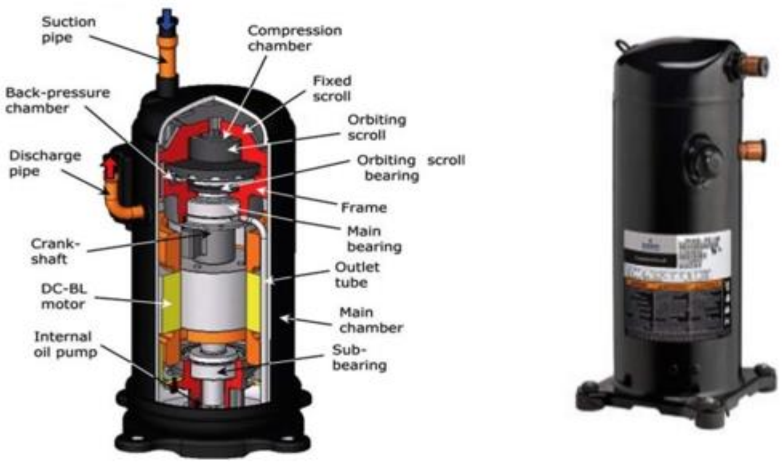


Figure 2-3 Scroll Compressor with fixed and orbiting scrolls enclosed in hermetic shell

When differential models are employed to simulate the compression process, the suction temperature is a critical starting condition, with the scroll temperature profile acting as the required boundary condition. In this study, a steady state one-dimensional model was used to estimate heat conduction and temperature distribution in the scrolls. The conduction model was merged with a thermodynamic model of the compression process developed by Pereira and a simplified thermal model developed by Diniz et al. As a result, the simulation was running many times, allowing for a full thermodynamic description of the compressor.

2.5.2 Screw compressor

The majority of screw compressors are oil lubricated. The semi hermetic and open- drive kinds are the two types. The motor is housed in the same housing as the compressor in the former, but the motor is housed outside the compressor housing in the latter, necessitating the use of a shaft seal. Screw compressors have only two moving parts: two intermeshing helical rotors. The rotors are made up of a male lobe that serves as a rolling piston and a female flute that serves as a cylinder. There are no surges in the system since rotary screw compression is a constant positive-displacement operation. Because the rotors rotate at slow speeds and are adequately lubricated with cooling oil, screw compressors require little maintenance. Fortunately, with screw compressors, the majority of the oil can be easily separated from the gas.

Figure 2-4 MAS oil injected screw compressor for marine.

2.5.3 Semi Hermetic Compressor

Semi hermetic compressors have a two-piece shell that houses the motor and compressor housing. The covers are bolted together and may be removed for cleaning. Due to the bolts and O-rings required to connect the covers, semi hermetic compressors are usually more costly than hermetic compressors. The simplicity with which this compressor can fail or be maintained is its greatest advantage over the hermetic kind. It was designed by a French monk, Abbe Audiffren, and erected by SIngrun in Epinal, France, in 1905.

Figure 2-5 Semi Hermetic Compressor

Semi-hermetic compressors increase gas pressure and transfer it via a pipe system to meet system distribution requirements. The refrigerant is supplied in a continually decreasing volume from low pressure to high pressure side. It mechanical working principle started form the motor is energised by electricity, which causes the compressor crankshaft to revolve. During the down stroke, the compressor pump has a piston that provides a low pressure rear between the piston top and the cylinder head. Gas rushes through the entrance of a suction valve and into the low pressure compartment. The suction valve closes during the piston upstroke, forcing the exhaust valve to open owing to increased pressure. The gas is compressed and driven through the system's discharge, or high pressure side. The discharge valve closes when the semi-hermetic compressor piston reaches the top of the cylinder. As the piston begins to descend, the suction valve opens, pulling in gas to complete the cycle. Additionally, screw compressor doesn’t even have suction or pressure valves, merely a non- return valve to guarantee that there is no refrigerant return flow when the compressor is turned off. Screw compressors can operate at high compression ratios becausethe oil absorbs compression and friction heat during the process in addition to lubrication and sealing. Proper oil cooling is therefore essential in a screw compressor, and can be achieved either through refrigerant injection into the compressor or through a separate oil cooling system. BPHEs are commonly utilized in oil coolers.

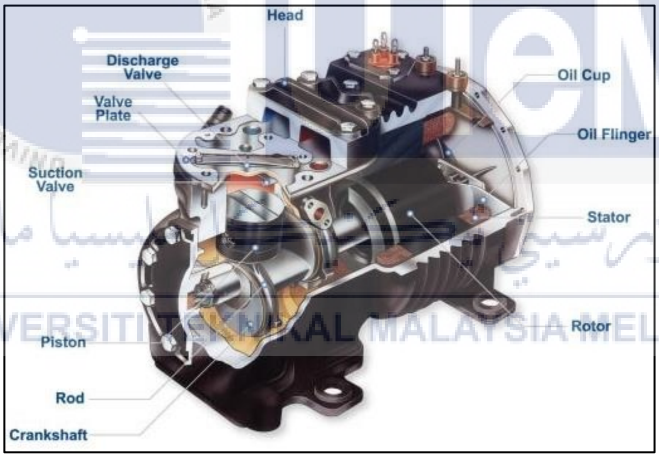


Figure 2-6 semi hermetic (Couplant Compressor) Emerson’s brand

Semi hermetic compressor common faults:

i. Oil leakage causes insufficient lubrication.
ii. Inadequate oil in the system.
iii. Slugging oil happen in the compressor.
iv. Overheated compressor.
v. Due to contaminant inside system degrade valve and seal.

2.5.4 Hermetic Compressor

Compressors that are hermetically sealed and inaccessible are known as hermetic compressors. The motor and compressor housing are held together by a casing. The steel shell is welded to establish a hermetic seal against the environment. Because the shell is welded, it is more difficult to reach the welded shell in order to perform maintenance work. If the motor or compressor is damaged, the compressor must be discarded for maintenance purposes. Semi-hermetic compressors, on the other hand, feature a metal casing with covers that allow the user to access any damaged or malfunctioning pieces, such as pump components or the motor. In term to differentiate between hermetic and semi hermetic compressor can be observing from its size where the hermetic compressor is compact than the semi hermetic compressor. For maintenance purpose, the cost for maintenance and repair for hermetic is costlier due to its size. Both compressor has been widely used in many sector as domestic refrigeration, smallcommercial refrigeration and air conditioning systems.

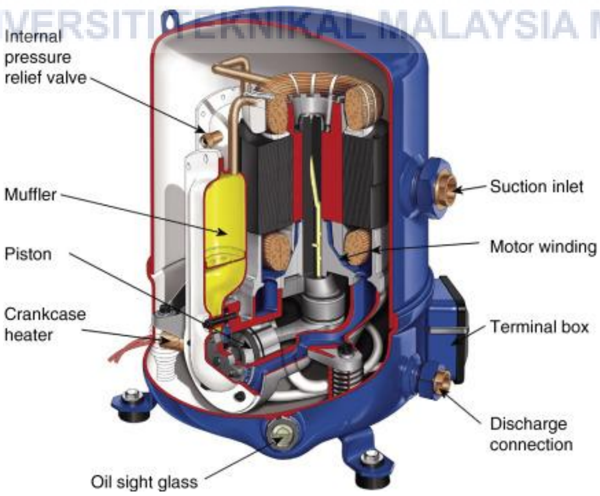


Figure 2-7 Hermetic Compressor

Advantages of hermetic system:

i. Due to it sealed mechanical process it protected the system from pollution.

ii. Dust particles unable to enter and contaminate the lubricant.

iii. Simple design and small in size.

2.5.5 Reciprocating Compressor

A hermetic or sealed compressor is one in which both the compressor and the motor are enclosed in a single welded steel casing for small compression while cast iron of the body compressor for high compression required. With the motor inside the refrigeration circuit, the motor and compressor are directly connected on the same shaft. And if a larger cooling capacity is required, this sort of compressor is typically used on the Offshore platform. It's usually placed in pairs and runs in duty and standby mode in that order.

Table 2-2 Main Components of Reciprocating Compressor (Hermetic)

Name	Function	Failure Mode	Effect
Body of compressor	The body of the compressor is built of high-strength metals that can sustain high pressure compression and lastfor a long time. It also houses theessential components that allow it to function as a compressor.	The body compressor part can be damaged due to lack of lubrication atthe surface. Then will cause the compressor to overheat	The compressor will increase in temperature and produce rattling sound until the compressor severely damage before it ends its life.

Piston	Internal combustion engines rely on pistons as a key component. It turns heat energy into mechanical power through a reciprocating motion. When the engine produces power, it goes up and down inside the cylinder. The piston's job is to stop gases from expanding and sending them to the crankshaft.	Worn pistons rings and cylinder, damage and also liquid slugging happens when the oil in the compressor head heats up to the point where it loses its capacity to lubricate effectively.	This wears down the rings, piston and cylinder causing blow-by, leaky valves and metal debris in the oil. Punch hole top of piston will occur due to overheat and other effect such as worn pistons scored cylinder walls & wear on wrist pin.
Connecting rod	The connecting rodjoins the piston to the crankshaft, converting the crankshaft rotating action into the piston's reciprocating motion.	Liquid slugging	Connecting rods break & crankshaft break
Cross head	A crosshead is a mechanism used to alleviate sideways pressure on thepiston in long reciprocating engines andreciprocating compressors as part of the slider-crank couplings. The crosshead		

	also allows the connecting rod to move freely outside of the cylinder.		
Crankshaft	The primary shaft of a reciprocating compressor. One side of the crankshaft is connected to the electric motor, while the other is attached to the connecting rod.	If the crankcase oil level is low due to lack of oil in the crankcase to adequately lubricate the running gear. Then, overheat will occur.	The overheating in crankcase affect the crankshaft working continuously results to damage component.
Motor winding	The power is usually supplied by an electric motor, which is constructed using either star or delta winding principles.	Many motors fail to function due to mechanical failure. Shorting windings and overheating happens due to exterior electrical components that are not working.	The whole winding gets overheats and burn, also causing voltage unbalance affects to electrical damages and system shutdown.
Gasket, piston ring, shaft seals	Components guarantee that the compressor does not leak refrigerant, oil, or air	Usually the failure mode that will occur in this part is wear & tear because of that failure mode will cause to inadequate lubrication to the system.	Then, due to inadequate lubrication effecting discharge valve failed, gasket plate blown effect pin hole to wear. Also cause discolored pistons and worn

			pistons because of the friction between the parts.
Oil sump	Oil pumps maintain the running gear elements adequately lubricated in order to prevent premature damage to the cylinder and other sections of the commercial compressor.	At the oil pumps part leaking will happen if the cover is not tightly closed. And causes of oil loses.	Low level of oil reading due to oil leaking then will cause to low refrigerant velocity as there not enough lubricants moving into the parts, such as broken fan belts, failed fan motors, dirty coil and unloaded compressor operation.
Bearings	Pistons, rotors, scrolls, and impellers all have shafts that need to be supported. These components are critical because they can sustain the varying loads that occur during compressor operation and prevent metal-to-metal contact between the rolling elements and stationary castings, which reduces friction-related wear.	If the bearing damage it will cause contaminants present in the oil of the compressor that will damaging. Another failure mode that will occur is overload as the bearing is continue to working excessive temperatures.	When bearing fails to achieve its performance requirements it causes bearing damage as the bearing failed to function and prevents proper lubrication (affect to short winding & fail motor) to the system causing

			totally system to breakdown.
Discharge valve	The discharge valve directs the high-pressure refrigerant to the discharge line, which leads to the condenser.	Due to high discharge temperature will cause to dicolored valve and low suction pressure because the oil loses its capacity.	Causes compression effect evaporation ratio effect evaporator coil problem, improper pressure.
Suction valve	Through the suction piping and valve, the refrigerant is pulled into the compressor.	The failure mode that will occur is wear and slugging because when the oil becomes too hot, it loses its capacity to lubricate adequately. Also, cause leaky valves.	Unable to lubricate properly lead to suction valve break, and dented valves. Next, from leaky valve it will affect to high discharge pressures & temperature.

2.6 Operating Requirements

Reciprocating compressors are designed to work continuously for long periods of time, up to a year, without requiring substantial maintenance if properly maintained. Oil should be changed at least once a year, and compressor parameters should be inspected solely on a regular basis to ensure that the compressor is still in excellent working order.

2.6.1 Continuous Duty

When selecting equipment for continuous operation, consistency, efficiency, and dependability are all critical variables to consider. Before valve and seal wear becomes too severe to handle, reciprocating compressors can only run for roughly a year. When equipment is not maintained on a regular basis, the chances of failure grow.

2.6.2 Intermittent Duty

Reciprocal compressors are tolerant of duty variations, but because they are positive displacement devices, recycling control is usually used to handle flow changes. Unloading mechanisms are included in some machines, which can be sophisticated and result in high temperatures in specific areas. If comprehensive tests are completed and, most importantly, there is no liquid in the compressor or suction system, reciprocating compressors may be set up quickly.

2.6.3 Emergency Duty

Corrosion is more severe when process deposits (salts, oxides) are exposed to wet air under inadequate ventilation conditions. This can happen if there is a failure that prevents a routine procedural clean out. The system is then opened for inspection and remained open until components and resources are obtained. This may be avoided by completing thorough cleaning and venting following the inspection, as well as using the proper chemicals. In the crankcase and cross-head sections, which should be completely isolated from the process, clean lubricating oil without contamination should be utilized. However, there should be little chance of rusting. It's possible that moisture from the refrigerant system will combine with the compressor oil. Therefore, the oil become acidic becomes enemy of the inner parts of compressor.

2.7 Application of Semi Hermetic and Hermetic Compressor

2.7.1 Application for Refrigeration in Residential Building

Hermetic compressors are used in both household refrigeration and small business refrigeration and air conditioning systems. In Beijing, for example, burning charcoal to heat up during the winter is not ecologically friendly. As a result, in Beijing, using an air source heat pump to heat residential buildings is considered ecologically friendly and encouraged (Wang et al., 2011). As the working concept of the system, which consists of a primary refrigerant circle, would give a huge quantity of heat to the building while keeping the same operational conditions, the kind of compressor employed in the building is the hermetic compressor type. As stated in the journal, the bypass refrigerant may be utilised to raise the density of refrigerant at the inlet of the hermetic compressor used in the refrigeration cycle.

Semi hermetic compressor often used in appliances such as refrigeration and air- conditioning units suited to supermarkets and other commercial industrial applications, as well as major air conditioning project systems such as shopping malls. They are preferred choice of compressor system for larger size machines as these compressor type may give more financially efficient solution. According to Saengsikhiao & Taweekun, 2021, presented a research on energy efficiency enhancement option to the refrigerators in supermarket. In the journal stated that the installation of digital semi-hermetic compressor can adjust its duty cycle to match the present load while neither sucking or compressing the refrigerant in the unloaded condition, resulting in a 50% reduction in compressor energy usage.

Figure 2-8 A Digital Semi Hermetic Compressor Application At Supermarket.

Thailand's household sector has been ranked as the country with the second-highest rate of energy consumption. The adoption of a semi-hermetic compressor helps to save money and energy while guaranteeing that energy conservation measures do not have an impact on maintenance costs. As an energy efficient upgrade alternative, the researcher proposes a low E glass door for open refrigerators and a digital semi-hermetic compressor to set the speed of the semi-hermetic compressor. In both circumstances, the use of hermetic compressors in residential buildings necessitates energy efficiency, and many methods have been proposed to improve it while keeping maintenance costs low.

2.7.2 Application For Refrigeration in Offshore Platform

The semi hermetic compressor is then used in the HVAC oil and gas platform living cabin. Cooling plant, which consists of four basic components such as a compressor, condenser, expansion valve, and evaporator, is one of the applications that has been used of an air conditioning system (HVAC) on offshore platforms. The application is determined by the kind of offshore installation of the equipment, including whether it is water-cooled or air-cooled. It will be difficult to maintain a comfortable interior atmosphere without a cooling plant when cooling is necessary. While, the application of semi hermetic and hermetic compressor in living cabin provide electrical warming and cooling to improve and provide personal comforts (Heinen & Hopman). Same goes in book (Refrigeration units in marine vessels, 2011) by Prof. Dr. –Ing.A. Hafner et al. write that refrigeration on passenger and cargo ships has a wide variety of cooling capacity, primarily to give comfort to passengers and crew via air conditioning and to preserve food. Life in the Oil and gas living cabin platform has many rigs house and employ over 200 persons, with the interiors resemble a mix between a hotel and a workplace. The cabins are shared with generally with minimum two people per room and shared canteen and restrooms with other cabins.

Figure 2-9 A Water-Cooled Chiller With Hermetic & Semi HermeticCompressor Used For Marine Air Conditioning System By DMA Marine Group

2.8 Maintenance of HVAC

The methods for recognizing and eliminating performance issues have been more advance as the systems have grown larger and more involved in larger temperature control applications. Due to that, FMEA is one of approach to prevent recurring failures from occur.

In order to keep the HVAC system in excellent working order, the building owner, engineer, technicians or contractor in charge recommends that it be serviced once a year, andthe pump should be serviced every six months. Regular maintenance ensures that the heating, ventilation, and air conditioning (HVAC) system runs smoothly and efficiently for a long time. The HVAC system keeps the environment of the home comfortable and clean. Its jobis to ensure that the indoor air quality is up to standard.

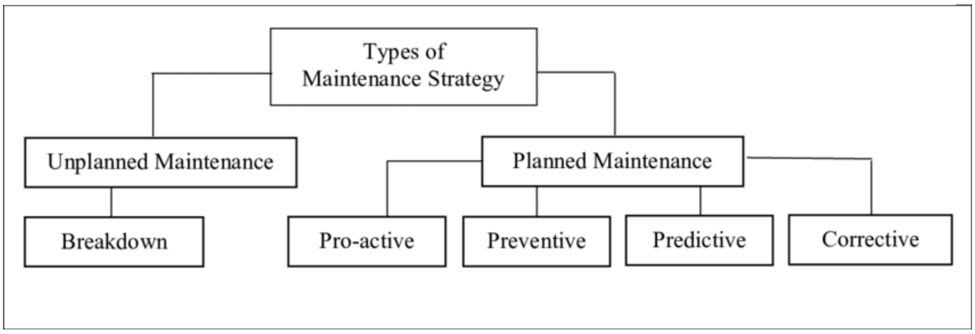
2.8.1 Importance of Maintenance

The number of variables to consider while making maintenance management choices is also notable. It's crucial to look into how the maintenance staff communicates their maintenance goals. Even though maintenance is carried out on the offshore platform. However, when the maintenance department's maintenance schedule fails to determine the priority of maintenance alternatives for each piece of equipment, the same challenges arise (Lee, H.H.Y, et al., 2009). Machine and equipment maintenance is necessary to keep them in top working order. As a result, in a well-functioning production system, plant maintenance is a vital and unavoidable service job (Jain. M, 2010). Maintenance has been shown to be critical in ensuring that equipment lasts as long as possible, especially on offshore platforms where maintenance costs are higher than onshore owing to harsh surroundings and a higher risk of equipment failure.

2.8.2 Type of Maintenance

There are two type of maintenance strategy which planned maintenance and unplanned maintenance. Planned maintenance is widely practiced in the field of maintenance management, consists of preventive maintenance, predictive maintenance, corrective maintenance and proactive maintenance. While unplanned maintenance also known as reactive maintenance. It is preventative maintenance in the event of unforeseen circumstances, which results in high maintenance costs, consists of breakdown maintenance.

Figure 2-10 Type of Maintenance



- **Preventive Maintenance**

Preventive maintenance (PM) is the routine repair of equipment and assets to keep them functioning and avoid unplanned downtime due to unexpected equipment breakdown. Prior to a problem occurring, a good maintenance approach necessitates planning and scheduling equipment maintenance.

- **Breakdown Maintenance**

A piece of equipment that has broken down, malfunctioned, or cannot be operated in any other manner is subjected to breakdown maintenance. The aim of breakdown maintenance is to bring something back to life after it's been broken. Preventive maintenance, on the other hand, is performed to ensure that something continues to function.

- **Predictive Maintenance**

Predictive maintenance is a subset of condition-based maintenance in which systems are constantly monitored on a regular basis, allowing maintenance staff to perform timely actions such machine modification, repair, or overhaul. Direct monitoring of mechanical condition and other indicators is used in predictive maintenance to compute the true mean time to failure during the machine's life lifetime.

- **Corrective Maintenance**

  Corrective maintenance is widely applied in HVAC maintenance which the fault is replaced at after the faults is occur. Because it is based on the state of the equipment, it differs from preventive maintenance. According to (Nik Myeda et al., 2011) corrective maintenance is what most maintenance managers rely onto complete daily maintenance activities. CM lowers emergency repairs and promotes employee's safety since corrective maintenance concerns are discovered on time. Corrective maintenance may be quite costly since the failure of one thing might result in a lot of damage to other parts of the structure, and the failure of one item can happen at an inopportune moment.

- **Proactive Maintenance**

  According to (Jabar, 2015), proactive maintenance is a type of maintenance that discovers issues at their cause. It has the ability to boost production capacity while also extending the equipment's lifespan. Proactive maintenance differs from preventive and predictive maintenance. By employing a high level of expertise in terms of operational accuracy, proactive maintenance aims to extend the useable life of equipment until it reaches the wear-out stage.

2.9 Risk Maintenance On Maintenance Strategy Of Compressor

Risk assessment is a term used to represent the entire process or approach of detecting hazards and risk variables that have the potential to cause harm(hazard identification). Analyze and evaluate the danger posed by that threat (risk analysis, and risk evaluation).

2.9.1 Objectives of Risk Assesment

- Identifies and evaluates risk.
- Minimize and remove dangerous hazards.
- Encourage resources efficiency.
- Better communication with an organization

2.9.2 Steps in the Risk Assesment Process

- Identify the hazards
- Figure out who could be damaged.
- Access the dangers and take safeguards.
- Record the findings.

The risk analysis process aids the organization's effective and efficient operation by identifying hazards that demand management's attention. They'll have to prioritize risk management activities based on their ability to benefit the company. If the refrigeration system's compressor overheats, the problem can only be remedied by upgrading the refrigeration system's design and maintenance. The problem cannot be solved fundamentally by replacing a new compressor.

Table 2-4 Likelihood of Occurence

LIKELIHOOD (L)	EXAMPLE	RATING
Most likely	The most likely result of the hazard	5
Possible	Has a good chance of occurring and is not unusual	4
Conceivable	Might be occur at sometimes in future	3
Remote	Has not been known to occur after many years	2
inconceivable	Is practically impossible and has never occurred	1

Table 2-3 Severity of Hazard

SEVERITY	EXAMPLE	RATING
Catastrophic	Numerous fatalities, irrecoverable property damage and productivity	5
Fatal	Approximately one single fatality major property damage if hazard is realized	4
Serious	Non-fatal injury, permanent disability	3
Minor	Disabling but not permanent injury	2
Negligible	Minor abrasions, bruiser, cuts, first aid type injury	1

Table 2-5 Risk Matrix

Likelihood (L)	Severity (S)				
	1	2	3	4	5
5	5	10	15	20	25
4	4	8	12	16	20
3	3	6	9	12	15
2	2	4	6	8	10
1	1	2	3	4	5

Table 2-6 Priority Based on the Range

Risk	Description	Action
15 – 25	High	A high risk requires immediate action to control the hazard as detailed in the hierarchy on the risk assessment form including date for completion.
5 – 12	Medium	A medium risk requires a planned approachto controlling the hazard and applies temporary measure if required. Actions taken must be documented on the risk assessment form including date for completion.
1 - 4	Low	A risk identified as low may be considered as acceptable and further reduction may not be necessary. However, if the risk can be resolved quickly and efficiently, control measures should be implemented and recorded.

2.10 Pressure Requirements Of HVAC Compressors Commonly Used At The Platform

There is a difference of requirement for HVAC compressor for the specific type of gasses such as R22, R407C, and R410. For R22, the low pressure is 60-70psi while high pressure is between 250-300psi. R407C requires 75-80psi at low pressure and 275-300psi at high pressure. Lastly for gas R410a, the low pressure is at 120-130psi, and for high-pressure 450-500psi. If the requirement of the compressor is not followed such as refrigerant overcharge or refrigerant undercharge, it may cause some result that can be creating risk. Some of the risks are: -

i. Compressor motor overheating

This may prevent the compressor from starting or cause the circuit breaker to trip prematurely. Left unchecked, the motor will eventually burn out and fail to run at all.

ii. Loss of cooling capacity

The system is no longer able to maintain the humidity and temperature at the requiredlevels.

iii. Flooded condenser

Condenser flooded with liquid refrigerant, which will reduce its capacity; besides causing excessive sub-cooling at the condenser outlet, this condition may cause the compressor to short cycle on the high-pressure cut-out.

iv. Liquid refrigerant enters the suction line

Commonly referred to as “liquid slugging”, this is a dangerous condition potentiallyleading to compressor damage.

2.11 Cause and Impact of Vibration on HVAC Compressors

HVAC systems involve plenty of moving components, it is normal to have some vibration and noise, even in a correctly installed and well-maintained system. Excessive vibration and noise, on the other hand, signal that an installation needs to be maintained, and they can also lead to additional problems. Because vibration and noise are so closely connected, they are usually discussed simultaneously. The second is frequently a result of the first. Some property owners focus just on noise and install a lot of soundproofing, but this isn't the greatest method because it doesn't address the fundamental problem.

Here are some common sounds that an HVAC system can make:

i) Banging :

Banging is usually a sure sign that there's a loose or broken part a connecting rod,piston pin, or crankshaft inside the air conditioning compressor.

ii) Clicking :

The clicking of electrical components at start-up and shutdown is a normal part of the system’s operation, but constant or ongoing clicking is not typical. It could be a sign of a defective control or a failing thermostat.

iii) Buzzing :

A buzzing noise from the outside unit could mean, it had loose parts, debris in eitherthe indoor or outdoor unit, the outdoor fan motor is loose or about to fail, fan blades are looseor out of balance, the copper lines from outside to inside are rubbing against something.

2.12 Special Design Of Explosion-Proof HVAC Compressors For Onshore

Air conditioners are not made to explode. Yet, few cases of HVAC system explosion were failed in past years. The explosion-proof of HVAC systems is essential in hazardous areas in offshore production areas such as the oil and gas industry. As the explosion-proof heating, ventilation, and air conditioning systems are designed by a skilled engineer to ensure safety. This system is very durable and reliable in use. Since it is an offshore used compressor, so its anti-corrosion ability is enhanced. This is purposely to increase the machine's life working time and prevent unexpected shut down of the machine. As the explosion-proof is the internal sparks or explosion that occurs in the casing which causes a larger blast. This could damage the compressor, especially internal components. Therefore, it is important to minimize the explosion of the compressor. Besides, some standards can be referred to reduce the explosion occurs.

2.13 Effect of High Suction And Discharge Temperature of HVAC Compressors

i) High return gas temperature

The return gas temperature is calculated using the evaporating temperature. A return superheat temperature of 20°C is usually required to prevent fluids from returning to the compressor. If the return gas line is not appropriately insulated, the superheat temperature will be far above 20°C. If the return gas temperature is higher, the suction and discharge temperatures will be higher. The return gas temperature will rise by 1°C, while the discharge gas temperature will climb by 1°C to 1.3°C.

ii) Burned valve reeds Reed

Valves are a form of check valve that restricts fluid flow to a single direction and opens and closes as the pressure on each face changes. Flexible metal or composite materialsare frequently used in modern versions (fiberglass or carbon fiber).

iii) High compression ratio

The compression ratio has a significant impact on discharge temperature. The higher the compression ratio, the higher the discharge temperature. Reducing the compression ratio, as well as raising the suction pressure and lowering the discharge pressure, can considerably lower the discharge temperature. Evaporating pressure and suction line resistance determine suction pressure. The suction pressure may be efficiently raised by raising the evaporation temperature, and the compression ratio can be swiftly lowered, lowering the discharge temperature. The temperature difference can be increased by lowering the evaporation temperature, but the compressor cooling capacity is lowered, so the freezing speed is not guaranteed. Besides, the lower the evaporation temperature, the lower the refrigeration coefficient; yet, since the load has grown, the power consumption will rise if the operating duration is extended.

iv) Stator spot burns from metal debris

Thermal degradation of insulation in one phase of the stator winding can be caused by unequal voltage between phases caused by uneven loads on the power supply, a poor connection at the motor terminal, or a high resistance contact.

2.14 Study of caused compressor motor damage

Excessive discharged temperatures are frequently a symptom of compressor failure, and some of the metrics are advised to test first when compressors exhibit signs of distress. It's critical to understand these factors in order to avoid failures and fix issues. If a troubleshooter for compressor failure exists, a new compressor will have the same issue. A multitude of electrical or mechanical issues might lead to compressor motor failure. On returning compressors, all compressor manufacturers do a spot disassembly study. A compressor manufacturer may, on occasion, take down all returned compressors for a period of time in order to evaluate them and establish the cause or causes of failure**.** This is expensive, but the information gathered helps the manufacturer to improve the product, the manufacturing process, and theliterature regarding installation and maintenance.

Here are some of simplify and explanation causes that are mostly found in the causesof compressor motor damaged. Which are:

i) Slugging: Broken component, break connection rods, even crankshaft.

ii) Flood back: The continuous return of liquid refrigerant.

iii) Loss or lack of lubrication: Not enough oil in the crankcase.

iv) Electrical problem: Unbalance of current towards the compressor system.

v) Contamination: The debris or any slight dirty substance affecting flow system 6.

vi) Overheating: Increase of temperature of the compressor system.

vii) Flooded start: Oil in the crankcase-absorbing refrigerant during the mix cycle.

Electric motor inspection testing is an important part of establishing the condition ofthe motor and beginning the troubleshooting process. There are several different tests involved, and basic knowledge of what the tests are can help understand the repair data received back from the electric company that handles electrical maintenance.

The most critical motor inspection tests include the following:

i. Winding phase-to-phase resistance: To detect any large differences in resistance thatexist between the winding.

ii. Insulation resistance (IR) to the ground: Resistance measured between each motorwinding and frame.

iii. DC hi-pot: Stress test for insulation and requires the use of DC hi-pot tester.

iv. Surge comparison: Detect insulation weaknesses and short. Incorrect internalconnection.

v. Polarization index: Act as insulation resistance to ground test.

vi. AC and DC voltage drop (DC motors): DC motor repair to identify shorted.

These tests should be carried out by skilled technicians who follow EASA (Electrical Apparatus Service Association) and IEEE (Institute of Electrical and Electronics Engineers) standards for procedures and voltages. Before executing the high voltage DC hi-pot and surge comparison tests, all phase-to-phase resistance testing and IR tests must pass. It's worth noting that the original inspection test data and the final inspection test data are compared to confirm that improvements were achieved. To summarise, the study of completing a motor winding inspection is complete, and electric motor inspection testing is taken seriously. Each test's findings were meticulously documented, and the data was saved in a safe and secure data collection for future reference. If the results are unsatisfactory, clean the coil again and look for any components that are required for the test or the coil itself, such as the armature rewind. Repair any broken components of the testing portion or replace any damaged components required for motor winding examination. Knowing the state of the windings is one of the most critical aspects of assuring the proper operation of a motor.

2.15 Failure Mode and Effect Analysis (FMEA)

Failure mode and effect analysis is a technique for identifying a system's probable failure modes and the most likely causes of those failures. The US Defense Department devised this strategy to reduce the consequences of failures. This strategy is also widely used to reduce risk and increase the dependability of products and services. In the marine business, this is the most common method. The marine sector is one of the most common users of this approach. FMEAs are critical components of the safety design and operation of a maritime vessel. They are frequently called upon to undertake a variety of jobs linked to maritime safety in order to increase the vessel's reliability and reduce the number of unfavourable incidents.

The FMEA is a conceptual framework that identifies the expected operational modes of a particular system. It is generated through a process that involves identifying the variousdesign and configuration weaknesses of that system.

2.15.1 FMEA Purpose

FMEA method use as supporting documentation as this method used to analyse the product design characteristic in relation to manufacturing process and to experiment with the design. When the potential failure modes are identified, a corrective action can be taken to eliminate those failures and reduce the likelihood of an occurrence. FMEA procedure involves analysing the failure within a system and categorising them based on the severity and the occurrence to develops risk priority number (RPN).

2.15.2 FMEA Procedure

The FMEA is created using analytical process that identifies system design and configuration flaws in expected operational modes of specific system. Once listed, FMEA will be performed. By mitigating the expected failure modes, FMEA method assists engineer in designing a reliable and safe system. Each failure mode's risk is assessed using the Risk Priority Number (RPN) which are calculated by multiply the severity, an occurrence and detection rating. Throughout the analysis process, corrective action is recommending.

i. Gathering of Data Analysis

Data may be acquired from a variety of sources, including field service reports containing actual industrial risk data, personal experience, and discussion with supervisors. Data is gathered through picture capture as well as interviews with industry personnel. Also, review the relative effect of various failures to identify portions that require commentary and action, as well as evaluate and identify the entire system where it may fail.

ii. List of Failure Mode and Failure Effects

Specific failure modes will manifest themselves in the form of system behaviour and a number of indications. FMEA requires the identification of a failure detection mechanism for each failure mode. Detection by comparing before and after physical views, from increased noise.

iii. List and assign severity, an occurence & detection rating

According to list of failure mode and failure effects list down and assign each severity, occurrence and detection rating which usually in a group of tables given numbering and thedescription. Severity measured the seriousness of the effect; Occurrence likelihood failureoccur in system and lastly Detection rating determine failure mode occurred.

2.15.3 Identify Failure Mode

Failure mode identifications allow engineers to assess the possibility of finding or recognizing faults for each function. The potentials failure modes are identified through examining the gathered data taken from the functional components reports. These failure modes the are discovered and explained within the physical and operational boundaries of the research scope. Further details need to ensure that the failure modes reveal a loss of that function. The functions of the component consideration must be specified before performing a functional failure FMEA.

2.15.4 FMEA Failure Effect

A list of the consequences of each failure mode on the system that is connected to the system or process is derived from failure effects. Then assess the severity of each failure's consequences. The severity rating, abbreviated as S, is usually assessed on a scale of one to ten, with one being insignificant and ten being devastating. If several effects occur for each failure mode, the failure mode with the highest severity level is included into the FMEA Table.

2.15.5 FMEA Disposition

Determine probable root cause for each failure mode. Then, determine the occurrence rating (O) for each cause. This grade predicts the likelihood of failure due to the cause occurring throughout the lifespan of the component. Lastly, from the current process control, determine the detection rating (D) this rating graded the control is certain to identify or goes undetected.

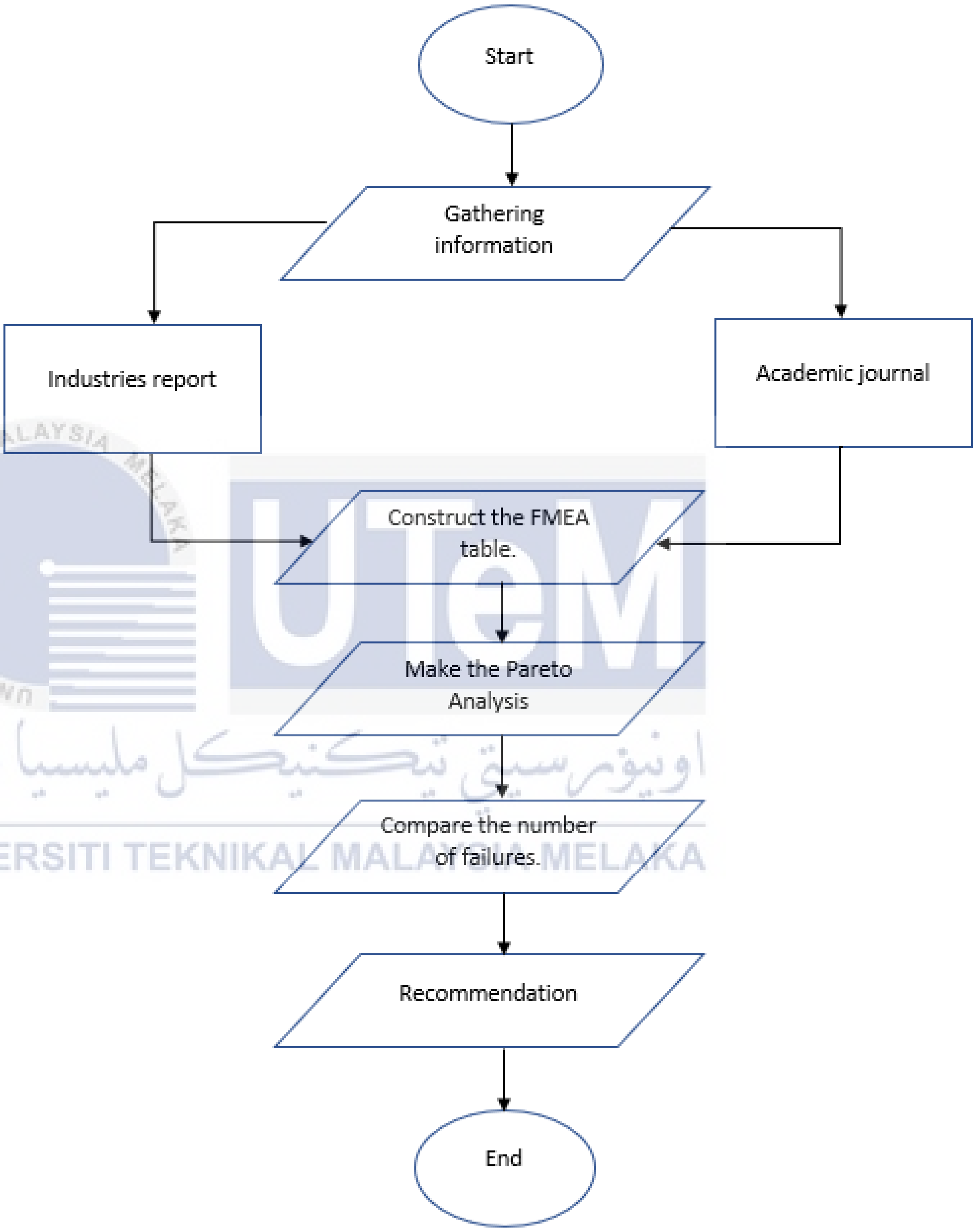
CHAPTER 3

METHODOLOGY

3.1 Introduction

In this study, structural integrity is evaluated through the identification of failure mode and failure impact in HVAC systems in order to reduce energy consumption, increase system dependability, and discover system defects, as well as provide optimum maintenance practises for the system. It's critical to keep the HVAC support system in good working order so that it can last longer and continue to provide outstanding service. This is possible if you combine it with excellent maintenance. One strategy for preventing systematic mistake is Failure Mode and Effects Analysis. The method's early discovery of the system's problem has made it popular to use since it identifies the problem earlier in the design phase. The FMEA table was created for a semi hermetic compressor used in a Malaysian offshore platform in order to determine the largest failure risk, and it was then compared to comparable semi hermetic compressors used in commercial buildings in academic literature. In this thesis, the failure modes that occur in the compressor are given a risk severity, occurrence, and detection grade. The investigation was carried out using an analysis table based on a four-year maintenance report from two companies. FMEA approaches aid in the definition, identification, and elimination of failures through maintenance type recommendations, resulting in high system dependability.

3.2 Methodology Procedure



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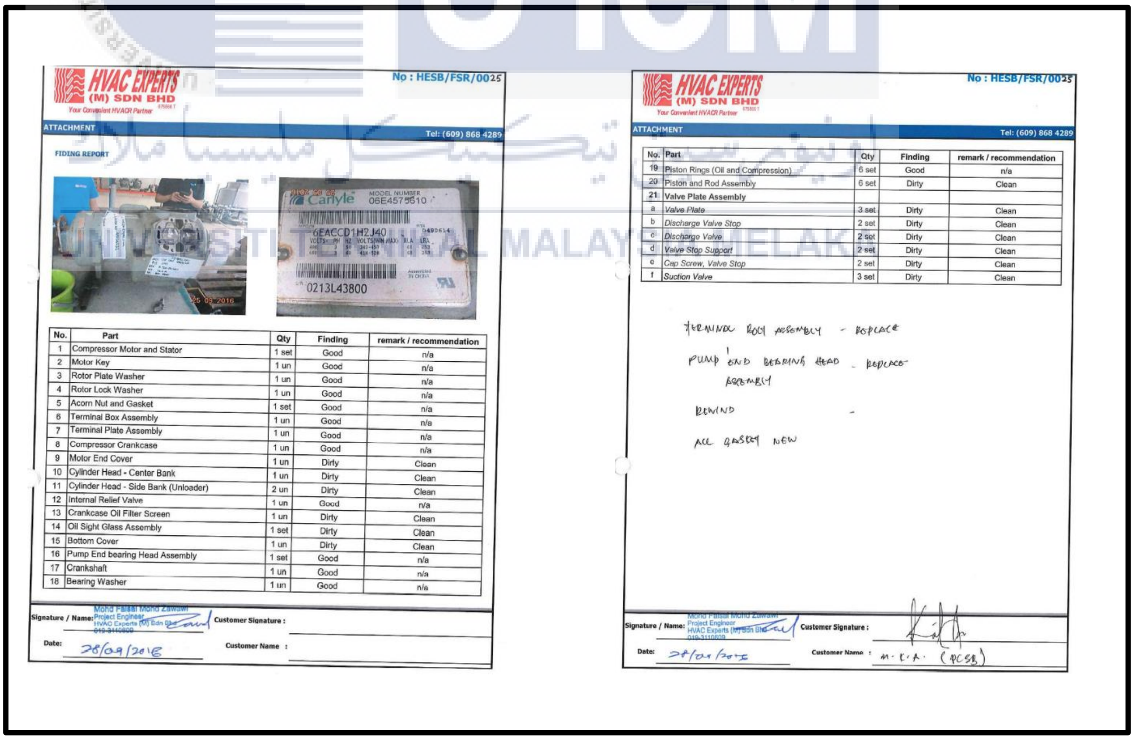
3.3 Gathering Data Analysis

Data was gathered for the study by reading maintenance records produced by the maintenance service. There are total of four maintenance report from the company. That consist of the maintenance report, daily service report and the testing that has been done to the sub-systems along from the year 2017 to the latest March 2021. Observation of failure mode occur in the maintenance report data for five years then are conclude into the FMEA table and are categorized by the type of sub-system. Then each of failure mode are listed and assigned by their severity, occurrence, and detection rating lastly the RPN number are calculate.



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FIDING REPORT

No.	Part	Qty	Finding	remark / recommendation
1	Compressor Motor and Stator	1 set	Good	n/a
2	Motor Key	1 un	Good	n/a
3	Rotor Plate Washer	1 un	Good	n/a
4	Rotor Lock Washer	1 un	Good	n/a
5	Acorn Nut and Gasket	1 set	Good	n/a
6	Terminal Box Assembly	1 un	Good	n/a
7	Terminal Plate Assembly	1 un	Good	n/a
8	Compressor Crankcase	1 un	Good	n/a
9	Motor End Cover	1 un	Dirty	Clean
10	Cylinder Head - Center Bank	1 un	Dirty	Clean
11	Cylinder Head - Side Bank (Unloader)	2 un	Dirty	Clean
12	Internal Relief Valve	1 un	Good	n/a
13	Crankcase Oil Filter Screen	1 un	Dirty	Clean
14	Oil Sight Glass Assembly	1 set	Dirty	Clean
15	Bottom Cover	1 un	Dirty	Clean
16	Pump End bearing Head Assembly	1 set	Good	n/a
17	Crankshaft	1 un	Good	n/a
18	Bearing Washer	1 un	Good	n/a

Signature / Name: Mohd Faisal Mohd Zawawi, Project Engineer, HVAC Experts (M) Sdn Bhd — Customer Signature :

Date: — Customer Name :

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No.	Part	Qty	Finding	remark / recommendation
19	Piston Rings (Oil and Compression)	6 set	Good	n/a
20	Piston and Rod Assembly	6 set	Dirty	Clean
21	Valve Plate Assembly			
a	Valve Plate	3 set	Dirty	Clean
b	Discharge Valve Stop	2 set	Dirty	Clean
c	Discharge Valve	2 set	Dirty	Clean
d	Valve Stop Support	2 set	Dirty	Clean
e	Cap Screw, Valve Stop	2 set	Dirty	Clean
f	Suction Valve	3 set	Dirty	Clean

Signature / Name: Mohd Faisal Mohd Zawawi, Project Engineer, HVAC Experts (M) Sdn Bhd, 019-3110609 — Customer Signature :

Date: — Customer Name :

Figure 3-1 Maintenance Report from HVAC Experts Sdn. Bhd

The key system in this investigation is air conditioning. The sub-system is a semi-hermetic compressor. In addition to the compressor, the condenser, expansion valve, and evaporator are the other sub-systems. Because these three sub-systems do not contain any moving parts, their failure rates are not explored in depth in this study. The focus of this research is on compressor failure analysis.

The condition of the compressors was inspected. All compressors are included, whether they are new, old, or still under warranty. The malfunction had an impact on all of the compressors. Since all of the data has been collected, the data is inserted into the paper to generate an FMEA worksheet paper. The needed facts concerning failed components and potential failure were documented and analyzed further in the works.

No.	Process Input	Item	Failure Mode	Failure Effects	Severity	Failure Cause	Occurrence	Current Controls	Detection	S	O	D	RPN
1.	Mechanical	Bearing	Corroded	Damage to bearing and shaft	8	Chemical and electrochemical reactions between the surface	4	Replace new bearing	3	6	8	3	144
2.	Electrical	Compressor motor and stator	Physical winding melting	Overheat	10	Can't make the windings rigid and tight	6	Rewinding	8	10	6	8	480
3.	Mechanical	Crankshaft	Scratch on the shaft	Wear and tear	7	Liquid enter compressor	5	Suggest to replace new	3	7	5	3	105
4.	Mechanical	Oil sight glass assembly	Oil level not seen at sight glass	Compressor oil not return back	5	Dirty and insufficient compressor oil	7	Clean the dirt	5	5	7	5	175
5.	Mechanical	Cylinder head	Corroded	Piston ring damage	8	Contaminated with water particles over time	4	Clean the corroded or replace new	4	8	4	4	128
6.	Mechanical	Piston	Piston and rod assembly wear	Long term use, bad lubrication	8	Inadequate lubrication	7	Replace new piston and rod assembly	3	8	7	3	168
			Bore piston body deep scratch	Suction valve debris at	6	Excessive rocking of the piston	2	Repolish bore piston	3	6	2	3	36

				bore piston body				body/Replace new compressor					
			Piston ring wear	Oil finding its way into the combustion chamber	8	Seal between the piston and the cylinder is no longer airtight	5	Suggest replacing new piston ring	3	8	5	3	120
			Piston head damage	Have the nocking debris off suction valve plate	8	Faulty cylinder head components	2	Replace new compressor	3	8	2	3	48
7.	Electrical	Oil sump cable	Compressor crankcase heater	Damage	8	Become less effective for lubrication	5	Replace/repair use tape	2	8	5	2	80
8.	Mechanical	Valve plate assembly	Discharge valve stop wear	Friction damage	8	Work abnormal	4	Suggest replace new	4	8	4	4	144
			Valve plate wear	Debris in cylinder	8	Mechanical damage to piston and valves	7	Change new valve plate	4	8	7	4	224

			Suction valve wear and tear	Contaminated fuel and dirt	5	Difficulty starting engine	5	Suggest to replace new	4	5	5	4	100
			Discharge valve wear	High compression ratio	6	Low suction and high head	8	Change new discharge valve	4	6	8	4	192
			Valve stop support wear and tear	Fatigue, failure, friction damage	8	Valves damage	8	Suggest to replace new	4	8	8	4	256
			Cap screw wear	Leaking	5	Valve plate loose	8	Suggest to replace new	2	5	8	2	80
									TOTAL				**2480**

Table 3-1 FMEA Table of Company A

The severity rating is assign starting from 1 the lowest effect to the system until 10 the highest rating that give hazardous and the effect will threaten the life of the system. Next, Occurrence rating indicate the chance of the failure mode present in the system, rated from 1 extremely less chance to occur to 10 extremely high chance of occurrence of the failure mode. The occurrence ranking based on the analysed from the industrial maintenance report. Lastly, List of the detection rating each cause on FMEA table graded on scale of one to ten to identify the problem from extremely certain to less detection of the problem (no inspection = none exists).

a) Damage compressor piston b) Deep scratch body piston

Figure 3-3 Picture failure of piston

Both Picture shown Deep Scratch on Crankshaft compressor

Figure 3-2 Picture failure of crankshaft

3.4 Pareto Analysis

Form of fault or failures	Number of fault or failures	Cumulative number of faults or failure	Relative number %	Cumulative relative number %
Valve plate assembly faults	40	40	46%	46%
Piston faults	16	56	18%	64%
Oil level not seen at sight glass	7	63	8%	72%
Compressor motor physical winding	6	69	7%	79%
Crankshaft scratch	5	74	6%	85%
Damage compressor crankcase heater	5	79	6%	91%
Bearing corroded	4	83	5%	95%
Cylinder head corroded	4	87	5%	100%
		87		**100%**

Table 3-2 Pareto Analysis of Company A

Figure 3.4 Pareto Chart and Pie Chart demonstrate the outcomes of the analysis. A Pareto Chart is a graph that shows the frequency of flaws as well as the cumulative impact of those problems. These diagrams are frequently used to determine which areas of process improvement should be prioritised. The ordered frequency counts of values for the several levels of a categorical or nominal variable are shown in Pareto charts. The bars reflect individual values in decreasing order, while the line represents the sum of the % values for each failure mode. For easy observation, the pie charts demonstrated that the predominant failure mode occurs in the semi hermetic compressor.

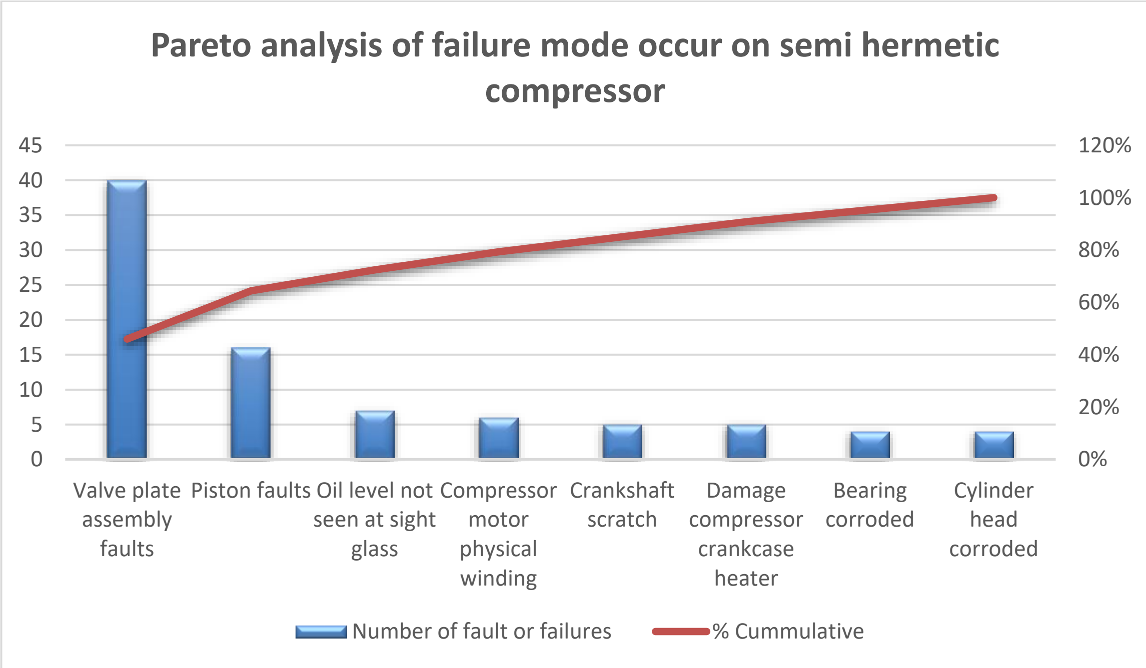

Figure 3-4 Pareto chart of failure mode occur on semi hermetic compressor

(Company A)

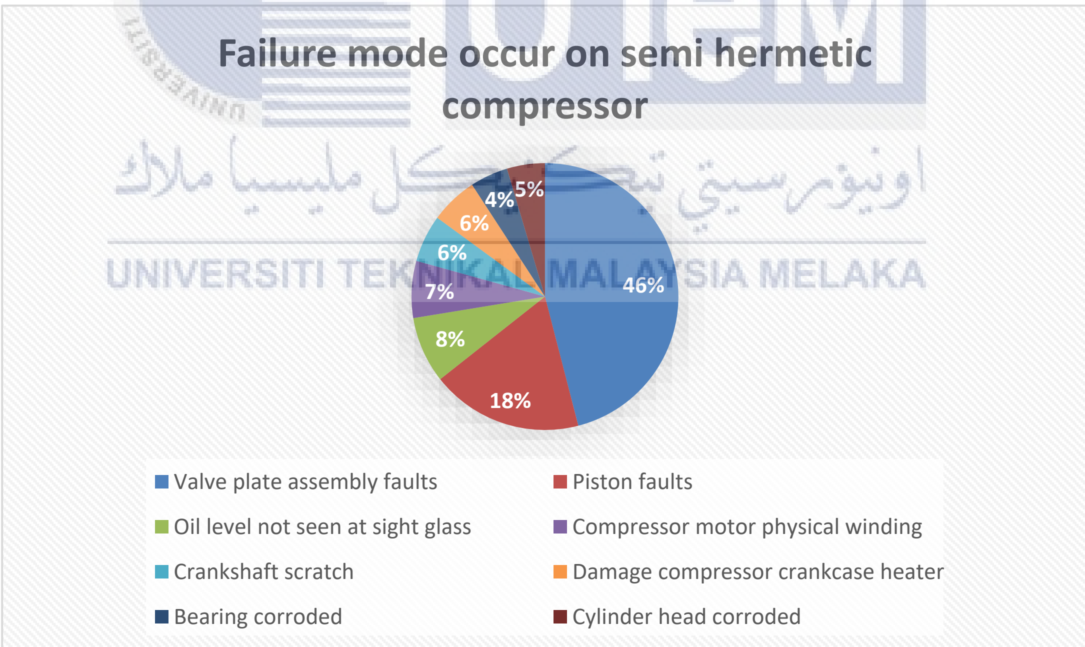

Figure 3-5 Pie chart of failure mode occur on semi hermetic compressor.

According to the pareto analysis, the most failure mode occur in semi hermetic compressor is valve plate assembly faults which is 46%. Then, follow with piston faults 18%. Oil cannot see is 8% while compressor motor physical winding is 7%. There are two types of faults or failure with 6% which is crankshaft scratch and compressor crankcase heater damage. Lastly, bearing corroded and cylinder head corroded share the 5% each for the failure occur in semi hermetic compressor**.**

3.5 Instrumentation

The combination of these three parameters called the risk priority number (RPN) to reflect the priority of the failure mode identified as described in Figure 3.4. The risk priority number (RPN) is simply calculated by multiplying the severity rating, times the occurrence probability rating, times the detection probability rating. Usually the RPN can up to more than 1000.

Risk Priority Number = Severity x Occurrence X Detection

Level	Severity	Occurrence	Detection
10	May effect other components and danger to operation without warning, life threatening	Extremely high	No chance
9	May effect other components and danger to operation with warning, safety risk	Very high	Very remote
8	Loss primary function affect other component, system inoperable	High	Remote
7	Loss primary function does not affect other component, major effect	Frequent	Slight
6	Loss function reduce level performance, significant effect	Moderate	Low chance
5	Moderate effect causing change component	Occasional	Medium
4	Slight effect to with annoyance	Slight	Moderate
3	Slight effect noticed	Very slight	High
2	Minor slight effect to system unnoticed	Remote	Very high
1	No effect	Extremely less	Certain

Table 3-3 Parameter Instrumentation

3.6 Summary

This chapter presents the proposed methodology in order to develop a FMEA table for Company A report and Company B report. From the report, find the failure mode, failure effects, failure cause and assign the severity, occurence and detection for the failure mode happen. Risk Priority Number (RPN) calculated with formula “severity x occurence x detection”. Then analysis the number of failure with pareto. There are two chart that obtained after do the pareto analysis which is pareto chart and pie chart.

Then, do some research on academic journal. But on this time, find the failure mode occur on not only on semi hermetic comprresor but every types of compressor such as reciprocating compressor, hermetic compressor and others in multiple application.

From FMEA table that constructed based on the Company A and Company B report, the table should be merged and construct new FMEA table for failure mode that was merged. In addition, pareto analysis need also to do new. The pie chart and pareto chart need to show the result that was merged.

Lastly, compared the result of pareto analysis between the merged FMEA and academic journal FMEA. The results shown that the valve faults is very frequently and critically failures that happen on semi hermetic compressor neither in real offshore industries nor in academic journal research.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents the results and analysis on the total Risk Priority Number of the failure mode occur in the compressor. There will be two result comparison of failure mode and RPN number between Company A and Company B reports and Academic Journals results.The chosen academic journal according to the type of compressor used which is semi hermetic, hermetic and reciprocating compressor that are in multiple of application. By finding the failure mode occur in these journals and assigned the severity, occurrence and detection rating on each failure. The reason is to make comparison between the failure mode occur in the multiple application with failure mode occur in offshore industries based on the maintenance reports.

The failure mode and effect analysis (FMEA) tables of Company A are done in previous chapter taken based on the maintenance report. These results are shown in Pie Chart and Graph.

4.2 Results and Analysis of FMEA for Company B

No	Process Input	Item	Failure mode	Failure effects	Severity	Failure cause	Occurrence	Current control	Detection	RPN
1.	Mechanical	Nipple service valve	Leak on nipple service valve	Acidic oil compressor	9	Leaks formation on windings' and compressor's burning	2	Install new nipple service valve	5	90
2.	Electrical	Comp A	Compressor trip	Low pressure in compressor	7	High voltages can also damage the motor causing the compressor to overheat	5	Rectify and Top-up freon R22	3	105
3.	Mechanical	Compressor	Compressor valve leaking	Drain oil	8	Compressor will shut down.	3	Changed new o ring valve and filter core/ Changed new compressor oil	5	120
4.	Mechanical	Discharge valve	Flair cracked	Connection compressor cracked	6	Leaking at press gauge tubing	1	Repair flair fitting leak and test leak and	4	32

								vacuum system		
5.	Mechanical	Capacitor	Overheat and capacitor fault	Overload relay compressor	3	Lack of cooling power	2	Change new capacitor	2	12
6.	Mechanical	Discharge service valve	Discharge service valve leaking	High compression ratio	5	Higher than normal suction pressures with low discharge pressures	3	Change new discharge valve	2	30
7.	Mechanical	TXV	TXV issue	Overfeeding or underfeeding	8	Valve will get sticky	2	Change new TXV and service strainer	4	64
8.	Mechanical	Evaporator	Leaking copper pipe	Damage to walls and other areas	7	Cause corrosion area	1	Fix new elbow and copper tube using brazing	4	32
9.	Electrical	Gasket	Gasket worn out	A gasket terminal box compressor has a significant leak.	6	Compressor system malfunctions, causing a trip on the terminal.	4	Make a new gasket and RTV and fix it with a terminal box.	3	72

10.	Mechanical	Compressor	Compressor tripped	Compressor worn out	8	Compressor totally grounded	6	Change new compressor.	3	144
11.	Mechanical	Terminal plate	Terminal plate worn out	Refrigerant circuit clogging	5	Liquid refrigerant flood back	5	Change new terminal plate	3	75
12.	Electrical	Compressor	Compressor jammed	Overheat, many leaks and corrosion on all parts.	10	System can't function properly and material sludge found inside the unit.	2	Check for unbalanced voltage during interval maintenance activity. Replace compressor	8	160
13.	Mechanical	Discharge main valve	Leaking on gasket	Discharge main valve will break	6	Low suction and high head	5	Fabricated new gasket for discharge main valve	4	120
14.	Mechanical	Pressure switch	Leakage	Failure of the control circuit system and decrease in	9	System performance insufficient	2	Change new switch	3	54

				pressure						
15.	Mechanical	Mounting	Mounting wear and tear	Vibration on mounting	8	The compressor will lack the steadiness necessary to operate free rattles and shakes	3	Install new mounting and fixed the compressor on the skid.	3	72

Table 4-1 FMEA of Company B

4.2.1 Pareto analysis of Company B

Form or fault of failure	Number of fault or failure	Cummulative number of fault or failure	Relative number %	Cummulative relative number %
Compressor tripped	11	11	24%	24%
Terminal plate worn out	5	16	11%	35%
Leaking on gasket	5	21	11%	46%
Gasket worn out	4	25	9%	54%
Compressor valve leaking	3	28	7%	61%
Discharge service valve leaking	3	31	7%	67%
Mounting wear and tear	3	34	7%	74%
Nipple service valve leaking	2	36	4%	78%
Capacitor fault and overheat	2	38	4%	83%
TXV issue	2	40	4%	87%
Compressor jammed	2	42	4%	91%
Pressure switch leakage	2	44	4%	96%
Flair cracked	1	45	2%	98%
Leaking copper pipe	1	46	2%	100%

Table 4-2 Pareto analysis (Company B)

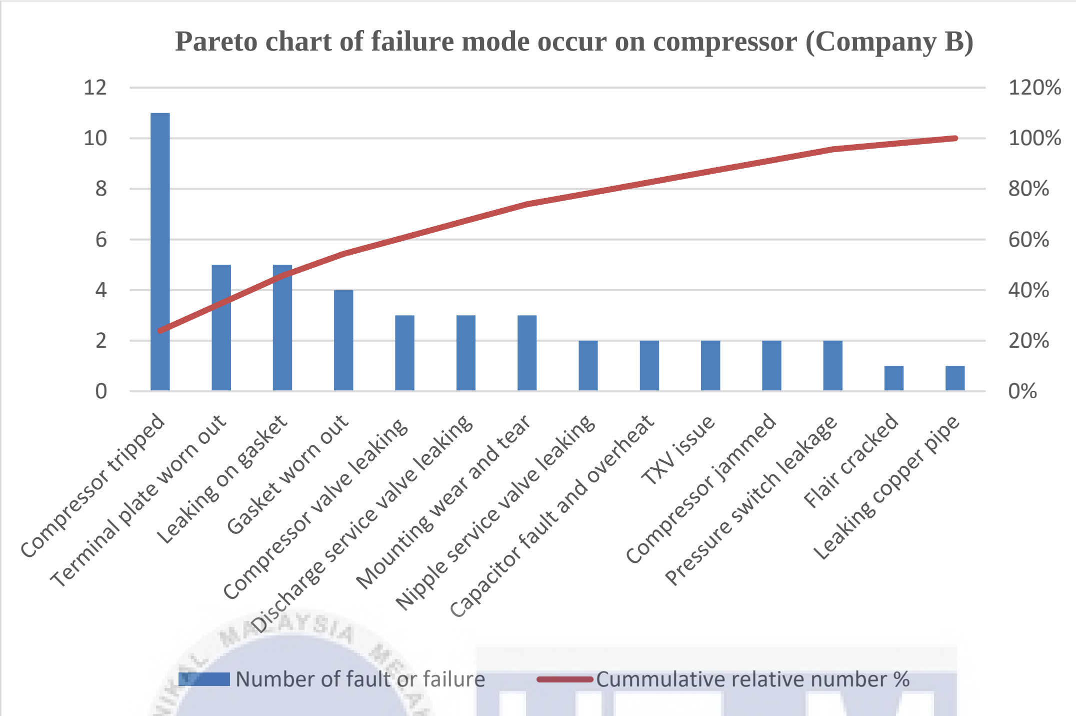

Figure 4-1 Pareto chart of failure mode occur compressor (Company B)

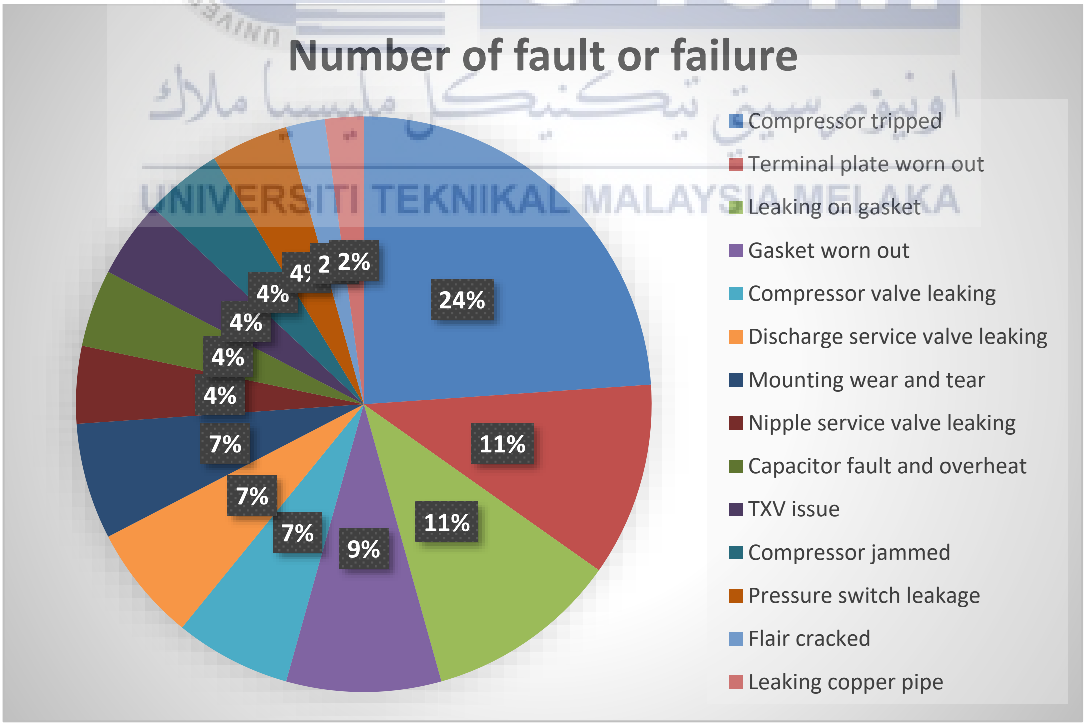

Figure 4-2 Pie chart of failure mode occur on compressor (Company B).

Pareto Analysis Explaination

Figure 4-1 Pareto Chart and Figure 4-2 Pie Chart demonstrate the outcomes of the analysis. A Pareto Chart is a graph that shows the frequency of flaws as well as the cumulative impact of those problems. These diagrams are frequently used to determine which areas of process improvement should be prioritised. The ordered frequency counts of values for the several levels of a categorical or nominal variable are shown in Pareto charts. The bars reflect individual values in decreasing order, while the line represents the sum of the % values for each failure mode. For easy observation, the pie charts demonstrated that the predominant failure mode occurs in the semi hermetic compressor.

According to the pareto analysis, the most failure mode occur in compressor (Company B) is compressor tripped which is 24%. Then, follow with terminal plate worn out and leaking on gasket which is both of them is 11%. Gasket worn out is 9% while compressor valve leaking, discharge service valve leaking and mounting wear and tear is 7% each. There are five types of faults or failure with 4% which is nipple service valve leaking, capacitor fault and overheat, txv issue, compressor jammed, and pressure switch leakage. Lastly, 2% number of failure is flair cracked and leaking copper pipe.

4.2.2 Identifying The Mechanical and Electrical Failures

- In Company A

MECHANICAL FAILURES

Bearing corroded

Effect: Damage to bearing and shaft	Cause: Chemical and electrochemical reactions between the surface
Solution: Replace new bearing	

Crankshaft scratch on the shaft

Effect: Wear and tear	Cause: Liquid enter compressor
Solution: Suggest to replace new	

Oil level not seen at sight glass

Effect: Compressor oil not return back	Cause: Dirty and insufficient compressor oil
Solution: Clean the dirt	

Cylinder head corroded

Effect: Piston ring damage	Cause: Contaminated with water particles over time
Solution: Clean the corroded or replace new.	

Piston and rod assembly wear

Bore piston body deep scratch

Piston ring wear

Piston head damage

<table>
<tr><td>Effects:
-Long term use, bad lubrication
-Suction valve debris at bore piston body
-Oil finding its way into the combustion chamber
-Have the nocking debris off suction valve plate</td><td>Cause:
-Inadequate lubrication
-Excessive rocking of the piston
-Seal between the piston and the cylinder is no longer airtight
-Faulty cylinder head components</td></tr>
<tr><td colspan="2">Solution:
-Replace new piston and rod assembly
-Repolish bore piston body/Replace new compressor
-Suggest replacing new piston ring
-Replace new compressor</td></tr>
</table>

Discharge valve stop wear

Valve plate wear

Discharge valve wear

Valve stop support wear and tear

Cap screw wear

<table>
<tr><td>Effects:
-Friction damage
-Debris in cylinder
-Contaminated fuel and dirt
-High compression ratio
-Fatigue, failure, friction damage
-Leaking</td><td>Cause:
-Work abnormal
-Mechanical damage to piston and valves
-Difficulty starting engine
-Low suction and high head
-Valves damage
-Valve plate loose</td></tr>
<tr><td colspan="2">Solution:
Suggest replace new
Change new valve plate
Suggest to replace new
Change new discharge valve
Suggest to replace new
Suggest to replace new</td></tr>
</table>

ELECTRICAL FAILURE

Physical winding melting

Effect: Overheat	Cause: Can’t make the windings rigid and tight
Solution: Rewinding	

Compressor crankcase heater

Effect: Damage	Cause: Become less effective for lubrication
Solution: Replace/repair use tape	

- In Company B

MECHANICAL FAILURES

Leak on nipple service valve

Effect:	Cause:
Acidic oil compressor	Leaks formation windings' and compressor's burning
Solution: Install new nipple service valve	

Compressor leaking valve

Effect:	Cause:
Drain oil	Compressor will shut down.
Solution: Changed new o ring valve and filter core Changed new compressor oil	

Flair cracked

Effect:	Cause:
Connection compressor cracked	Leaking at press gauge tubing
Solution: Repair flair fitting leak and test leak and vacuum system	

Overheat and capacitor fault

Effect:	Cause:
Overload relay compressor	Lack of cooling power
Solution: Change new capacitor	

Discharge service valve leaking

Effect:	Cause:
High compression ratio	Higher than normal suction pressures with low discharge pressures
Solution: Change new discharge valve	

<u>TXV issue</u>

Effect: Overfeeding or underfeeding	Cause: Valve will get sticky
Solution: Change new TXV and service strainer	

<u>Leaking copper pipe</u>

Effect: Damage to walls and other areas	Cause: Cause corrosion area
Solution: Fix new elbow and copper tube using brazing	

<u>Compressor tripped</u>

Effect: Compressor worn out	Cause: Compressor totally grounded
Solution: Change new compressor.	

<u>Terminal plate worn out</u>

Effect: Refrigerant circuit clogging	Cause: Liquid refrigerant flood back
Solution: Change new terminal plate	

<u>Leaking on gasket</u>

Effect: Discharge main valve will break	Cause: Low suction and high head
Solution: Fabricated new gasket for discharge main valve	

<u>Pressure switch leakage</u>

Effect: Failure of the control circuit system and decrease in pressure	Cause: System performance insufficient
Solution: System performance insufficient	

ELECTRICAL FAILURE

Compressor trip

Effect: Low pressure in compressor	Cause: High voltages can also damage the motor causing the compressor to overheat
Solution: Rectify and Top-up freon R22	

Gasket worn out

Effect: A gasket terminal box compressor has a significant leak.	Cause: Compressor system malfunctions, causing a trip on the terminal.
Solution: Make a new gasket and RTV and fix it with a terminal box	

Compressor jammed

Effect: Overheat, many leaks and corrosion all parts.	Cause: System can’t function properly and material sludge found inside the unit.
Solution: Check for unbalanced voltage during interval maintenance activity. Replace compressor	

4.2.3 Comparison Between Company A Case and Company B Case Study

There are two companies that I have studied doing my research about failure mode and effect analysis on semi hermetic compressor. The Company A and Company B. All the failure modes have been identified and recorded in FMEA table.

Firstly, the failures of semi hermetic compressor that found in Company A report is 8 issues but the failures of semi hermetic compressor in Company B report is more than Company A which is 14 issues. The most failures in Company A case are valve plate assembly fault. There are form 40 faults and failures in their reports. Valve plate assembly faults also divided into six major problems. There is discharge valve stop wear, valve plate wear, suction valve wear and tear, discharge valve wear, valve stop support wear and tear and cap screw wear. This fault or failure is having the highest RPN in Company A case which is 1016 totally when all the six problems in valve plate assembly faults were combined. The severity also affected the RPN since each valve plate assembly failure have the severity within 5-8 times.

Difference with Company B, the most failure in this report is compressor tripped faults. There are form 11 faults and failures. The RPN is 249 which is the highest RPN in FMEA Company B. There is a lot of difference since the occurrence in Company A has very high frequency.

The Company A report have 8 types of faults or failures lower than the Company B report that have 14 types of faults or failures. But, although

Company A report have a little of failure mode on semi hermetic compressor than Company B, the occurrence of failure mode in Company A is quite high because it is often happened. That's why, the RPN for each of failure mode in Company A case is totally high. The issue is repeatedly happened. For Company B case, although there are 14 failure modes that we can identify, the occurrence for each failure mode is not as high as Company A case. That's why their RPN also is around two digits only.

In Company A, the compressor is too old in industry. That's why there are more problems in mechanical issue on semi hermetic compressor such as bearing, crankshaft, cylinder head, piston and valve plate assembly. When the compressor is too old, the other components also will wear. Difference with Company B that used new compressor. I found that mostly the failure mode in Company B is leaking components such as compressor leaking valve, discharge service valve leaking, leaking copper pipe, leaking on gasket and pressure switch leakage. The difference between Company A and B is old semi hermetic compressor will cause wear and tear failure effects and should replace and change new while new compressor will cause some minor failure effects like leaking and the problem can be fix and repair.

4.2.4 FMEA Merge of Company A and Company B

No	Process Input	Item	Failure mode	Failure effects	Severity	Failure cause	Occurrence	Current control	Detection	RPN
1.	Mechanical	Bearing	Corroded	Damage to bearing and shaft	8	Chemical and electrochemical reactions between the surface	4	Replace new bearing	3	144
2.	Electrical	Compressor motor and stator	Physical winding melting	Overheat	10	Can't make the windings rigid and tight	6	Rewinding	8	480
			Compressor tripped	Compressor worn out	8	Compressor totally grounded	10	Change new compressor.	3	240
			Compressor jammed	Overheat, many leaks and corrosion all parts.	10	System can't function properly and material sludge found inside the unit.	2	Check for unbalanced voltage during interval maintenance activity.	8	160

								Replace compressor		
3.	Mechanical	Crankshaft	Scratch on the shaft	Wear and tear	7	Liquid enter compressor	5	Suggest to replace new	3	105
4.	Mechanical	Oil sight glass assembly	Oil level not seen at sight glass	Compressor oil not return back	5	Dirty and insufficient compressor oil	7	Clean the dirt	5	175
5.	Mechanical	Cylinder head	Corroded	Piston ring damage	8	Contaminated with water particles over time	4	Clean the corroded or replace new	4	128
6.	Mechanical	Piston	Piston and rod assembly wear	Long term use, bad lubrication	8	Inadequate lubrication	7	Replace new piston and rod assembly	3	168
			Bore piston body deep scratch	Suction valve debris at bore piston body	6	Excessive rocking of the piston	2	Repolish bore piston body/Replace new compressor	3	36
			Piston ring wear	Oil finding its way into the combustion chamber	8	Seal between the piston and the cylinder is no longer airtight	5	Suggest replacing new piston ring	3	120
			Piston head damage	Have the nocking debris off	8	Faulty cylinder head components	2	Replace new compressor	3	48

				suction valve plate						
7.	Electrical	Oil sump cable	Compressor crankcase heater	Damage	8	Become less effective for lubrication	5	Replace/repair use tape	2	80
8.	Piping	Valve plate assembly	Discharge valve stop wear	Friction damage	8	Work abnormal	4	Suggest replace new	4	144
			Valve plate wear	Debris in cylinder	8	Mechanical damage to piston and valves	7	Change new valve plate	4	224
			Suction valve wear and tear	Contaminated fuel and dirt	5	Difficulty starting engine	5	Suggest to replace new	4	100
			Discharge valve wear	High compression ratio	6	Low suction and high head	8	Change new discharge valve	4	192
			Valve stop support wear and tear	Fatigue, failure, friction damage	8	Valves damage	8	Suggest to replace new	4	256
			Cap screw wear	Leaking	5	Valve plate loose	8	Suggest to replace new	2	80

			Leak on nipple service valve	Acidic oil compressor	9	Leaks formation windings' and compressor's burning	2	Install new nipple service valve	5	90
			Compressor valve leaking	Drain oil	8	Compressor will shut down.	3	Changed new o ring valve and filter core/ Changed new compressor oil	5	120
			Discharge service valve leaking	High compression ratio	5	Higher than normal suction pressures with low discharge pressures	8	Change new discharge valve	2	80
			Flair cracked	Connection compressor cracked	6	Leaking at press gauge tubing	1	Repair flair fitting leak and test leak and vacuum system	4	32
9.	Mechanical	Capacitor	Overheat and capacitor fault	Overload relay compressor	3	Lack of cooling power	2	Change new capacitor	2	12

10.	Mechanical	TXV	TXV issue	Overfeeding or underfeeding	8	Valve will get sticky	2	Change new TXV and service strainer	4	64
11.	Piping	Evaporator	Leaking copper pipe	Damage to walls and other areas	7	Cause corrosion area	1	Fix new elbow and copper tube using brazing	4	32
12.	Electrical	Gasket	Gasket worn out	A gasket terminal box compressor has a significant leak.	6	Compressor system malfunctions, causing a trip on the terminal.	4	Make a new gasket and RTV and fix it with a terminal box.	3	72
13.	Instrument	Pressure switch	Leakage	Failure of the control circuit system and decrease in pressure	9	System performance insufficient	2	Change new switch	3	54

14.	Mechanical	Mounting	Mounting wear and tear	Vibration mounting	8	The compressor will lack the steadiness necessary to operate free rattles and shakes	3	Install new mounting and fixed the compressor on the skid.	3	72
15.	Instrument	Terminal plate	Terminal plate worn out	Refrigerant circuit clogging	5	Liquid refrigerant flood back	5	Change new terminal plate	3	75

Table 4-3 FMEA of merge Company A and Company B

4.2.5 Pareto Analysis of Company A and Company B Merged

Category	Number of fault or failures	Cumulative number of faults or failure	Relative number %	Cumulative relative number %
Piping	55	55	45%	45%
Mechanical	33	88	27%	72%
Electrical	27	115	22%	94%
Instrument	7	112	6%	100%

Table 4-4 Pareto analysis Company A and Company B Merged

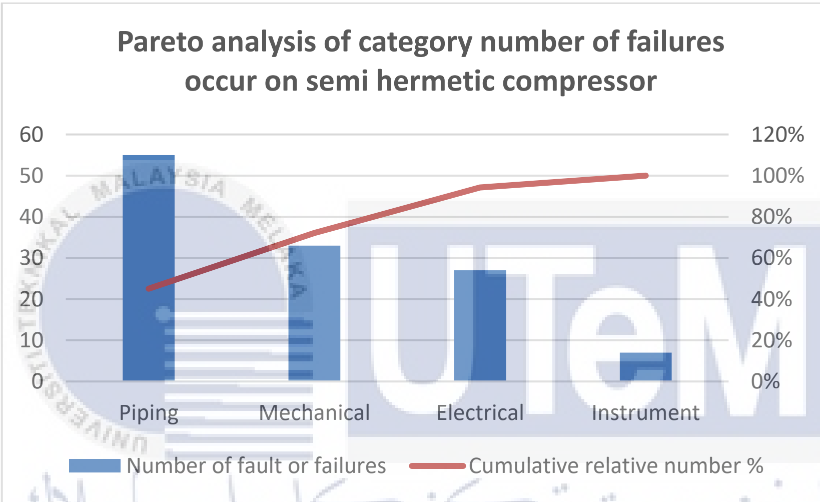

Figure 4-3 Pareto chart of category number of failures occur on semi hermetic compressor.

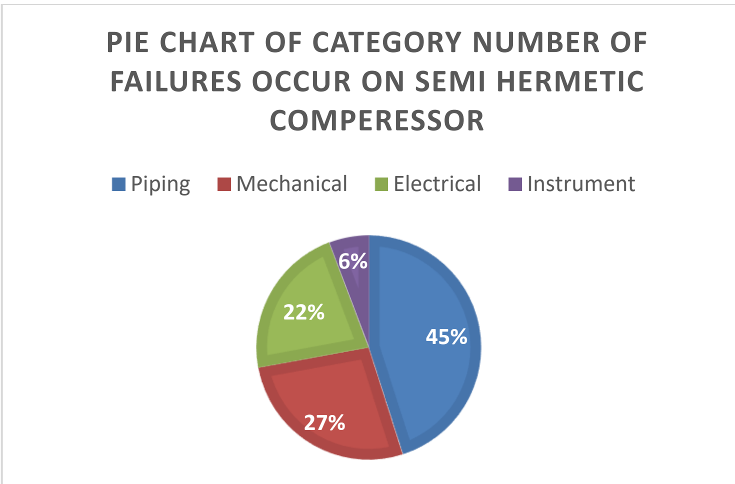

Figure 4-4 Pie chart of category number of failures occur on semi hermetic compressor.

4.2.6 Mechanical Problems on Semi Hermetic Compressor in Multiple Application

No	Author	Year	Topic	Failure Mode	Failure Effects	Recommendation
1.	I. Bellanco, E. Fuentes, M. Vall`es, J. Salom	2021	A review of the fault behavior of heat pumps and measurements, detection and diagnosis methods including virtual sensors	Fan damage	It will ultimately stop functioning, leaving the AC system with no method to cool itself, leading to system failure.	Change and replace the fan.
				Evaporator faults	unable to properly absorb the heat from the air, causing the condensation to become too cold and freeze.	Repair is not an option. Change new.
2.	Riccardo Tigani	2020	Electrical problems in refrigeration compressors	Motor fails	whole compressor will stop working.	Inspect wiring and make sure suction line are clear.
3.	Alpar belenyi, Gheorghe Achimaş	2017	Reconditioning an eccentric shaft from a semi-hermetic compressor	Loss of lubrication and greasing problems	Oil dilution by the refrigerant, decreasing of the oil level, reduction of the oil viscosity by excessive heating.	Perform inspection periodically. Change the better filter
4.	William Harris, Keith Birkitt	2016	Offshore compressor	Corrosion fatigue in crankshaft	Oil leaking	Check the material and the coating thickness

5.	Dr. Eduardo Calixto	2016	Gas and oil reliability engineering	Bearing damaged	Fan broken cause water temperature does not cool down	Perform inspection periodically based in maintenance plan.
				Motor damage, short circuit	Fan broken cause water temperature does not cool down	Repair and change the motor
				Valve damaged	Waste of water because diaphragm broken	Perform inspection periodically
6.	Zhaoxiang Chu, Jianhu Ji, Xijun Zhang, Hongyuan Yan, Haomin Dong, Junjie Liu	2016	Semi-hermetic screw compressor and its application on local air conditioning in underground long-wall face	Leakage of refrigerant	Wastes energy and can eventually damage your system. Can cause your system to cool inefficiently.	Replace the flare valve.
7.	Anthony Reynolds	2016	The semi hermetic compressor book	Draining oils	Gray Worn rods and bearings	Recheck superheat to ensure 15 degrees at the suction service valves. Check oil pressure for proper operating parameters.
				Liquid slugging	Broken reeds, rods or crankshaft Blown gaskets Backer bolts sheared off	Maintain proper oil management.

				High discharge temperature	Discolored valve plates, Burned reed valves	Correct high compression ratios from low load conditions.Check low pressure switch settings
8.	Yuantao Fan, Slawomir Nowaczyk, and Thorsteinn Rognvaldsson	2015	Evaluation of Self-Organized Approach for Predicting Compressor Faults in a City Bus Fleet	Condenser fan fail	fail to produce cold air, but can even result in damage to the AC system due to overheating	Change new and replace the fan.
9.	Meng Zhang, Wei Liang, Weijun Li, Yanfeng Yang	2015	Analysis method for equipment failure by combining petri net reasoning and an extended fmea using for safe oil and gas storage	Piston ring wear	-Reciprocating compressor failure -Piston rod overheated -Cylinder overheated	-Repair or replace the cylinder -Increase lubrication volume -Observe or detected if there are piston rod overheated, cylinder overheated, crosshead or overheated crankshaft wear
				Cylinder overheated	-Piston ring wear -Crankshaft wear -Crossheads overheat -Reciprocating compressor failure	-Keep lubrication pressure steady -Repair or replace inlet filter -Increase cooling waterflow

10.	Zhinong Jiang, Jinjie Zhang, Mengyu Jin, Bo Ma	2013	An expert system based on multi-source signal integration for reciprocating compressor	Fracture of piston rod	cannot transfer the engine's running gear and cross head with the power generated in the combustion chamber.	Immediately stop and check the damage of piston rod, piston and cylinder
				Fracture of valve plate	Slow internal pressure buildup	Continue running in short time, stop and take maintenance on valve.
11.	Hamid Reza Feili, Navid Akar, Hosein Lotfizadeh, Mohammad Bairampour, Sina Nasiri	2013	Risk analysis of geothermal power plants using Failure Modes and Effects Analysis (FMEA) technique	Fouling of the condenser tube	Poor cooling, loss of efficiency	Improve quality of cooling water by treatment and adding fresh water
				Rotor vibration	Misalignment	Ensure turbine generator exciter alignment
				Failure of motors	Downtime	Monitor all motors performance
12.	Izeds Felipe Facchini Bassetto, Alberto Hernandez Neto & Gilberto Francisco Martha de Souza	2011	Semi hermetic compressor in food product conservation	Compression in chamber	Fatigue and high aggressive wear	Maintain evaporator and compressor superheat at suitable levels.
				Wear bearing	Contamination due to moisture	Make sure sufficient oil and properly lubricate in the crankcase
13.	A-1 compressor	2010	Semi-hermetic compressor troubleshooting information	Blown valve plate.	Cylinder head bolts not properly torque	Replace gaskets. Re-torque cylinder head bolts to manufacturers specs.

				Worn pistons and cylinders.	The liquid washed the oil off the pistons and cylinder walls during the suction stroke causing them to wear during the compression stroke.	Maintain proper evaporator and compressor superheat.
14.	S.A. Tassou, Y.Ge, A.Hadawey, D. Marriott	2010	Energy consumption and conservation in food retailing.	Refrigerant leakage	cause your system to cool inefficiently.	Always make the inspection using soap bubbles for leak detection.
15.	Dagkinis Ioannis, Lilas Theodoros, and Nikitakos Nikitas	2012	Application of FMEA to an Offshore Desalination Plant under Variable Environmental Conditions	External rupture compressor	Loss of air supply to the system. The air compressor fails to start.	Change new compressor.
				Wiring circuit broken	Pump fails to start, No water flow	Change the new wire for the circuit.
16.	Robert C. Scutt	2012	Installation and maintenance manual	Compressor superheat too high	Too high of a suction superheat will cause excessive discharge temperatures which	Measure the suction pressure at the suction service valve of the compressor. Determine the saturated temperature

					cause a break down of the oil and will result in piston ring wear, piston and cylinder wall damage.	corresponding to this pressure
				Evaporator superheat too high	Not enough refrigerant is entering the coil. Pressures will be lower than normal.	Measure the suction pressure in the suction line at the bulb location by either a gauge in the external equalizer line will indicate the pressure directly and accurately or gauge directly in the suction line near the evaporator or directly in the suction header will suffice.
17.	Christopher Reed Laughman	2008	Fault detection methods for vapor-compression air conditioners using electrical measurements	Motor winding shorted	The system breakdown	Rewinding or replacing the motor
				Locked stator	May lead to buring of stator / rotor	Perform the inspection periodically

				Liquid slugging	Excessive pressure buildup inside the cylinder.	Provide suction line accumulator to protect from slugging
18.	Raghuram Puthali Ramesh	2007	Compressor valve failure detection and prognostics	Discharge valve leak	Low discharge Pressure	Perform the necessary repairs
				Valve plate overheat	High temperature causing the oil to breakdown and lead to scoring and damage parts.	Control the heat and temperatures enter in the system
19.	Ramesh Paranjpey	2004	Air conditioning and refrigeration	Liquid slug	a large quantity of liquid refrigerant to the compressor.	Provide suction line accumulator to protect from slugging.
				Compressor overheating	it can stop working	need to be repaired or completely replaced.

20.	M. Villaran, M.Subudhi	1996	Aging Assessment of Large Electric Motors in Nuclear Power Plants	Stator winding to ground fault	Electrical trip	Good maintenance practice to keep motor clean and ventilation clear and unrestricted
				Shaft assembly misaligned	Increased vibration	Periodic visual inspection and alignment checked
				Wear of bearing roller	Excessive vibration	Monitor and trend bearing temperature

Table 4-5 Failures occurs on semi hermetic compressor in multiple application

4.2.7 Pareto Analysis of Failure Mode Occurs on Semi Hermetic Compressor in Multiple Application

Failures mode occurs on semi hermetic compressor in multiple application	**Number of faults or failure**	**Cummulative Number of faults or failure**	**Relative Number (%)**	**Cumulative Relative Number (%)**
Valve faults	8	8	16%	16%
Compressor overheating	8	16	16%	32%
Motor and stator fail	7	23	14%	46%
Piston worn	4	27	8%	54%
Condenser fan broken and damage	3	30	6%	60%
Evaporator coils superheat	3	33	6%	66%
Crankshaft corroded and missaligned	3	36	6%	72%
Bearing damaged	3	39	6%	78%
Oils sight glass faults	3	42	6%	84%
Liquid slugging	3	45	6%	90%
cylinder overheated	3	48	6%	96%
Copper pipe leakage	2	50	4%	100%

Table 4-6 Pareto analysis of Failure Mode Occurs on Semi Hermetic Compressor in Multiple Application

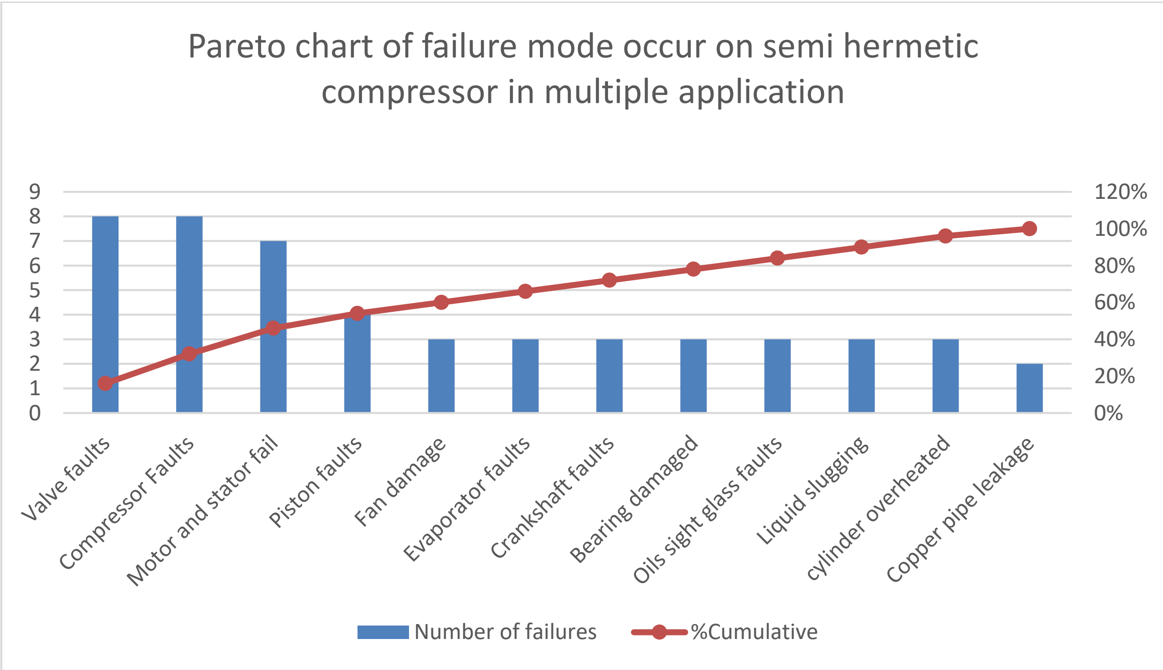

Figure 4-5 Pareto chart of failure mode occur on semi hermetic compressor in multiple application

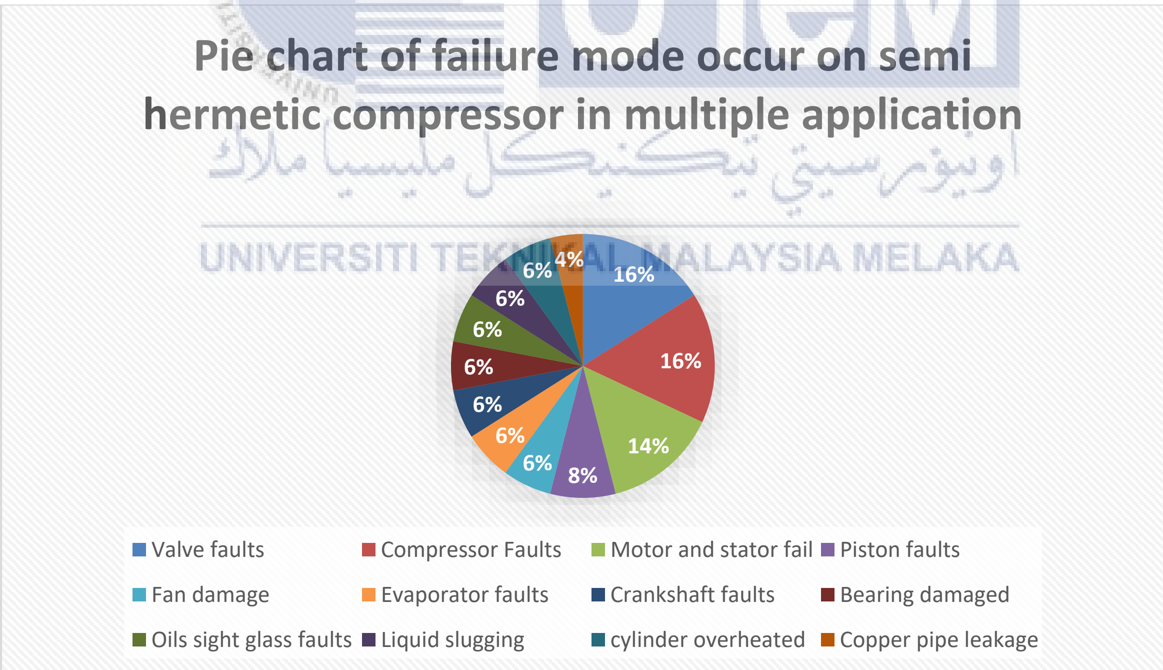

Figure 4-6 Pie chart of failure mode occur on semi hermetic compressor in multiple application.

Pareto Explanation

According to the pareto analysis, the most failure mode occur in the semi hermetic compressor in multiple application based on my journals research is valve fault and compressor faults, 16%. The valve faults including the valve damaged, blown valve plate, fracture of valve plate, discharge valve leaked, and valve plate overheat. While for compressor faults including the compressor overheat and vibrations. Then, follow with motor and stator fail which is 14%. This included about the motor and stator winding, motor fails and motor damage. After that, piston faults with 8% was followed with some failures such as piston ring wear, worn piston and fracture of piston rod. Others, there are seven types of faults or failure with 6% which is condenser fan broken and damage, evaporator coils superheat, crankshaft corroded and misaligned, bearing damaged, oils sight glass faults, liquid slugging, and cylinder overheated. Lastly, 4% relative number of failure is copper pipe leakage.

4.2.8 Cost Semi Hermetic Compressor Parts

Semi Hermetic Compressor Parts (Company A)	**Cost (RM)**
Stator and motor	RM 4880.00
Crankshaft	RM 38462.00
Oil sight glass	RM 937.00
Cylinder head	RM 1951.65
Piston	RM 1998.00
Oil pump	RM 2106.00
Valve plate assembly	RM 3988.35
Compressor crankcase	RM 882.00
Bearing	RM 1390.86
Terminal plate	RM 5324.00

Table 4-7 Cost semi hermetic compressor parts (Company A)

Semi Hermetic Compressor Parts (Company B)	**Cost (RM)**
Mounting	RM 782.00
Pressure switch	RM 283.45
Discharge valve	RM 1060.00
Terminal plate	RM 5324.00
Semi hermetic compressor	RM 70578.00
Evaporator	RM 3583.00
TXV	RM 738.72
Discharge service valve	RM 1042.57
Capacitor	RM 139.00

Table 4-8 Cost semi hermetic compressor parts (Company B)

Acquisition Cost

Acquisition cost is consisting of fixed (C_{FA}) and replacement cost. Fixed cost is the initial cost of equipment while replacement cost (C_{RA}) is the purchased cost of subcomponents when the equipment is failed. The acquisition cost can be defined using Equation:

$$C_{aq} = C_{FA} + C_{RA}$$

Semi Hermetic Compressor Parts (Company A)	Acquisition Cost (RM)
Stator and motor	RM 70578.00 + RM 4880.00 = RM 75458.00
Crankshaft	RM 70578.00 + RM 38462.00 = RM 109040.00
Oil sight glass	RM 70578.00 + RM 937.00 = RM 71515.00
Cylinder head	RM 70578.00 + RM 1951.65 = RM 72529.65
Piston	RM 70578.00 + RM 1998.00 = RM 72576.00
Oil pump	RM 70578.00 + RM 2106.00 = RM 72684.00
Valve plate assembly	RM 70578.00 + RM 3988.35 = RM 74566.35
Compressor crankcase	RM 70578.00 + RM 882.00 = RM 71460.00
Bearing	RM 70578.00 + RM 1390.86 = RM 71968.86
Terminal plate	RM 70578.00 + RM 5324.00 = RM 75902.00

Table 4-9 Acquisition cost of Semi Hermetic Compressor Parts (Company A)

Semi Hermetic Compressor Parts (Company B)	Cost (RM)
Mounting	RM 70578.00 + RM 782.00 = RM 71360.00
Pressure switch	RM 70578.00 + RM 283.45 = RM 70861.45
Discharge valve	RM 70578.00 + RM 1060.00 = RM 71638.00
Terminal plate	RM 70578.00 + RM 5324.00 = RM 75902.00
Semi hermetic compressor	RM 70578.00 + RM 70578.00 = RM 141156.00
Evaporator	RM 70578.00 + RM 3583.00 = RM 74161.00
TXV	RM 70578.00 + RM 738.72 = RM 71316.72
Discharge service valve	RM 70578.00 + RM 1042.57 = RM 71620.57
Capacitor	RM 70578.00 + RM 139.00 = RM 70717.00

Table 4-10 Acquisition cost of Semi Hermetic Compressor Parts (Company B)

4.3 Summary

Nowadays, there are tremendous growth usage of hermetic and semi hermetic compressor in many applications that because of it smaller size, lightweight and easy to maintain. In this thesis, focused on failure mode occur in offshore platform based on Company A and Company B reports and academic journals. Based on two reports that researched, the failure mode was merged and divided into four category; mechanical, electrical, piping and instrument.

From the reports, identified that piping failures is the highest number of failure among the four. Pie chart in pareto analysis shown that piping failures is the 45%. Following with mechanical is 27%, electrical is 22% and instrument is 6%. The piping failures was included with discharge valve stop wear, discharge service valve damaage, discharge valve wear, suction valve wear and tear, valve plate wear, cap screw wear and leak on nipple service valve. Evaporator also was included in piping since it fault in leaking copper pipe.

For the mechanical, there are many equipment that has their own failure mode such as bearing corroded, crankshaft scratch, cylinder head corroded and piston wear. Other than that, the electrical issues like compressor tripped, physical winding melting, compressor crankcase heater damage, and gasket worn out. The lowest category of number of failures is instrument which is terminal plate worn out and pressure switch leakage.

From my research in academic journal, there are many failure mode occurs on semi hermetic compressor in multiple application. The highest number of failure is valve faults and compressor overheating. The percentage of number of failures is 16%. Basically, these component are highest because of the high severity and high occurrence of the failure mode occur in the compressor. Majority type of failure occur due to wear and tear happen a lot on the component that can lead to the damaged of the component and system.

Besides that, the second highest number of fault or failures is motor and stator fail that have 14% of number of failures. Following with the piston faults such as piston ring wear, fracture of the piston rod, and worn piston and cylinder. Then, there are seven failures that average the same percentage value 6%. This is uncommon failure found in the academic journal. For example are condenser fan broken and damage, evaporator coils superheat, crankshaft corroded and misaligned, bearing damaged, oils sight glass faults, liquid slugging and cylinder overheated. Lastly, the unusual failures on compressor that found in the journal is leaking copper pipe which is 4% of failure.

From this report can compared that the failure that really critical and frequently happen is valve. There are several types of valves such as discharge service valve, suction valve, valve plate discharge valve and service stop valve.The valves are the most crucial components that can wear out or be damaged out of all the tiny components that make up a compressor. It must be routinely inspected to keep it in excellent functioning condition. In this method, valves can operate without any interuptions or malfunctions. All the types of compressor want the compressor valves to stay effective in order to in order to keep the entire unit operating.

To sum up, the design and preventative maintenance procedures used to guarantee that the system functions properly constantly affect the compressor efficiency. Your top priorities should be checking for leaks, checking the worn components, replacing filters often, utilising pressure regulators, and running the system at the lowest pressure necessary. Working with a compressor expert to seek for energy-saving solutions will result in financial savings and increased system effectiveness.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Based on my research, there are few analyses has been done on the reliability of the compressor used in industry in different application. Following the evaluation of the compressor's functions subsystem, the failure mode and effect analysis of the compressors has been evaluated, and a risk number has been assigned. To improve dependability and system availability, the failure mode is being examined.

The failures that influence the system and the key to the failure on these applications then are examined. From the Company A and Company B report, tabulated into two FMEA analysis. Then the failures are assigned with the severity, occurrence and detection rating lastly calculated the Risk Priority Number for each failure. Based on analysis results, the report Company A show that the valve plate assembly is the highest number of fault or failure. For report Company B, show that compressor tripped is the highest number of fault or failure. Both of this failure is crucial components that must be maintenance as it will lead to other components damage on offshore platform.

Then, make the pareto analysis to all the failures. Pareto chart is a graph that displays both the frequency of defects and the overall effect of those issues. These diagrams are widely used to establish the order of importance for various process improvement initiatives. Pareto charts display the ordered frequency counts of values for the various levels of a nominal or categorical variable. The line indicates the total of the% values for each failure scenario, whereas the bars show individual numbers in decreasing order. For easy observation, the pie charts demonstrated that the predominant failure mode occurs in the semi hermetic compressor.

Other than that, with the comparison of failures occur on semi hermetic compressor in offshore platform and academic journal, we noticed that the valve parts are really frequently fail. Besides that, compressor faults also have the highest number of failures in industries such as compressor tripped and compressor overheating.

Based on my research, we can know the cost of each part in semi hermetic compressor. All the equipment is very expensive price. Acquisition costs have also been calculated. Proper maintenance of the compressor is important as the compressor to ensure smooth operation and minimize interruptions as well as unexpected downtime to the system. Furthermore, it will prevent an industry from incurring huge losses to overcome this failure.

5.2 Recommendations

For the compressor to guarantee smooth operations, reduce interruptions, and unexpected system downtime, proper compressor maintenance is essential. It should regularly examine its maintenance schedule, which includes the compressor and its system, to ensure its operability and longevity. On industry compressors, corrective and preventative maintenance is often carried out. Even when there is upkeep, it is still insufficient.

For future recommendation, suggested to do Risk Based Condition Maintenance (RBM) taken into the maintenance work. As it targets the part or component that has the highest risk of failing. Additionally, risk-based maintenance is the most economically advantageous maintenance technique since it prioritizes maintenance work from the component failure with the highest risk to the one with the lowest risk. It may decrease the risk of the breakdown.

5.3 Project Potential

The study finding could be applied on typical industries based on the FMEA table. The Failure Modes and Effects Analysis (FMEA) is a systematic set of procedures designed to identify and assess probable product/process failures and their consequences. Determine the steps that may be taken to avoid or lessen the likelihood that the possible failure would occur. This help a company reduce a big losses when repair or replace the components that have failed.

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Author links open overlay panelHamid RezaFeiliaPersonEnvelopeNavidAkarbHosseinLotfizadehcMohammadBairampourbSinaNasirid, RezaFeiliaPersonEnvelope, H., a, NavidAkarb, b, HosseinLotfizadehc, c, MohammadBairampourb, SinaNasirid, d, Highlights•Using Failure Modes and Effects Analysis (FMEA) to find potential failures in geothermal power plants.•We considered 5 major parts of geothermal power plants for risk analysis.•Risk Priority Number (RPN) is calculated for all failure modes.•Cor, & AbstractRenewable energy plays a key role in the transition toward a low carbon economy and the provision of a secure supply of energy. Geothermal energy is a versatile source as a form of renewable energy that meets popular demand. Since some Geothermal . (2013, April 24). Risk analysis of geothermal power plants using failure modes and effects analysis (FMEA) technique. Energy Conversion and Management. https://www.sciencedirect.com/science/article/pii/S0196890413001325

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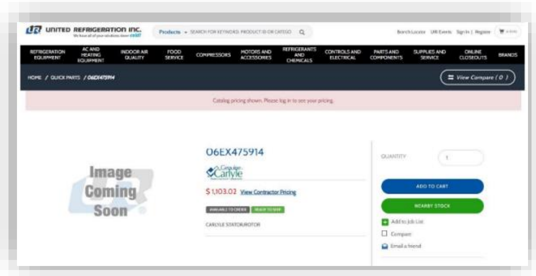
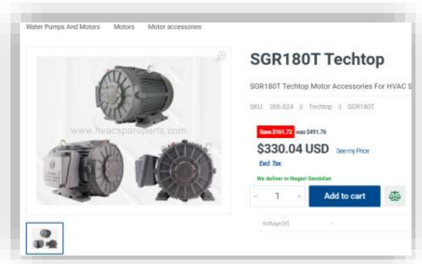
APPENDICES

APPENDIX A Cost of semi hermetic compressor parts

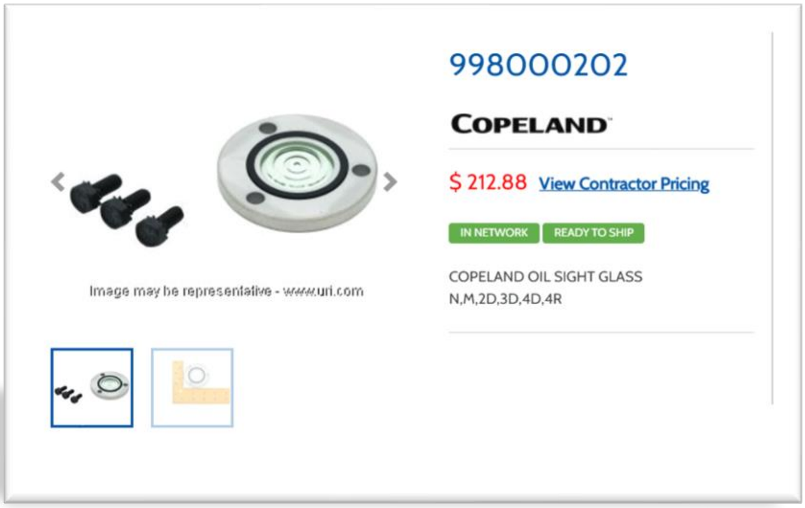
1. Stator and motor



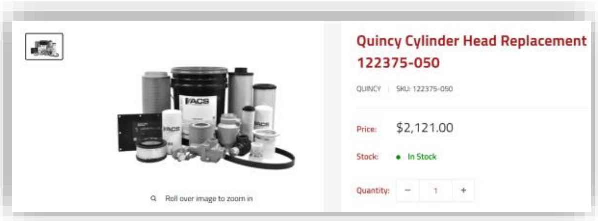


2. Crankshaft

3. Oil sight glass

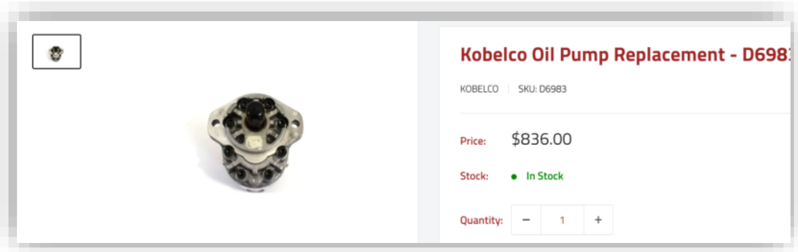


4. Cylinder head

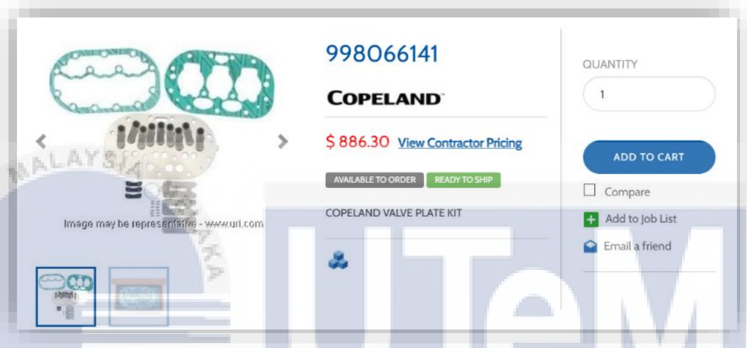


5. Piston

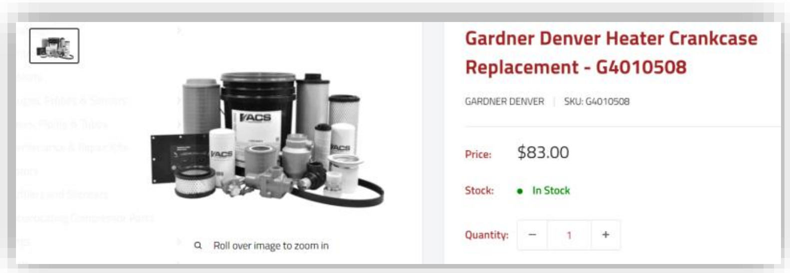
6. Oil pump



7. Valve plate assembly



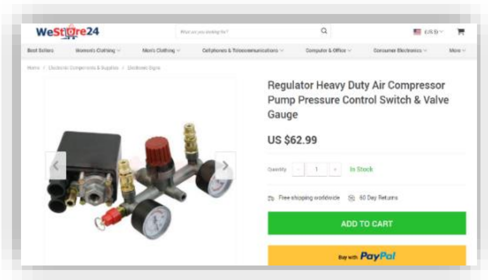
8. Compressor crankcase heater

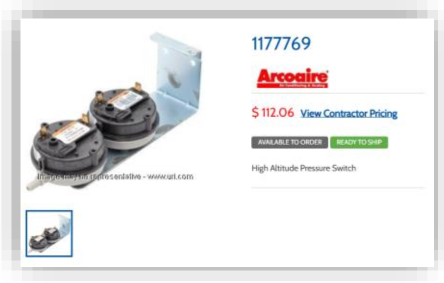


9. Bearing

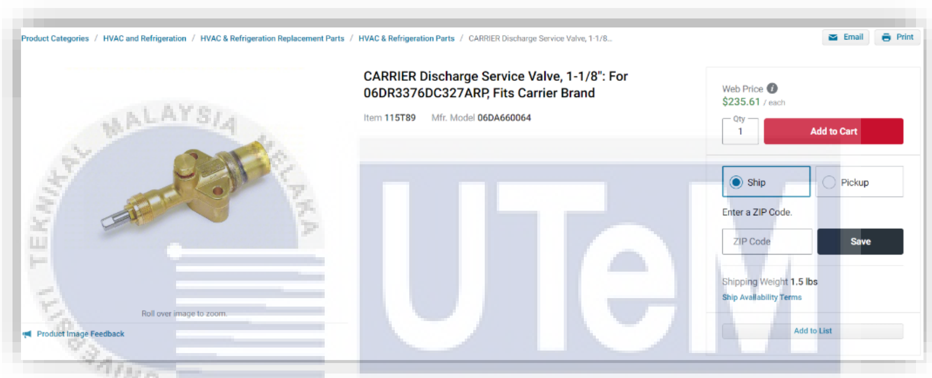
10. Terminal plate

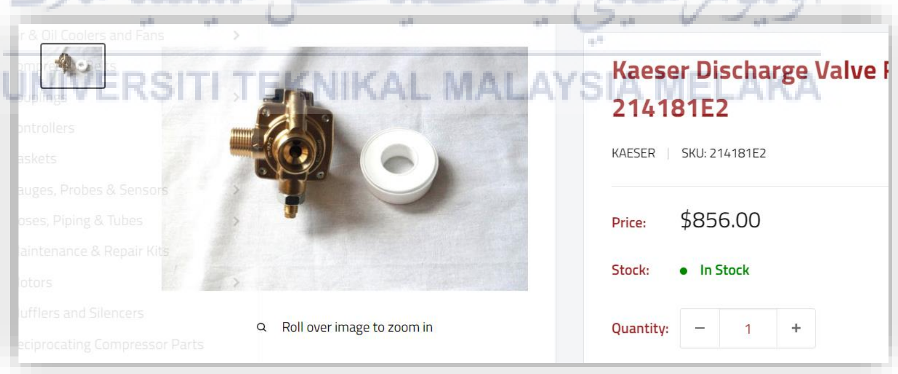
11. Pressure switch



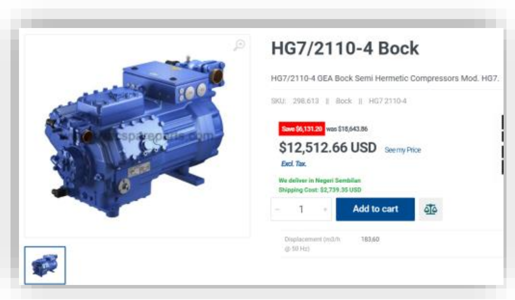


12. Discharge valve

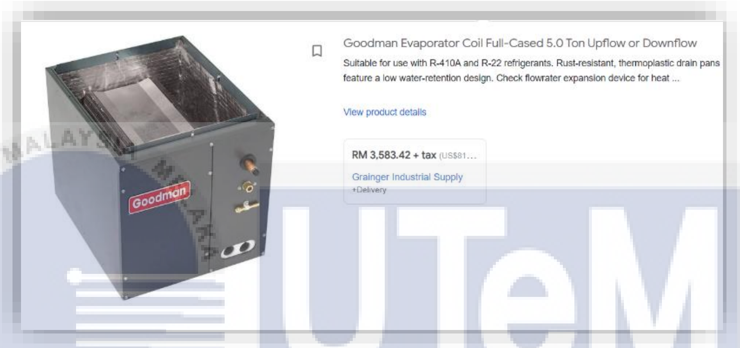




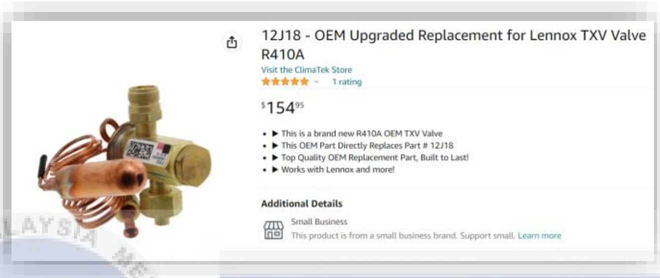
13. Semi hermetic compressor



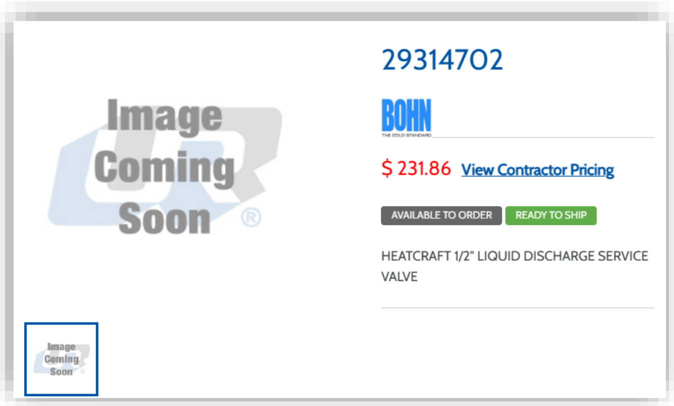
14. Evaporator



15. TXV



16. Discharge service valve



Rujukan Kami (Our Ref):
Rujukan Tuan (Your Ref):
Tarikh (Date): 31 Januari 2021

Chief Information Officer
Perpustakaan Laman Hikmah
Universiti Teknikal Malaysia Melaka

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Tuan

PENG□ELASAN TESIS SEBAGAI TERHAD BAGI TESIS PRO□E□ SAR□ANA MUDA

Dengan segala hormatnya merujuk kepada perkara di atas.

2. Dengan ini, dimaklumkan permohonan pengkelasan tesis yang dilampirkan sebagai TERHAD untuk tempoh **LIMA** tahun dari tarikh surat ini. Butiran lanjut laporan PSM tersebut adalah seperti berikut:

N□□ □ □□□□r□MUHAMAD AIMAN BIN IBRAHIM

T□□□ T□□□□MAINTENANCE STRATEGY DEPLOYMENT OF HVAC SEMI HERMETIC COMPRESSOR USING FAILURE MODE EFFECT ANALYSIS PROCESS (FMEA) METHOD

3. Hal ini adalah kerana IANYA MERUPAKAN PROJEK YANG DITAJA OLEH SYARIKAT LUAR DAN HASIL KAJIANNYA ADALAH SULIT.

Sekian, terima kasih.

"BERKHIDMAT UNTUK NEGARA"
"KOMPETENSI TERAS KEGEMILANGAN"

Saya yang menjalankan amanah,

Fuad Ghani

Ts. Dr. Ahmad Fuad Bin Ab Ghani
Pensyarah Kanan
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Fakulti Teknologi Kejuruteraan Mekanikal dan Pembuatan
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