Journal of Energy and Safety Technology

JEST

RESEARCH ARTICLE

Open Access

Risk Assessment of Horizontal Wet Etching Equipment System in Manufacturing Plant Industry

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Article History

Received: March 04, 2020 Received in revised form: June 01, 2020 Accepted: June 03, 2020 Published Online: June 30, 2020

Abstract

Maintenance is one of the important roles in the high technology manufacturing industry. It is related to the key performance factors of the company such as quality, productivity, and cost. To achieve these factors, a reliability plan should be implemented which helps to maximise production value by implementing successful asset maintenance. This research project aims to focus on the critical process equipment known as Horizontal Wet Etching Equipment (HWEE) used in the wet etching process. The components in the HWEE system were identified by referring to the process and instrumentation diagram (P&ID) of the equipment and were categorised in different modes. Data on mean time to repair (MTTR) and mean time between repairs (MTBF) were collected based on previous company records. The data were analysed using MAROS software. Failure Mode and Effect Analysis (FMEA) was done to understand the risk of each of the components. The result shows that piping and gearbox have the highest RPN with 126 and 105, respectively. This study helps to identify critical components and is able to help the company to improve equipment reliability and reduce maintenance cost. Corrective action can be implemented to reduce the RPN for both components. Thus, it would help the industry to increase the key performance and become more competitive in the business environment.

Keywords: Maintenance; Reliability; Horizontal Wet Etching Process; Key Performance; Failure Mode and Effect Analysis.

1.0 INTRODUCTION

The high technology manufacturing industry involves processes of converting raw materials or parts into finished goods that can be sold in wholesale or retail markets or exported for sale in other countries. Basically, it is driven by the desire to produce saleable finished products at the lowest possible cost while still maintaining acceptable standards of quality, functionality and timeliness. There are four basic elements of an idealised process in a high technology manufacturing plant. These are product design, process design, shop floor production, and business process. Currently, the high technology manufacturing plant industry is growing and expanding worldwide.

An example of a high technology manufacturing plant is the solar photovoltaic (PV) and semiconductor industry which is one of the key economic industries in the world. Solar PV is a technology that uses the basic properties of semiconductor materials to transform solar energy into semiconducting materials. There are many of process steps involved in the large-scale high technology manufacturing plant industry (i.e. solar PV industry). This process equipment deals with a lot of flammable, spontaneous combustion, toxic corrosive, special gases and chemicals [1] [2] [10]. One of the critical process steps is the wet etching process.

Wet etching refers to the process by which material is removed from a wafer either from the silicon substrate itself or from the film or layer of material on the wafer. This process involves various chemicals or etchants to remove the unwanted material from the wafers. Most wet etching processes in the high technology manufacturing plant industry entail potentially hazardous phenomena including overflow, boiling, bubbling, two-phase swelling, temperature rise, and autocatalytic behaviour [3] [9]. The cause of these hazardous phenomena is related to the strategy of maintenance implemented in the plant.

Plant maintenance should be conducted properly as it plays a vital role in production management. Breakdowns will create problems such as production loss, material loss, need for overtime, need for subcontracting work, and temporary work shortage [4] [7] [11]. A reliability plan should be implemented in order to achieve these key performance factors. It is a roadmap that helps to maximise production value by implementing successful asset maintenance [5].

In reliability, there are three terms which are always used; maintainability, availability, and failure. Technical maintenance strategies can be divided into several categories; breakdown or corrective run to failure maintenance, preventive maintenance (PM), planned maintenance, proactive maintenance (PrM), condition-based maintenance (CbM), design-out maintenance and reliability centred maintenance (RCM).

Yaasad and his team used the Reliability Centred Maintenance model (RCM) to optimise the maintenance management of equipment while Vishnu and Regikumar conducted a study on Reliability Centred Maintenance (RCM) where the result showed that all critical equipment needs a preventive maintenance strategy rather than scheduled maintenance and breakdown maintenance [11] [12]. RCM is a systematic method to maintain a balance between preventive and corrective maintenance. It also can be characterised by maintaining system functions, identifying failure modes, prioritising functions, and choosing efficient maintenance. The main objective of RCM is to reduce the maintenance cost by focusing on the most important functions of the system.

There are many methods used to improve the reliability of maintenance such as Preventive Maintenance (PM) and Corrective Maintenance (CM) [13]. However, there are limitations to the stated methods for the current study. For example, they lead to excessive costs of maintenance due to an improper maintenance strategy. The most reliable and suitable method to improve the reliability of equipment is by conducting FMEA. Mauro and other researchers had used the FMEA approach in order to optimise the maintenance plan of photovoltaic (PV) systems. Their finding can help to improve various failure modes which mostly affect production [6]. Conducting FMEA may also help in minimising operating costs such as maintenance cost and avoid any major downtime that could cause production interruption.

In this research study, FMEA will be used as a method to conduct a risk assessment of the critical process equipment known as Horizontal Wet Etching Equipment (HWEE) used in the wet etching process. The process was identified by referring to the process and instrumentation diagram (P&ID) system from industry. FMEA is a tool that helps to identify critical components in equipment and is able to prevent any safety issues such as chemical and gas exposure or explosion.

2.0 METHODOLOGY

A reliability assessment of Horizontal Wet Etching Equipment (HWEE) was carried out to understand the consistency of the equipment in meeting equipment design and requirement and also to prevent production losses. Critical components were identified in the HWEE system by referring to the Process and Instrumentation Diagram (P&ID) as shown in Figure 1. Mean Time To Repair (MTTR) and Mean Time Between Failure (MTBF) data were taken from the Manufacturing Execution System (MES) between 2017 to 2018. MTTR data refers to the average time required to troubleshoot and repair failed equipment while MTBF data is the average time between equipment breakdown. MAROS software [14] was used for this study as it is able to calculate the reliability of the equipment based on the components identified. The software helps to analyse and develop an analysis of the reliability, availability, and maintainability of a system or equipment. Figure 2 shows the MAROS software interface. Figure 3 shows the step flow to conduct the reliability assessment [8]:

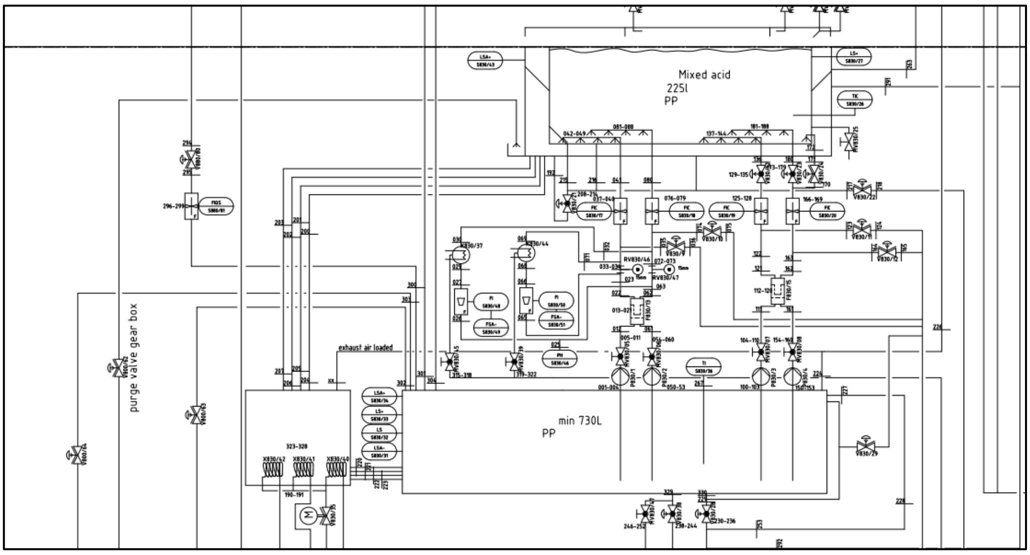

Figure 1 P&ID of HWEE System

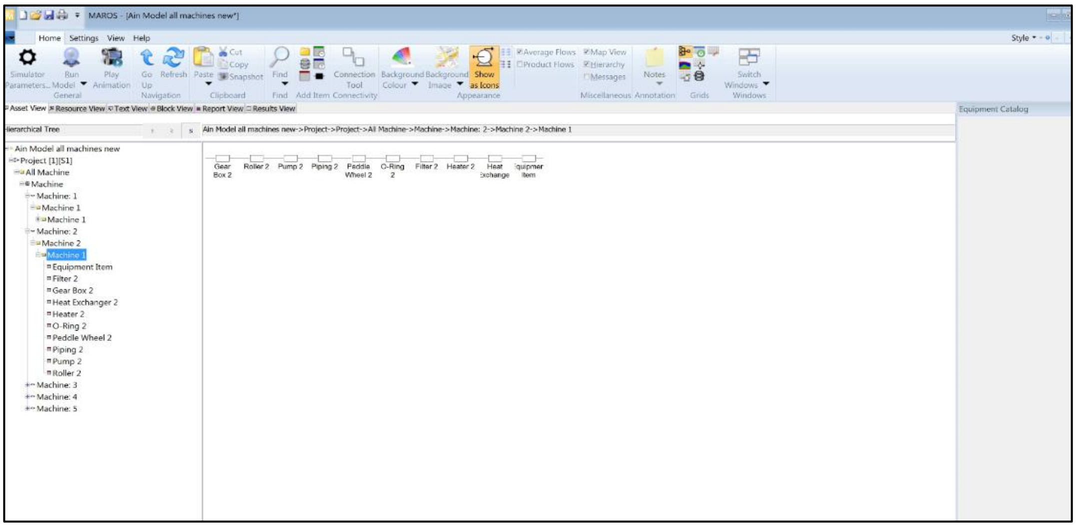

Figure 2 Interface of MAROS Software

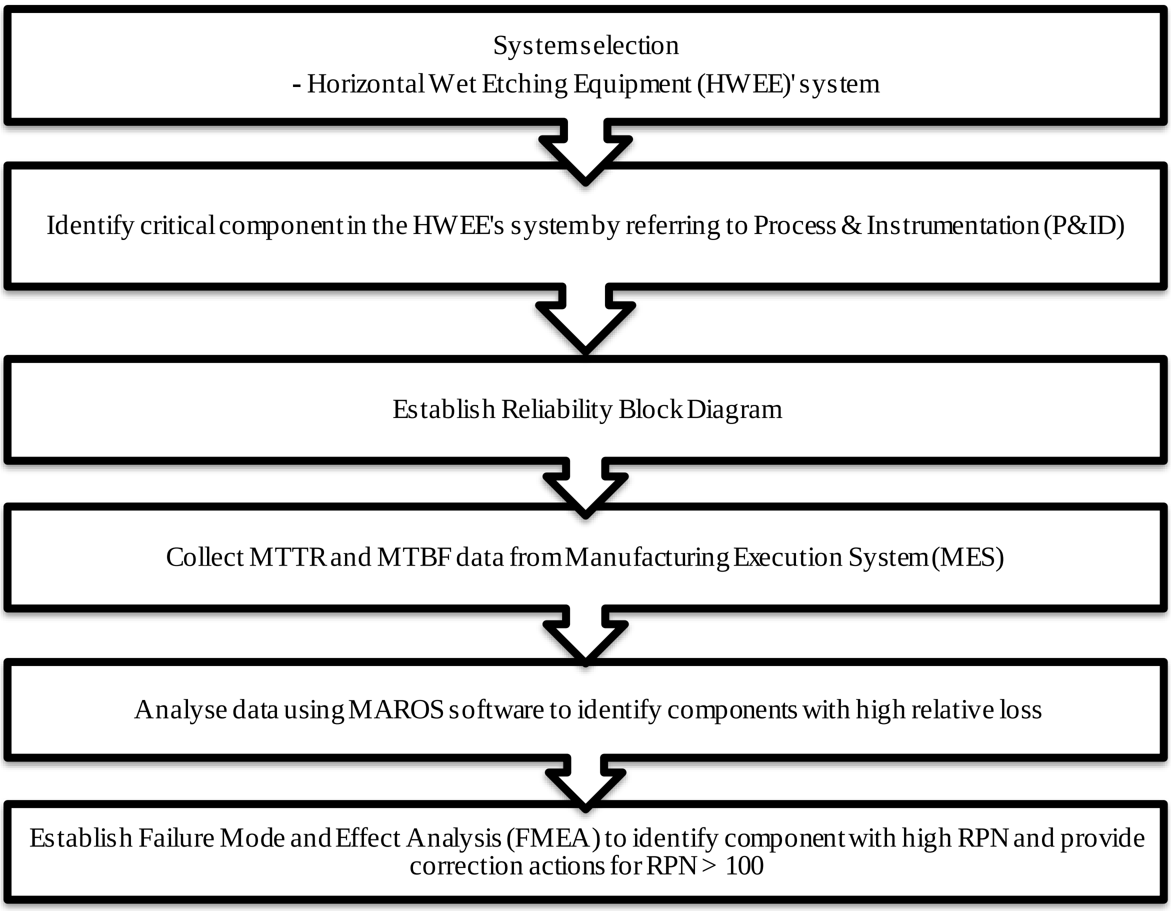

Figure 3 Step flow to conduct reliability assessment

FMEA was established based on the critical components in the HWEE system. The criticality using FMEA is defined by the Risk Priority Number (RPN) which is the combination of ratings; severity of the effects (S), occurrence (O), and detection (D) as mentioned in Table 1, Table 2, and Table 3, respectively. Severity relates to the seriousness of the end effect of a component failure, occurrence is the frequency that a malfunctioning event is likely to occur, and detection is the likelihood to detect a potential failure situation before it occurs. RPN is calculated using Equation 1:

$$RPN: S \times O \times D \qquad (1)$$

Table 1 The Severity ranking criteria

RANK	DESCRIPTION
9 - 10	Failure will occur with warning. Safety issue with warning. 100% product recall after installation.
7 - 8	Customer dissatisfied. 100% product recall before installation.
5 – 6	Customer experiences some dissatisfaction.
4	Defect noticed by most customers (>75%).
3	Defect noticed by average customers (~50%).
2	Defect noticed by discriminating customers (<25%).
1	No nuisance.

Table 2 The Occurrence ranking criteria

RANK	DESCRIPTION
9 - 10	**Very high**: Failure is almost inevitable.
7 - 8	**High**: Generally associated with processes similar to previous processes that have often failed.
4 – 6	**Moderate**: Generally associated with processes similar to previous processes which have experienced occasional failures, but no in major proportions.
3	**Low**: Isolated failures associated with similar processes.
2	**Very Low**: Only isolated failures associated with almost identical processes.
1	**Remote**: Failure is unlikely. No failures ever associated with almost identical processes.

Table 3 The Detection ranking criteria

RANK	DESCRIPTION
10	No known controls available to detect failure mode.
9	Weekly monitoring schedule is in place, but there are no available prevention controls.
8	Daily monitoring schedule is in place, but there are no available prevention controls
7	Daily monitoring schedule is in place with regular PM monitoring.
6	Reliability Modeling System used (Equipment Monitoring).
5	Failure analysis tools employed regularly, such as vibration analyzer, thermal scanner, oscilloscope, etc.
4	Controlled and monitored set-up with first article check (for set-up causes only).
3	Potential cause has a real-time feedback; the correction has a human intervention. Real-time feedback means that there is a built-in alarm (audible or visual display).
2	Potential cause has a real-time feedback; the machine automatically corrects the error.
1	The system has built-in Fault Detection Controls.

3.0 RESULTS AND DISCUSSION

There were eight critical components identified in the system; gearbox, roller, pump, piping, paddle wheel, O-ring, filter, and heat exchanger. These components were categorised based on two different modes, which are critical and degraded. Critical mode is referring to the 100% losses to production, and degraded mode is referring to if the impact is only some portion (i.e. 50%) of the production loss. The selection of the percentage is based on the criticality of the components that will affect the performance or reliability of the equipment that leads to major downtime in production. The main eight components are as shown in Figure 4 and known as the Reliability Block Diagram (RBD) of the HWEE system.

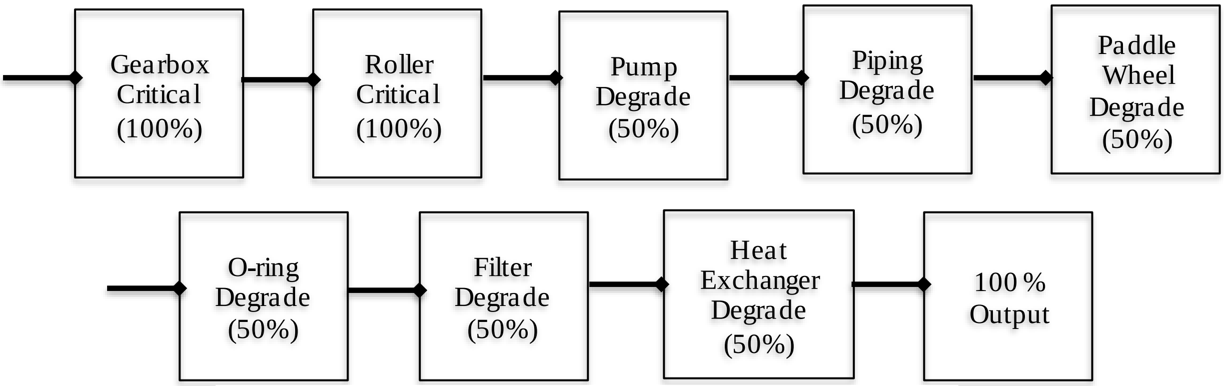

Figure 4 Reliability Block Diagram (RBD) of HWEE system

Based on the RBD, the gearbox and filter were identified as critical while the roller, pump, piping, paddle wheel, O-ring, and heat exchanger were identified as degraded. The identification of the components in the HWEE system enables a reliability assessment to be carried out. Table 4 shows the MTBF and MTTR data of the HWEE components from the Manufacturing Execution System (MES) record.

Table 4 MTBF and MTTR data of the HWEE components

Component	Mode	MTBF (days)	MTTR (hour)
Gearbox	Critical	90	14.01
Roller	Critical	180	9.79
Pump	Degraded	290	2.10
Piping	Degraded	60	15.75
Paddle Wheel	Degraded	10	0.63
O-ring	Degraded	270	14.73
Filter	Degraded	60	0.63
Heat Exchanger	Degraded	200	4.50

MTBF is a basic measure of a system's reliability. MTTR is the expected time to recover a system from a failure. This includes the time to diagnose the problem by an onsite technician or the time it takes to physically repair the system. The MTBF and MTTR data show that the pump has the highest MTBF number at 290 days while the paddle wheel has the lowest MTBF at only 10 days. This means that the pump has a longer reliability compared to the paddle wheel as pump maintenance has been done by replacing the impeller material from PP to PVDF. For MTTR, piping has the highest number at 15.75 hours and paddle wheel and filter have the lowest MTTR number at only 0.63 hours.

From the MAROS simulation [14], the components with high relative loss are piping and gearbox with 31.81% and 29.79% relative loss, respectively, as depicted in Figure 5. Piping has the highest relative loss due to a leaking issue which causes production downtime to carry out repairs. The leak only occurs at the welding joint area on the piping. The component with low relative loss is the pump with 0.83% relative loss. This is because the design of the pump is compatible with the operating parameters and process design of the HWEE system. The impeller used in the pump is made from PVDF.

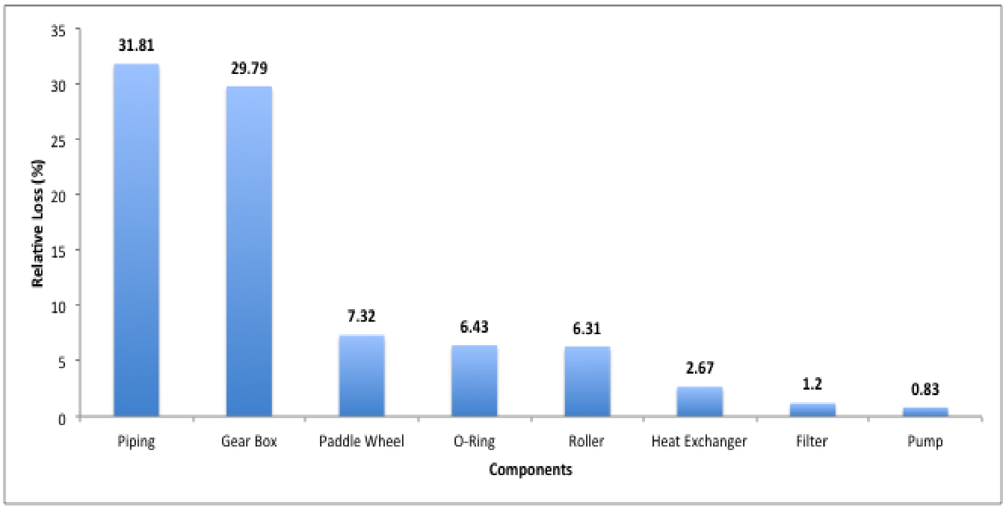

Figure 5 Invidual component in HWEE system based on relative loss

Failure mode and effect analysis (FMEA) can be established in order to analyse the risk and failure modes from the components listed. All the information from MAROS software [14] can be used to determine the impact each failure would have on the product; thus, improvements can be made to the product design and reliability of the system. Table 5 shows the FMEA for each component in the HWEE system. Only two components i.e. piping #1 and gearbox #3 show RPN > 100 and corrective actions have been taken to improve the maintenance of the system. There are eight components in the HWEE system and total of 17 failure modes have been identified for each of the components.

Table 5 FMEA on HWEE components

Component	Potential Failure Mode #	Potential Failure Mode	Potential Cause(s)/ Mechanism(s) of Failure	Current Design Controls		Severity	Occur	Detect	RPN
				Prevent	Detect				
Roller	#5	Broken roller	Friction between the rollers	None	Visual inspection	7	2	7	98
	#6		Worn out roller	None	Visual inspection		2	7	98
	#7		Manual handling of the roller by technicians	None	Visual inspection		2	7	98
	#8	Bend roller	Expose to high vapor of H_2O_2	Auto drain system	Visual inspection	7	1	7	49
	#9	Inaccurate dimension of roller	Fabrication issue	None	Visual inspection using roller jig	7	2	5	70
Pump	#10	Low flowrate	Broken impeller	Change the impeller material from PP to PVDF	Machine real time feedback: Alarm on low flowrate	5	2	3	30
	#11	Low level of chemical in the process bath	Broken impeller	Change the impeller material from PP to PVDF	Machine real time feedback: Alarm on low flowrate	5	2	3	30
Paddle wheel	#12	Inaccurate reading of actual flowrate	Broken blade	None	Machine real time feedback: Alarm on low flowrate	4	2	3	24
O-ring	#13	Degradation of roller O-ring	Mixing of incompatible O-ring in material the modules	None	Visual inspection	7	2	7	98
Filter	#14	Low flow circulation	Filter clogged	Scheduled replacement of filter	Machine real time feedback: Alarm on low flowrate	5	2	3	30
	#15		Sludge build up	Scheduled replacement of filter	Machine real time feedback: Alarm on low flowrate	5	2	3	30
Heat exchanger	#16	Chemical concentration is out of specification	Heat exchanger leak	Scheduled replacement of heat exchanger	Chemical concentration Sampling analysis	4	1	6	24
	#17	Dilution in the process bath	Heat exchanger leak	Scheduled replacement of heat exchanger	Chemical concentration Sampling analysis	4	1	6	24

Table 5 FMEA on the HWEE components (cont.)

Component	Potential Failure Mode #	Potential Failure Mode	Potential Cause(s)/ Mechanism(s) of Failure	Current Design Controls		Severity	Occur	Detect	RPN	Corrective Action(s)	Severity	Occur	Detect	RPN
				Prevent	Detect									
Piping	#1	Leaking of chemical from the piping installed at the equipment	Poor welding at the joint area on the piping	None	Machine real time feedback: Alarm on leaking	7	6	3	126	Conduct thermal stress on the piping and improve welding material	5	6	3	90
	#2		Incompatible piping material	None	Visual inspection	7	3	3	63	N/A	N/A	N/A	N/A	N/A
Gearbox	#3	Chemical penetrate into the gearbox	Broken seal in the gearbox	Scheduled replacement of gearbox	Visual inspection	5	3	7	105	Change the seal material of the gearbox	5	2	7	70
	#4	Gearbox finger broken	Friction between the rollers	Scheduled replacement of gearbox	Visual inspection	5	2	7	70	N/A	N/A	N/A	N/A	N/A

Figure 6 represents the overall Risk Priority Number (RPN) for the failure modes of each of the components in the HWEE system. The highest RPN is 126, which refers to the piping component where the potential failure mode is chemical leakage from the piping installed on the equipment. The potential cause for the failure is poor welding at the joint area of the piping. There is no control for the leak in terms of prevention, but it can be detected by an alarm on the equipment.

The gearbox has the second highest RPN at 105 where the potential failure mode is chemical penetration into the gearbox. The failure mechanism is a broken seal in the gearbox which will allow chemicals to attack or penetrate the gearbox. The recommended action for preventing or reducing the occurrence of this failure is changing the seal material to another suitable material which can protect the gearbox and withstand the chemicals. The current prevention method is by maintenance where a scheduled replacement of the gearbox is carried out every 4 years based on data collection. Gearbox failure is detected by visual inspection.

Potential failure modes with a RPN of more than 100 can be reduced to less than 100 by taking the appropriate corrective action. As discussed earlier in the FMEA, potential failure modes #1 and #3 have RPN of more than 100. Failure mode #1 represents the piping component and the potential failure mode is leaking with an original RPN of 126. The RPN can be reduced to 90 whereby the severity is reduced from 7 to 5 by conducting thermal stress treatment on the piping and improving the welding method and material. Failure mode #3 refers to the gearbox component where the potential failure mode is chemical penetration into the gearbox. Changing or replacing the seal material of the gearbox can reduce the RPN by reducing the occurrence from 3 to 2. Thus, the RPN can be reduced from 105 to 70.

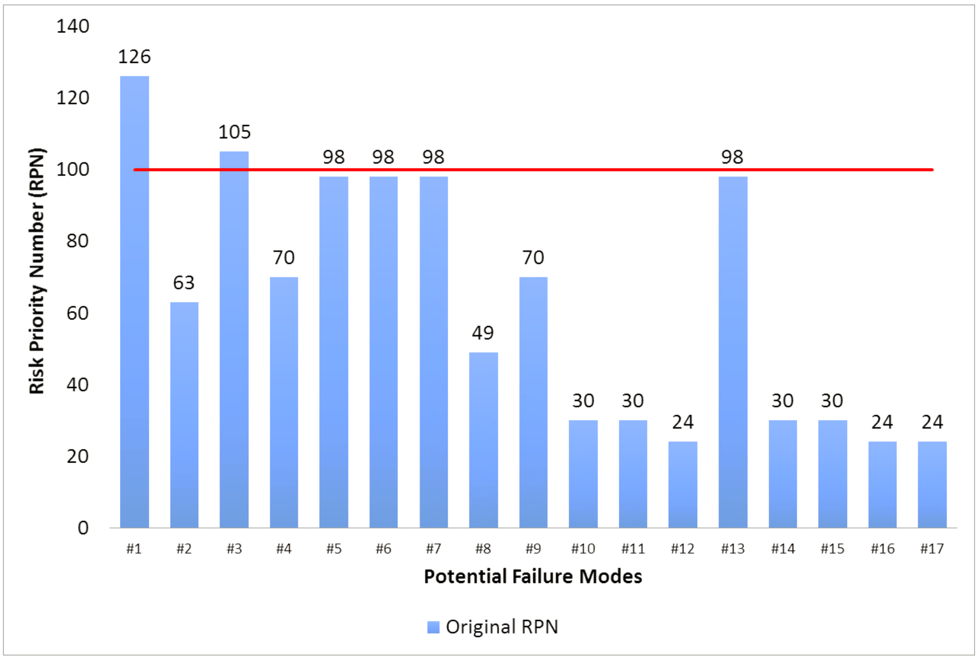

Figure 6 RPN calculated from FMEA

As discussed earlier, the RPN for potential failure modes #1 and #3 are reduced from 126 to 90 and 105 to 70, respectively, as shown in Figure 7. The RPN are reduced due to the implementation of the described corrective actions. Another corrective action that might be able to reduce the RPN for piping leakage is installing a coupling between the joint area of the welding on the piping. For the gearbox, instead of replacing the seal material, another corrective action that can be taken is monitoring the gearbox performance using a vibration meter and defining the limits for replacement. Other potential failure modes with RPN of less than 100 do not require corrective action. The target RPN of 100 is based on a common industrial target in order to achieve low RPN and higher reliability.

Therefore, by conducting FMEA, potential hazardous impact such as chemical leakage from the piping, human handling during pipe welding, and replacing the gearbox can be minimised or avoided. It can benefit the industry in terms of achieving key performance such as cost, productivity, and quality.

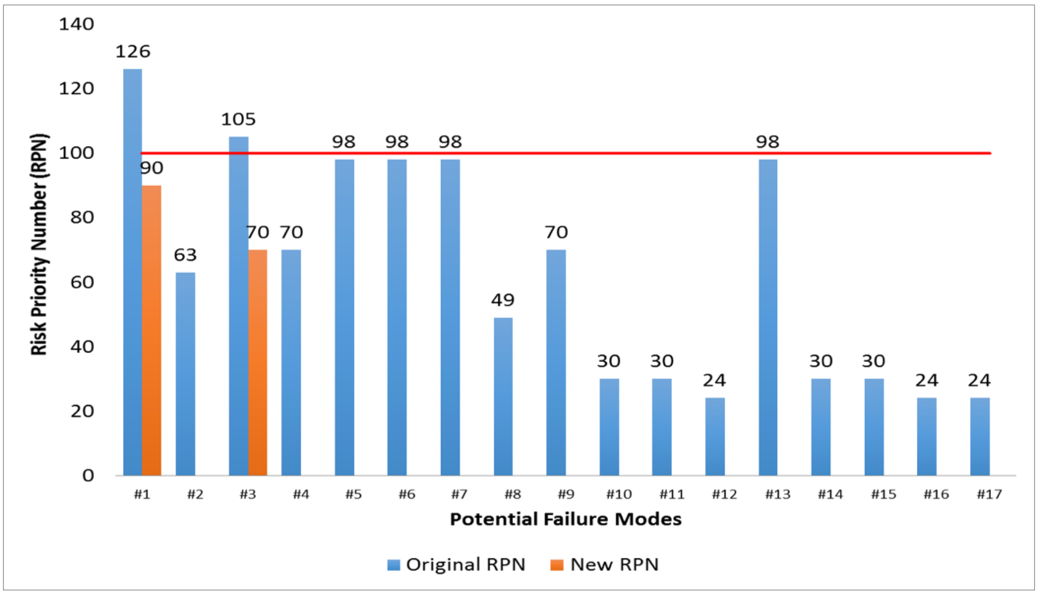

Figure 7 Comparison of original RPN and new RPN

CONCLUSION

The critical components in the HWEE equipment are identified using MTTR and MTBF data. The reliability assessment of the components is carried out and the assessment shows that two components which have high relative loss are the piping and gearbox. With that, potential failure modes are identified, which show that both components have high RPN from FMEA. Corrective actions have been taken for both components in order to improve the RPN by conducting thermal stress on the piping and improving the welding method and material for the piping, while the seal material in the gearbox is replaced. The implementation of the above corrective actions could help reduce the RPN to less than 100. Therefore, the investigation of the critical components has successfully identified and prevented losses in terms of maintenance cost. Among the limitation of the study is the inability to include details of the piping failure. This is due to a limitation in the metrology tool to analyse the root cause of the piping failure in the etching process equipment. In the future, an advance tool for root cause analysis can be used, and thus for further reliability assessment.

Acknowledgements

This work was carried out with data coming from the respective High Technology Manufacturing Company, Department of Chemical & Environmental Engineering, Universiti Putra Malaysia and Process Safety and Loss Prevention Programme. We would like to thank them all heartily.

List of Abbreviations

PV	Solar Photovoltaic
HWEE	Horizontal Wet Etching Equipment
FMEA	Failure Mode and Effect Analysis
MES	Manufacturing Execution System
PVDF	Polyvinylidene fluoride
RPN	Risk Priority Number
MTTR	Mean Time to Repair
MTBF	Mean Time between Repair
P&ID	Process & Instrumentation Diagram
PM	Preventive maintenance
PrM	Proactive maintenance
CbM	Condition based maintenance
RCM	Reliability centered maintenance

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