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RESEARCH ARTICLE

Study of Frequency Preventive Maintenance Consumable Item for HPU Rotating Equipment

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ABSTRACT

Frequency of preventive maintenance consumable item for HPU rotating equipment is basically is governed by Preventive Maintenance Schedule (PM) which are following due timing either by calendar or running hours. Therefore, this research is aiming to gain knowledge about how the Condition Base Monitoring (CBM) method in Predictive maintenance can influence in giving an ideal right timing for Preventive Maintenance Schedule including the replacement of consumable item. There are three data collected to analysed which are Vibration analysis, Lubricant analysis and Rotating Expertise survey. All data will be analysed via Mini tab and SPSS. From the result, the researcher will examine and recommend the new ideal timing for preventive maintenance schedule either maintaining existing schedule 3 months or extended up to 6 months.

INTRODUCTION

Introduction

Facilities and equipment maintenance in oil and gas plant is a back bone of the company to ensure the reliability and safety of overall operational process of production and others business activities related. This research will be studied on the consumable item maintenance schedule for centrifugal type rotating pump in Hydrogen Processing Unit (HPU) in Pengerang Integrated Complex (PIC), Johor, Malaysia. To ensure the effectiveness, efficiency and reliability of pump, the scheduled of maintenance need to be studied and define the perfect time to carry out the maintenance work and at the same time avoid process interruption (Yunlong, Z., & Peng, Z. 2012)

One of the best ways to know the perfect timing for schedule maintenance is by predictive maintenance that often called as Condition Base Monitoring (CBM) that including vibration trend analysis and lubrication oil analysis. Basically, during preventive maintenance implementation schedule, it will cross check with the predictive maintenance result to know the current status of pump and also can generate proposal timing to optimize the operation and reduce the maintenance cost. Actually, CBM task is one of predictive maintenance type that help to react on actual system state of machine such as vibration analysis, minimizing both maintenance costs, reducing the number of equipment failures and unnecessary interventions during production time, and at the same time improving operational safety (Alaswad, S., & Xiang, Y. 2017)

In this research, there are two types of analysis will be studied on the selected centrifugal pump at HPU which vibration data analysis and lubricant analysis are. Other than that, survey from rotating expertise is also included to support the evident. Overall, the expected outcome will be giving strong evident to support the new recommendation of an ideal maintenance schedule in conjunction with safety, economy, efficiency and quality of overall performance of rotating pump in Hydrogen Process Unit (HPU).

RESEARCH FRAME WORK

The objective of this research is to provide new recommendation schedule for an ideal preventive maintenance consumable item for HPU rotating pump based on vibration and lubricant behavior, as well as based on frequency of preventive maintenance consumable item.

Figure below show the overall research framework that used in this research.

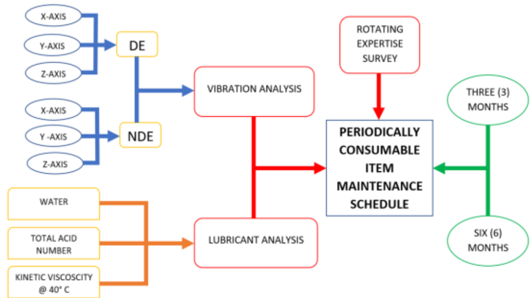


Figure 2.1: Research Framework

METHODOLGY

Research design

Table 3.1 show the detail of research design approach

Research objective / Research question	Research philosophy		Research approach	Research choice	Research strategy			Time horizon	Data collection method	Data analysis
	Knowledge assumption	Research paradigm								
RO1/ RQ1	Epistemological	Pragmatism (Incorporated Constructivism & Positivism as cross-paradigm)	Abductive research approach (Associated the Inductive & Deductive)	Mixed methods	Sequential strategy of inquiry	Quantitative	Archival & Survey	Cross-sectional	Vibration analysis, Lubricant analysis	Descriptive
RO2/RQ2							Archival & Survey		Vibration analysis, Lubricant analysis	Descriptive
RO3/RQ3							Archival & Survey		Vibration analysis, Lubricant analysis, Questionnaire	Descriptive, Kendall's Coefficient of Concordance

Data Collection method

For data collection method, this research will conduct on archival data recorded from CBM department. This research will be taking two types of common condition monitoring parameters which are:

- Vibration analysis
- Lubricant analysis

The selection of vibration analysis and lube oil analysis from the strategy of predictive techniques is due to the fact that both of this are applied in a higher number of industrial plants (Christer, A. H., Wang, W., & Sharp, J. 1997).

In addition, this study also used Kendall's coefficient of concordance (W) as a data analysis technique to analyse the level of agreement among the expertise of rotating pump regarding to the proposal new ideal of preventive maintenance consumable item. Through Kendall's coefficient of concordance this study can make a realistic determination of whether any consensus has been reached, whether the consensus is increasing, and the relative strength of consensus (Schmidt, 1997).

For this research, as per table 3.2 below, six of HPU 1 pump was selected to examine the condition and performance within six-month period.

Table 3.2: six selected HPU pump details

NO	TAG NUMBER	PRODUCT	TYPE OF PUMP
1	1511-P-741 A	CLEAN CONDENSATE	CENTRIFUGAL
2	1511-P-741 B	CLEAN CONDENSATE	CENTRIFUGAL
3	1511-P-761 A	PROCESS CONDENSATE	CENTRIFUGAL
4	1511-P-761 B	PROCESS CONDENSATE	CENTRIFUGAL
5	1511-P-701 A	BOILER FEED WATER	CENTRIFUGAL
6	1511-P-701 B	BOILER FEED WATER	CENTRIFUGAL

Data screening

In this research, data screening was conducted to ensure the data have been correctly entered and the distribution of data is normal (Field, 2009). Screening for missing data, outliers, normality and multicollinearity were conducted as the first step in the data analysis. In this research, the data collected will examined using Mini tab application to segregate the result from several test such as Chi square test, independent sample T- test, Kruskal Wallis test, Mann-Whitney and Kendall's coefficient of concordance.

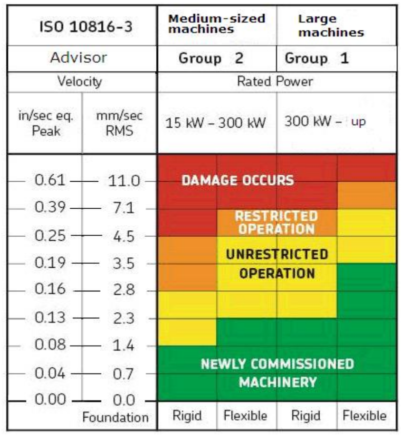
Data Analysis Method

Vibration analysis

For this research, the vibration device that used for taking vibration reading is Bently Nevada SCOUT 140-EX. SCOUT140-EX is a portable four-channel vibration data collector, analyzer and balancer. Velocity measurements and monitoring of vibration actually is the most common unit to identify various problems or acceptability such as pump unbalance, misalignment, looseness (machinery structural, foundations, or bearings), harmonics, and many other issues in the machinery frequency range and many multiples of actual speed. To get the velocity reading from vibration device, it can be measured in peak units such as inches per second (inch/s) or millimeters per second (mm/s). To get the completed vibration reading, three important directions at all main bearing points which are Horizontal axis, Vertical axis and Axial axis are being taken.

Vibration analysis result basically is following ISO 10816-3 standard as per table 3.4 below:

Table 3.4.1: ISO 10816-3



Lubricant Analysis

Lubricant analysis consists of analysis of the state of different physical and chemical parameters of oil in order to verify the condition of the lubricant and the machinery which requires investigation of the state of wear of the equipment, level of oil contamination, and oil condition and includes a recommendation outlining any corrective or preventive maintenance actions that are necessary.

For lubricant analysis in this research, the oil sample have been examined for every cycle of lube oil changing which are perform for every three months. Each of the result will be compared to the table 3.4.2 below for the reference and specification of limitations for each parameter test of the lubricant analysis result. The limitation of each parameter tested are very important to confirm the healthiness status of current pump condition.

Table 3.4.2: Table for Lubricant Analysis Test

NO	PARAMETER STANDARD	VARIANT	PARAMETER	STANDARD FORM	UNIT OF MEASURE (UOM)	SPEC LIMIT	
						MIN	MAX
1	ASTM D6304	831 KF	Water	H20	ppm	0.00	0.045
2	ASTM D664	907 UOP 565	Total Acid Number	TAN	mg KOH/g	0.00	0.31
3	ASTM D445	HVM 472	Kinetic Viscosity @ 40°C	KVIS40	cSt	38.8	48.8

Kendall's coefficient of concordance (W)

Kendall's Coefficient of Concordance is a measure of the agreement between several judges who have rank ordered a set of entities (Field, A. P. 2005). This study used Kendall's coefficient of concordance (W) as a data analysis technique to analyse the level of agreement among the expertise of rotating pump regarding to the proposal new ideal of preventive maintenance consumable item. To interpret the Kendall's W, this study refers the interpretation table from (Schmidt 1997) as shown in Table 3.4.3 below:

Table 3.4.3: Interpretation of Kendall's W (Adopted from Schmidt, 1997)

W	Interpretation	Confidence in Ranks
0.1	Very weak agreement	None
0.3	Weak agreement	Low
0.5	Moderate agreement	Fair
0.7	Strong agreement	High
0.9	Unusually strong agreement	Very High

RESULT AND DISCUSSION

Vibration and lubrication analysis reading schedule

In this research, vibration reading is taken from six of pump from HPU 1 within 5 months from December 2020 until April 2021. Every vibration reading is taken four (4) time in four hours for every cycle whereby the interval for every reading is recorded an hour. This is to ensure to get the most accurate reading by average four reading and also to complete the cycle of wave form for better analysis. Meanwhile for lubricant analysis, the lubricant sample will take once in every 3-months cycle which is on month Feb 2020 and May 2020 and send to the lab for examination and result.

Detail of Selection of pump at HPU 1

In this research, six of centrifugal pump for HPU 1 will be selected to determine the healthiness based on vibration reading and lubricant analysis. Details of pump selected is shown in Table 4.2.

Table 4.2: Detail of Selection of pump at HPU 1

NO	TAG NUMBER	POWER RATING (kW)	FOUNDATION	CATEGORY MACHINE	SPECIFIC VELOCITY LIMIT (mm/sec)	
					MIN	MAX
1	1511-P-741 A	15 kW	RIGID	MEDIUM SIZE	0.00 mm/sec	1.4 mm/sec
2	1511-P-741 B	15 kW	RIGID	MEDIUM SIZE	0.00 mm/sec	1.4 mm/sec
3	1511-P-761 A	18 kW	RIGID	MEDIUM SIZE	0.00 mm/sec	1.4 mm/sec
4	1511-P-761 B	18 kW	RIGID	MEDIUM SIZE	0.00 mm/sec	1.4 mm/sec
5	1511-P-701 A	180 kW	RIGID	MEDIUM SIZE	0.00 mm/sec	1.4 mm/sec
6	1511-P-701 B	180 kW	RIGID	MEDIUM SIZE	0.00 mm/sec	1.4 mm/sec

Result analysis on overall vibration data

Descriptive analysis

Descriptive analysis was used to provide a basic summary of each variable by showing a proportionate breakdown of the categories for each variable. Figure 4.3.1 determined the overall vibration result collected form six pumps at HPU 1. Data also consisting all the reading from three on three mutually perpendicular coordinate axes which are the x-axis, the y-axis, and the z-axis from both DE and NDE side. The data is range from month December 2020 until month April 2021.

OVERALL

Kruskal-Wallis Test: Data (mm/s) versus Month

Descriptive Statistics

Month	N	Median	Mean Rank	Z-Value
April 21	144	0.335	371.8	0.73
Dec 20	144	0.325	347.0	-0.87
Feb 21	144	0.330	357.5	-0.19
Jan 21	144	0.330	359.3	-0.08
Mac 21	144	0.330	366.9	0.41
Overall	720		360.5	

Test

Null hypothesis H_0: All medians are equal

Alternative hypothesis H_1: At least one median is different

Method	DF	H-Value	P-Value
Not adjusted for ties	4	1.20	0.878
Adjusted for ties	4	1.20	0.878

Figure 4.3.1: Summary report overall vibration data

Figure 4.3.1 above show that the data result is abnormal because of the P-Value is less than 0.05, so the median value will be selected which is show the value 0.33. Maximum value recorded is 1.21 which is less than maximum allowable reading permitted 1.4 in ISO 10816-3. Based on 95% of confidence interval for median, the minimum vibration is 0.32 and maximum is 0.34, therefore the reading still below the maximum allowable reading.

Kruskal-Wallis test Vibration data (mm/s) versus month

When see the overall graphical summary report for vibration is all indicated abnormal because the P-value is lower than 0.05, Kruskal-Wallis test will be used to precise the comparison results as per figure 4.3.2.

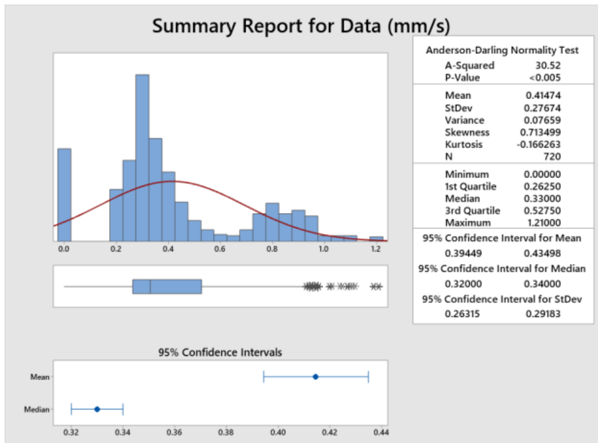


Figure 4.3.2: Kruskal-Wallis test Vibration data

The Kruskal-Wallis result from Figure shows the P-value is 0.878 which is higher than 0.05 and thus the result test is normal. So, the Null hypothesis (Ho) is accepted whereby the overall result indicate that all medians are equal. In other words, the overall vibration reading from month Dec 2020 until April 2021 are showing no obvious different reading within this five month and at the same time the overall reading absolutely is within the allowable range

Result analysis on overall lubrication data

In this research, lubricant analysis is carried out two times from Dec 2020 until April 2020 whereby the sample is taking on month Feb 2021 and April 2021 for all six pumps at HPU 1. There are 3 types of parameters for lubricant analysis conducted in this research which are Kinetic Viscosity @ 40 Deg c, Total Acid Number (TAN) and Water Content. Based on data collected, the result will help to see the rate or number of changes either it’s exceeding the limitation or not.

Summary report for Kinetic Viscosity at 40 Deg C

First lubricant analysis is about Kinetic Viscosity at 40 Deg C of lubricant data from all six pump at HPU 1. The data is summarized from month Dec 2020 until April 2021 whereby the sample is taking on month Feb 2021 and month April 2021. Figure 4.4.1 below show that the data is normal because of the P-value is 0.528 which is more than 0.05 and hence, the mean reading will be taken which is 41.542 cSt. The maximum value for Kinetic Viscosity at 40 Deg C permitted is 48.8 cSt and the minimum value is 0.00 cSt as per standard ASTM D445. Based on 95% of confidence interval for mean, the minimum reading is 40.796 and maximum is 42.288, therefore the reading still below the maximum allowable reading.

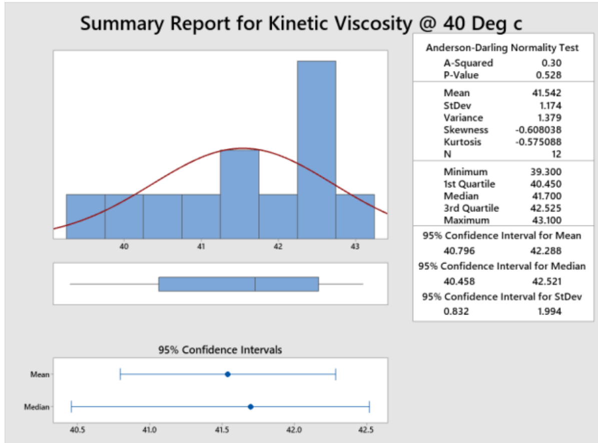


Figure 4.4.1: Summary report for Kinetic Viscosity at 40 Deg C

Summary report for Total Acid Number (TAN)

Second lubricant analysis is about Total Acid Number (TAN) of lubricant data from all six pump at HPU 1. The data is summarized from month Dec 2020 until April 2021 whereby the sample is taking on month Feb 2021 and month April 2021. Figure 4.4.2 below show that the data is normal because of the P-value is 0.348 which is more than 0.05 and hence, the mean reading will be taken which is 0.068 mg KOH/g. The maximum value for Total Acid Number (TAN) permitted is 0.31 mg KOH/g and the minimum is 0.00 mg KOH/g as per standard ASTM D664. Based on 95% of confidence interval for mean, the minimum reading is 0.063 and maximum is 0.073, therefore the reading still below the maximum allowable reading.

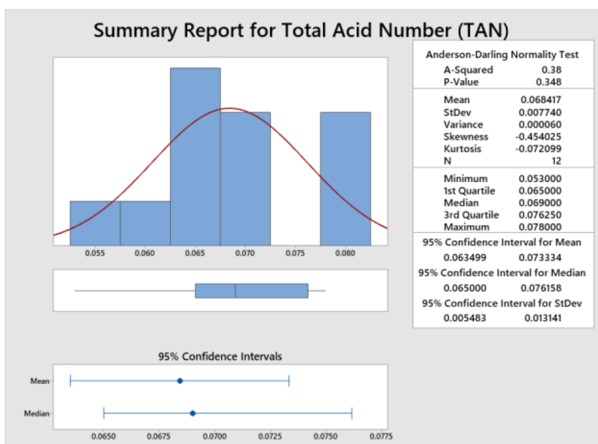


Figure 4.4.2: Summary report for Total Acid Number (TAN)

Summary report for Water Content

Third lubricant analysis is about Water Content of lubricant data from all six pump at HPU 1. The data is summarized from month Dec 2020 until April 2021 whereby the sample is taking on month Feb 2021 and month April 2021. Figure 4.4.3 below show that the data is normal because of the P-value is 0.589 which is more than 0.05 and hence, the mean reading will be taken which is 0.024 ppm. The maximum value for Total Acid Number (TAN) permitted is 0.045 ppm and the minimum is 0.00 ppm as per standard ASTM D6304. Based on 95% of confidence interval for mean, the minimum reading is 0.019 and maximum is 0.029, therefore the reading still below the maximum allowable reading.

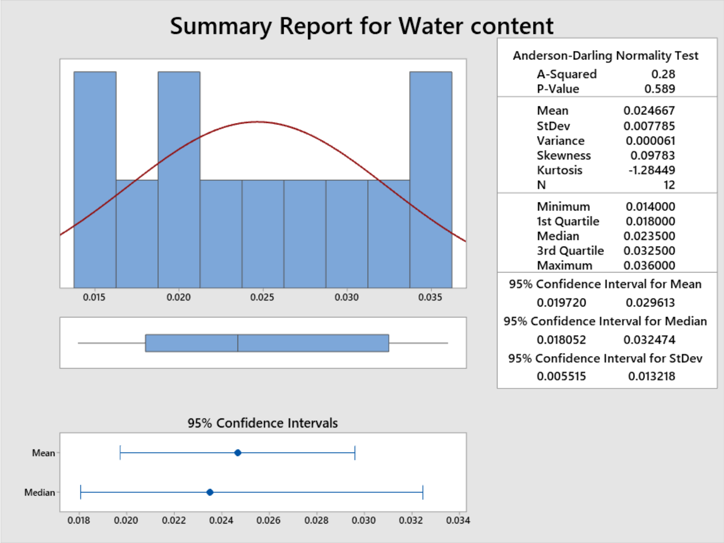


Figure 4.4.3 Summary report for Water Content

Rotating Expertise Feedback (REF) - Kendall's Coefficient of Concordance

In this study, the feedback from rotating expertise at PIC was conducted to support the proposal of New Recommendation Schedule (NRS) of an ideal preventive maintenance consumable item for HPU rotating pump. This feedback was conducted through a survey and base on three attribute which are Pump performance, Pump Reliability and Pump Maintenance cost. Each quality attribute contains several requirements and responses from the team were uniquely coded to ensure better traceability and identification when analysing in SPSS. Table 4.5.1 below shows the requirement in the survey with its code.

Table 4.5.1: REF quality attributes and requirements with coding

Code	REF on pump Performance - The indication of NRS will sustain it performance following the standard operation over a specified time interval
P1	Pump performance still good when implement NRS
P2	NRS helping in reduce downtime for maintenance
P3	NRS contribute to increasing the optimization of pump performance
Code	REF on pump Reliability - The ability of NRS will not fail to perform its intended function over a specified time interval
R1	NRS can implement permanently
R2	NRS not effecting pump lifetime
R3	The possibility pump damaged is low during implement NRS
Code	REF on Pump maintenance cost – The implication of NRS on overall maintenance cost
C1	NRS will reduce man power working hours on preventive maintenance
C2	Consumable item used for maintenance will be reduced
C3	Optimize the maintenance operation with ideal ratio between man power and rotating equipment.

The team was requested to rank the REF survey based on the level of acceptance criteria. Scale 1 and 2 show the NRS need further improve and scale 3 and 4 shows the NRS meet the requirement. The result of the survey is summarized in Table 4.5.2. The result shows the NRS is good to be implement and make it permanent. The data were subsequently analysed with Kendall's coefficient of concordance (W) to assess the agreement among the member of the team.

Table 4.5.2: Result of REF survey

	Mr. Mngr A	Mr. Engg B	Mr. Engg C	Mr. Engg D	Mr. Planner E	Mr. Supv F	Mr. Supv G	Mr. Supv H	Mr. Tech I	Mr. Tech J	AVG
P1	4	3	4	3	4	4	4	4	3	4	3.70
P2	4	3	4	3	4	4	4	4	3	4	3.70
P3	4	3	4	4	4	4	4	4	3	4	3.80
R1	4	3	4	3	4	4	4	4	3	4	3.70
R2	4	3	3	3	4	4	3	4	3	4	3.50
R3	4	3	4	3	3	4	4	3	4	4	3.60
C1	4	3	4	3	4	4	4	4	3	4	3.70
C2	4	3	4	3	4	4	4	4	4	4	3.80
C3	4	3	4	3	4	4	4	4	3	4	3.70

The analysis result of Kendall's coefficient of concordances (W) via SPSS is shown in Figure 4.4.5 below. From there, the result shows the Kendall's coefficient of concordances and p-value are 0.714 and 0.000 respectively. The Kendall's W show a strong agreement among the team member and at the same time the p-value is less than 0.05, thus the finding shows there is a significant agreement among the team member.

Test Statistics

N	9
Kendall's W[a]	.714
Chi-Square	57.871
df	9
Asymp. Sig.	.000

a. Kendall's Coefficient of Concordance

Figure 4.4.5: Kendall's Coefficient of Concordance test statistic result

Overall Data conclusion

In conclusion, this chapter is showing the result of vibration and lubricant analysis that using several descriptive and comparison method via Mini Tab application for the reference and evident before comparing the frequency of replacement lubricant of selected pump at HPU 1.

From the both result vibration and lubricant analysis, generally there are no significant reading that exceeding the limitation standard allowable for pump operation from month December 2021 until month May 2021 that maintaining using the existing lubricant. Even there are some increasing trending either form vibration or lubricant result, actually this is a normal trending but overall reading is still accepted and are safe for management to decide for extending the frequency schedule for lubrication consumable changing.

Other than that, the survey result from Kendall's coefficient of concordance (W) shows that the strong agreement among the team member and also the p-value is less than 0.05, therefore shows there is a significant agreement among the team member. From there, this REF survey basically is agreed on proposal of new schedule preventive consumable item for HPU rotating pump. This evident become a crucial supportive document when implement the new schedule.

CONCLUSION AND RECOMMENDATION

Review of the findings

Implementation of an ideal frequency of preventive maintenance program (consumable item) of rotating pump in HPU at Pengerang integrated complex (pic) is one of effort to improve the quality of equipment, reliability, safety and economy for overall maintenance processes. According to Lin et al. (2015), Preventive maintenance activities performed at a high reliability threshold can not only significantly improve the system availability but also efficiently extend the system lifetime.To ensure the pump's efficacy, efficiency, and dependability, the maintenance schedule must be analysed to determine the best time to perform maintenance while avoiding process interruption (Yunlong, Z., & Peng, Z. 2012). Therefore, beside the aim of objective to study on optimization maintenance schedule, the criteria of pump condition are based on standard requirement must be complied before making the schedule decision.

With the current challenging situation, company survivor is the most priority and thus, with a great management and decision, it will lead to business sustainable and moving forward to success. Base on two methods from vibration and lubricant analysis on the selected pump at HPU 1, there are evident and reference that can used for the selection of ideal schedule preventive maintenance especially for consumable lubrication changing. Therefore, from the analysis result of chapter four previously, this research will be proposed the new ideal preventive maintenance consumable item schedule that align with this research objective.

Limitation of the research

a) Limited access to the private pump data

b) Number of Respondents

c) Limited Literature Review Research

d) Cannot Generalize to all industry

Future recommendation

Table 5.3.1 below was the existing (old) Schedule Preventive Maintenance Consumable Item for HPU 1 pump. From this schedule, it shows that the frequency for lube oil changing is every three (3) month cycle in a year which is on month February, May, August and November. Although the condition is still good and acceptable as per result in this study, the existing schedule basically is not an ideal timing in term of maintenance optimization concept and thus the alternative schedule as per Table 5.3.2 below can slot in to become an ideal option.

Table 5.3.1: Existing (old) Schedule Preventive Maintenance Consumable Item for HPU 1 pump

Pump Tag	MONTH											
Number	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV
1511-P-741 A			LUBE OIL CHANGING			LUBE OIL CHANGING			LUBE OIL CHANGING			LUBE OIL CHANGING
1511-P-741 B												
1511-P-761 A												
1511-P-761 B												
1511-P-701 A												
1511-P-701 B												

Table 5.3.2: New recommendation Schedule Preventive Maintenance Consumable Item for HPU 1 pump

Pump Tag	MONTH											
Number	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV
1511-P-741 A			EXTENDED TIME			LUBE OIL CHANGING			EXTENDED TIME			LUBE OIL CHANGING
1511-P-741 B												
1511-P-761 A												
1511-P-761 B												
1511-P-701 A												
1511-P-701 B												

In this research recommendation on new schedule preventive maintenance consumable item for HPU 1 is illustrated as per Table 5.3.2 above. This new schedule actually is based on the both vibration and lubricant analysis result and because of good trending condition of selected pump at HPU 1, therefore the frequency of preventive maintenance consumable item (lubricant) can be differed up to six-month cycle. In addition, the lube oil changing (preventive consumable maintenance) will be implement. This proposal from condition-based maintenance strategy is help in determine the optimal action (e.g., no action and corrective replacement) based on the system state in order to minimize the average cost rate (Wei, G., Zhao, X., He, S., & He, Z. 2019). With this new schedule, it will be affected to reduce the maintenance cost rate base on man power cost, consumable item usage and also inventory cost.

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