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Using Reliability Centered Maintenance to Reduce Operational Cost of Heat Exchanger and Feed Water Pump in a Brewery

Ogra, Olatunbosun Abiodun, Nkoi, Barinyima and Isaac, Elemchukwu O.
Mechanical Engineering Department, Rivers State University, Port-Harcourt, Nigeria.
morellaus@yahoo.co.uk +2347031377217

ABSTRACT

In this research, reliability-centered-maintenance (RCM) was applied to reduce the operational cost of heat exchanger and feed water pump in a brewery. The feed water pump and heat exchanger system were selected for RCM analysis as they both have significant impacts on the quantity and quality of the beer produced in the brewery. The failure mode effects and criticality analysis (FMECA) of the production systems were examined, and a maintenance task was developed for the systems. The exponential reliability method was employed to analyse the failure data collected from the maintenance logbook and records to determine the reliability of their feed water pump and heat exchanger systems for operational cost efficiency. Broad based results showed that the RCM had great impact on the preventive maintenance (PM) tasks. The Run-To-Failure (RTF) frequency was reduced. The result showed that by carrying out the proposed RCM labour plan- the labour cost decreased from ₦108, 000, 000.00/year to ₦67, 200, 000.00/year with the proposed PM task. The results showed that about 36.19% of the annual spare parts cost are saved when proposed PM planning is adopted other than the current maintenance (RTF) plan. The maintenance program applied in this study could be adopted by production firms to improve upon the reliability and operational cost of their production equipment.

KEYWORDS: Brewery, Feed Water Pump, Heat Exchanger, Operational Cost, Reliability Centered Maintenance.

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1.0 INTRODUCTION

Management of production industries considers maintainability, availability, and reliability as some of the most important requisite for effective use of their production equipment and components. Failures and breakdown in brewery equipment led to several problems such as high maintenance cost, reduced production output and catastrophic accidents. Thisis a major concern of this research work as it affects beer production cost and time. Reliability Centred Maintenance (RCM) is a systematic approach to determine the maintenance requirements of plant and equipment in its operating system. It is used to optimize preventive maintenance (PM) strategies as it ensures that maintenance tasks are performed in an efficient, cost-effective, safe, and reliable manner.

New research shows that the issue of using reliability centered maintenance to reduce operational cost of production equipment is receiving considerable attention. Bhangu *et al*. (2011) focused on reliability centred maintenance in a thermal power plant: a case study, Ahasan (2015) studied an application of reliability centred maintenance in lead oxide production system while Bergman (1999) studied reliability centred maintenance applied to electrical switchgear. Damon *et al*. (2006) studied reliability centred maintenance study on voltage regulators. Eti and Probert (2004) investigated the reliability of the Afam Electric Power Generating Station, Nigeria. Harmesh *et al*. (2009) evaluated the implementation of reliability centred maintenance in lamp manufacturing unit while Iselin (2015) studied the application of RCM to construct a maintenance program for a maritime vessel, and Goodfellow (2000) applied reliability centred maintenance to overhead electric utility distribution systems.

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Most studies related to reliability centered maintenance considered other production systems such as electrical switched gears, lamp manufacturing unit, voltage regulators, but this study provides evidence of optimizing maintenance actions for heat exchanger and feed water pump which reduces their operational cost. This fills up the research gap bordering on applying RCM to reduce heat exchanger and feed water pump's operational cost as the approach this study applied resulted in performing optimal and cost-effective set of maintenance actions for high priority (more critical) subsystems of the equipment.

The objectives of this study include:

i. To examine the failure mode effects and criticality analysis of the feed water pump and heat exchanger in a brewery.
ii. To analyse the reliability of the feed water pump and heat exchanger.
iii. To develop a maintenance task for the feed water pump and heat exchanger centred on the analysed reliability indices with operational cost savings.

Reliability is defined as the ability of equipment or its parts to perform its required functions under stated conditions for a specific period of time. Maintenance refers to all the activities suitable for keeping equipment or its part in operation. Reliability-centered maintenance is a technique used to identify the maintenance demands of any operational equipment.

The reliability centered maintenance program consists of condition-based maintenance, preventive maintenance, reactive maintenance, and proactive maintenance, as shown in Figure1.

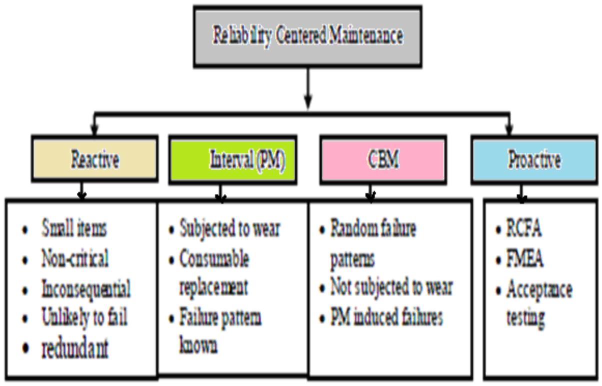

Figure 1: Components of Reliability-Centred Maintenance (Samuel *et al*. 2018).

1.1 Feed Water Pump System in Brewery

The brewery uses centrifugal pumps (see Figure 2) to increase the water pressure; high enough so it can be pumped into the boiler drum for the wort boiling process. It helps maintain proper working of a boiler or brew kettle providing continuous feed water supply. A continuous feed water supply is essential for the brew kettle as it not only avoid overheating but any further damage to the boiler which could affect the brewery process. The pumps also feed water for malt mashing and the wort fermentation processes.

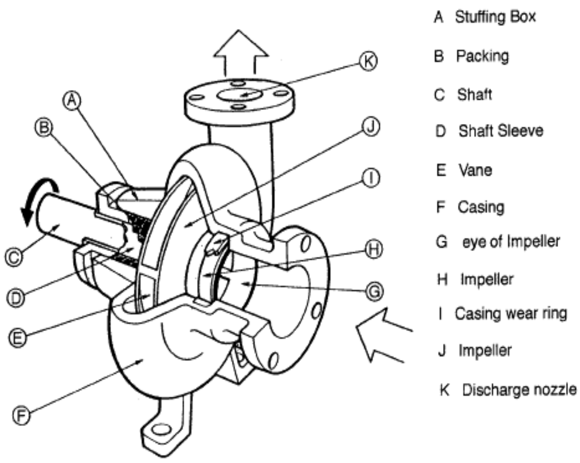

Figure 2: Components of Centrifugal Pump System (Singh &Suhane, 2013).

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1.2 Heat Exchanger System in Brewery

Heat exchangers are mechanical process equipment in which heat is continuously or semi-continuously transferred from a hot to a cold fluid directly or indirectly through a heat transfer surface that separates the two fluids (see Figure 3). The heat exchanger in a typically brewery is a piece of equipment designed to quickly raise or lower the temperature of wort or beer.

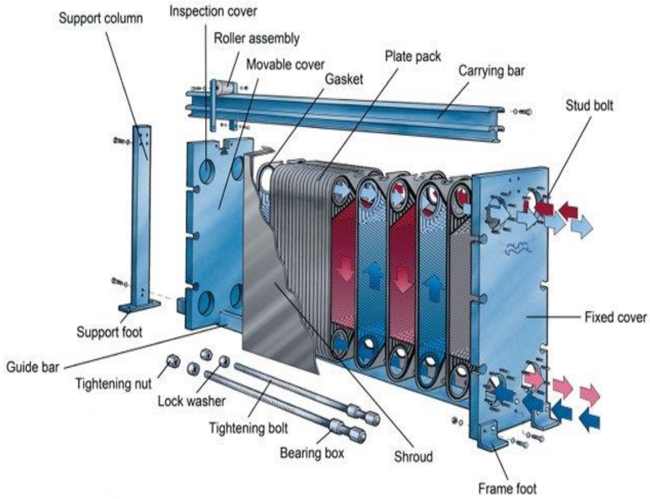

Figure 3: Components of Plate Heat Exchanger (Muller-Steinhagen, 2000)

1.3 Functional Block Diagram

The functional block diagram for the brewery process showing the input resources and output for the brewery equipment is introduced in Figure 4.

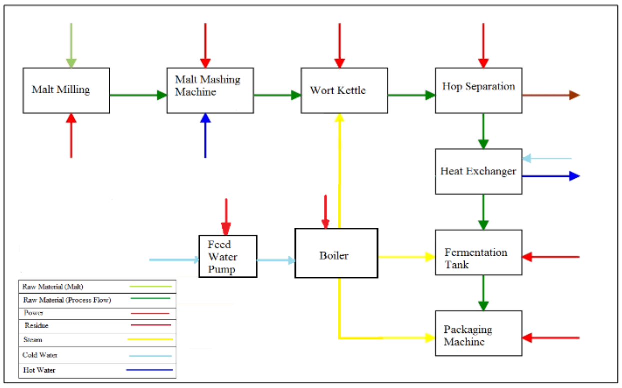

Figure 4: Functional Block Diagram of the Brewery System

In this lay out, the feed water pumps, and heat exchanger systems has significant impact on beer production capacity and are selected for RCM analysis.

2.0 MATERIALS AND METHODS

Failure data of the heat exchanger and feed water pump equipment that was obtained from International Brewery Plc were materials used to analyze the production equipment's reliability.

2.1 Reliability-Centred Maintenance Methodology

As shown in Figure 5, the RCM steps are as follows:

Step1: system selection and data collection.
Step2: system boundary definition.
Step3: system description and functional block.
Step4: system function functional failures.
Step5: failure mode effect analysis
Step6: logic tree diagram.
Step7: task selection.

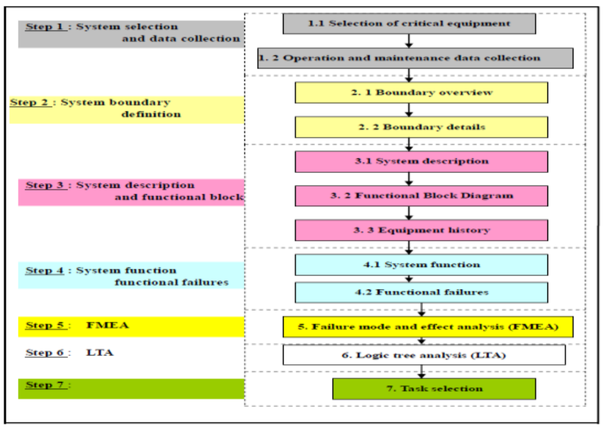

Figure 5: Main steps of the RCM (Samuel *et al.*, 2018).

2.2 System Selection and Data Collection

Selection of system and data of the system components is one of the first steps in RCM. The data is required by the parameters for the reliability analysis which are as follows:

i. Meantime between failures (MTBF).
ii. Mean time to repair (MTTR).
iii. Failure rate (λ)
iv. Availability (A)
v. Repair rate

2.2.1 Mean Time Between Failures (MTBF)

The MTBF is a basic measure of reliability for repairable items and is estimated by:

$$MTBF = \frac{\sum t_I}{n} \quad (1)$$

where:

$\sum t_I$ = the total running time in operation of the system during an investigation period.

n = number of failures (breakdowns) of the system occurring during a certain investigation period.

2.2.2 Mean Time to Repair (MTTR)

Mean time to repair is defined as the average time to fix and return failed equipment back in operation. It is given by:

$$MTTR = \frac{\sum t_i}{n} \quad (2)$$

where:

$\sum t_i$ = total accumulative time of the system to repair or maintain in statistical time.

n = number of repair actions in the population of the system during the specified investigation time period.

2.2.3 Failure Rate (λ)

Failure rate is defined as the rate at which failure occurs. It is the inverse of the meantime between failure parameters. Mathematically,

$$\lambda = \frac{1}{MTBF} = \frac{n}{\sum t_1} \quad (3)$$

where:

$\sum t_I$ = the total running time in operation of the system during an investigation period.

n = number of failures (breakdowns) of system occurring during a certain investigation period.

2.2.4 Availability

The availability measure is used for system as failure consequences lead to economic losses. It is given by:

$$A = \frac{MTBF}{(MTBF + MTTR)} \quad (4)$$

2.2.5 Repair Rate

Repair rate is the rate at which repair, and troubleshooting occurs. It is the inverse of the meantime to repair parameter. Mathematically,

$$\mu = \frac{1}{MTTR} \quad (5)$$

2.2.6 Reliability

Reliability is defined as the probability of an item or system to perform its intended function without failure under stated condition within a specified period of time, given as:

$$R(t) = e^{-\lambda t} \quad (6)$$

where:

t = time in operation.

2.2.7 Logic Tree Analysis (LTA)

The basic LTA uses the decision tree structure shown in Figure 6. Figure6 recognized safety, outage and economic related resolution.

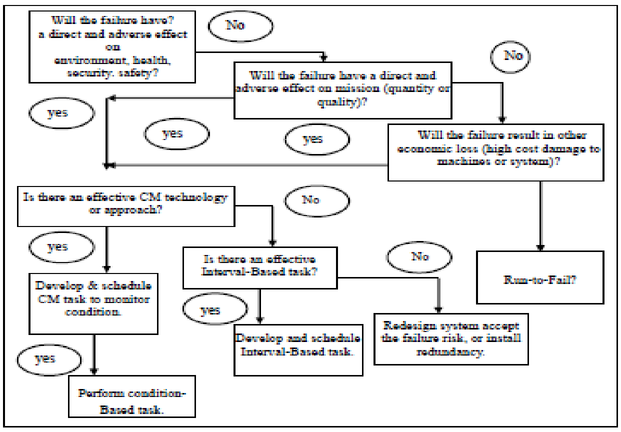

Figure 6: Logic Tree Analysis (Samuel *et al*., 2018).

2.2.8 System Root Cause Failure Analysis (RCFA)

The root cause analysis is method of solving problem by identifying the root causes of faults or failures in equipment. It gives birth to the FMECA of the equipment.

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2.2.9 Failure Mode Effect and Criticality Analysis (FMECA)

Failure mode and effect analysis is a tool that examines potential product or process failures, evaluates risk and criticality priorities, and helps determine remedial actions to avoid identified problems.
Criticality analysis measures the impact of equipment failure on the performance of the industry so as to prioritize the maintenance action for the equipment and its reliability improvement initiatives. In Figure 7, flowchart for the calculation of equipment criticality is presented.

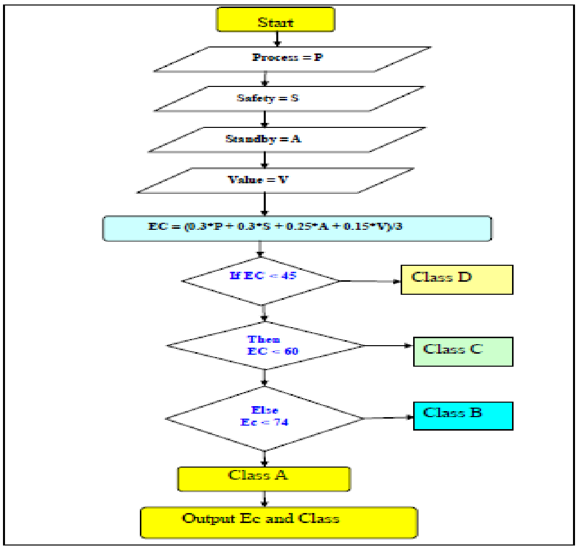

Figure 7: Equipment Criticality Flowchart

2.2.10 Maintenance Task Selection

Maintenance tasks are consisting of run-to-failure (RTF), time-directed maintenance (TD), condition-directed maintenance (CD) and failure-finding (FF) for the feed water pump and heat exchanger system that reduces the downtime in the system's operation, consequently reducing the running cost and thereby enhancing the system operation. The RCM approach identifies the root causes of the failures in systems and employs the appropriate maintenance approach for each failure based on the analysed failure mode, effect and criticality index of the system.

2.2.11 Data Collection and Analysis

Data of the operating time, downtime and number of failures for the brewery feed water pump and heat exchanger equipment was collected from troubleshoot datasheets and interviews with International Brewery Plc's staff. In the analysis, SPSS software and MATLAB computer program were employed to analyse and determine the reliability of the feed water pump and heat exchanger equipment in International Brewery Plc, Ilesha, for operational cost reduction.

3.0 RESULTS AND DISCUSSION

3.1 Reliability Analysis

These results for the feed water pump and heat exchanger reliability indices during the study periods 2018 and 2019 are presented in Tables 1 and 2 respectively.

Table 1: Reliability Indices for the Feed Water Pump System in International Brewery Plc

FWP	Operating Time (hrs)	Downtime (hrs)	MTBF (hrs/failure)	MTTR (hrs/repair)	Failure rate (failure/hr)	Repair rate (repair/hr)	Availability	Reliability
FWP-1A	14890.32	613.68	2481.20	102.28	0.000403	0.00978	0.9604	0.78
FWP-2A	14366.56	1137.44	1306.05	103.40	0.000706	0.00967	0.9266	0.42
FWP-1B	15612.42	491.58	2230.35	70.22	0.000448	0.01423	0.9695	0.80
FWP-2B	15, 094.87	409.12	3773.72	102.28	0.000264	0.00977	0.9736	0.89

The mean time between failures of the feed water pump system in the brewery is represented in Figure 8. The results show that, out of the four (4) feed water pump that makes the pumping system in the brewery, the feed water pump FWP-2B has the highest MTBF with 3773.72 hours and feed water pump FWP-1B has the lowest MTBF with 1306.05 hours within the study period.

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This result gotten and the research approach conform to the results obtained and the approach followed by previous research works as highlighted in the literature review of this work (Iselin, 2015; Bhangu *et al*. 2011; Ahasan, 2015; Samuel *et al*., 2018). These studies utilized the production systems' historical failure data to assess the maintenance metrics of the systems.

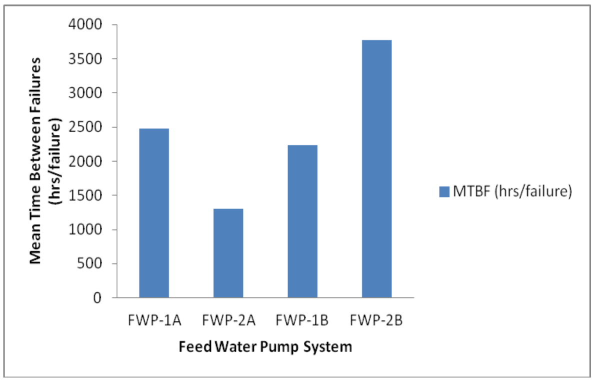

Figure 8: Feed Water Pumps' Mean Time Between Failures (MTBF)

The mean time between failures of the heat exchanger system in the brewery is represented in Figure 9. The results show that of the two (2) heat exchanger systems used in the brewery, the heat exchanger HEX-1A has the highest MTBF with 4975.83 hours and heat exchanger HEX–1B has the lowest MTBF with 2908.7 hours within the study period. This result gotten is in good agreement with the results obtained in the studies put forward by Bhangu *et al*. (2011), Ahasan (2015), Samuel *et al.*, (2018), as well as Iselin (2015)

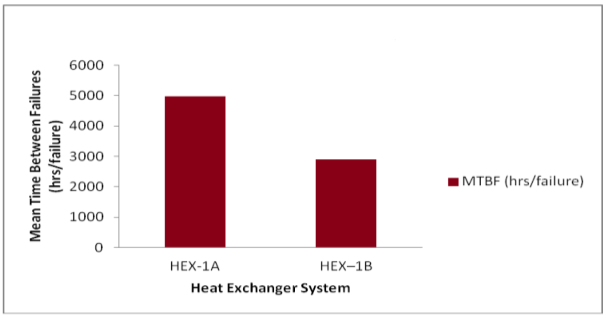

Figure 9: Heat Exchangers' Mean Time Between Failures (MTBF)

Table 2: Reliability Indices for the Heat Exchanger System in International Brewery Plc

HEX	Operating Time (hrs)	Downtime (hrs)	MTBF (hrs/failure)	MTTR (hrs/repair)	Failure rate (failure/hr)	Repair rate (repair/hr)	Availability	Reliability
HEX-1A	14927.50	576.50	4975.83	192.17	0.000201	0.00520	0.9628	0.89
HEX–1B	14543.50	1060.50	2908.70	212.10	0.000344	0.00471	0.9320	0.69

3.2 System Root Cause Failure Analysis (RCFA)

As shown in Tables 3 and 4, root cause failure analyses for the most critical feed water pump and heat exchanger equipment (that is FWP-2A and HEX–1B) in the brewery system are presented respectively which gave birth to the FMECA of the two equipment as seen in Tables 5 and 6.

Table 3: Feed Water Pump Root Cause Failure Analysis

Failure Mode	Mechanism	Reason	Root Cause
Pump low efficiency	Discharge pressure	Low discharge pressure	Water excessively hot
	Impeller	Low flow rate & low delivery pressure	Impeller damaged Impeller loss on shaft Flooding of oil reservoir Overfilling of oil reservoir Mechanical seal failure Improper installation of bearing
	Oil	Loss of oil contamination	
		Operation condition	Insufficient NPSH Water excessively hot
	Low flow		Impeller damaged or loose on shaft
Pump Shutdown	Bearing	High bearing temperature Operation condition Pump driver motor	Bent shaft Operation at low flow Misalignment of pump drive motor
	Vibration	Bearing Mechanical seal	Worn bearing Mechanical seal failure

Table 4: Heat Exchanger Root Cause Failure Analysis

Failure Mode	Mechanism	Reason	Root Cause
Heat Exchanger low efficiency	Fouling heat transfer surfaces	High resistance to heat transfer	Thermal overstress and cycling Chemical attack on heat transfer surfaces Foreign matters intrusion heat transfer surfaces degradation
	Plugging tubes	High pressure drop	Complete system blockages Internal leakages from seal Damaged tube sheet/joint Corrosion attack Thermal cycling, tube in contact with baffles
	Leakages from tubes	High pressure drop	Damaged gasket and O-rings Tube degradation by vibration
Heat Exchanger erosion-corrosion	Corroded heat transfer surfaces	High resistance to heat transfer	Foreign matters intrusion, Chemical attack from fluid Poor fluid temperature control Poor control of fluid velocities Thermal and hydrodynamic boundary layer interaction
Heat Exchanger Fouling	Fouling heat transfer surfaces	High thermal resistance	Foreign matters intrusion, Chemical attack from fluid Poor control of fluid temperature Poor control of fluid velocities

Table 5: Criticality Group.

Group	Criticality Index
A	3 - 2.5

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B	2.5 – 2
C	2 - 1.5
D	1.5 – 1

Table 6: Failure Mode and Criticality Analysis for the Feed Water Pump

Equipment	Failure Mode	Failure Cause	Criticality Analysis			Criticality Index	Group
			Safety	Production	Cost		
Pump	Low discharge pressure	Water excessively hot	2	3	1	2.2	B
		Bent shaft	3	3	3	3	A
		Worn bearing	3	3	2	2.8	A
	High bearing temperature	Lack of lubrication	3	3	2	2.8	A
		Improper installation of bearing	3	3	2	2.8	A
	Pump casing overheats	Misalignment of pump drive motor	3	3	3	3	A
		Shaft sleeve worn	3	3	3	3	A
	Low flow	Impeller damaged on loose shaft	3	3	3	3	A

Table 7: Failure Mode and Criticality Analysis for Heat Exchanger System

Item	Failure Mode	Failure Effect	Criticality Analysis	Criticality Index	Safety	Production Cost	Group
Heat Exchanger 1B	Corroded heat transfer surfaces	Chemical attack and degradation of heat transfer surfaces	2	3	2	2.4	B
		Leakages from heat transfer surfaces	3	3	3	3	A
		Tube degradation	3	1	1	1.8	C
		Loss of heat transfer	2	2	3	2.2	B
	Fouling heat transfer surfaces	Leakages from heat transfer surfaces	2	2	2	2	B
		Tube degradation	3	1	1	1.8	C
		Degradation of heat transfer surfaces	2	2	3	2.2	B
		Chemical attack on shell	2	3	2	2.4	B
	Leakages from tubes	Fluid contamination	3	1	1	1.8	C
		Degradation of Shell and Tube	3	3	2	2.8	A
		Loss of heat transfer	2	2	3	2.2	B
		Corrosion/fouling attack	2	2	2	2	B
	Plugging tubes	Tube degradation	2	1	2	1.6	C
		Leakages from heat transfer surfaces	2	3	2	2.4	B
		Degradation of heat transfer surfaces	3	3	3	3	A
		Loss of heat transfer	3	2	3	2.6	A

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3.4 Maintenance Task Selection

Maintenance tasks are consisting of run-to-failure, time-directed maintenance, condition-directed maintenance and failure-finding. The maintenance tasks for the critical equipment are illustrated in Tables 8 and 9.

Table 8: Feed Water Pump Maintenance Task.

Equipment	Failure Mode	Failure cause	Group	Task	Description	Frequency
	Low discharge pressure	Water excessively hot	B	CD	Check temperature of water	Monthly
		Bent shaft	A	CD	Check and replace bent shaft	Monthly
	High bearing temperature	Worn bearing	A	CD	Check and replace worn bearing	Monthly
Pump		Lack of lubrication	A	CD	Lubricate adequately	Monthly
		Improper installation of bearing	A	CD	Check bearing for improper installation	Monthly
	Pump casing overheats	Misalignment of pump drive motor	A	CD	Check pump drive motor for misalignment	Monthly
		Shaft sleeve worn	A	CD	Check and replace worn shaft sleeve	Monthly
	Low flow	Impeller damaged on loose shaft	A	CD	Check for loose shaft and replace damaged impeller	Monthly

Table 9: Heat Exchanger Maintenance Task.

Equipment	Failure Mode	Failure cause	Group	Task	Description	Frequency
		Foreign matters intrusion, Chemical attack from fluid	B	CD	Check fluid flow for foreign matter intrusion	Monthly
		Poor fluid temperature control	A	CD	Control fluid flow temperature, Routine pressure test	Weekly
	Corroded heat transfer surfaces	Poor control of fluid velocities	C	FF	Control fluid velocities, Routine pressure test	Weekly
		Chemical attack from fluid	B	CD	Check system flow for contaminants	Monthly
		Poor control of fluid temperature	B	CD	Check and control fluid flow temperature	Weekly
		Poor control of fluid velocities	C	FF	Control fluid velocities, Routine pressure test	Weekly
Heat Exchanger 1B	Fouling heat transfer surfaces	Foreign matters intrusion	B	CD	Check fluid flow for foreign matter intrusion	Monthly
		Corrosion attack	B	CD	Check system flow for contaminants	Weekly
		Thermal cycling, tube in contact with baffles	C	FF	Check temperature of flow	Weekly
	Leakages from tubes	Tube degradation by vibration	A	CD	Check interaction between boundary layers	Weekly
		Chemical reaction on tubes	B	CD	Check fluid for contaminants	Weekly
	Plugging tubes	Corrosion/fouling attack on tube	B	CD	Inspect and clean tube condition	Six Monthly
		Chemical attack on tubes	C	TD	Inspect and clean tube condition	Six Monthly
		Poor control of fluid temperature	B	CD		Weekly

			Check and control fluid flow temperature	
Internal leakages from seal	A	CD	Check seal for leakages	Monthly
Damaged tube sheet/joint	A	CD	Check tube for damages, Pressure test	Monthly

3.5 Maintenance Labour Force

The maintenance labour force is presented in Table 10. In addition, the savings in labour cost is introduced in Table 11. The proposed labour cost (₦103,320,000.00/year) decreased with respect to the current values (₦77, 280,000.00/year).

Table 10: The Size of Annual Maintenance Labour Force.

PM Level	Frequency	Duration (Hours)	No. of Workers	Man-hour per PM level
Six months	2	21	4	168
Months	10	5	2	100
Weekly	50	6.15	1	325

.

Table 11: Savings in the Labour Cost.

Item	Labour type	Number of labours Per day (Current maintenance)	Number of labours Per day (proposed)
Engineers (₦400, 000.00/month)	Mechanical	5	3
	Electrical	5	3
	Control	5	3
Technician (₦ 250, 000.00/month)	Mechanical	6	4
	Electrical	6	4
Total cost (Naira/year)		**108, 000, 000**	**67,200,000**
Saving cost (%) = 37.778			

3.6 Spare Parts Program

The proposed spare parts program is shown in Table 12. This table shows that the spare parts for the feed water pump main component. Proposed spare parts program results indicate a saving of about 36.192% of the spare parts total cost as compared with that of the current maintenance (CM).

Table 12: Proposed Spare Parts Plan (Yearly).

Equipment	Spare part	Quantity (Current)	Cost (current) ₦ /year	Quantity (Proposed)	Cost (Proposed) ₦ /year
Feed water pump	Coupling	3	1, 800, 000	1	600, 000
	Mechanical seal	6	4, 800, 000	4	3, 200, 000
	Motor bearing	6	9, 600, 000	4	6, 400, 000
	Pump bearing	6	4, 800, 000	4	3, 200, 000
Total cost (₦ /year)			**21, 000, 000**		**13, 400, 000**
Saving cost %			**36.19%**		

4.0 CONCLUSION

The results of the RCM technique applied to the brewery plant show that the Run-To-Failure frequency has been reduced. The preventive maintenance task was made up of scheduled reliability-centered maintenance which had great impact on the routine maintenance task by recommending the tasks to be carried out monthly and six-monthly. With the proposed labour program carried out, the results show that the labour cost decreases from ₦108, 000,000.00/year to ₦67, 200,000.00/year for the proposed PM planning.

The proposed spare parts plan for the brewery equipment is generated. The results showed that about 36.19% of the annual spare parts cost are saved when proposed PM planning is adopted other than the current maintenance plan.

5.0 ACKNOWLEDGEMENTS

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