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The Use of Equipment Condition Monitoring Techniques on Cost Reduction in the Chemical Industry: A Case Study

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ABSTRACT:
In this study, reducing the running cost of a chemical plant, and also increasing profitability using equipment condition monitoring (ECM) were done. Condition monitoring data of critical equipment were collected from case study plant and different condition monitoring techniques were used for analysis. A regular bearing failure of a turbine led to carrying out a root cause of failure analysis (RCFA) using ishikawa diagram. The analysis revealed lube oil as the culprit, a lube oil analysis was done using Spectro oil analyzer (Spectro-Q153) which showed high water in oil of about 41,250ppm and a viscosity of 287.5cst. Cost benefit analysis were done on four equipment. The cost analysis revealed that ECM increased availability of all equipment and a downtime savings of 35.89% for Waste Heat Boiler (WHB), 88.2% for Firebox, 60% for Aux. Boiler, and 70.8% for the Carbonate pump turbine was achieved. Also achieved was a savings on Total Maintenance Cost of ₦3,328,389,446 for WHB, ₦11,376,330,000 for Firebox, ₦1,306,198,614 for Aux. boiler and ₦1,776,304,000 for the Carbonate pump turbine. This research proposed running a steam turbine at a pressure good enough to constantly get rid of steam condensate which is a high source of water in oil. The findings revealed that though setting up an ECM program may be expensive in the early stage, it promised great financial savings as related to maintenance and downtime cost. This savings tends to increase profitability of a firm.

KEYWORDS: Condition Monitoring, Critical Equipment, Downtime, Lube oil Analysis, Maintenance Cost.

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1. INTRODUCTION:

Shutdown of most chemical industries are caused by planned maintenance activities and repairs, or by failures. According to Ciprian and Loránd (2012), in most industrial processes, unplanned stops due to failures have a high economic impact on the cost of the process and may result in significant process downtime. In any case, their shutdown brings financial losses, increases environmental pollution and sharply intensifies process of wear of the equipment because of negative influence of shock arising from sudden shut-down and start-up of the equipment. To successfully run a chemical plant, the role of maintenance cannot be over emphasized as lack/ no maintenance poses a great challenge/risk to the personnel, equipment and the environment. Poor maintenance strategies can substantially reduce a plant's productive capacity and no-good establishment will joke with it else its repute and the company remaining in business is at stake.

The desire of every management team is to operate ageing equipment for longer durations as to sustain production output and satisfy market demand while running on minimum cost. To achieve this, there is a need for stringent maintenance which aim at operating equipment within their agreed limits and ensure minimal outage which could result in production losses, costly maintenance activities and severe safety and environmental hazards. Condition Monitoring (CM) is a predictive maintenance technique that forms a vital part of mitigating these risks and ensuring the company's sustainability. The cost and uptime trade-off of preventive and reactive maintenance (i.e., repair) must be balanced. This can be achieved via condition monitoring (Akula *et al.*, 2017). Incessant failure/breakdown of critical equipment in a chemical plant can lead to loss of production, reduced productivity, reduced customer satisfaction, loss of relevance in the competitive market and reduce profitability. According to Wever (2008), downtime in one unit can affect productivity down the line; relying principally on time-based preventive maintenance to protect equipment from failure was inefficient and did not prevent production losses making it a very costly strategy, exceeded only by letting equipment run to failure and then reacting in emergency mode. To avoid this, comes the need for condition monitoring; a maintenance strategy aimed at reducing plant downtime and increasing plant uptime, a maintenance strategy that can detect failure in its incipient stage and a decision to arrest the failure at a low maintenance cost.

Since the purpose of every business is to make profit; to achieve that, the productivity of the firm should be on the steady increase with minimal downtime. This study shows maintenance manager, plant manager and the production manager a means of using a more proactive maintenance program rather than reactive maintenance to reduce the running cost of a chemical plant and also increase profitability. The process plant used for this study is located in Rivers state, Nigeria. The work looks at different condition monitoring techniques used in critical equipment of an Ammonia/Urea plant only, compares the cost of using condition monitoring with the other generic maintenance method. To achieve this the following objectives were considered: To undertake an equipment root cause failure analysis (RCFA), to analyze the financial benefits of using equipment condition monitoring, to show that equipment condition monitoring can increase plant uptime. Kothamasu *et al*. (2006) developed taxonomy of maintenance concepts where they divided maintenance into two facets, namely, planned and unplanned maintenance. Veldman *et al.* (2011) described unplanned maintenance as taking place after the failure has occurred while planned maintenance is proactive in nature.

Banga and Sharma (2008) identified two causes of breakdown of a machine and stated that in breakdown or corrective maintenance, defects are rectified only when a machine cannot perform its function any longer. This may disrupt the whole production if it is performing an important work. They concluded by saying that corrective or breakdown maintenance is much expensive. According to Mobley (2002), analysis of maintenance costs has shown that repairs made in a reactive mode are three times greater than the same repairs made on a scheduled basis. If the productivity of an organization must increase, there is need to reduce cost and increase production. One of such ways of cost reduction and production increase is by the use of Equipment Condition Monitoring. Mellor (2012) asserted that condition Monitoring is frequently deployed as part of an asset management strategy and brings promises of significant savings in maintenance costs and improvements in production capacity.

Ruiz-Cárcel *et al*. (2016) highlighted that most modern installations are heavily automated with much of the process data already available to monitor the condition of systems. According to Banga and Sharma (2008), the health of equipment is regularly monitored and recorded in the form of mechanical vibrations, noise, acoustic, thermal emissions; change in any of the recorded parameter help in diagnosis and detection of faults. According to Bill (2017), to eliminate bearing failure, you must first identify the cause. On that score, most experts are already in agreement, that poor or inadequate lubrication is the primary cause of industrial equipment wear and failure. A factor is considered the root cause of a problem if removing it prevents the problem from reoccurring. According to Nancy (2005), Ishikawa analysis can be used when identifying possible causes for a problem and when a team's thinking tends to fall into ruts.

If the benefit proposed is not translated to monetary figures, management most times do not invest into an idea no matter how technically sound it may seem. This work presents in figures the financial benefit ECM tend to give to plant management and upper management which will aid in decision making.

2 MATERIALS AND METHODS:

2.1 Materials

The materials used for this study are: The critical equipment of the ammonia plant used as the case study (turbine, waste heat boilers, auxiliary boiler and the firebox), lube oil samples collected from

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the lube oil console of a turbine, Spectro oil analyzer (Spectro-Q153), SDT-270, Pyrometer (Cyclops C390), Sonaphone.

2.1.1 Sources of Data Collection

Most information as it relates to this study was collected using primary and secondary data. The primary data consists personal interviews, Field observations were necessary like observing how ECM data are being taken in the field, observing a centrifuge operation. Secondary data used include reviewing of existing literatures on condition monitoring, textbooks, the company annual and published gazettes and maintenance logbook.

2.2 Methods

Maintenance data of critical equipment were collected from the case study plant and comparative analysis done to show that ECM was a good cost reduction tool than the conventional maintenance strategy.

2.2.1 Analytical Techniques

These are methods for the analysis of some problems, here brainstorming, fish bone analysis, and the 80/20 rule was used to do a root cause of failure analysis (RCFA) to proffer a lasting solution to a consistent bearing failure of a turbine

(a) Ishikawa Analysis (Fish Bone Analysis)

The consistent bearing failure of the semi lean carbonate pump turbine led to a high accrued maintenance cost and loss of production which in turn led to reduction in profit. Root cause analysis was done using Ishikawa analysis also known as Fish bone analysis. The analysis revealed many possible causes of the failure as seen in figure 1. From experience, the 80/20 rule was used and other possible causes of failure were eliminated revealing labyrinth seal failure to be the culprit. This failure occurred as a result of poor/no lubrication and when that was resolved the failure rate for that equipment reduced.

EFFECT

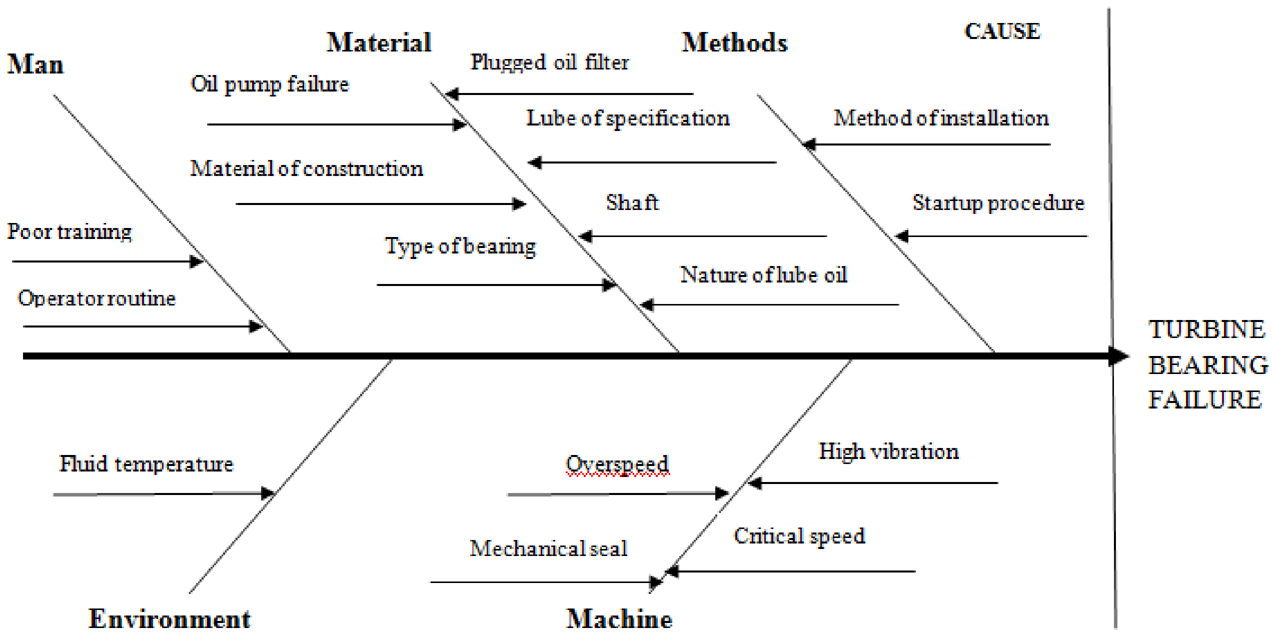

Figure 1: Fish-bone Diagram of Bearing Failure

2.2.2 Lube Oil Analysis

Machines don't just die, people murder them. Going by this statement, and the result from the root cause analysis, a lube oil analysis was carried out using Spectro oil Analyzer (Spectro-Q153), then an advice from the ECM team was issued.

Lube oil sample was collected from the field using lube oil cup sample collector, the lube oil sample is then analysed in the mini-lab where different internal parameters of the machines will be revealed. Figure 2 show a set-up of the Lube oil mini-lab spectro analyzer.

Figure 2: Lube Oil Mini-lab Spectro (Q-153)

2.2.3 Financial Analysis

Financial analysis was used to confirm the cost implication and show if truly ECM is a cost reduction tool in the chemical industry as compared to other maintenance process. This was achieved using a comparative cost benefit analysis.

Maintenance cost parameters of both ECM and that of the generic corrective maintenance was calculated and a comparison made. This forms part of the comparative cost analysis used in the study. The following maintenance cost impacting tool and formula will be used to show that ECM is a better option of maintenance. They are as follows:

(a) Total Maintenance Cost

The total maintenance cost of an equipment is obtained by the addition of the downtime cost of that equipment, (which includes cost of production loss) to the cost of maintenance (which includes repair cost, cost of removing broken parts, replacing cost, installation cost, labor cost etc.).

$$TMC = C_D + C_M \quad (1)$$

where, TMC = Total Maintenance cost
C_D = Cost of downtime
C_M = Cost of maintenance

(b) Mean Time to Repair (MTTR)

Mean time to repair (MTTR) is the average time required to troubleshoot and repair failed equipment and return it to normal operating condition.

$$MTTR = \frac{\text{Total maintenance time}}{\text{Total number of repairs}} \quad (2)$$

(c) Availability (A)

Total availability is the required availability minus the downtime, divided by the required availability.

$$A = \frac{AR - D}{AR} \times 100 \quad (3)$$

$$OH = AR - D \quad (4)$$

$$AR = TO - DP \quad (5)$$

$$TA = \frac{OH}{AR} \times 100 \quad (6)$$

$$OT = TAT - D \quad (7)$$

where, A = Availability
AR = Required availability
D = Downtime
OH = Operating hour
TO = Time to operate
DP = *P*lanned downtime
TA = Total availability
OT = Operating time
TAT = Total available time.

(d) Downtime

The downtime of equipment is the actual time the equipment is down for repairs or change over.

$$D = \frac{DT}{\text{Available hour per shift}} \times 100 \quad (8)$$

Cost of downtime is given mathematically as:

$$CD = DC \times D \quad (9)$$

where, D = Downtime,
DT = Total downtime,
CD = Cost of downtime,
DC = Downtime cost.

2.3 Case Study where ECM Tools and Techniques Were Used in Predicting Failures

Case study 1: 101-CA/CB Predicted Failure

Thermographic survey of both equipment indicating the point of incipient failure and point of functional failure of the equipment is shown in Figure 3. As the temperature differential increases, it shows failure of any one of the two vessels. Allowable temperature differential limit is 10°C; at this temperature differential point it is an indication of incipient failure. An advice to shut down the plant and fix the equipment was given but the plant ran beyond the time agreed to fix the equipment and subsequently there was a functional failure of the equipment.

Case Study 2: 101-B Predicted Failure Using thermograph and Ultra-Sound

Thermographic survey was done on the penthouse (101-B) using Infrared thermometer. The survey revealed that there was an impending failure on Row1 tubes.

Case Study 3: 101-BA Failure and prevented failure using Vibration Analysis

The vibration data of the Auxiliary boiler/burners were taken and trended, a high peak is an indication of impending failure. The vibration chart is as given in Figure 4. From the figure the highest vibration occurred on the 19th of February, 2018. Because of steam crisis the burner wasn't throttled as advised by ECM team and unfortunately the bearing failed.

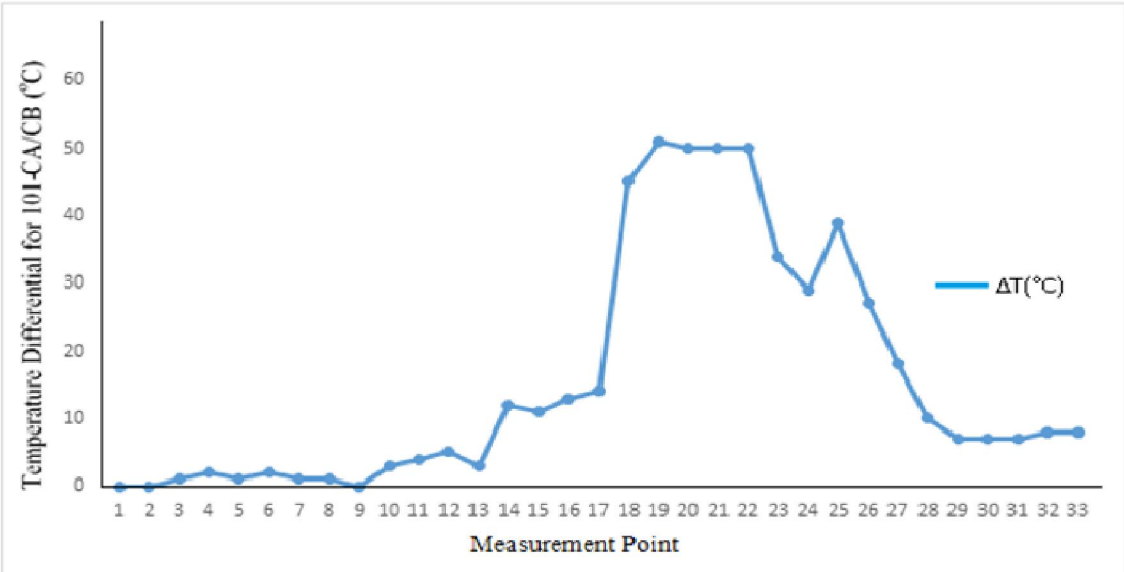

Figure 3: Thermographic Survey of 101-CA/CB Showing Failure

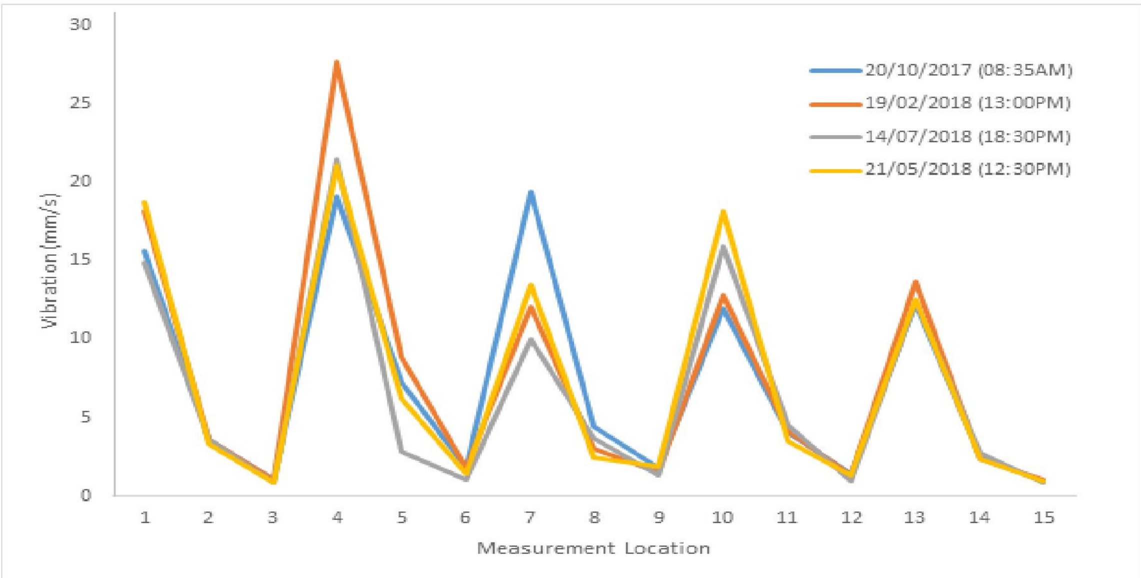

Figure 4: Vibration Chart Showing Highest and Lowest Peak

3. RESULTS AND DISCUSSION:

3.1 Results

Major critical equipment from the plant is selected for Condition monitoring. It is important to note that a functional failure of any one of this equipment will lead to loss of production. Hence, all equipment listed in Table 1 has a significant impact on production. Failure records for the listed equipment as found in the maintenance record/logbook in 3 production year (October 2016- October 2018) is as shown in Table 2.

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Table 1: Name and code of Critical Equipment Used in the Study

S/N	Equipment Name	Equipment Code Used	Function
1.	Primary waste heat boilers	101-CA/CB	It's a Bayonet Heat exchanger which exchanges heat from the process gas and boiler feed water to makes steam.
2.	Fire box (Primary Reformer)	101-B	Contains catalyst tubes, riser, and burners. This is where reforming of the process gas takes place hence the name.
3.	Auxiliary boiler	101-BA	Used to support steam production of the Ammonia plant
4.	Carbonate Pump/Turbine	1107-J/JT	Used for carbonate circulation for absorption and stripping CO2 off the process gas and CO2 sent for urea production

For each equipment listed in the table, total number of failures = total number of Repair

Total available time (TAT) = 3yrs

= 26280 hr.

OT is obtained using Equation 7 as seen in Table 2.

Table 2: Failure Records of Critical Equipment

S/N	Equipment	Number of Failure	Operating Time(hr)	Down Time(hr)	Downtime on ECM(hr)	Total Available Time(hr)
1.	Waste heat boiler (101-CA/CB)	1	24408	1872	1200	26280
2.	Fire box (101-B)	17	23424	2856	336	26280
3.	Aux Boiler (101-BA)	10	25800	480	192	26280
4.	Carbonate pump/Turbine	8	25704	576	168	26280

(Source: Case study Ammonia plant maintenance logbook, 2016 - 2018).

3.1.1

The result of the lube oil test revealed the following: A severe dissolved water contamination in the lube oil which was above acceptable limits (41,250ppm), severe wear metal (Iron) particle was present in the lube oil (130.0ppm), viscosity was above acceptable tolerance of the lube oil (287.5cst at 40degrees).

From the result, it showed that dissolved water contamination in the lube oil and the oil viscosity were the reason for the bearing failures. And these water contamination and poor viscosity is as a result of steam condensate ingress to the lube oil from the sealing steam of the turbine. Operating the turbine in just enough pressure and centrifuging drastically reduced the dissolved water and improved the viscosity of the oil. A section of the lube oil result is as shown in Figure 5.

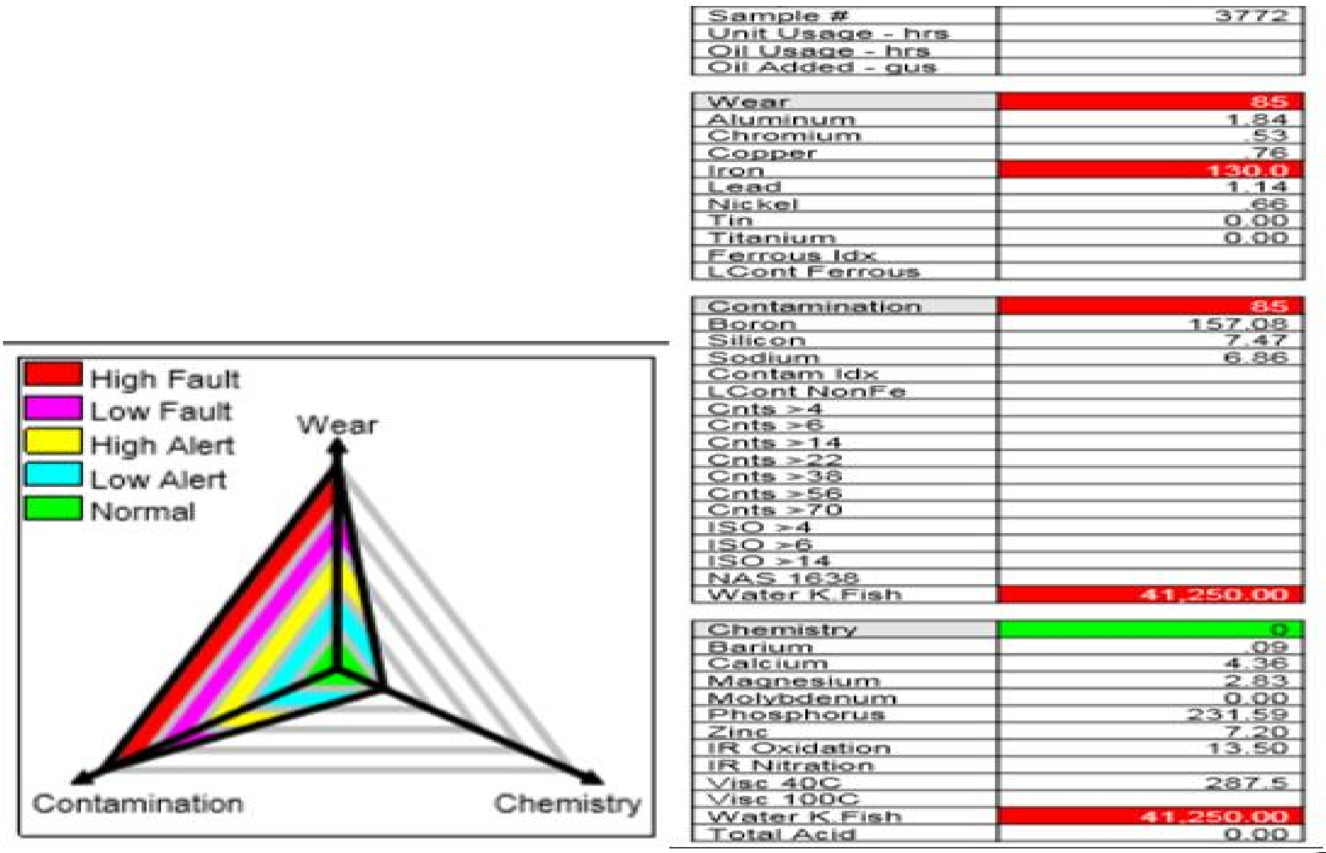

Figure 5: Lube Oil Result of Carbonate Pump Turbine

3.1.3 Cost Analysis

The Company Downtime cost is ₦4,500,000/hr.
TAT (Total available time) is the same as the AR (Required availability).
Maintenance cost data for WHB and Firebox is seen in Table 3.

Table 3: Maintenance Cost Data of WHB and Firebox

Parameter	WHB		FIREBOX	
	Corrective Maintenance	ECM	Corrective Maintenance	ECM
CM (₦)	387,330,964.2	82,941,517.9	2,330,000	1,640,000
AR (hr.)	26280	26280	26280	26280
D (hr.)	1872	1200	2856	336
OT (hr.)	24408	25080	23424	25944

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For WHB

Using Corrective Maintenance (Running till Failure)

Total Availability using Equation (6) for WHB will be

$$TA = \frac{OH}{AR} \times 100$$

OH which is same as OT and AR values are gotten from Table 3.

$$TA = \frac{24408}{26280} \times 100$$

$$TA = 92.87\%$$

Cost of Downtime can be calculated using Equation (9)

$$CD = DC \times D$$

$$CD = 4{,}500{,}000 \times 1872$$

$$CD = ₦8{,}424{,}000{,}000$$

TMC is obtained using Equation (1) as

$$TMC = CD + CM$$

Cost of maintenance is as seen in Table 3.

$$TMC = 8{,}424{,}000{,}000 + 387{,}330{,}964.20$$

$$TMC = ₦\,8{,}811{,}330{,}964$$

Using ECM

Total Availability is obtained using Equation (6)

$$TA = \frac{26280 - 1200}{26280} \times 100$$

$$TA = 95.43\%$$

Cost of downtime using Equation (9) is calculated below

$$CD = 4{,}500{,}000 \times 1{,}200$$

$$CD = ₦5{,}400{,}000{,}000$$

TMC is calculated with the use of Equation (1) as

$$TMC = CD + CM$$

Maintenance cost for ECM WHB is gotten from Table 3 to be ₦82,941,517.90 (Source: ECM report)

$$TMC = 5{,}400{,}000{,}000 + 82{,}941{,}517.90$$

$$TMC = ₦5{,}482{,}941{,}518$$

Savings Made if ECM Was Used

Downtime savings = ₦8,424,000,000 – ₦5,400,000,000

= ₦3,024,000,000

Which is approximately equal to about 35.89% cost saved on downtime if ECM was followed.

Savings on Total Maintenance Cost = ₦ 8,811,330,964 - ₦ 5,482,941,518

= ₦ 3,328,389,446

$$\%\ \text{Savings on TMC} = \frac{8811330964 - 5482941518}{8811330964} \times 100$$

$$\%\ \text{Savings on TMC} = 37.77\%$$

From the applied result for WHB it shows that if ECM was obeyed, we could have increased the availability of the component from 92.87% to 95.4%, uptime to 672hours (28 days) and downtime reduced from 1872hours to 1200hours. This will give us a downtime savings of ₦ 3,024,000,000 that is about 35.89% downtime cost saved and a savings of ₦ 3,328,389,446.3 on the Total maintenance cost which is around 37.77% of total maintenance cost saved as seen in Table 4.

Table 4: ECM and Corrective Maintenance Cost for WHB

	Downtime cost on 1 failure	**TMC on 1 failure**	**Downtime cost for period**	**TMC for period**
Corrective maintenance cost (N)	**0**	**0**	8424000000	8811330964
ECM cost (N)	**0**	**0**	5400000000	5482941518
Savings made (N)	**0**	**0**	3024000000	3328389446
% Savings	**0**	**0**	35.897	37.774

For Firebox

Using Corrective Maintenance (Running till Failure)

Total Availability using Equation (6) for Firebox will be

$$TA = \frac{23424}{26280} \times 100$$

$$TA = 89.13\%$$

$$MTTR = \frac{\text{Total downtime}}{\text{Total number of repairs}} = \frac{2856}{17}$$

$$MTTR = 168hr$$

(Each repair period takes 7days).

CD on 1 failure is calculated using Equation (9)

$$\text{CD on 1 failure} = 4{,}500{,}000 \times 168$$

$$CD = ₦756{,}000{,}000$$

Cost of maintenance for 1 failure as seen in Table 3 is ₦ 2,330,000 (Source: Firebox repair report)

TMC on 1 failure is gotten using of Equation (1) as

$$TMC_1 = 756{,}000{,}000 + 2{,}330{,}000$$

$$TMC_1 = ₦758{,}330{,}000$$

$$\text{Downtime cost for period} = 4500000 \times 2856$$

OR

$$\text{Downtime cost for period} = 756000000 \times 17$$

$$\text{Downtime cost for period} = ₦12{,}852{,}000{,}000$$

$$\text{Maintenance cost for period} = 2{,}330{,}000 \text{ x} 17$$

$$\text{Maintenance cost for period} = ₦39{,}610{,}000$$

TMC for the period is calculated using Equation (1)

$$TMC_p = 12{,}852{,}000{,}000 + 39{,}610{,}000$$

$$TMC_p = ₦12{,}891{,}610{,}000$$

Using ECM

With ECM we had just 2 failures

Total Availability using Equation (6) will be

$$TA = \frac{26280 - 336}{26280} \times 100$$

$$TA = 98.72\%$$

CD on 1 failure is obtained using Equation (9)

$$\text{CD on 1 failure} = 4{,}500{,}000 \times 168$$

$$CD = ₦756{,}000{,}000$$

Maintenance Cost on 1 failure from Table 3 is ₦1,640,000

TMC on 1 failure is obtained using Equation (1)

$$TMC_1 = 756{,}000{,}000 + 1{,}640{,}000$$

$$TMC_1 = ₦757{,}640{,}000$$

$$\text{Downtime cost for period} = 4{,}500{,}000 \text{ x } 336$$

OR

$$\text{Downtime cost for period} = 756{,}000{,}000 \times 2$$

$$\text{Downtime cost for period} = 1{,}512{,}000{,}000$$

$$\text{Maintenance cost for period} = 1{,}640{,}000 \text{ x } 2$$

$$\text{Maintenance cost for period} = ₦3{,}280{,}000$$

TMC for the period is obtained using Equation (1)

$$TMC_p = 1{,}512{,}000{,}000 + 3{,}280{,}000$$

$$TMC_p = ₦1{,}515{,}280{,}000$$

ECM Savings Made:

Savings on Downtime cost for 1 failure = ₦0.00

TMC savings on 1 failure =758,330,000-757,640,000

$$\text{TMC savings on 1 failure} = ₦690{,}000$$

Downtime cost savings for period = ₦12,852,000,000 – ₦1,512,000,000

$$\text{Downtime cost savings for period} = ₦11{,}340{,}000{,}000$$

TMC savings for the period =12,891,610,000–1,515,280,000

$$\text{TMC savings for the period} = ₦11{,}376{,}330{,}000$$

$$\%\text{ Savings on TMC} = \frac{12891610000 - 1515280000}{12891610000} \times 100$$

$$\%\text{ Savings on TMC} = 88.24\%$$

From the result for Firebox, it shows that if ECM was obeyed, we could have increased the availability of the component to 98.72%, uptime to 2520hours (105 days) and downtime reduced to 336 hours which gives us a downtime savings of about 88.2% and a savings of ₦690,000 for the total maintenance cost for one failure which is 0.09% saved on TMC as seen in Table 5. On considering the total cost saved for the period under review, it was seen in Table 5 that we had savings of about 88.24% on TMC.

Table 5: ECM and Corrective Maintenance Cost for Firebox

	Cost of downtime on 1 failure	TMC on 1 failure	Downtime cost for period	TMC for period
Corrective maintenance cost (₦)	756000000	758330000	12852000000	12891610000
ECM cost (₦)	756000000	757640000	1512000000	1515280000
Savings made (₦)	0	690000	11340000000	11376330000
% Savings	0	0.091	88.235	88.246

For Aux. Boiler

Using Corrective Maintenance (Running till Failure)

For Aux boiler, if ECM was obeyed, we could have increased our availability of the component to 99.26%, uptime to 288hours (12 days) and downtime reduced to 192 hours which will give us a downtime savings of about 60%. Though there were no savings on total maintenance cost for one failure, on considering the total cost saved for the period under review it was seen that we had a total maintenance cost savings of about 60%.

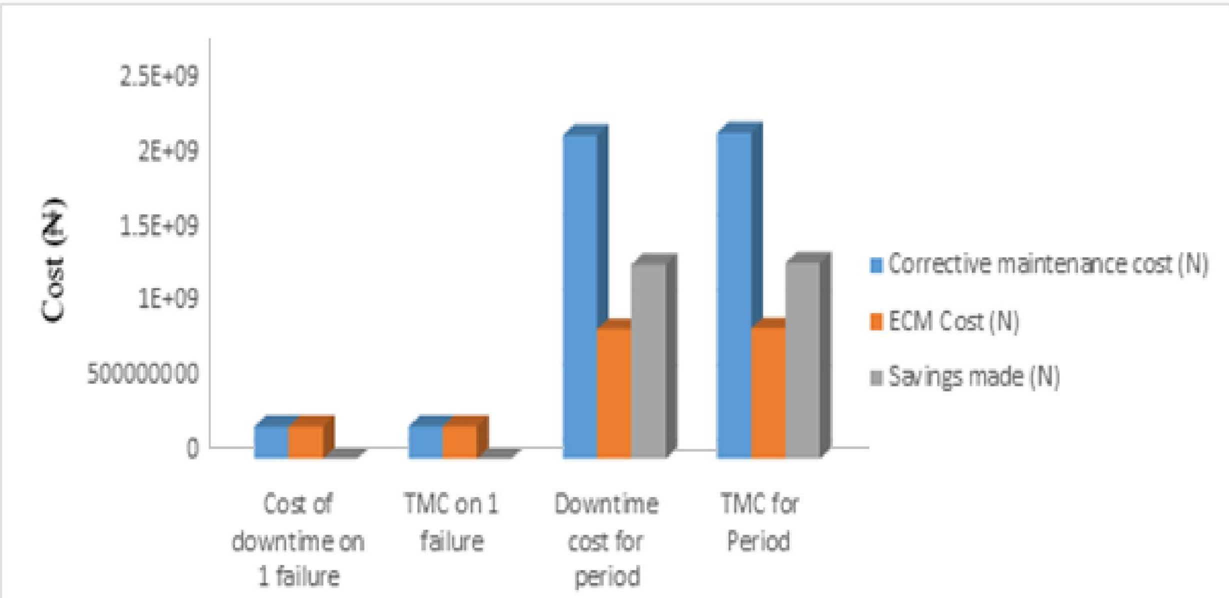

Figure 6: Comparing ECM and Corrective Maintenance Cost Savings for Aux Boiler

For Carbonate Pump Turbine

Using Corrective Maintenance (Running till Failure)

For Carbonate pump turbine, if ECM was obeyed, we could have increased our availability of the component to 99.36% in the period of review. There was no savings on Downtime cost for one failure but rather a loss of ₦108,000,000 as we had to invest more to acquire and train some personnel on the ECM equipment. Also, there were no savings on the Total maintenance cost for one failure as we had losses of about ₦181,000,000. But for the period under review, if ECM was obeyed, we would have had an uptime of 408hours (17 days) and downtime reduced to 168 hours which will give us a downtime savings of about 70.8% and around 68.05% savings on total maintenance cost for the period under review

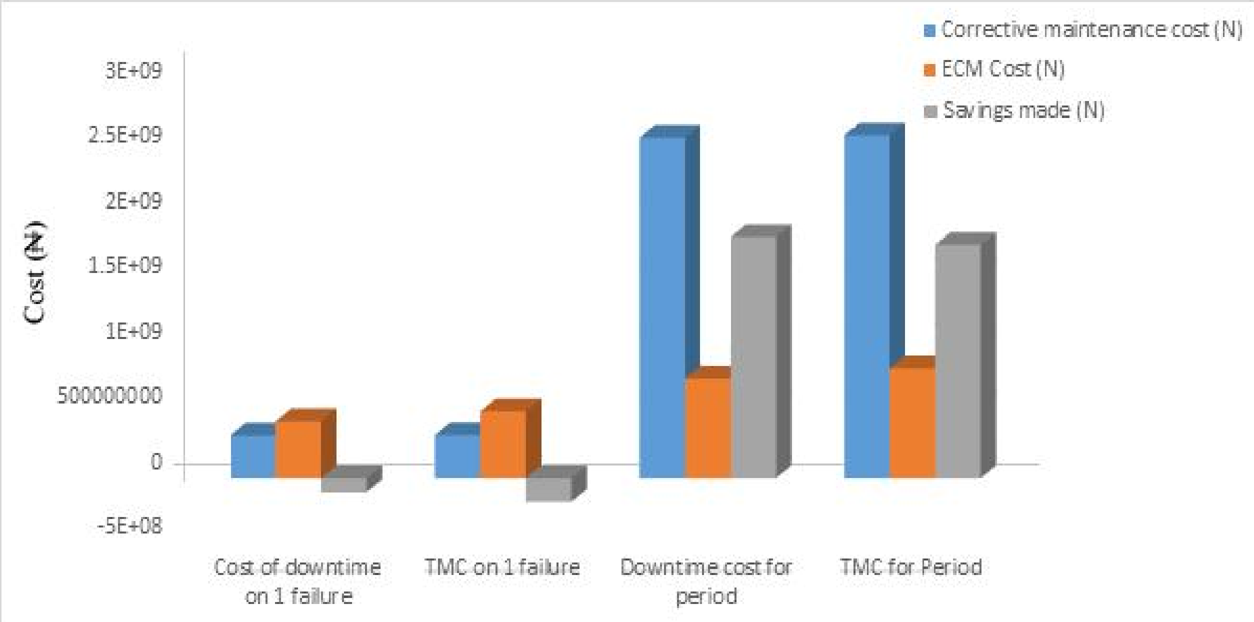

Figure 7: Comparing ECM and Corrective Maintenance Cost Savings for Carbonate Pump Turbine

3.2 Discussion of Results

RCFA was done to find solution to a bearing failure, RCFA revealed lube oil to be the culprit hence lube oil analysis was carried out and the result revealed the water in the lube oil displaced the lube oil in the bearing housing since water is denser than oil and the shaft instead of sitting on lube oil was now sitting on water which always led to poor/low lubrication. This causes high friction, makes the machine to run dry, causes mechanical seal and labyrinth seal failures and a high vibration. If the water can be continually removed so the oil maintains its quality the failure will be avoided. Hence, operating at just enough pressure and centrifuging of the lube oil will mitigate the water in the oil and improve the oil viscosity. The above statement confirms the word of Andrew (2019) that 80% causes of machine failure is lubrication related.

From the analysis, it shows that all equipment where ECM is deployed their availability increased. Most of the savings achieved are gotten from the reduced downtime period (increase in uptime), reduction in cost of maintenance, reduced secondary damage/failure of other related components which could have hiked maintenance cost were avoided. For WHB, there were secondary damage which affected some major parts and which greatly imparted on the cost of maintenance, these secondary failures led to the increased downtime period which if ECM was obeyed these secondary failures would have been avoided thereby validating the words of Kanth *et al*. (2012) that predictive maintenance can improve plant efficiency by reduced cost of maintenance, less likelihood of secondary damage, reduced inventory amongst others. For the carbonate pump turbine and the Aux boiler there were no initial savings but rather losses but over the period of review the savings made using ECM is tremendous as we had a savings of 68.05% for carbonate pump turbine and 60% for Aux boiler. This confirms the findings of Ahmad and Kamaruddin (2012) that associated equipment for condition monitoring may involve high cost which companies were not willing to invest in. It also went on to validates the findings of Jardine *et al*. (2006) where he stated that condition monitoring is the preferred choice where equipment failures are costly. The cost estimate in this study confirms the conclusion made by Banga and Sharma (2008) that corrective maintenance is much expensive

4. CONCLUSION:

From the study we could say that the aim of the research was achieved by greatly reducing maintenance cost which impact greatly on the running cost of a chemical industry, and as running cost is reduced profitability will be increased. The first objective was achieved where some analytical techniques were used to do root cause of failure analysis and the analysis revealed poor/low lubrication as the cause of consistent bearing failure of a carbonate pump turbine. And a lube oil analysis was carried out and revealed high water in oil and viscosity above specification. These led to reoccurring bearing failure if a way to reduce these waters into the oil is achieved, we can reduce this failure thereby saving us downtime and cost.

Financial benefits of ECM were analysed; the cost analysis compared the cost of maintenance using ECM to the cost of maintenance using corrective maintenance. This revealed that there are huge savings made when ECM is been used. From the analysis we saw how uptime was increased for all four equipment and downtime greatly reduced.

From the study, we saw that the initial cost for ECM in some cases seem to be very high this makes proposing ECM programs to management unattractive. Nevertheless, over a period of time the financial benefit ECM put to the organisation outweighs the initial setup cost. This was as observed in the Firebox and Aux boiler case study where for one failure there was no benefit but over the period in view, we had a cost benefit of on downtime cost and Total maintenance cost. Also of great importance was the fact that for Carbonate pump there was also no initial benefit but rather we had to invest more for ECM programs this from the onset would make management frown at ECM project but on the long run we made great financial benefit.

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