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Application of Condition Based Maintenance with Reliability Technique to Reduce Failure of a Rotating Equipment: A case Study

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ABSTRACT

This study seeks to use reliability techniques to appraise condition based maintenance technique of a rotating equipment (reciprocating compressor). The reciprocating compressor used for hydrogen compression at the polypropylene plant of Indorama/Eleme Petrochemical Limited, Aleto Eleme, Rivers State was used as a case study. Five parts of the reciprocating compressor were investigated. They include Bearing, Connecting rod, crank shaft, Piston and discharge valve. The reliability analysis study was carried out for a period of five years from January 2016 to December 2020. The investigations showed the mean time between failure, failure rate, downtime, lost time to repair, reliability, unreliability and availability of the components parts of the compressor. The study presented decrease in reliability of some parts. For example the reliability of bearing component reduced from 13.54% to 1.804%, the connecting rod reduced from 13.62% to 1.879%, crank shaft reduced from 13.54% to 1.828%, Piston reduced from 13.54% to 1.828%, discharge valve reduced from 13.54% to 1.828% within the period of five years. This research work recommends that the compressor should be readily available for replacement in the inventory and the storeroom to reduce the downtime in a year as well as enhance productivity. Maintenance personnel should always look out for spares to reduce downtime and always carry out preventive maintenance as at when due. This will reduce failure and increase availability of the equipment.

Key words: Application, condition based, maintenance, reliability technique, failure, rotating equipment.

1. INTRODUCTION

Maintenance is a means to hold, keep, sustain or preserve facilities to an acceptable standard [1]. Maintenance is also a combination of technical and administrative activities to keep a machine or equipment in its functional state [2]. Machines or equipment with poor maintenance will result in dysfunction

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that might likely result to production of defective products which affect the quality of the product in a production process [3-6]. It involves reliability of the machines and equipment to perform to a standard level of quality assurance [7-9]. Again, poor maintenance of production facilities can result in poor end-product quality and customer dissatisfaction, lost production runs, cost inefficiencies, and sometimes, unavailability of the facility for future use [10-14].

Maintenance is one of the major activities which account for up to 40% of total costs, in some Nigeria organizations [15-17]. Therefore, engineering managers are saddled with the responsibility of reducing maintenance cost and ensuring that maintenance and production target are achieved at every time. This can only be achieved using appropriate optimized maintenance strategy [18].

The main goal of condition based maintenance (CBM) is to perform a real-time assessment of equipment conditions to make appropriate maintenance decisions, consequently reducing unnecessary maintenance and related costs [19-20]. Furthermore, condition-based maintenance continuously monitors assets to spot impending failure, so maintenance can be proactively scheduled before failure occurs [21]. The idea is to do a real time monitoring which gives maintenance teams enough lead time before failure occurs or performance drops below an optimal level [22].

Engineers are faced with the challenge of adopting maintenance strategy that meets the need of the plants while optimizing operations cost. This research provides an insight on condition based maintenance (CBM) practice that will aid maintenance decision of critical asset or equipment [3-5]. The aim of this study is to examine and improve condition based maintenance (CBM) performance of reciprocating compressor of the propylene plant using reliability technique.

2. MATERIALS AND METHODS

Source of Data

In order to complete this study, relevant information to address the subjects have been collected. Information is collected from Indorama Eleme Petrochemical Company Limited documents, presentations, journals and other academic literature (books) available at magazine and articles and internet databases. Discussions with my supervisors at Rivers State University have also contributed to a great deal of the relevant information.

CBM Method and Tools

Vibrational analysis method

This type of condition monitoring identifies potential failure by spotting changes in normal vibration signature. Vibration is affected by amplitude, intensity, and frequency. Sensors can detect abnormalities in these elements, which can be a sign that something is wrong with an asset. For example, rotating equipment, such as compressors and motors, exhibit a certain degree of vibration. When they degrade or fall out of alignment, the intensity of the vibration increases. Sensors can detect when the vibration becomes excessive and the component can be repaired or replaced.

Apart from the sensors mounted on rotating equipment for Condition monitoring the following tools are used for data collection, which include the following: Accelerometer and analyzer

Experimental Procedure

Procedure for CBM Operations

i. Collect data from reciprocating compressor type ISI/006-A1 model (as seen in plate 1). This done with the aid of accelerometer, sensors and analyser or vibration meter. The sensor which is used for measuring fluctuating accelerometer or speed in vibration measurement. The accelerometer seen in Figure 1, makes it easier for the analyser to obtain the readings in vibration measurement was created in the computer interface of the analyser and then uploaded to the analyser. The analyser (CSI 2140) is seen in Figure 2. It a hand held measuring device for individual assessment of vibrations on rotating equipment. It is used for collecting the data with the help of accelerometer for polypropylene plant. Vibration data is collected with help of sensors mounted on the rotating equipment. Data should be collected in 3 measurement axis as seen in Figure 3 to avoid mistakes
ii. Download data collected to the computer. All the collected data as seen in plate 2 from the analyser should be downloaded to the computer interface software and viewed, showing the location Overall values and the spectra as seen in Figure 4.
iii. Analyse data. During Analysis (Spectrum and wave form as seen in Figure 4 and Plate 3, 4 and 5) in given state, model would show characteristics of having misaligned shaft or bearing failure .This would be seen due to the occurrence of peaks e.g 1x 2x or 3x.
iv. Data collection happens monthly except if equipment is critical then it would be done weekly.
v. Trend Data. Data trending as seen in Figure 5 is continuous until a fault is detected and communicated to the maintenance

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operation team. If a fault is detected it shows deviation from standard operating parameters

vi. Maintenance operation team use opportunity to change other parts of the reciprocating compressor that needs to be changed for effective operations and to reduce downtime.

Plate 1: Reciprocating Compressor with Sensor

Figure 1: Vibration Sensors

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Figure 2: Accelerometer

Figure 3: Vibration Meters or Analysers

Figure 4: Data collection

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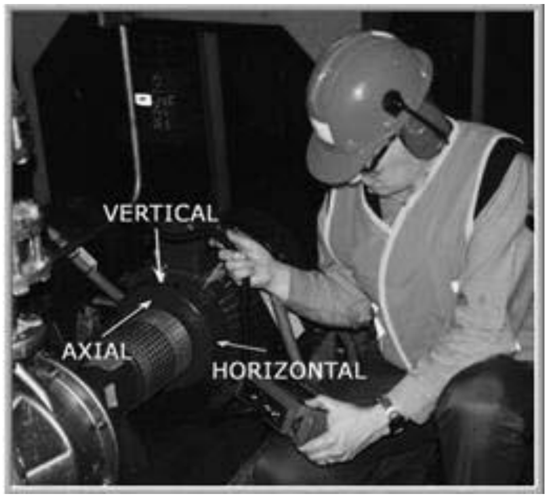

Figure 5: The 3 Measurement Axis

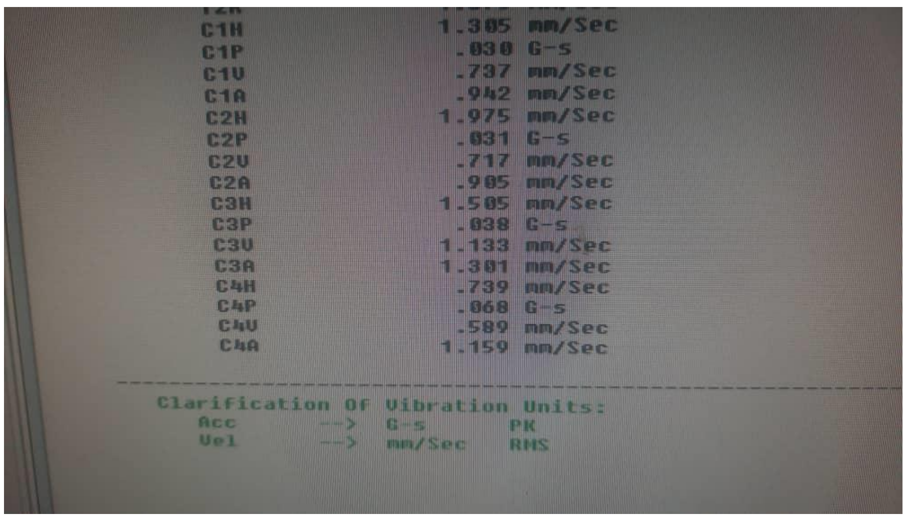

Plate 2: Raw data (Data Collected by the analyser)

Figure 6: Data analysis

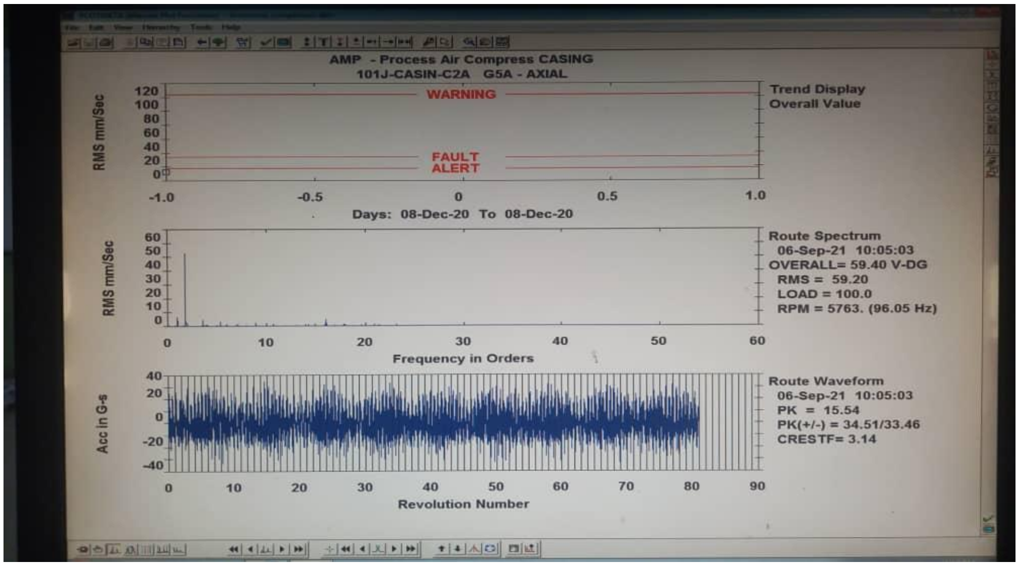

Plate 3: Vibration spectra (Axial)

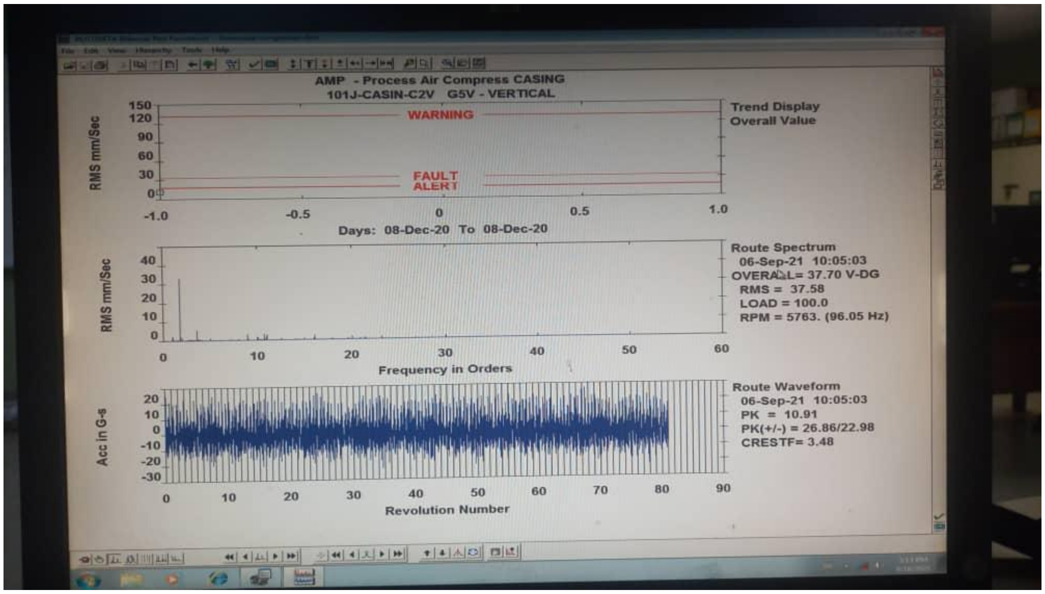

Plate 4: Vibration spectra (Vertical)

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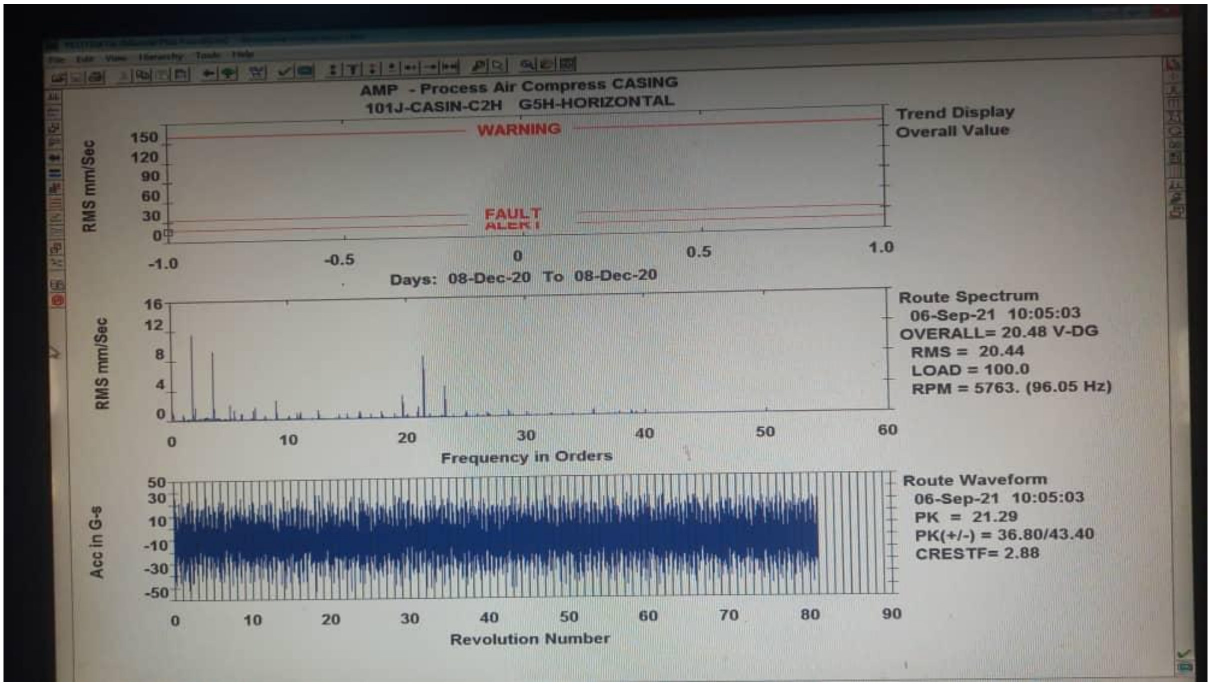

Plate 5: Vibration spectra (Horizontal)

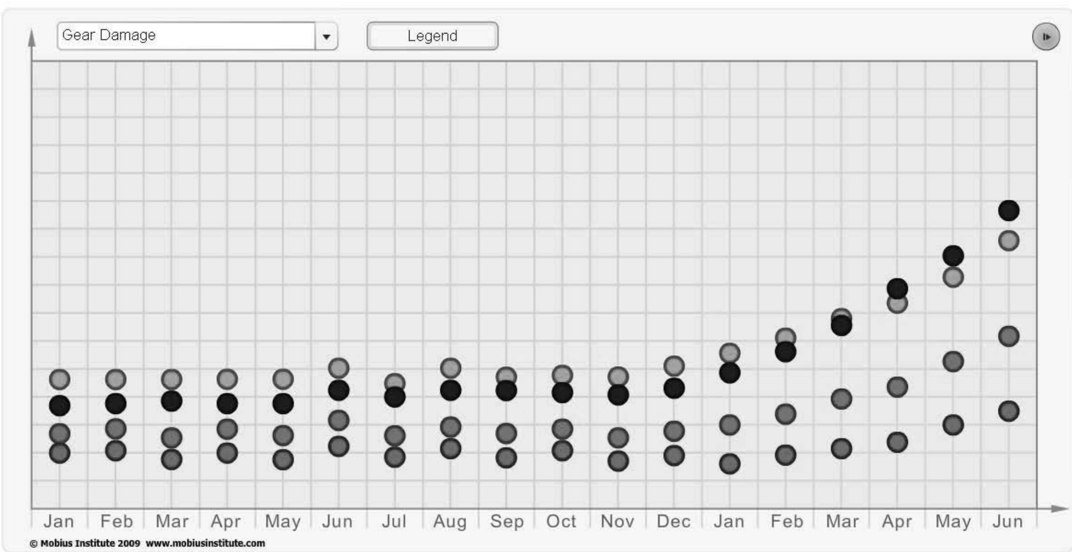

Figure 7: Trending Data

3. CASE STUDY

The Reciprocating Compressor type ISI/006-A1 for propylene plant was used as a case study. The reciprocating compressor is used to compress hydrogen.

Analytical Methods and Tools

The analytical method used are the vibrational Analysis (Spectrum and time wave) and micro log Analyzer AX

Computational Tools and Software

The computational tools used for calculations was Microsoft Excel.

Mathematical Models and Statistical Model

The mathematical model for this research was established by considering five years study interval (SI) as well as the number of failures (NF) and the corrective time per failure (CTPE).

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Let the symbols below represent the reliability parameters, Ψ = Failure rate, β = Mean time between failure (MTBF), γ = Reliability, ϕ = Availability and T = Unreliability

Mean Time between Failures (MTBF)

$$\beta = \frac{SI}{NF} = \frac{TO}{NF} \qquad (1)$$

Where, SI= study interval, NF = number of failure (year) and TO = Total operating time (hour/year)

Failure Rate (FR)

$$(\Psi)`` = \frac{1}{MTBF} = \frac{1}{\beta} \qquad (2)$$

$$(\Psi))_A = (\frac{1}{MTBF})_A = (\frac{1}{\beta})_A \qquad (3)$$

Total mean time between failures

Thus,

Total failures per year (TFPy) =

$$[\frac{1}{(\beta)A} + \frac{1}{(\beta)B} + \frac{1}{(\beta)C} + \frac{1}{(\beta)D} + \frac{1}{(\beta)E}]$$

$$\text{TMTBF} = \frac{Annual\ hours\ per\ year}{Total\ failures\ per\ year} \frac{AHPy}{TFPy} \qquad (4)$$

Where TMTBF = Total Mean Time between Failure

Total Failure Rate (TFR)

$$\text{TFR} = [(\Psi)_A + (\Psi)_B + (\Psi)_C + (\Psi)_D + (\Psi)_E] \qquad (5)$$

Reliability Model (γ)

The Compressor components reliability (CCR) equation is expressed mathematically as:

$$CCR(\gamma) = e^{-}(\frac{1}{\beta})\ x\ t \qquad (6)$$

$$CCR\ (\gamma) = e^{-}(\Psi)\ x\ t \qquad (7)$$

where: CCR = compressor component reliability

MTBF = mean time before failure

$\Psi = \frac{1}{\beta}$

t = operating time/year

Whereas for the various compressor components investigated, the reliability is determined by the summation of each compressor component reliability, as stated below as:

$$BR = e^{-}(\frac{1}{\beta})_A + (\frac{1}{\beta})_B + (\frac{1}{\beta})_C + (\frac{1}{\beta})_D + (\frac{1}{\beta})_E\ x\ t \qquad (8)$$

$$\gamma = e^{-}(\Psi)_A + (\Psi)_B + (\Psi)_C + (\Psi)_D + (\Psi)_E\ x\ t \qquad (9)$$

Unreliability Model (Maintainability (T))/ Monte Carlo Model

The compressor components unreliability (CCUR) is expressed as:

$$BU = 1 - e^{-(\Psi)\ x\ t} \qquad (10)$$

$$T = 1 - e^{-(\Psi)\ x\ t}$$

$$\Psi = \frac{1}{\beta}$$

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Availability Model

The compressor components availability (CCA) is expressed as:

$$CCAV = \frac{Mean\,Time\,Between\,Failure - lost\,time\,per\,year}{Mean\,Time\,Between\,Failure} \quad (11)$$

Which is also

$$CCAV(\phi) = \frac{Uptime}{Uptime + downtime} \quad (12)$$

Where: CCAV (ϕ) = Compressor component Availability

4. RESULTS AND DISCUSION

The results obtained from the investigation and reliability analysis of reciprocating compressor of the propylene plant are presented in Figures 8 to 17.

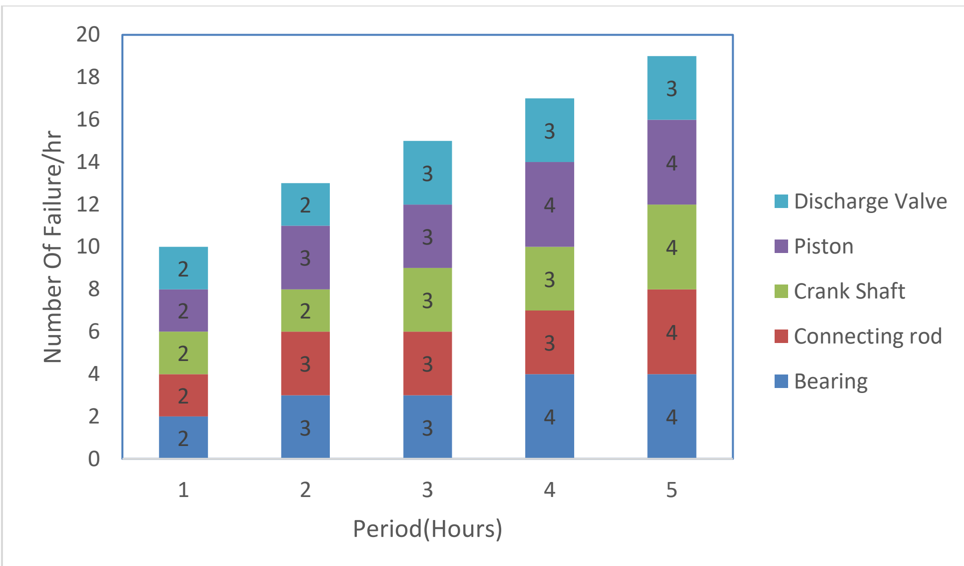

Fig. 8: Plot of Numbers of Failure against Periods

A total of five parts was investigated and result from investigation shows that the reciprocating compressor which is use for compressing hydrogen in the propylene plant undergoes scheduled maintenance. From Fig 8 the bearing and piston have the highest number of failure 16. The crankshaft and the connecting rod both has the second highest number of failure with 15 and the third number of failures followed by the discharge valve 13.

Table 1: Results of Computational Parameters of Bearing

Parameters	Period (year) 1	2	3	4	5
Operating time (OT)	8064	7728	7440	7200	6864
Meantime Between Failure (MTBF (β)	4032	2576	2480	1800	1716
Failure Rate (Ψ)	0.000248	0.000388	0.000403	0.000556	0.000582
Downtime (DT)	4	6	6	8	8
Reliability (γ)	0.1354	0.04986	0.04987	0.01826	0.01804
Unreliability (T)	0.8646	0.9504	0.9501	0.9807	0.9820
Availability (ϕ)	0.9995	0.9992	0.9991	0.9989	0.9820

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Table 1 shows the analysis and the computational data of the bearing as a component part of the reciprocating compressor. From the table, the operating time decreases from 8064 hours to 6864 hours within the period of 5 years. The mean time between failures (β) also decreased from 4032 hours to 1716 hours within the period of 5 years. Other parameters like the failure rate was observed to increase from 0.000248/year to 0.000582/year at the end of the 5^{th} year of the study. Parameters like downtime was observed to be on a gradual increase from 4 hours in year to 8 hours in year 5.The availability of the bearing component also declined from 0.9995 at year 1 to 0.9820.

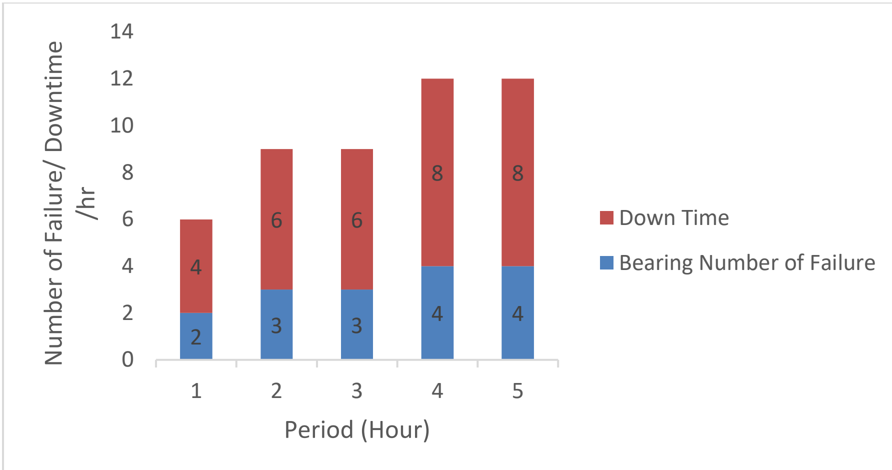

Figure 9: Number of Failure/Year and Downtime (DT) against the Period/Study time or Interval

Figure 9 shows the relationship between the number of failures in a year and the downtime from those failures. It was observed that as the number of bearing failures increases from 2 to 4 with the downtime increasing from 4 to 8 within the time of study.

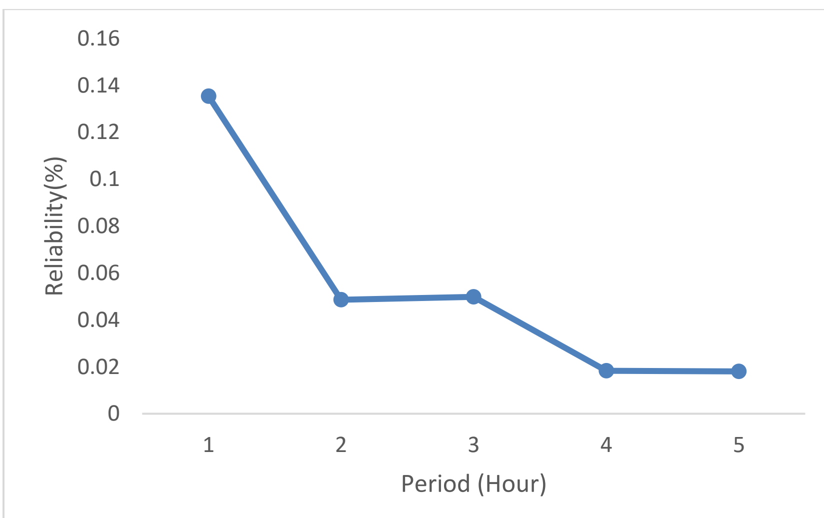

Figure 10: Reliability against the Period

Figure 10 shows the reliability of the bearing component. It was observed that the reliability of the bearing components gradually declines as the year increases. It declined from 0.1354(13.54%) at year 1 to 0.01804(1.804%) at the end of year 5. At the end of year 5 the percentage decrease in reliability is 86.68%.

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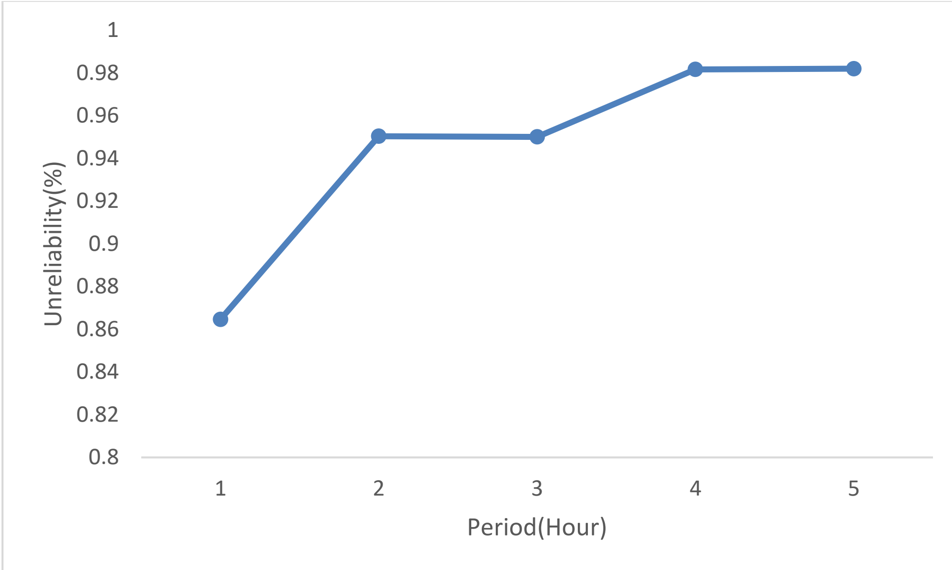

Figure 11: Unreliability against the Period

Figure 11 shows the unreliability of the bearing component. A gradual increase in the unreliability of the bearing component was observed. The unreliability increased from 0.8646 to 0.9820 which signifies 13.58 % increase.

Table 2: Results of Computational Parameters of Connecting Rod

Parameters	**Period (year)**				
	1	**2**	**3**	**4**	**5**
Operating time (OT)	8064	7728	7440	7200	6864
Meantime Between Failure (MTBF (β)	4032	2576	2480	2400	1716
Failure Rate (Ψ)	0.000248	0.000388	0.000403	0.000417	0.000582
Downtime (DT)	10	15	15	15	20
Reliability (γ)	0.1362	0.05004	0.04987	0.04967	0.01879
Unreliability (T)	0.8638	0.9500	0.9501	0.9503	0.1879
Availability (ϕ)	0.9988	0.9981	0.9980	0.9979	0.9971

The result presented in Table 2 shows the analysis and the computational data of the connecting rod as a component part of the reciprocating compressor. It is observed that operating time decreases from 8064 hours to 6864 hours within the period of 5 years. The mean time between failures (β) also decreased from 4032 hours to 1716 hours within the period of 5 years. Parameters like the failure rate was observed to increase from 0.000248/year to 0.000579/year. The downtime was also observed to be on a gradual increase from 10 hours in year 1 to 20 hours in year 5.The availability of the connecting rod declined from 0.9988 at year 1 to 0.9971 at year 5.

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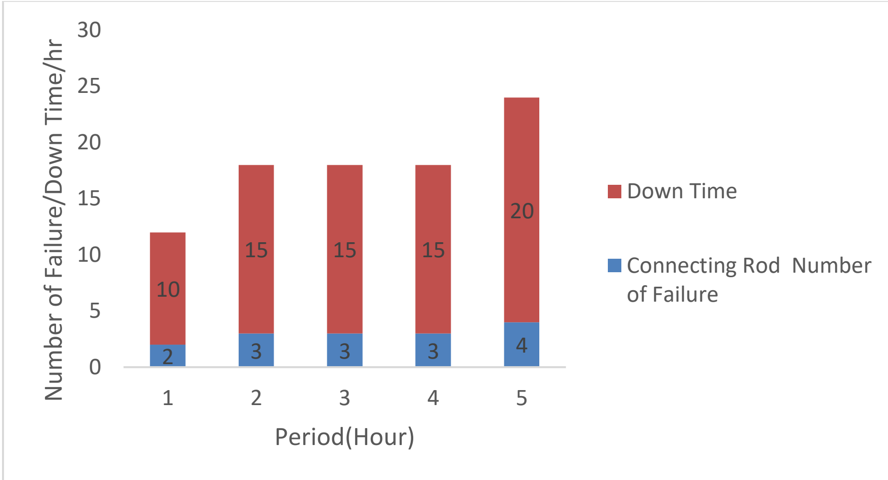

Figure 12: Number of Failure/Year and Downtime (DT) against the Period

Figure 12 illustrates the relationship between the connecting rod number of failures in a year and the downtime from those failures. The Connecting rod failure was observed to have increased gradually from 2 to 4 while the downtime increases from10 to 20.

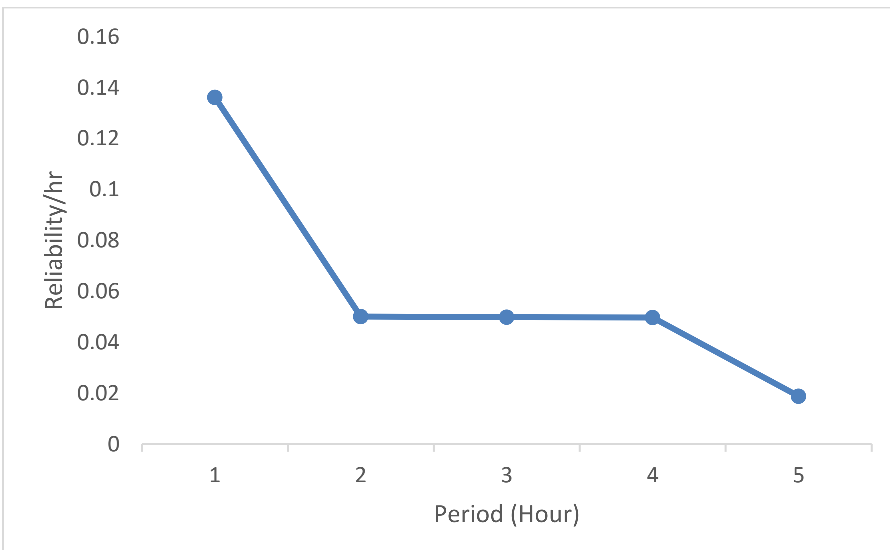

Figure 13: Reliability against the Period

Figure 13 shows the reliability of the bearing component. The reliability of the connecting rod was observed to have declined gradually from year 1 to year 5. It declined from 0.1362(13.62%) at year 1 to 0.01879(1.879%) at the end of year 5. At the end of year 5 the percentage decrease in reliability is 98.62%.

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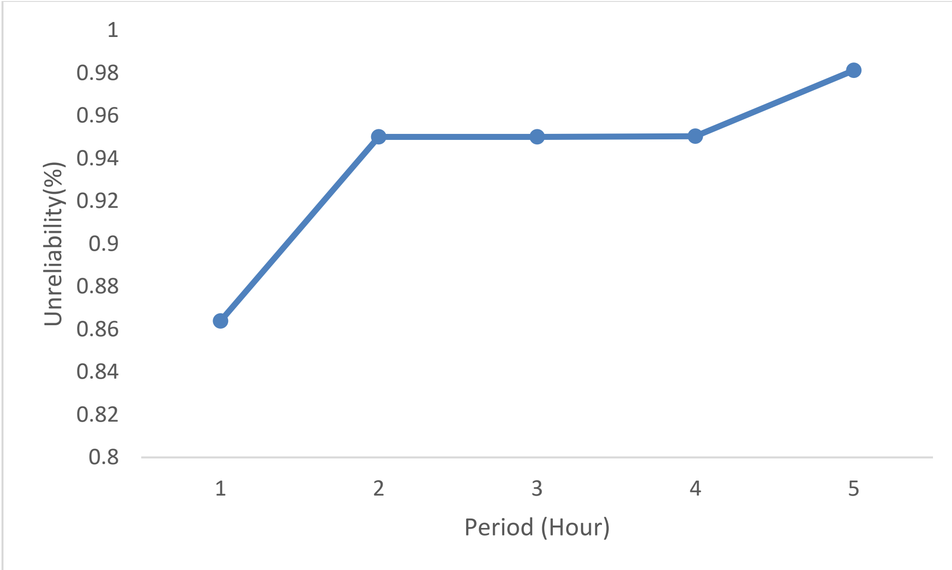

Figure 14: Unreliability against the Period

Figure 14 shows the unreliability of the connecting rod. The unreliability of the connecting rod was observed to increase gradually. The unreliability increased from 0.8638 to 0.9812 which signifies 13.59 % increase.

Table 3: Results of Computational Parameters of Crank Shaft

Parameters	**Period (year)**				
	1	**2**	**3**	**4**	**5**
Operating time (OT)	8064	7728	7440	7200	6864
Meantime Between Failure (MTBF (β)	4032	3864	2480	2400	1716
Failure Rate (Ψ)	0.000248	0.000259	0.000403	0.000417	0.000583
Downtime (DT)	16	16	24	24	32
Reliability (γ)	0.1354	0.1351	0.05017	0.04967	0.01828
Unreliability (T)	0.8646	0.8649	0.9498	0.9503	0.9867
Availability (ϕ)	0.9980	0.9979	0.9968	0.9968	0.9954

The result presented in Table 3 illustrates the analysis and the computational data of the crank shaft as a component part of the reciprocating compressor. It is observed that operating time decreases from 8064 hours to 6864 hours within the period of 5 years. The mean time between failures (β) also decreased from 4032 hours to 1716 hours within the period of 5 years. Parameters like the failure rate was observed to increase from 0.000248/year to 0.000583/year. The downtime was also observed to be on a gradual increase from 16 hours in year 1 to 32 hours in year 5.The availability of the connecting rod declined from 0.9980 at year 1 to 0.9954 at year 5.

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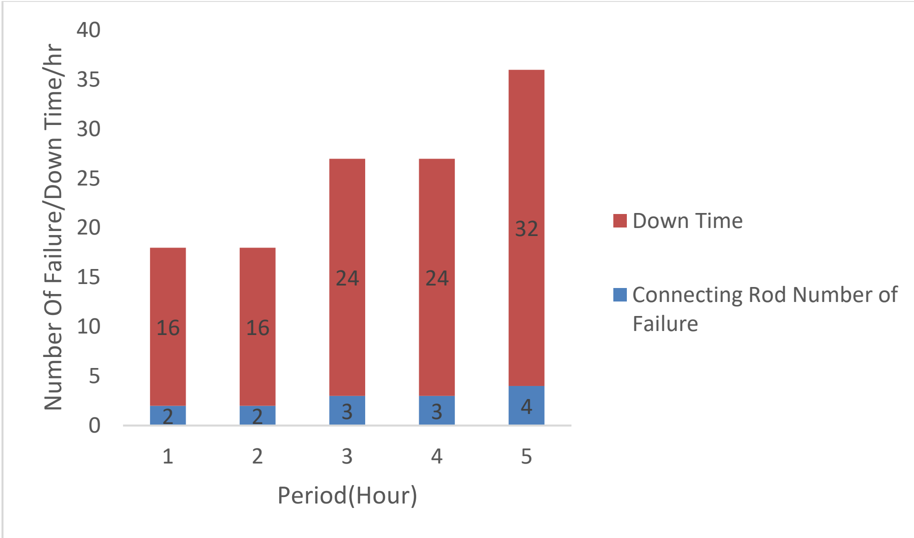

Figure 15: Number of Failure/Year and Downtime (DT) against the Period

Figure 15 illustrates the relationship between the crank shaft number of failures in a year and the downtime from those failures. The failure of crank shaft was observed to have increased gradually from 2 to 4 while the downtime increases 16 to 32

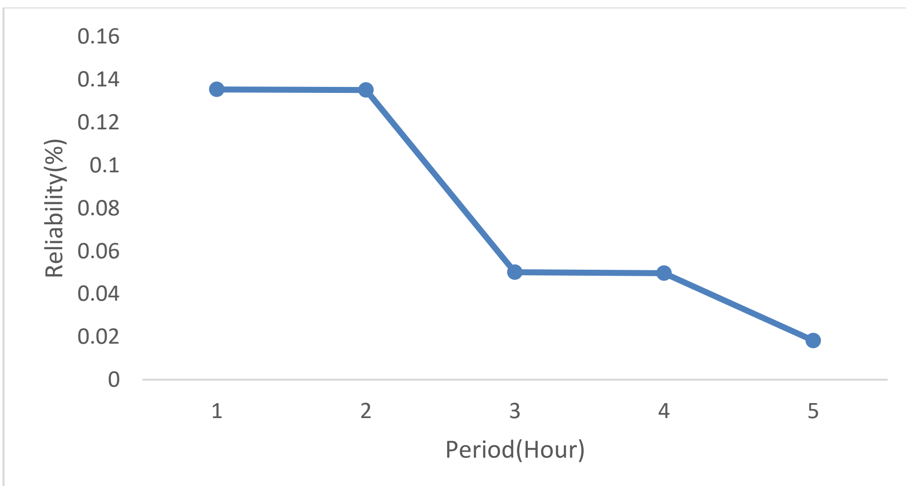

Figure 16: Reliability against the Period

Figure 16 shows the reliability of the bearing component. The reliability of the connecting rod was observed to have declined gradually from year 1 to year 5.It declined from 0.1354(13.54%) at year 1 to 0.01828(1.828%) at the end of year 5. At the end of year 5 the percentage decrease in reliability was 86.50%.

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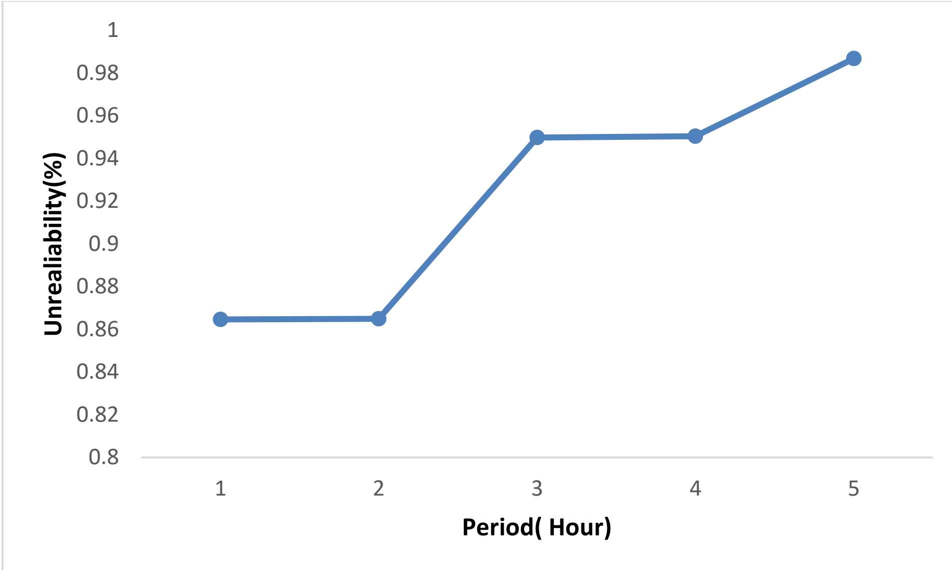

Figure 17: Unreliability against the Period

Figure 17 shows the unreliability of the connecting rod. The unreliability of the connecting rod was observed to increase gradually. The unreliability increased from 0.8646 to 0.9867 which signifies 14.12 % increase.

Table 4: Results of Computational Parameters of Piston

Parameters	Period (year)				
	1	2	3	4	5
Operating time (OT)	8064	7728	7440	7200	6864
Meantime Between Failure (MTBF (β)	4032	2576	2480	2400	1716
Failure Rate (Ψ)	0.000248	0.000388	0.000410	0.000556	0.000583
Downtime (DT)	14	21	21	28	28
Reliability (γ)	0.1354	0.04986	0.04734	0.01826	0.01828
Unreliability (T)	0.8646	0.9501	0.9527	0.9817	0.9817
Availability (ϕ)	0.9983	0.9979	0.9972	0.9961	0.9959

The result presented in Table 4 shows the analysis and the computational data of the piston as a component part of the reciprocating compressor. It is observed that operating time decreases from 8064 hours to 6864 hours within the period of 5 years. The mean time between failures (β) also decreased from 4032 hours to 1716 hours within the period of 5 years. Parameters like the failure rate was observed to increase from 0.000248/year to 0.000583/year. The downtime was also observed to be on a gradual increase from 14 hours in year 1 to 28 hours in year 5. The availability of the Piston declined from 0.9983 at year 1 to 0.9959 at year 5.

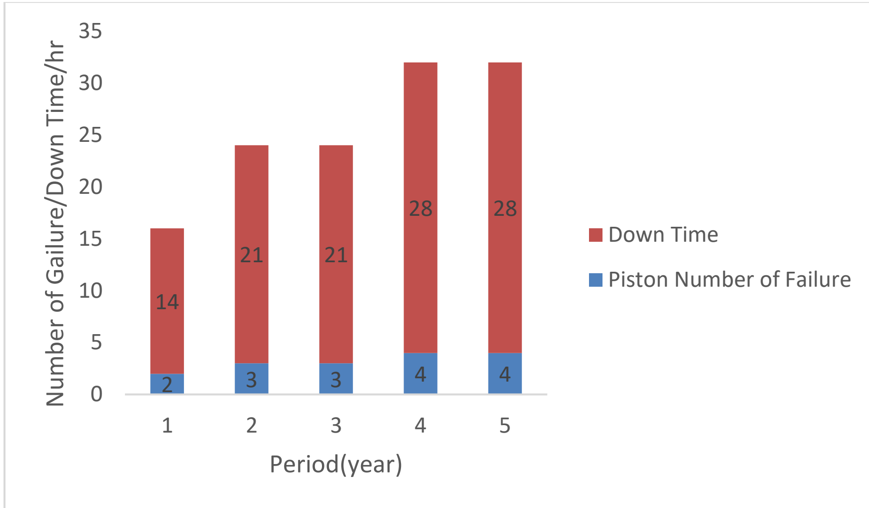

Figure 18: Number of Failure/Year and Downtime (DT) against the Period

Figure 18 illustrates the relationship between the piston number of failures in a year and the downtime from those failures. The failure of crank shaft was observed to have increased gradually from 2 to 4 as the downtime increases from 14 to 28.

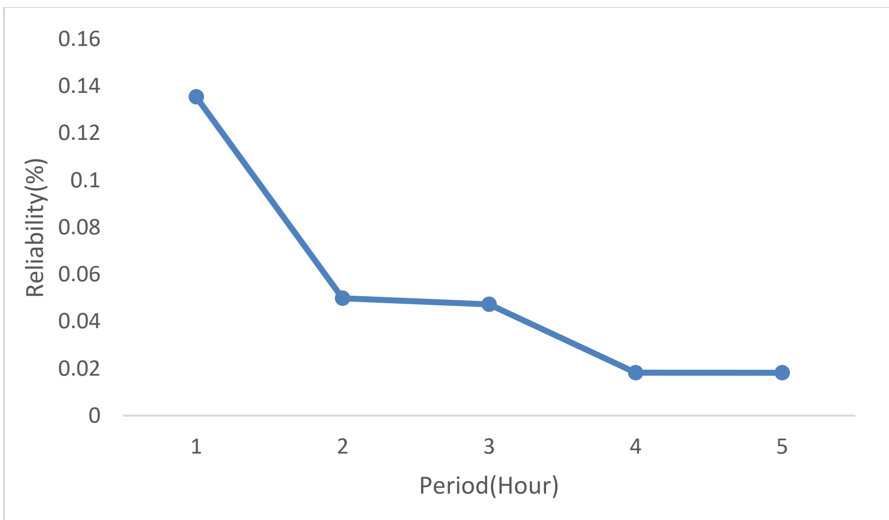

Figure 19: Reliability against the Period

Figure 19 shows the reliability of the bearing component. The reliability of the piston was observed to have declined gradually from year 1 to year 5.It declined from 0.1354(13.54%) at year 1 to 0.01828(1.828%) at the end of year 5. At the end of year 5 the percentage decrease in reliability was 86.50%.

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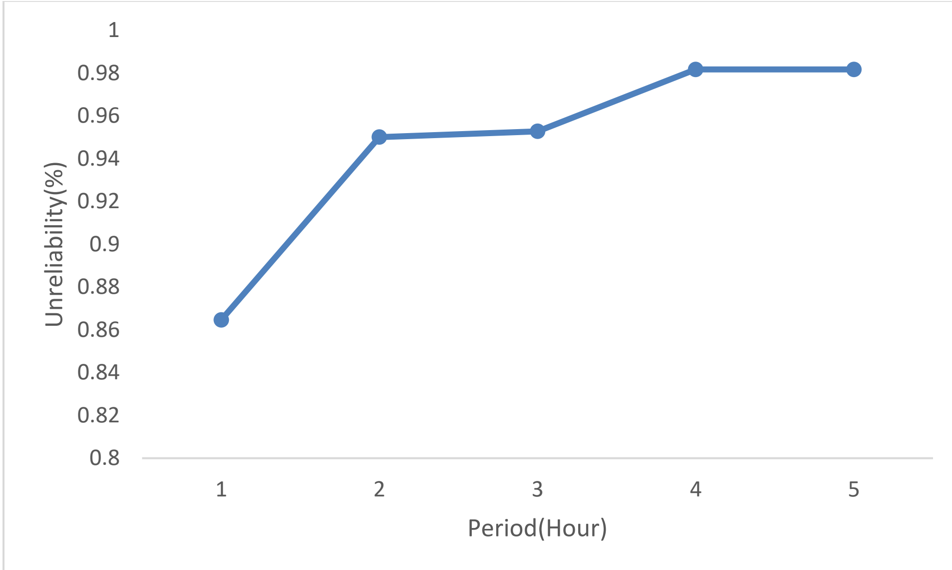

Figure 20: Unreliability against the Period

Figure 20 shows the unreliability of the piston. The unreliability of the piston was observed to increase gradually .The unreliability increased from 0.8646 to 0.9817 which signifies 13.54 % increase.

Table 5: Results of Computational Parameters of Discharge Valve

Parameters	Period (year)				
	1	2	3	4	5
Operating time (OT)	8064	7728	7440	7200	6864
Meantime Between Failure (MTBF (β)	4032	3864	2480	2400	1716
Failure Rate (Ψ)	0.000248	0.000259	0.000403	0.000417	0.000583
Downtime (DT)	6	6	9	9	12
Reliability (γ)	0.1354	0.1351	0.04987	0.04967	0.01828
Unreliability (T)	0.8646	0.9501	0.9563	0.9817	0.9817
Availability (ϕ)	0.9983	0.9992	0.9988	0.9988	0.9983

The result presented in Table 5 illustrates the analysis and the computational data of the discharge valve as a component part of the reciprocating compressor. It is observed that operating time decreases from 8064 hours to 6864 hours within the period of 5 years. The mean time between failures (β) also decreased from 4032 hours to 1716 hours within the period of 5 years. Parameters like the failure rate was observed to increase from 0.000248/year to 0.000583/year as in the case of the crank shaft. The downtime was also observed to be on a gradual increase from 6 hours in year 1 to 12 hours in year 5.The availability of the Piston declined from 0.9993 at year 1 to 0.9983 at year 5.

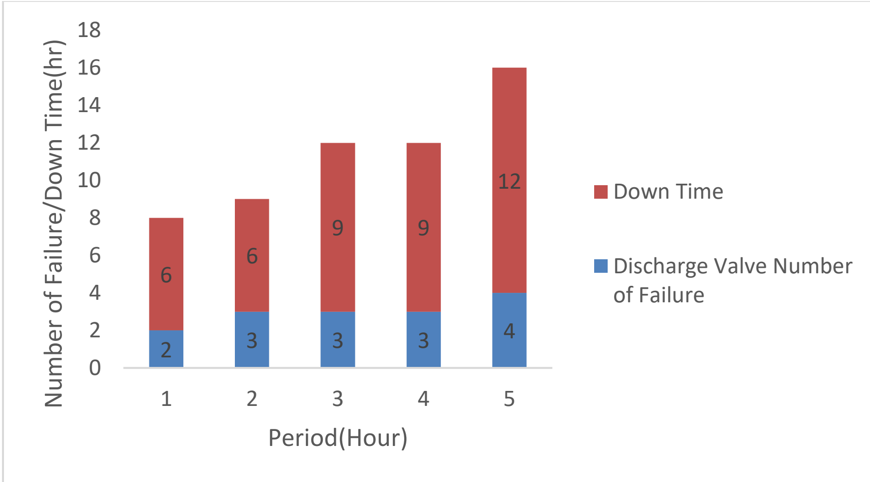

Figure 21: Number of Failure/Year and Downtime (DT) against the Period

Figure 21 illustrates the relationship between the piston number of failures in a year and the downtime from those failures. The failure of crank shaft was observed to have increased gradually from 2 to 4 as the downtime increases from 6 to 12.

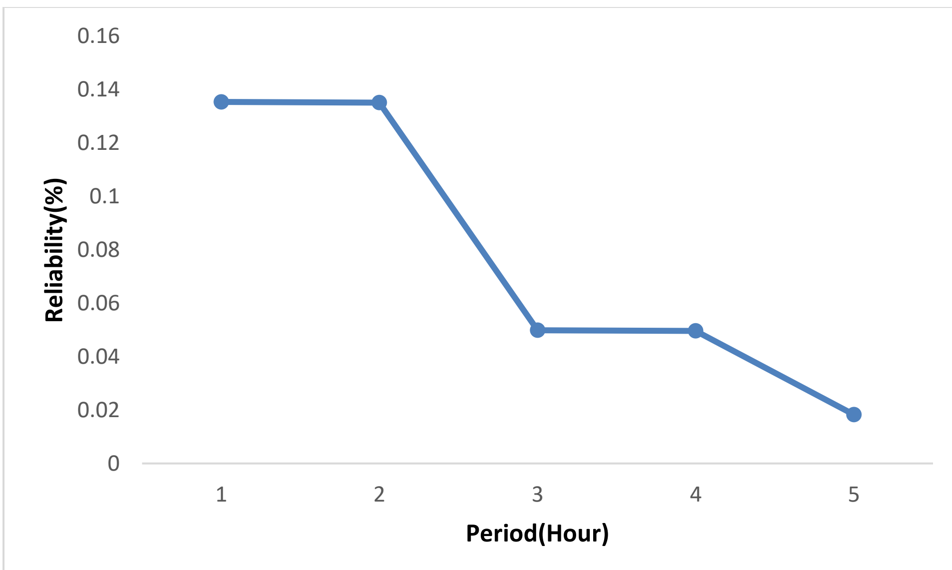

Figure 22: Reliability against the Period

Figure 22 shows the reliability of the bearing component. The reliability of the piston was observed to have declined gradually from year 1 to year 5.It declined from 0.1354(13.54%) at year 1 to 0.01828(1.828%) at the end of year 5. At the end of year 5 the percentage decrease in reliability was 86.50%.

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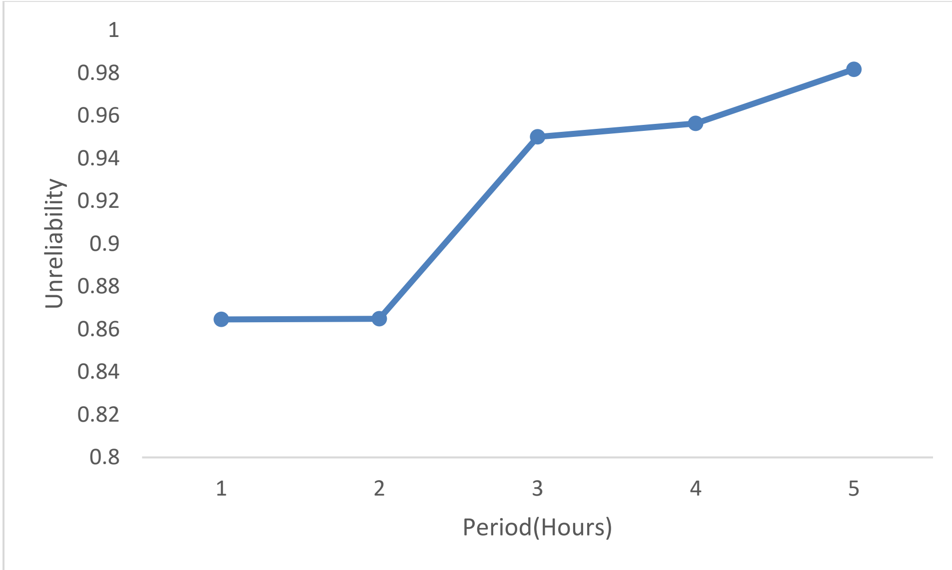

Figure 23: Unreliability against the Period

Figure 23 shows the unreliability of the piston. The unreliability of the piston was observed to increase gradually .The unreliability increased from 0.8646 to 0.9817 which signifies 13.54 % increase

5. CONCLUSION

This study was carried out mainly on rotating equipment of propylene plant of the Eleme Petrochemical Company Limited. A reciprocating compressor used for hydrogen compression was investigated for a period of 5 years to check the rate of failure, reliability, and the unreliability of the plant using condition based maintenance. The compressor component investigated are the bearing, connecting rod, crank shaft, piston and discharge valve. The investigation shows high failure rate, decline in reliability and increase in unreliability of the compressor. This has affected the availability of the compressor and reduced production target.

The first objective was to investigate the cause of rotating equipment failures (reciprocating compressor). The second objective was to examine the CBM approach used in the polypropylene plant. The third objective was to examine the effectiveness of the CBM approach for reliability, availability and Unreliability. The first and second objective was achieved through a detailed study of maintenance records of polypropylene plant especially for the reciprocating compressor under study. The record showed that poor maintenance culture resulting from inadequate training of personnel caused equipment failure. The maintenance record also showed the CBM method used (Vibrational and lubricant analysis). This was useful in predicting failure time of equipment and identifying equipment parts to be replaced. Furthermore, the results from computation analysis of various reliability, availability and unreliability parameters shows that the third objective of the study has been achieved. The CBM was effective in ensuring equipment reliability, unreliability and availability. For instance equipment reliability, unreliability and availability was calculated to be 0.1354, 0.8646 and 0.9983 respectively.

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Conflicts of interests

The authors declare that there are no conflicts of interests.

Data and materials availability

All data associated with this study are present in the paper.

REFERENCES AND NOTES

1. Baydar, N., & Ball, A. (2003). *Detection of gear failures via vibration and acoustic signals using wavelet transform. Mechanical Systems and Signal Processing*, *17*(4), 787-804.
2. Eti M.C, Ogaji S.O, Probert S.O. (2006). Development and

ISSN 2278–5469 EISSN 2278–5450 I OPEN ACCESS

implementation of preventive maintenance practices in Nigeria industries. *Applied Energy*, 83(10):1163-1179

3. Glowacz, A. (2014). Diagnostics of synchronous motor based on analysis of acoustic signals with the use of line spectral frequencies and K-nearest neighbor classifier. *Archives of Acoustics*, *39*(2), 189-194.
4. Gupta,A. and Lawsirirat,C.(2006) Strategically optimum maintainance of mornioring-enabled multi-component system using continuous-time jump deterioration models. *Journal of Quality in maintenance Engineering*, 12(3), 306-329
5. Hariharan, V., & Srinivasan, P. S. S. (2011). Vibration analysis of parallel misaligned shaft with ball bearing system. *Sonklanakarin Journal of Science and Technology*, *33*(1), 61-68
6. Lavy S, John A. G, Phil S & Manish K. D (2014). Key Performance Indicators for Facility Performance Assessment: Simulation of Core Indicators, *Construction Management and Economics*, 32(12), 1183 – 1204.
7. Lei, Y., & Zuo, M. J. (2009). Gear crack level identification based on weighted K nearest neighbor classification algorithm. *Mechanical Systems and Signal Processing*, *23*(5), 1535-1547.
8. Lim, G. M., Bae, D. M., & Kim, J. H. (2014). Fault diagnosis of rotating machine by thermography method on support vector machine. *Journal of Mechanical Science and Technology*, *28*(8), 2947-2952.
9. Loutas, T. H., Roulias, D., Pauly, E., & Kostopoulos, V. (2011). The combined use of vibration, acoustic emission and oil debris on-line monitoring towards a more effective condition monitoring of rotating machinery. *Mechanical systems and signal processing*, *25*(4), 1339-1352.
10. Nandi, S., Toliyat, H. A., & Li, X. (2005). Condition monitoring and fault diagnosis of electrical motors—A review. *IEEE transactions on energy conversion*, *20*(4), 719-729.
11. Nejadpak, A., & Yang, C. X. (2016). A vibration-based diagnostic tool for analysis of superimposed failures in electric machines. In *Electro Information Technology (EIT), 2016 IEEE International Conference on* IEEE, Washington D.C.
12. Nejadpak, A. (2017). *Failure Analysis of Rotating Equipment Using Vibration Studies and Signal Processing Techniques*. Theses and Dissertation. 2297. *University Of North Dakota*
13. Patel, T. H., & Darpe, A. K. (2009). Experimental investigations on vibration response of misaligned rotors. *Mechanical Systems and Signal Processing*, 23(7):2236-2252
14. Rafiee, J., Arvani, F., Harifi, A., & Sadeghi, M. H. (2007). Intelligent Condition Monitoring of a Gearbox Using Artifical Neural Network. *Mechanical Systems and Signal Processing*, 21(4), 1746-1754.
15. Ruotolo, R., & Surace, C. (1999). Using SVD to detect damage in structures with different operational conditions. *Journal of Sound and Vibration*, 226(3), 425-439
16. Safizadeh, M. S., & Latifi, S. K. (2014). Using multi-sensor data fusion for vibration fault diagnosis of rolling element bearings by accelerometer and load cell. *Information Fusion*, 18, 1-8.
17. Samanta, B., & Al-Balushi, K. R. (2003). Artificial neural network based fault diagnostics of rolling element bearings using time-domain features. *Mechanical systems and signal processing*, *17*(2), 317-328.
18. Saxena, A., & Saad, A. (2007). Evolving an artificial neural network classifier for condition monitoring of rotating mechanical systems. *Applied Soft Computing*, *7*(1), 441-454.
19. Tandon, N., & Choudhury, A. (1999). A review of vibration and acoustic measurement methods for the detection of defects in rolling element bearings. *Tribology international*, *32*(8), 469-480.
20. Wadhwa, N., Rubinstein, M., Durand, F., & Freeman, W. T. (2013). Phase-based video motion processing. *ACM Transactions on Graphics (TOG), 32(4), 80.*
21. Yang, D. M., Stronach, A. F., & MacConnell, P. (2003). The application of advanced signal processing techniques to induction motor bearing condition diagnosis. *Meccanica*, *38*(2), 297-308.
22. Zhang, L., Xu, J., Yang, J., Yang, D., & Wang, D. (2008). Multiscale morphology analysis and its application to fault diagnosis. *Mechanical Systems and Signal Processing*, *22*(3), 597-610.

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