RELIABILITY ANALYSIS OF PUMP FAILURE MODES IN LINEAR ALKYL BENZENE PLANT OF (K R P C) FOR MAINTENANCE STRATEGY SELECTION

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Abstract- The Work Involves the Examination of the Possible Failure Modes/Causes that occur in a pump for safety of operation, time and routine maintenance. The failure modes/causes constitute the total failure of a pump which if identified and eliminated will ensure high level of reliability, availability and efficiency of the system. The methodology employed the identification of significant few and insignificant many pump failures using Pareto analysis in capturing the failure modes, which help in determining which of these modes/causes, have an overriding importance in terms of frequency of occurrence and extent of possible damage, it is also crucial in reliability assessment. Field failure data were collected from Kaduna Refinery and Petrochemicals (KRPC) Linear Alkyl Benzene (L.A.B) Plant Maintenance Handbook from 1987 to 1992 a period at which the plant almost run at full capacity. The Pareto chart was then plotted using line-column in two axis Microsoft Excel spreadsheet. The result indicates that attending to mechanical seal, gasket, bearing, coupling, Packing, inboard bearing, main bearing, outboard bearing, gear and pinion and wearing ring failures will lead to reliability increase. Hazard and probability plots were made which shows the mean time before failure MTBF of $\mu = 39.89$ hours. They indicate the distribution of failure time to be exponential with a failure rate of $\lambda = 0.02501[hr]^{-1}$.

Keywords- Reliability Analysis, Alkyl Benzene Plant

I. INTRODUCTION

The probability that a component part, equipment, or system will satisfactorily perform its intended function under given circumstances, such as environmental conditions, limitations as to operating time, and frequency and thoroughness of maintenance for a specified period of time is known as reliability (http://www.Answer.com.).

Reliability being an inherent characteristic of a product has to be designed into the product in the first place. However, complete information to achieve optimal designed reliability may not be available until the component or system has been put into field use. The performance in the field can be fed back into the design stage and the cycle goes on. The condition of use and maintenance also has a bearing on the performance of the item. Pumps were installed at various locations within the plant to aid in transporting petrochemical products from one processing location to the other and are prone to probabilistic failures at any time.

This work, reliability analysis of pump, constitutes a partial survey of some of the common and more elementary methods in reliability engineering analysis. A Pareto chart is created using frequency of failure modes and cumulative percentage arranged in descending order. 80% of the failure modes to the left of the Pareto chart are the significant few failure modes. The factors that lead to failures do not impact on the process at the same degree. It is therefore necessary to determine the factors that impact most on reliability and determine control measures to be adopted in order to reduce their effect.

II.METHOD

The work involves collection of failure data of pump by going through the Kaduna Refinery and Petrochemicals (KRPC), Linear Alkyl Benzene (L.A.B) Plant Maintenance Handbook from 1987 to 1992 to identify the most common types of failure. As a first step in reliability data analysis we use the Pareto principle of' significant few' and the 'insignificant many' to analyze and also calculate the reliability of the pump (O'Connor, 2002). The significant few account for about 70% to 90% of the failures. Pareto analysis uses the principle that problem solvers should focus on 20% of factor causing 80% of the problem instead of the 80% factors causing 20% of the problems. It is also called the 80/20 rule (Leavengood and Reebs, 2002). In other words, it can also be stated that by doing 20% of work you can generate 80% of the advantage of doing the entire research (Mindtools Ltd, 2007). This principle was named after Vilfredo Pareto, an Italian sociologist and economist in the 19th century who observed that 80% of Italy's wealth was owned by 20% of the population (Strickland, 2006). This methodology has been employed in the design and optimization of industrial processes (Haaland, 1989).

From the failure frequencies the reliability of the pump is evaluated. We then use the failure time to determine failure distribution using Hazard probability plots which helped in arriving at the mean time before failure MTBF μ and the failure rate λ.

The hazard is calculated as follows: (O'Connor, P. D. T, 2002)

a. Sort and rank the N failure times from shortest to longest failure time. Note that the hazard can accommodate data where the time may be a censoring time rather than a failure time (i.e., the unit was taken out of service before it failed).
b. Calculate a hazard value at each of the failure times. Note that the hazard is only calculated at failure times, not censoring times. The hazard is 100.0* 1/(K) (O'Connor, P. D. T, 2002), where K is the reversed ranking of the failure time. This expresses the hazard as a percentage. You can express the hazard as a proportion by omitting the multiplication by 100.
c. The cumulative hazard is the cumulative sum of the hazard. That is, the cumulative hazards at the failure time with reverse rank K. See Table 1.

Theory of hazard plotting By definition reliability is the probability of a component or system to perform its designated function under specific condition of maintenance and time satisfactorily.

$$R(t)=1-F(t) \text{ or } F(t)=1-R(t) \quad (1)$$

Now the hazard function $\lambda(t) = f(t)/F(t)$ (2)

Inserting the value of F(t) from equation 1 into equation 2

$$\lambda(t)=f(t)/[1-R(t)] \quad (3)$$

$$\lambda(t) = \{1/[1- R(t)]\}. \frac{dR(t).R(0)}{dt(t)} = 1 \quad (4)$$

and

$$R(t) = 1 - F(t) = \exp\{-\int_0^1 \lambda(t)dt\} \quad (5)$$

$$H(t) = \int_0^1 \lambda(t)dt \quad (6)$$

Therefore,

$$H(t) = -\ln[1-F(t)] \quad (7)$$

The relationship in equation 7 is utilized to derive a special paper with the graph of "t" versus H(t) plot as a straight line on a given hazard paper of the distribution.

III. EXPONENTIAL DISTRIBUTION

The exponential distribution of time to failure is given by:

$F(t) = 1 - e^t$ it follows that

$$H(t) = \lambda t \text{ and } t(H) = 1/\lambda t \quad (8)$$

Therefore, time to failure is a linear function of the cumulative hazard. The line passes through the origin and its slope is $1/\gamma$ which is the mean to failure. The advantage of hazard function theory is that when special hazard paper are not availably we can use any linear , log linear, or log - log graph paper to plot sample data; and also the theoretical relationships to estimate the parameter of the distribution.

IV. ANALYSIS

From the real life failure data that has been collected which relate to only about eight thousand five hundred and forty two (8711) cases where failure has caused damage to the pump were selected. The principle of Pareto analysis is employed to determine which of these failure modes and causes have the overriding importance in terms of frequency of occurrence and extent of possible damage. Frequency distribution is used to determine the frequencies of failure for each of the failure modes.

Table 1 (data collected) gives the summary of the failure modes/faults and cases collected as field data. In order to apply the Pareto principle, the data was arranged in descending order of occurrence. The relative and cumulative frequencies of each of the failure modes were calculated.

It is observed that the significant few cases of the Pareto analysis principle contribute almost 81.2% i.e. the first ten (10) components of the total failure of the pump. A sample calculation of relative frequency of mechanical seal failure is given as:

Total failure of 871 I.

Frequency of mechanical seal = 948
Relative frequency of mechanical seal
= (948/8711) X 100= 10.9%.

The cumulative frequency was used to show the combined effect of the significant few failures leading to the failure of the pump. This was carried out by adding the relative frequency of each type of failure to the sum of all preceding relative frequencies.

Using line-column in two-axis of Microsoft Excel spreadsheet, the Pareto chart Figure 1 below was plotted based on the data of Table 1.

The line plot and bar graph represent the cumulative failure frequency curve and frequency of failures respectively. In Figure 1 the 80% line was traced to intercept the cumulative frequency curve.

Mechanical seal, gasket, bearing, coupling, Packings, inboard bearing, main bearing, outboard bearing, gear and pinion and wearing ring are the significant few failures that need to be attended to. Solving these failure events, will lead to the following failure reduction in the pump system, Percentage of failure events that require attention

$$\left(\frac{\text{Few failure that required attention}}{\text{Total failures}}\right) \text{x } 100$$

$$\frac{6478}{8711} \text{ x } 100 = 74.5\%$$

Table 1 failures of pump arranged in descending order with relative and cumulative frequencies.

S/NO.	COMPONENTS	FREQ. OF FAULTS	R.FEQ	R. FREQ (%)	CUMUL.FREQ(%)	R(I)
1.	Mechanical seal	948	0.109	10.9	1.9	0.891
2.	Gasket	752	0.086	8.6	21.8	0.914
3.	Pac kings	750	0.086	8.6	30.4	0.914
4.	Inboard bearing	710	0.082	8.2	39.0	0.918
5.	Main bearing	706	0.081	8.1	47.2	0.919
6.	Outboard bearing	704	0.081	8.1	55.3	0.919
7.	Coupling	667	0.077	7.7	63.3	0.923
8.	Gear and pinion	451	0.052	5.2	71.0	0.948
9.	Impeller	439	0.050	5.0	76.2	0.950
10.	Casing ring	360	0.041	4.1	81.2	0.959
11.	Wearing ring	300	0.034	3.4	85.4	0.966
12.	Casing	260	0.030	3.0	88.8	0.970
13.	Fasteners	260	0.030	3.0	91.8	0.970
14.	Inter cool	250	0.029	2.9	94.8	0.971
15.	Suction pipe	244	0.028	2.8	97.6	0.972
16.	Strainer	235	0.027	2.7	100.4	0.973
17.	Inducer	225	0.026	2.6	103.1	0.974
18.	Carbon ring	225	0.026	2.6	105.7	0.974
19.	Flush pipe	225	0.026	2.6	108.3	0.974
		8711	1	100		0.355

A total of 8,711 failure cases were recorded, hence the relative frequency for mechanical seal is 948/8,711 = 0.109 and the reliability R_1 is 1 – 0.10 9= 0.891

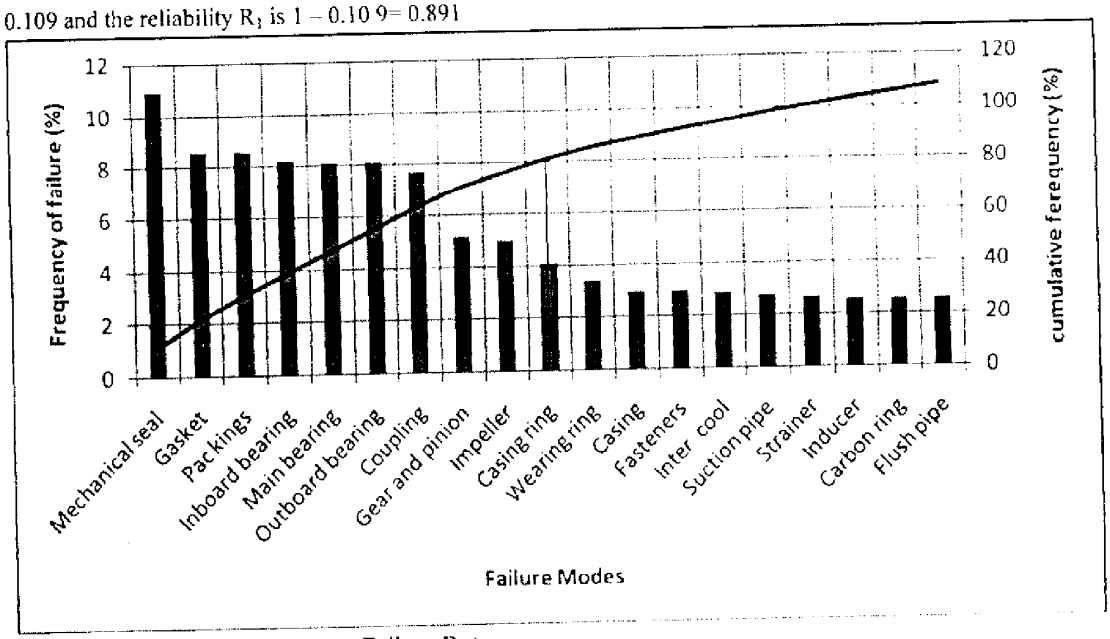


Figure 1 Pareto Charts Of Pump Failure Data

The reliability of the system is
Rs(t) = R1 x R2 x R3…… R19 = 0.355

From Table 1 the reliability of the pump system is 0.355.

Therefore,

Unreliability = 1 - 0.355 = 0.645

The improvement due to the application of the Pareto analysis is the product of the percentage of failures that require attention and unreliability, this is given as:

0.795X0.645 = 0.513

Thus, attending to Mechanical seal, gasket, bearing, coupling, Packings, inboard bearing, main bearing, outboard bearing, gear and pinion and wearing ring in the pump failure will lead to unreliability reduction of 0.513. This fraction reduction of unreliability will lead to the same fraction increase in reliability, thus the pump reliability becomes: 0.355+0.513=0.868

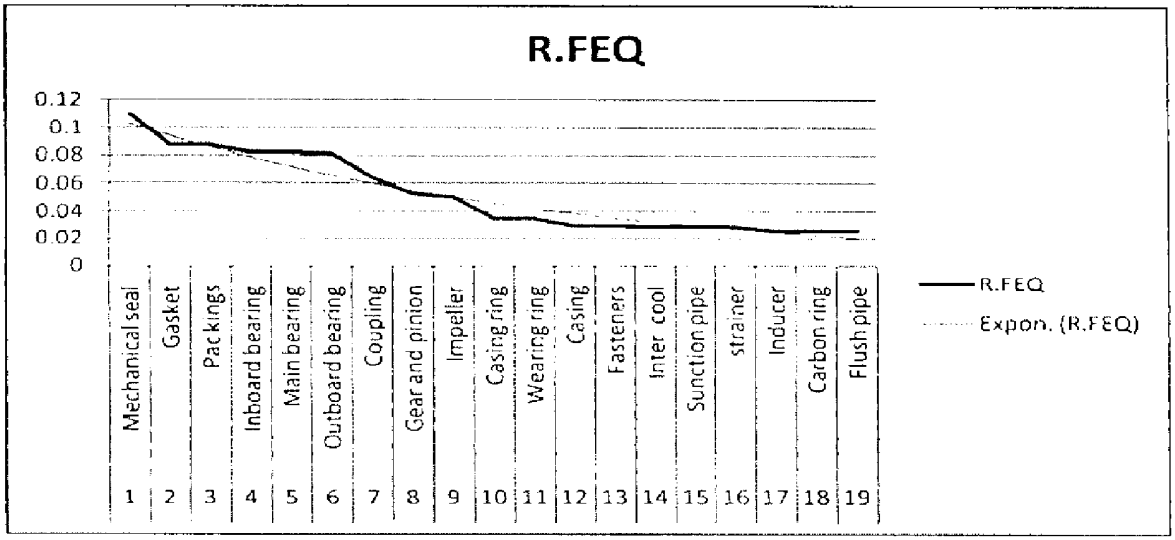


Figure 1 Relative Frequencies of Pump Failure Mode

Table 2 Hazard calculations for failure time

HOURS (T)	REVERSED (K)	HAZARD (100/K)	CUMULATIVE HAZARD (H)
28	88	1.1	1.1
79	83	1.2	2.3
107	78	1.3	3.6
179	75	1.3	4.9
327	66	1.5	6.4
330	63	1.6	8.0
476	53	1.9	9.9
572	50	2.0	11.9
693	44	2.3	14.2
813	39	2.6	16.8
959	31	3.2	20.0
1008	28	3.6	23.6
1300	19	5.3	28.9
1480	18	5.6	34.5
1850	8	12.5	46.8

Figure 3 below shows the plot on a linear graph paper. The straight line approximates the hazard function indicating that the distribution of the failure data is exponential this result is also shown in figure 2above. The slope is 39.98 hours this implies that:-

(a) The mean time before failure MTBF is given by:

MTBF = $\mu = 1/\lambda = 39.98$

Hence λ the failure rate

$= 1/39.98 = 0.02501$/hour

(b) The intercept = 35.7 hours indicate the failure free life (life of intrinsic reliability)

Thus $R(t) = e^{-0.02500(t)}$

Regression equation shows that:-

Intercept = 35.736,

slope = 39.98,

r = 0.985 and

$r^2 = 0.9796$

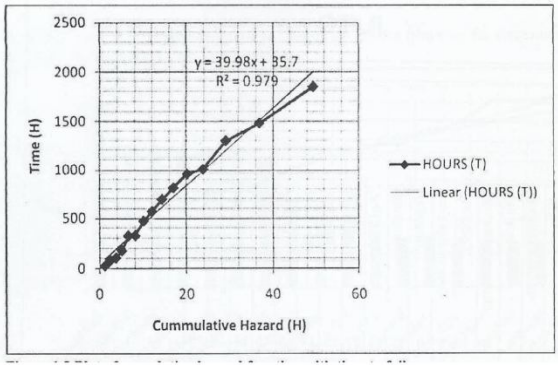


Figure 1.3 Plot of cumulative hazard function with time to failure

V. RESULTS AND DISCUSION

The Pareto analysis indicates which failure modes / causes occur most frequently and at which location and the likely affected part or component. The hazard and or probability plotting techniques assist in determining the underlying failure distribution (exponential) and the failure rate. The results of such analysis help in arriving at the design modification

and or maintenance strategy that would be employed for the component of the pump particularly the significant few. It also assists in deciding the maintenance culture that would be adopted, thus the maintenance team become well equipped with the information necessary to determine optimal maintenance strategy.

The reliability of the pump system at its present operating condition was calculated to be 0.355 and elimination of the identified significant failures will result in reliability increase to 0.868. The failure distribution turned out to be exponential with a constant failure rate λ of 0.02501/hour which is often referred to as memory less. This indicates that the remaining life of the pump system is independent of its current age. Hence for the pump to maintain such a high level of reliability, the maintenance term must strictly adhere to preventive maintenance strategy.

CONCLUSION

A Pareto analysis has been successfully applied to failures that lead to pumps system failure in Kaduna Refinery and Petrochemicals (KRPC), Linear Alkyl Benzene (L.A.B) Plant. The Pareto analysis generated from the frequency and cumulative frequency of failures, focuses attention on the significant few failures that when solved result in remarkable increase in pump reliability. The analysis shows that the elimination of failure of Mechanical seal, gasket, bearing, coupling, Packings, inboard bearing, main bearing, outboard bearing, gear and pinion and wearing ring will lead to having reliability increase from 0.355 to 0.868. Thus maintaining such a high level of reliability requires a consistent application of preventive maintenance plan.

The following details of the pump make/type/rating and location of service could not be provided in this paper because KRPC considers them as security information and should not be made public.

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