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Decision Making Reliability Approach for Maintainability of Economizer of Coal Based Boiler

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Abstract

This paper investigates the maintainability of economizers of three coal-based boilers for making decision of selection of replacement or maintenance practices. A sudden failure in the economizer can result huge production loss hence, a suitable decision model is essential which provides a strong data base for making optimal decision. A practical model for making decision is developed with respect to failure/repair data of three different economizers and trend with serial correlation tests are conducted. An investigation is carried out to determine the idealized statistical probability distribution providing best fit distribution. Further their Reliability and Maintainability are calculated. The tests of trend and serial correlation show very fast increasing failure rate of economizer # 1&2 with respect to economizer # 3. The present paper highlights that the failure data of economizer # 1 and economizer # 2 follow the NHPP model with poor reliability condition which indicates that these economizers should be replaced to restore boiler system as new as. However, failure data of economizer #3 follows the Lognormal distribution with poor reliability condition which suggests to develop the Preventive Maintenance Interval (PMI) to restore the boiler system. The present model serves a strong ground to decide replacement/preventive maintenance policy for not only to economizers but also to any pressure parts of coal based boilers.

Keywords: *Critical Subsystems, Lognormal, Maintainability, Reliability, Trend Analysis, Weibull*

1.0 Introduction

Demand of electricity all over the world is increasing day by day which results increased size of power plant. Coal based Power plant consists of several systems, where thermal energy is converted to electricity by using various equipment and different processes. The electrical power is mainly generated in a coal fired thermal power plant to supply the power requirement of a 70% population all across the world. The increased demand needs increase in coal requirement. However, as the coal beneath the earth's crust is available only for certain years. So, it will be more expensive with each passing years for the process of power generation. Secondly, all coal based thermal power plants have several types of critical equipment having certain amount of power loss associated with them. Hence, depending upon the plant capacity, the efficiency of the plant is restricted to only 40% as the end result of the total installed capacity of thermal power station as seen in power generation scenario. The mentioned constraints mainly emphasized on the fact, that the power generation process must be economized, and an economizer is that device which is used to do the same. Figure 1 shows a typical arrangement of several system of a coal based boiler (OPG 260 TPH).

The main parts of the plants are the steam generator, which is a complex integration of the boiler and its accessories (furnace, re-heater, super heater, economizer,

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boiler, and air pre-heater, etc.), as well as a number of auxiliary parts like pulveriser, fans, burners, dust collector, stokers, and precipitators, ash-handling equipment, and a chimney. The other main parts are the steam turbine, steam con According to Figure 3, there are three separate heat transfer regimes that take place to the water in the boiler. In the economizer, water is first sensibly pre-heated in the liquid phase at a specific pressure from stage 4 to state 5 till it reaches the saturation point. The saturated liquid is then sent to the evaporator, where it boils, causing a phase transition from 5 to 6, by absorbing the latent heat of vaporisation at that specific pressure. In order to transform this saturated vapour from state 6 into state 1, that is gaseous or vapour form, further heating is applied in the super-heater. The heat transfer equation for each of the three types of heat exchangers is given by,

$Q_{[Economizer]} = q5\text{-}q4$

$Q_{[Evaporator]} = q6\text{-}q5$

$Q_{[Super\ heater]} = q1\text{-}q6$

Only the economizer functions without consuming any fuel, making it one of the most essential and cost-effective pieces of instruments in a power plant. The main cause of forced outages in coal-fired thermal power facilities is boiler tube failure. Power plants must provide electricity without forced outages in order to keep up with the world's rising demand for electricity. To make the system lucrative and operationally viable, each subsystem must be optimised in respect to the others. The system's capacity to operate as expected, its availability, dependability, and maintainability have a significant impact on how effective the power generating equipment. The use of reliability analysis methodologies in the design and management of automatic and complicated power generation has progressively become common practise.

Since failures cannot be completely avoided, it is crucial to reduce their likelihood as well as their effects when they do exist. Reliability of the thermal power plant operation is directly linked with the plant safety/loss prevention and as far as operating cost is involved, it is directly related to steam boiler where 90% of operating cost is used on coal. An economizer is a critical subsystem the boiler economised. As a result, the economizer requires a thorough maintenance strategy because it frequently operates in severe conditions and with hazardous materials. So, today's plant managers and engineers must make crucial PM decisions focused on integrated loss prevention. Determine the impact of maintenance on dependability with the aid of quantitative methodologies that connect economizer deterioration to condition improvement by maintenance.

With the increase of commercial and domestic market in Indian electricity, consumption of coal also increases rapidly. Coal-fired thermal power plants contribute almost 70% of total required energy consumption. Maximizing a power plant's availability is one of the key conditions for maximising the supply of power. A power plant's availability is based on the high reliability and maintainability of the relevant equipment/components. The components/equipment will not perform satisfactorily unless properly maintained regularly, however well their design is. Therefore, the main objective

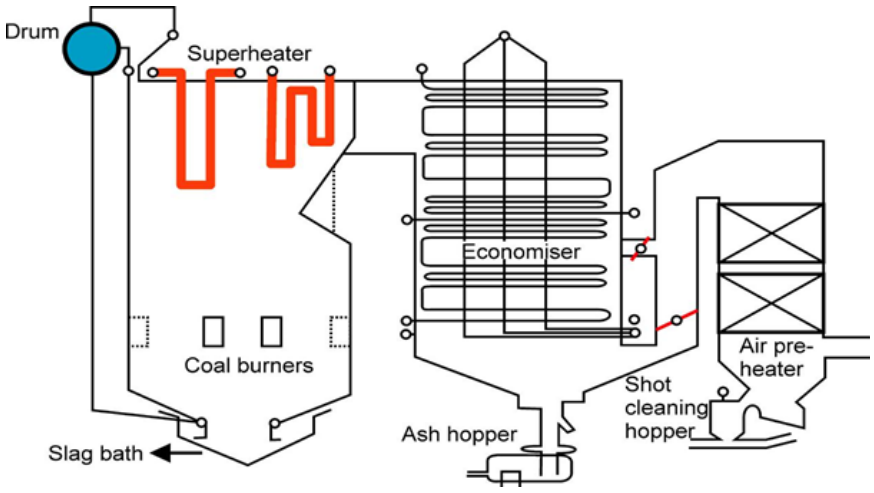


Figure 1. Typical arrangement of Economizer in Boiler (OPG 260 TPH).

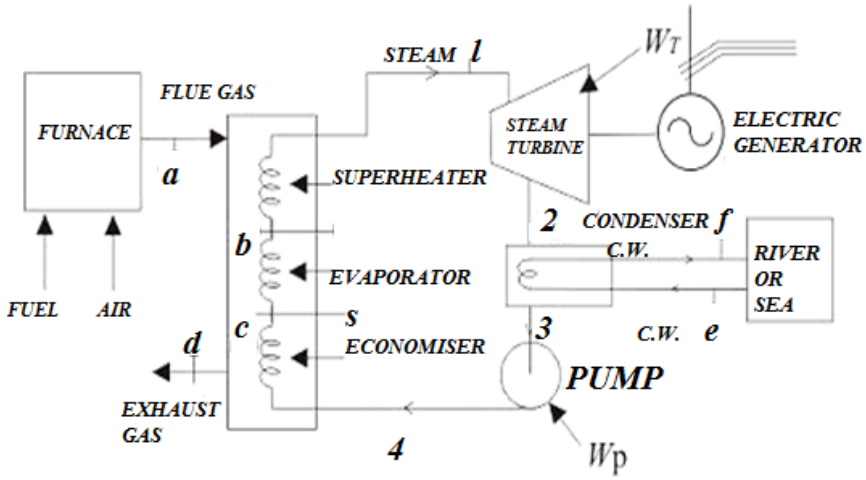


Figure 2. Heat Exchanger units of captive power plant.

of maintenance of components is to make the proper use of the corresponding information regarding failures and repairs. Reliability of a component is the ability of the component to deliver its desired function satisfactorily for a specified time in a particular environment. Several studies have been done on the individual components of coal-fired thermal power plants. A. Ahsen[1] has conducted the analysis of cost oriented failure mode and its effect. Model for reliability, aavailability and cost-centered preventive maintenance scheduling have been proposed by Debasis Das Adhikary *et al.*[2,3]. N. Arora *et al.*[4, 5] have conducted the availability analysis of Steam and Power Generation Systems and Stochastic analysis with maintenance planning of the ash handling system in the thermal power plant respectively. Barabady *et al.*[6,7] have performed a study on reliability and maintainability analysis of two crushing plants in a bauxite mine in which he concluded that the datasets of the subsystems are found to be independently and identically distributed and the Weibull distribution provided the best fit for their failure characterization. Klefsjö *et al.*[8] have utilized the methods of TTT plotting and maintenance policies. K Bouvard *et al.*[9] have proposed a model for condition-based dynamic maintenance operations planning and grouping. Similarly, M Braglia *et al.*[10] have provided a model for fuzzy modelling and analytical hierarchy processing as a way to estimate the risk levels connected to the different failure modes in the production system. K. Coffin[11] has estimated customer support during new product development using reliability techniques. A dempster-shafer theory-based approach to the Failure Mode, Effects and Criticality Analysis (FMECA) has been proposed by A. Certa *et al.* [12]. B.S. Dhillon[13] has carried out the Mining equipment reliability, maintainability and safety analysis. There are several reliability analysis techniques which are explained in details in the book of Charles E Ebeling[14]. L. A. Escobar *et al.*[15] have provided an important statistical prediction based model on censored life data for estimation of reliability analysis. G.F. Faiella *et al.*[16] have proposed an expanding healthcare failure mode and effect analysis model.

Therefore, it is necessary to investigate the trend analysis for describing the failure pattern of all mechanical equipment in order to maximize the power generation and supply. This paper investigates the trend characteristics of three economizers in unit-6, unit-7 and unit-8 of boilers which is labelled as Economizer number 1, 2, 3 respectively. The data collected are all original data of the power plant and no random number is used.

2.0 General Modes of Economizer Failures

There are generally two modes which lead to the failure of economizers. They are the followings:

2.1 Caustic Corrosion

As seen in Figure 3, caustic corrosion caused by feed water system corrosion deposits, greater concentration

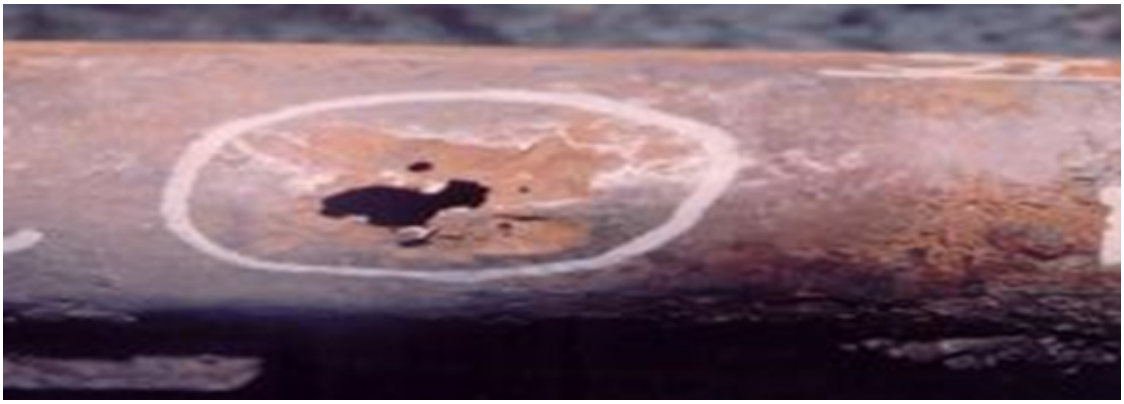


Figure 3. Failure due to Caustic Corrosion.

of NaOH in boiler water, condenser tube leakage, and temperature increase owing to internal deposits caused the boiler economizer tube to fail.

2.2 Fly Ash Erosion

According to a literature analysis, erosion is the main cause of tube failure in an economizer out of all the contributing elements. Material is stripped from an object's surface layers during erosion when it is struck by a stream of abrasive particles. The tube failure caused by fly ash erosion is depicted in Figure 4. In the regions of the economizer, re-heater, LTSH, and ash erodes the tube's outer surface due to its abrasive activity. Fly ash erosions commonly occur in gas by-pass channels, banks, and spaces between tubes. Fly ash erosions are mostly caused by the production of ferrous material close to huge ash accumulations, high coal ash concentration, high flue gas velocity, and high ash particle impingement angles.

3.0 Methodology

The evaluation of time to failure data and the amount of time required for repair can be used to evaluate the reliability analysis of an economizer. The methodologies adopted are discussed below:

- The given collection of failure and repair data will be used to identify which distributions offer the greatest fit for describing the failure pattern.
- To perform Trend Test and Serial Co-relation test for the same set of data.
- Putting the data in suitable distributions and estimating their parameters.
- To better grasp the nature of the economizer's failure pattern.
- To evaluate the reliability characteristics of economizers.

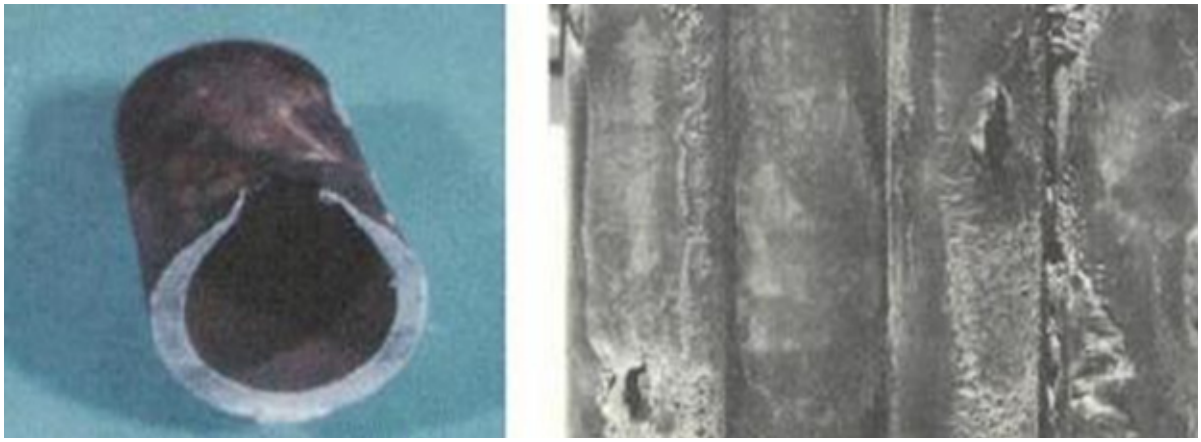


Figure 4. Failure due to Fly ash Erosion.

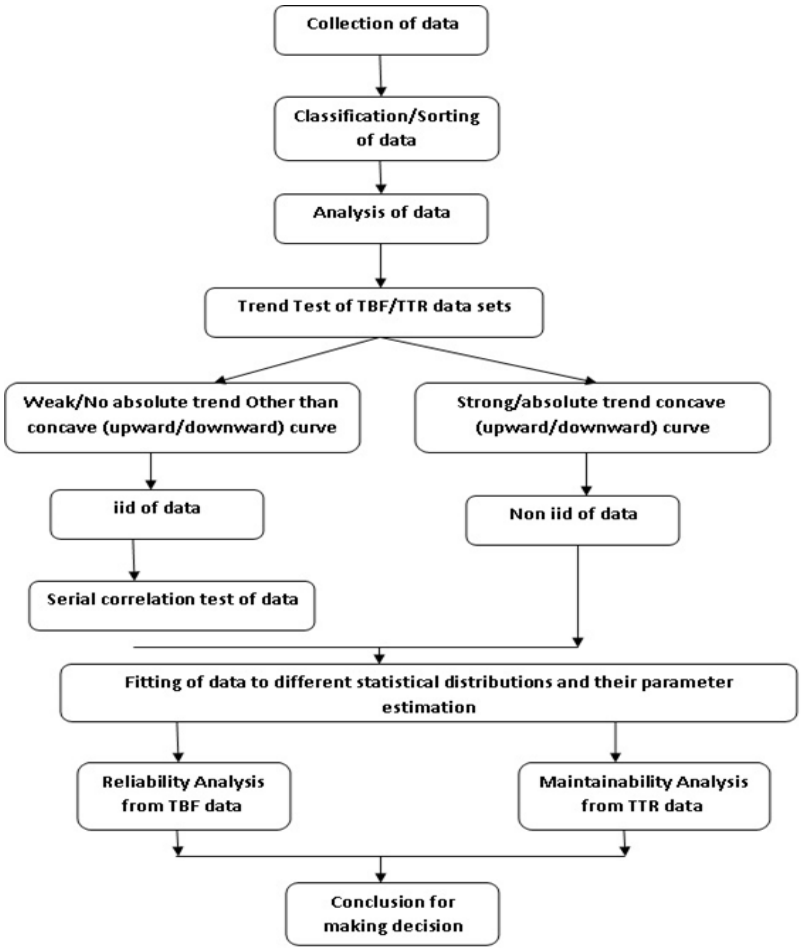


Figure 5. Algorithm of the entire methodology for describing the reliability characteristics of Economizers.

The complete methodology is summarized in Figure 5.

4.0 Data Collection and Analysis

The centre of collecting the data has been considered 'Bokaro Power Supply Co. Ltd. (A Joint Venture of SAIL & DVC) Bokaro, India. For actual failure/repair characterisation, data collects have been made over a long period of time. In the current study, maintenance data is gathered over a long period of time from the plant's maintenance logbook records, which are then sorted and categorised for analysis. Before the data can be examined to assess reliability qualities, three fundamental processes must be completed.

4.1 Trend Test

The frequency of failure/repair is plotted with TBF/TTR, respectively, to perform the Trend Test for TBF/TTR data graphically. Concave upward and concave downward curves on the Trend Test of TBF data represent an improvement and deterioration, respectively, in the system. However, when it comes to TTR statistics, a concave upward curve denotes a declining TTR. The data is uniformly distributed along a straight line.

4.2 Serial Correlation Test

Plotting the i^{th} TBF/TTR against the $(i-1)^{th}$ TBF/TTR for i = 1, 2, 3,..., n, where n is the overall number of failures, allows for the serial correlation test to be carried out visually.

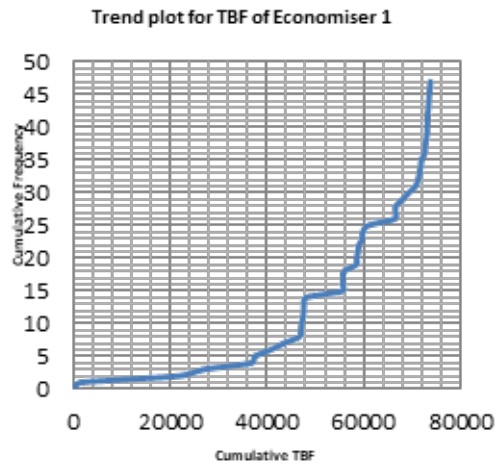


Figure 6.1 Trend Test Plot for TBF Datasets of Economizer 1.

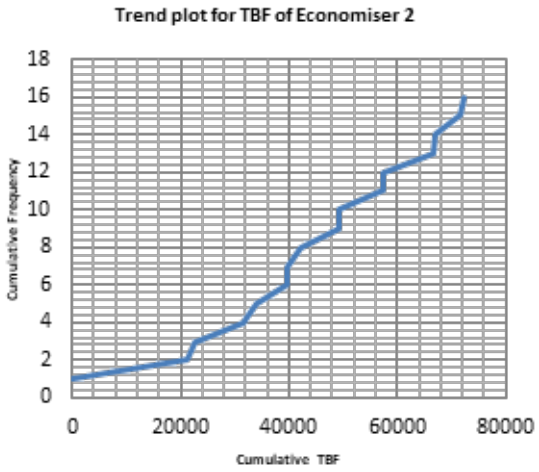


Figure 6.2 Trend Test Plot for TBF Datasets of Economizer 2.

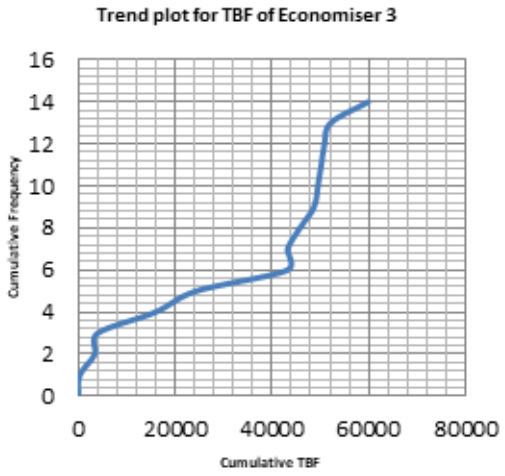


Figure 6.3 Trend Test Plot for TBF Datasets of Economizer # 3.

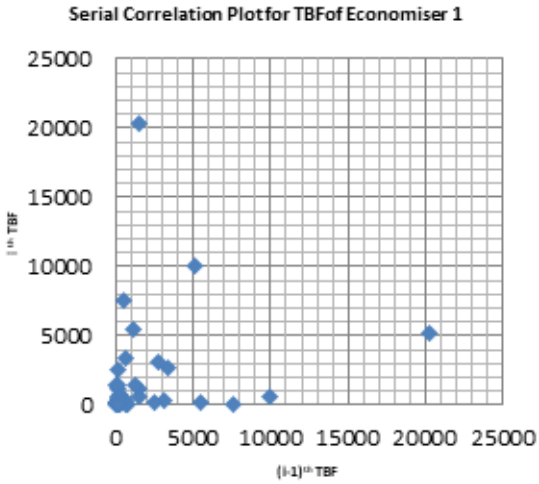


Figure 6.4 Serial Correlation Test for TBF Datasets of Economizer # 1.

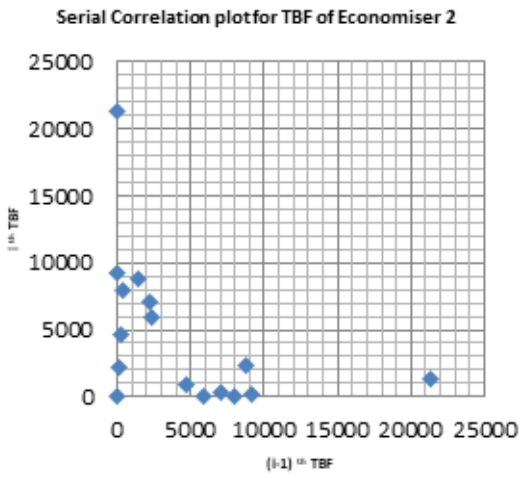


Figure 6.5 Serial Correlation Test for TBF Datasets of Economizer # 2.

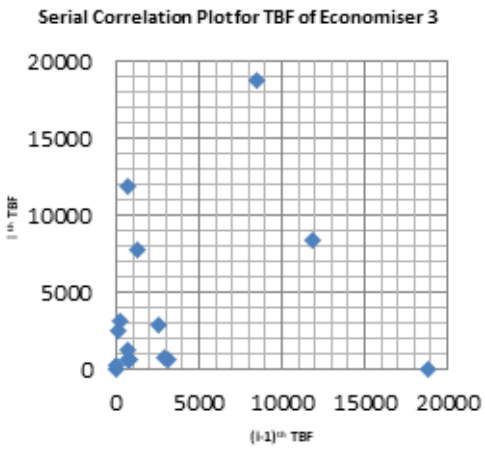


Figure 6.6 Serial Correlation Test for TBF Datasets of Economizer # 3.

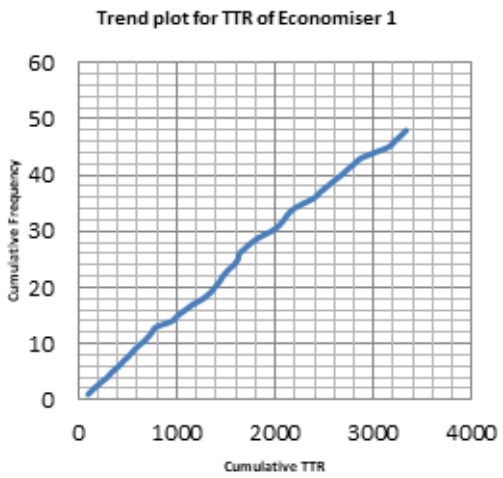


Figure 6.7 Trend plot for TTR Datasets of Economizer # 1.

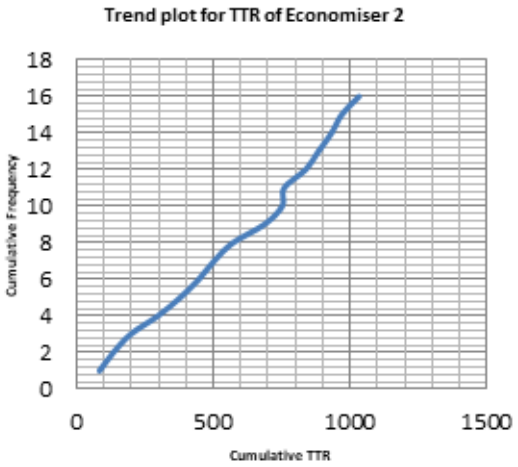


Figure 6.8 Trend plot for TTR Datasets of Economizer # 2.

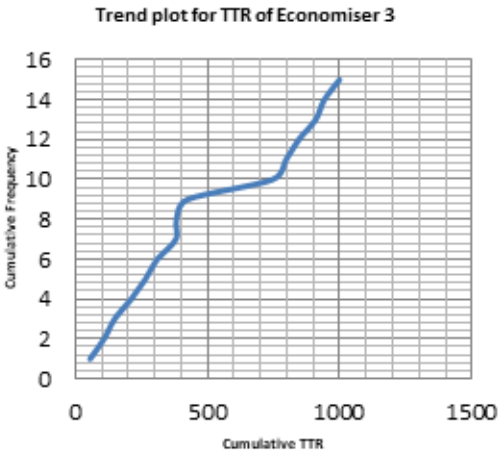


Figure 6.9 Trend plot for TTR Datasets of Economizer # 3.

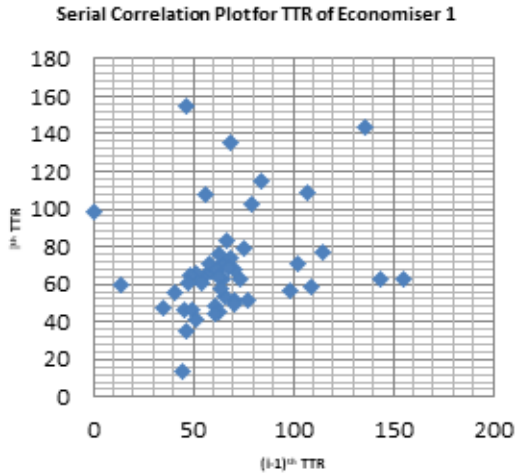


Figure 6.10 Serial Correlation Test for TTR Datasets of Economizer # 1.

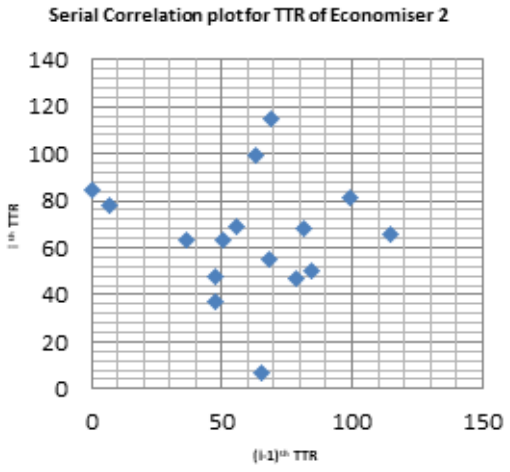


Figure 6.11 Serial Correlation Test for TTR Datasets of Economizer # 1.

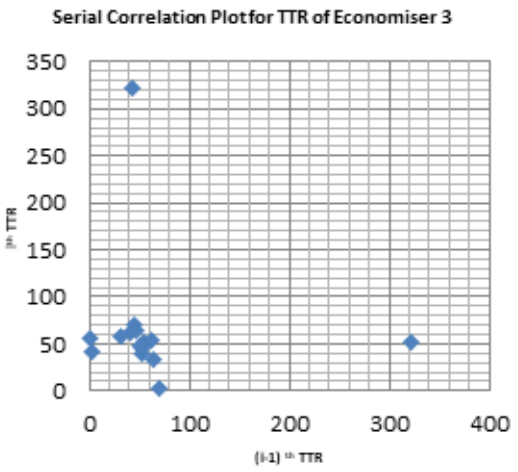


Figure 6.12 Serial Correlation Test for TTR Datasets of Economizer #.1.

The Trend Test and Serial Correlation Test are performed on TBF and TTR datasets of the economizers. The Trend Test of the TBF datasets of the three economizers is given in Figure 6.1, 6.2 and 6.3. From the Trend Test shown in Figure 6.1, the TBF datasets of the economizers 1exhibits the presence of trends. Figure 6.1 shows that the curve is concave upwards which indicates that the Economizer no. 1 is deteriorating after infant mortality stage. So the TBF datasets of this economizer is not independently and identically distributed.

From the Trend Test shown in Figure 6.2, the TBF datasets of the economizers 2 exhibits the presence of trends. Figure 6.2 shows that the curve is concave upwards which indicates that the Economizer no. 2 is deteriorating after infant mortality stage. So the TBF datasets of this economizer is not independently and identically distributed. From the Trend Test shown in Figure 6.3, the TBF datasets of the Economizer 3 shows the curve to be free from trends, in other words, it exhibits weak trend. Figure 6.3 shows the curve to exhibit irregular pattern or undulated pattern. The undulation causes by various external factors like vibration, noise, temperature, etc. So the TBF data of Economizer 3 is independently distributed.

The data points appear to be randomly dispersed and devoid of any discernible pattern in the serial correlation plots shown in Figures (6.4, 6.5 and 6.6), which suggests that the TBF data sets are independent or devoid of serial correlation. With the exception of ECN 1 & 2, the TBF data sets can therefore be considered independent and identically distributed (iid).

The trend graphs for the subsystems' TTR data sets show approximately straight lines (Figures 6.7, 6.8 and 6.9). Once more, it can be seen from the serial correlation plots in Figures 6.10, 6.11 and 6.12 that the data points (TTR) are dispersed randomly and lack any discernible pattern, suggesting that the TTR data sets are independent or free from serial correlation. Consequently, it is reasonable to assume that the TTR data sets are independently and identically distributed (iid).

5.0 Goodness-of-Fit Test for IID Data & NON IID and their Parameter Estimation

5.1 For IID Data

The parameters for the best fitted statistical probability distribution for the TTR datasets are estimated by using Matlab 2013 software. In the Weibull model, the shape parameter β and scale parameter θ is determined by plotting the datasets in Matlab 2013 software using 'dfittool' command in command window followed by importing the data, fitting it to a suitable distribution and estimating their corresponding parameters.

From the plot, the parameters for TTR datasets are found out and tabulated in the given Table 1.

Table 1 shows that the TTR datasets of all the three economizers follow Weibull distribution with Shape parameter β>1.

5.2 For Non-IID Data

A non-stationary model, such as the non-homogeneous Poisson Process (NHPP), should be used to analyse the TBF data of economizers with non-iid data. In this work, the ECN # 1 and ECN # 2 reliability models are modelled using the power law process NHPP model. The intensity function for the NHPP model is given by

$$\rho(t) = abt^{b-1} \quad \text{where } a, b > 0 \tag{1}$$

$$a = \frac{n}{T^{\hat{b}}} \text{ and } b = \frac{n}{n \ln T - \sum_{i=1}^{n} \ln t_i} \tag{2}$$

Table 1. Best-fit distributions for TTR datasets and their estimated parameters.

Sl. No.	Economizer No.	Best-fit distribution	Parameters	Parameters
1	1	Weibull	β = 2.61	θ = 78.23 hrs.
2	2	Weibull	β = 2.84	θ = 77.04 hrs.
3	3	Weibull	β = 1.15	θ = 70.99 hrs.

On analogy with weibull where

$$\lambda(t) = \frac{\beta}{\theta}\left(\frac{t}{\theta}\right)^{\beta-1} \quad (3)$$

$$b = \beta \text{ and } a = \theta = \frac{T}{n^{1/\beta}} \quad (4)$$

Where β = "Shape Parameter"
θ = "Scale Parameter"
n = "number of failure (or repair) events"
T = "Total running time"

t_i = "running time at the occurrence of failure (or repair) number i = 1,2,3....n"

It is crucial to determine whether the power lay process assumption is realistic before using the NHPP model. Power law method is found to be valid for the ECN # 1&2 subsystems of the boiler in the goodness-of-fit test conducted by TTT-plot for their subsystem. TTT plots for TDF data of ECN # 1&2 are shown in figure. By plotting and connecting the points (i/n, TTT_i^n) where $TTT_0 = 0$, by straight segments, the obtained curve is called the TTT (Total Time on Test) – plot.

$$TTT_i = \sum_i^n (n - i + 1)(X_{i:n} - X_{i-1:n}) \quad (5)$$

$$\sum_i^n TTT = {TTT_i}/{TTT_n} \quad (6)$$

Where i = 1,2,.....,n
X_i = i^{th} failure time

- A "power-law process" is a suitable model when the TTT plot is near the diagonal.
- A "power-law process" is a suitable model if the TTT plot is either concave up or concave down.
- The "power-law process" is inappropriate if there is no pattern or a curve that alternates between being concave up and down.

It is observed from the Figure 7.1 and 7.2 that the data points lay near the diagonal and shape is concave downwards. It suggests that the power law process is an appropriate model.

Form Table 2, it is observed that Economizer number 1 and 2 follow Power Law process NHPP model with shape parameter β>1, which shows an increase in failure

Table 2. Estimation of Parameters of TBF Data

System	Best fit distribution	Test	Parameters
Economizer # 1	NHPP model	TTT	β = 3.1, θ = 21351.88 hrs
Economizer # 2	NHPP model	TTT	β = 2.11, θ = 20024.9 hrs
Economizer # 3	Lognormal (2P)	C – S & K – S	s = 1.54, t_{med}= 1692 hrs

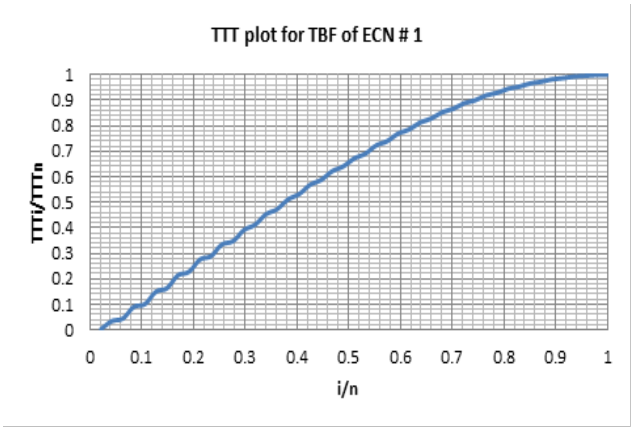


Figure 7.1 TTT plot for TBF Dataset of Economizer # 1.

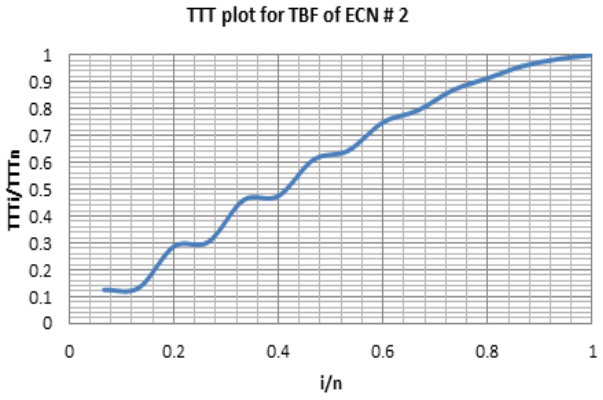


Figure 7.2 TTT plot for TBF Dataset of Economizer # 2.

rate due to aging process which implies as per trend plot in Figure 5.1 and 5.2 and hence they have obtained a minimal repair stage. Economizer 3 is best fitted to lognormal distribution.

6.0 Estimation of Reliability Analysis

Equations 7 and 8 are used, respectively, to calculate the reliability of subsystems using the Weibull (2 parameters) and Lognormal (2 parameters) distributions for TBF data.

For Weibull (2 Parameters):

$$R(t) = e^{-\left(t/\theta\right)^{\beta}} \quad (7)$$

Here, β is shape parameter, θ is scale parameter.

For Lognormal (2 Parameters)

$$R(t) = 1 - \emptyset\left(\frac{1}{s}\ln\frac{t}{t_{med}}\right) \quad (8)$$

Where, Φ is the probability density function, t_{med} is median time to failure, s is shape parameter.

Table 3. Reliability of the Economizers at the End of Different Time Intervals

TIME (HOURS)	ECN 1	ECN 2	ECN 3
0	1.0000	1.0000	1.0000
500	0.9999	0.9992	0.7852
1000	0.9999	0.9970	0.6351
1500	0.9998	0.9935	0.5299
2000	0.9997	0.9886	0.4596
2500	0.9994	0.9824	0.4015
3000	0.9989	0.9750	0.3559
3500	0.9981	0.9663	0.3193
4000	0.9971	0.9564	0.2877
4500	0.9957	0.9454	0.2620
5000	0.9939	0.9334	0.2421
5500	0.9916	0.9202	0.2206
6000	0.9888	0.9061	0.2061
6500	0.9854	0.8911	0.1911
7000	0.9813	0.8752	0.1770
8000	0.9709	0.8410	0.1586
9000	0.9571	0.8040	0.1380
10000	0.9394	0.7648	0.1250
20000	0.5263	0.3523	0.0548
35000	0.0149	0.0440	0.0244

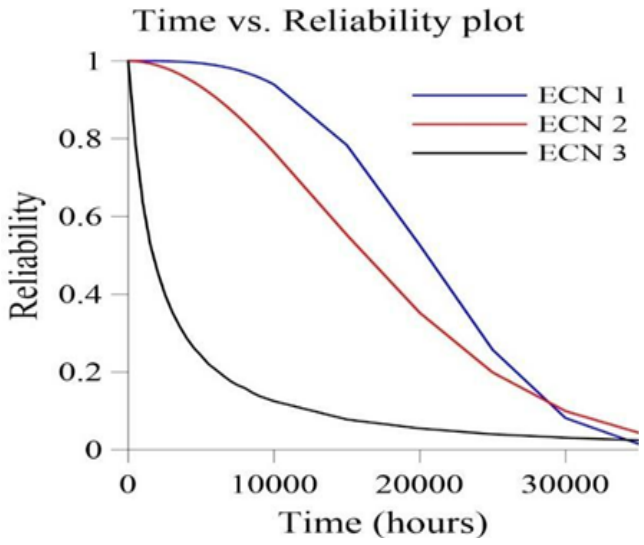


Figure 8. Time vs. Reliability Plots of the three economizers.

7.0 Maintainability Analysis

The Maintainability [M(t)] is only calculated for Economizer 3 as because of from Table 2, it evident that Economizer 1 & 2 need replacement.

$$M(t) = 1 - e^{-\left(\frac{t}{\theta}\right)^{\beta}} \quad (9)$$

Table 4. Maintainability of Economizer 3 at Different Time Intervals

Time (Hours)	Maintainability (Economizer # 3)
50	0.487
100	0.773
150	0.905
200	0.962
250	0.985
300	0.994

Table 4 shows that the maintainability of Economizer 3 is less than 1 even after 300 hours and for improvisation of maintainability of economizer 3, it not to practical approach to stop the working of economizer. For conducting the maintenance practice, whole system of boiler is brought to stop. Hence, due to short frequency level of repair of economizer 3 for better maintainability, it is advisable to replace the economizer for maximizing the plant availability & reliability.

8.0 Conclusions

The failure and repair data of three different economizers of captive power plant were analysed. The shape parameter of economizer # 1 is found more than one and follows the minimal repair distribution (NHPP, Power Law Model). Therefore, it is advisable to replace economizer # 1 to improve its reliability. Similarly, Economizer # 2 has also shape parameter near two and also follows the minimal repair distribution (NHPP, Power Law Model) which concludes that replacement is better option for reliability improvement. Economizer # 3 however, follows the lognormal distribution with shape parameter 1.54 which indicates that PMI should be planned effectively to improve the reliability but for the maintainability point of view, it is advisable to replace the economizer # 3 for better reliability.

This optimal decision model is naturally formulated based on reliability and maintainability analysis and it may be implemented for every pressure parts of coal based boiler. If set of failure data of any equipment follows NHPP process, certainly replacement of equipment is only optimal solution to improve reliability. Apart of this, increasing failure rate with short PMI also suggests to consider replacement policy. However, increasing failure rate with long PMI suggests implementing repair/ maintenance policy. Every organisation requires benefit in terms of cost; hence a bridge between the cost benefit and reliability is necessary and the present work provides a methodology for making decision between replacement and preventive maintenance.

9.0 References

1. Ahsen A. Cost oriented failure mode and effect analysis. Int. J. Qual. Reliab. Manag. 2008; 25:466-76. https://doi.org/10.1108/02656710810873871
2. Debasis Das A., Goutam Kumar B., Dipankar B, Souren M. Semiparametric Reliability Model in the Failure Analysis of a Coal-Fired Boiler Used in a Thermal Power Plant-A Case Study. Qual. Eng. 2015; 27(3):353-60. https://doi.org/10.1080/08982112.2015.1037395
3. Debasis Das A., Goutam Kumar B., Dipankar B, Souren M. Availability and cost-centered preventive mainte-

nance scheduling of continuous operating series systems using multi-objective genetic algorithm: A case study. Qual. Eng. 2016; 28(3):352-57. https://doi.org/10.1080/08982112.2015.1086001

4. Arora N, Kumar D. Availability analysis of Steam and Power Generation Systems in the Thermal Power Plant. Microelectron. Reliab.1997; 37(5):795-99. https://doi.org/10.1016/0026-2714(95)00115-8
5. Arora N, Kumar D. Stochastic analysis and maintenance planning of the ash handling system in the thermal power plant. Microelectron. Reliab.1997; 37(5):819-24. https://doi.org/10.1016/S0026-2714(96)00135-7
6. Barabady J. Reliability and maintainability analysis of crushing plants in Jajarm bauxite mine of Iran. Proceedings of the Annual Reliability and Maintain Ability Symposium, USA. 2005; pp. 109-15.
7. Barata J, Guedes Soares C, Marseguerra M, Zio E. Simulation modelling of repairable multi-component deteriorating systems for 'on condition' maintenance optimisation. Reliab. Eng. Syst. Saf. 2002; 76(3):255-64. https://doi.org/10.1016/S0951-8320(02)00017-0
8. Bengt Klefsjö, Ulf Westberg. TTT plotting and maintenance policies. Qual. Eng. 1996; 9(2): 229-35. https://doi.org/10.1080/08982119608919039
9. Bouvard K, Artus S, Bérenguer C, Cocquempot V. Condition-based dynamic maintenance operations planning & grouping. Reliab. Eng. Syst. Saf. 2011; 96(6):601-10. https://doi.org/10.1016/j.ress.2010.11.009
10. Braglia M, Bevilacqua M. Fuzzy modelling and analytical hierarchy processing as a means of quantifying risk levels associated with failure modes in production system. Tech. 2000; 5:125-34. https://doi.org/10.1080/135993700750364341
11. Coffin K. Evaluating customer support during new product development: an explorative study. Int J Oper Prod Manage. 1998; 21(3):221-2.
12. Certa A, Hopps F, Inghilleri R, La Fata CM. A dempster-shafer theory-based approach to the failure mode, effects and criticality analysis (FMECA) under epistemic uncertainty: application to the propulsion system of a fishing vessel. Reliab. Eng. Syst. Saf. 2017; 159:69-79. https://doi.org/10.1016/j.ress.2016.10.018
13. Dhillon BS. Mining equipment reliability, maintainability, and safety. Springer, London, UK. (2008); pp. 146-66. https://doi.org/10.1007/978-1-84800-288-3
14. Ebeling Charles E. An introduction to reliability and maintainability engineering. Mcgraw Hill Education (India) Edition. 2000.
15. Escobar LA, Meeker WQ. Statistical prediction based on censored life data. Technometrics. 1999; 41:113-24. https://doi.org/10.1080/00401706.1999.10485632
16. Faiella GF, Parand A, Franklin BD, Chana P, Cesarelli M, Stanton NA, et al. Expanding healthcare failure mode and effect analysis: a composite proactive risk analysis approach. Reliab. Eng. Syst. Saf. 2018; 169:117-26. https://doi.org/10.1016/j.ress.2017.08.003
17. Gavin HP, Yau SC. High-order limit state functions in the response surface method for structural reliability analysis. Struct. Saf. 2008; 30(10):162-79. https://doi.org/10.1016/j.strusafe.2006.10.003