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Failure Mode and Effect Analysis of Fire Tube Boilers Under Specific Operative Conditions

أنماط الأعطال و تحليل تأثيرها على مراجل مواسير اللهب تحت ظروف تشغيل محددة

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ABSTRACT

In many industrial fields, boilers are considered vital and an expensive assets. In addition to initial cost, they require high maintenance budget to be available in order to secure production in safe and acceptable working conditions .This kind of assets must be well operated under experienced well-trained supervision and subjected to strict maintenance programs executed by professional skilled personnel; otherwise dramatic consequences including loss of lives may result. The literature includes much research that studied maintainability & reliability for water tube boilers, in which FMEA (failure mode and effect analysis) and Ishikawa (fishbone) analysis are used. In addition, many of these researches are keen to use metallurgical and chemical analysis to study failure modes. For a long period of time researchers have given great interest in boiler tubes failures for different materials .This paper, presents a study of the maintenance and reliability of fire tube boilers from real case studies using FMEA "failure mode and effect analysis". Given the results of the study, the authors propose areas of improvement with significant impact for the state of art. Finally, it was found that around 30% of the failures could be prevented by means of proper maintenance procedures which are also highlighted and explained.

Key words: Boilers, Fire tube boiler, Maintenance, FMEA, Maintainability, Reliability.

1. INTRODUCTION

Boilers are a powerful example for the CHP (combined heat and power) machines. Boilers differs on the basis of type, brand, maximum output power, working principals, technologies or advanced features. The application of boilers in industry are vast, ranging from the pharmaceutical field, building operations to the food industry, the chemicals industry, oil refineries and the list goes on.

Boilers are CHP machines, that add energy to the thermal fluid (mostly water in this research), or transform water into steam for various applications.

Whatever type of the industrial application, the involved boilers are prone to malfunctions, what may result in loss of production or performance fluctuation. It is also common than not to suffer from unscheduled shut-downs because of boilers failures; which leads to financial and/or strategic consequences that negatively affect the return of investment of the organization. In extreme cases the failure of boiler may put lives and health at risk.

Any asset without maintenance is waste of investment, since boilers are vital equipment wherever they are implemented; their maintainability should be optimized in order to secure a safe, functional and profit making organization. Boilers are complex systems, that involve various sub-systems which vary in their characteristics. Given the complexity of the system, thorough studies and optimization efforts are required to build a maintenance system that leads to the required results namely properly-functioning and cost optimum boilers.

2. LITERATURE REVIEW AND PROBLEM FORMULATION

Researches directed much efforts towards the tube leakage detection such as constructing a model-based the mass balance equation (Xi Sun 2002) , they made a mass balance equation but did not measure the blowdown mass discharge or any other source of leakage ex: broken valve, malfunction accessories, water level indicator. Although the algorithm can detect the leak but it cannot detect exactly where the leak may be caused by valves, gaskets or other reasons. In a like manner mass-balances on both steam and combustion side of the boiler using Bayesian network, have been used in a research for early-warning for leakage in recovery boilers (Bjorn Widarsson 2007), in which they succeeded to get early-warning system . This method took the blow down mass in to consideration but still cannot detect exactly where the leak may be caused by valves, gaskets or other reasons.

Also researchers studied nondestructive tests, they used ultrasonic &EMAT (Electro Magnetic Acoustic Transducer) to measure the wall thickness and creep affected by hot spots (Anatoli Vakhguelt 2017). From another point of view, researches focused on the failure analyses chemically such aiming to help the researchers in selecting an appropriate and accurate coating material composition and avoiding hot spot corrosions (Santosh

Kumar 2018), The importance of Post welding heat treatment has been clarified in order to improve the ductility and to avoid unstable microstructure in the HAZ which in turn are responsible for the cracking failure (Wei Wang 2014) .

Moreover, the Post Welding Heat Treatment procedure, increases service loading due to geometrical effects not included in design calculation (Andreas Fabricius 2016) .

Stress corrosion cracking failure of SS316 L tubes have been studied Using visual inspection, optical metallography and chemical analysis , It was found that crack was initiated from tube external surface pitting , presence of chloride ions in the condensate are responsible for pitting (M. Ananda Rao 2018).also study the Microstructural evolution and oxidation of t92 boiler tubes has been done and showed that i) an outer layer of nanoscale iron oxide (Fe_2O_3); ii) inner layer of micro scale crystals of Fe_3O_4, and iii) a mixture of chromium oxide and chromite ($Cr_2O_3$and$FeCr_2O_4$) adjacent to the matrix (Kejian Lia 2017) . In case of low carbon steel tube it was found that tube wall thinning and steam leakage may be due to that combination of advanced hot galvanic corrosion and detachment due to a delamination defect (D. Luder 2017) .

The idea of burner ignition time adaptation according to the demand fluctuations was provided in form of “detection algorithm” using acoustic sensor (Thomas Neeld 2016). Failures due to cracks do not happen in tube only, for example, a fluidization nozzle made of 304 austenitic SS. After over 100,000 h of service at temperatures of 790–820 °, the root cause of the failure was the ash blockage which resulted in the scale cracking due to temperature fluctuation on the nozzle wall (Liu 2016).

Researches have worked on the life cycle time. Service life of the economizers of biomass fuel boilers is usually shorter than that of fossil fuel boilers (Liu 2013). CFD modeling, ANSYS FLUENT were used in life time decline of burners (Mahdi Pourramezan 2015).using steam side oxide scale thickness. , Non-Destructive Ultrasonic Oxide scale thickness measurements, residual life is calculated (K.S.N. Vikrant 2013).By using first order reliability method (FORM) failure probabilities can be estimated (Xueqian Fu 2017) . Boilers modeling were used also to make comparisons or detect performance of such design or efficiency (Jan Taler 2015), (Marco Tognoli 2017), (Ortiz 2011) .As doing experiments on a real boiler costs much, modeling is a good solution for that, a model constructed and its validation results are very encouraging considering the challenges posed by complex behavior and uncertainties in the actual power-plant boiler-drum (Sunil P U 2014). Also modeling has been used in Optimization of the boiler start-up taking into account thermal stresses (Jan Taler 2015). Also boiler efficiency improvement has been studied using fuzzy logic control algorithm in order to recalculate the flue gas in fuel pre-heating, they achieved 5.15% increase of boiler efficiency (Ratchaphon Suntivarakorn 2016). Boiler Is a vital machine so life cycle and its environmental impact had to be studied also (Vignali 2016), (B. Monteleone 2015). This research work focuses on the fire tube type running on gas/oil fuel.Unscheduled boiler outages may fail due to mechanical failure, electrical failure or temperature sensors failure (A. Mariajayaprakash 2013). His scope describes the failures of the fuel feeding system frequently occurred in boiler and gives the solution to rectify these failures. The above research has studied water tube boiler & its fuel feeding system. Our research on the fire tube type includes all its systems. As the aim of the maintenance program is to minimize the break down time there is Degradation modeling and condition-based maintenance of boiler heat exchangers using physical erosion model constructed gamma processes, are presented to predict the probability of key events in boiler operation: the bursting of a tube during operation and the plugging of a tube preventively during a scheduled shutdown. (Michael E. Cholette 2019).

3. Problem formulation

It is required to study the state of art of operating fire tube boilers in Egypt in order to improve their safety, availability and overall cost optimality. This study is to be achieved by means of analysis and scrutiny of real data.

In this research, real case studies of fire tube boilers are studied by means of FMEA “Failure Mode and Effect Analysis”, by the scrutiny of failure events altogether with their root causes, therefore to pave a way to improve the state of art and to achieve a better actuality of boilers operations in Egypt.

4. Methodology

This research is based on studying 40 real cases of fire tube boilers that were taken from all over Egypt (Alexandira, Cairo, Giza, Banisuif, Hurgada, Marsaalam, Sharm Elshaikh & Dahab), the data is retrieved from different sectors (factories, hospitals and hotels) which house different boilers manufacturers. In this research, only fire tube boilers are considered.

4.1.1 . Failure mode classification :

The causes of failures are categorized and abbreviated as follows:

- Normal wear out, “**Nw”;** is a damage that occurs to the machine due to normal deterioration and parts life time under normal operation conditions.
- Misuse “**Mu”;** is an Unintentional damage that is caused by the operator(s) to the machine during operation.
- Poor maintenance procedure, “**Pmp”**; is a damage that occurs to the machine because of lack of necessary maintenance or because of bad maintenance actions.
- Machine abuse, “**Ma”** is a damage that occurs to the machine because of an intentional sabotage or willingly exploitation.

4.1.2 Boiler main parts classification:

Boilers are divided into five main groups:

- Boiler body (heat exchanger): is the main metal barrel in which the heat transfer from the heating source and the water takes place. It includes furnace, fire tube and insulation.
- Burner: is the heating source system which supplies the boiler with the energy required as per rated design.
- Control: is the panel that includes the components that govern the functioning of the i.e. (PLC, sensors, pressure trolls, Relays, Timers, contactors switches etc..)
- Accessories: include valves, water level, gauges, gaskets, blow down check valves etc.
- Additional options: such as chemical manager system required to monitor the the (PH , Condtivity, etc), automatic blow down system , extra monitoring devices , economizer etc.)

4.1.3 Boiler parts classification:

From a different point of view boiler parts are classified into one of the four field groups: Mechanical; Electrical; Control; Pneumatic.

4.1.4 Failure impact classification:

The conclusive list of failures that may occur in the boilers subject of the study are classified with respect to the criterion "the intensity of the failure effect on the industrial site" this intensity ranges from posing an immediate danger to lives and/or health to having a trivial financial impact. For every category of effect intensity a code is given from I1 standing for the most impactful to I6 standing for the least impactful. The key to the six suggested categories is shown in Table 1

Table 1. Impact classification

Impact rank	Rank meaning
I1	may entail fatal injuries or death
I2	may entail Overhaul, major repairs & complete burner replacing
I3	will entail catastrophic loss (monitory) : production stoppage - product damage - lost opportunities
I4	will entail high losses : medium , regular
I5	med. Losses
I6	Trivial

4.2. DATA GATHERING:

Data has been collected from 40 studied cases of boilers.

4.3. DATA SORTING :

In order to process and analyze this huge quantity of data, a table was built to hold 40 cases of boilers, every boiler has 104 different parts, there classification, impact and its four failure modes. A data sheet that contains **18,620** cells of data was created.

4.4. DATA PREPARATION AND PROCESSING "I":

The data should be prepared by means of numeration in order to get exported for analysis in the next step.

4.4.1 Dara numeration by means of scoring techniques

In order to study the real effect of the fault it is required to focus on its impact not it occurrence count, therefore, we constructed a scoring technique to give a true weight for the fault.

Weighting impact Calculation:

Percentage of occurrence = Total count of a specific failure mode for the same part / Total count of all failure modes for the same part.

Weighted value = Percentage of occurrence × Equivalent weight

4.4.2 *Example 1*:

- For electro-mechanical part "A"

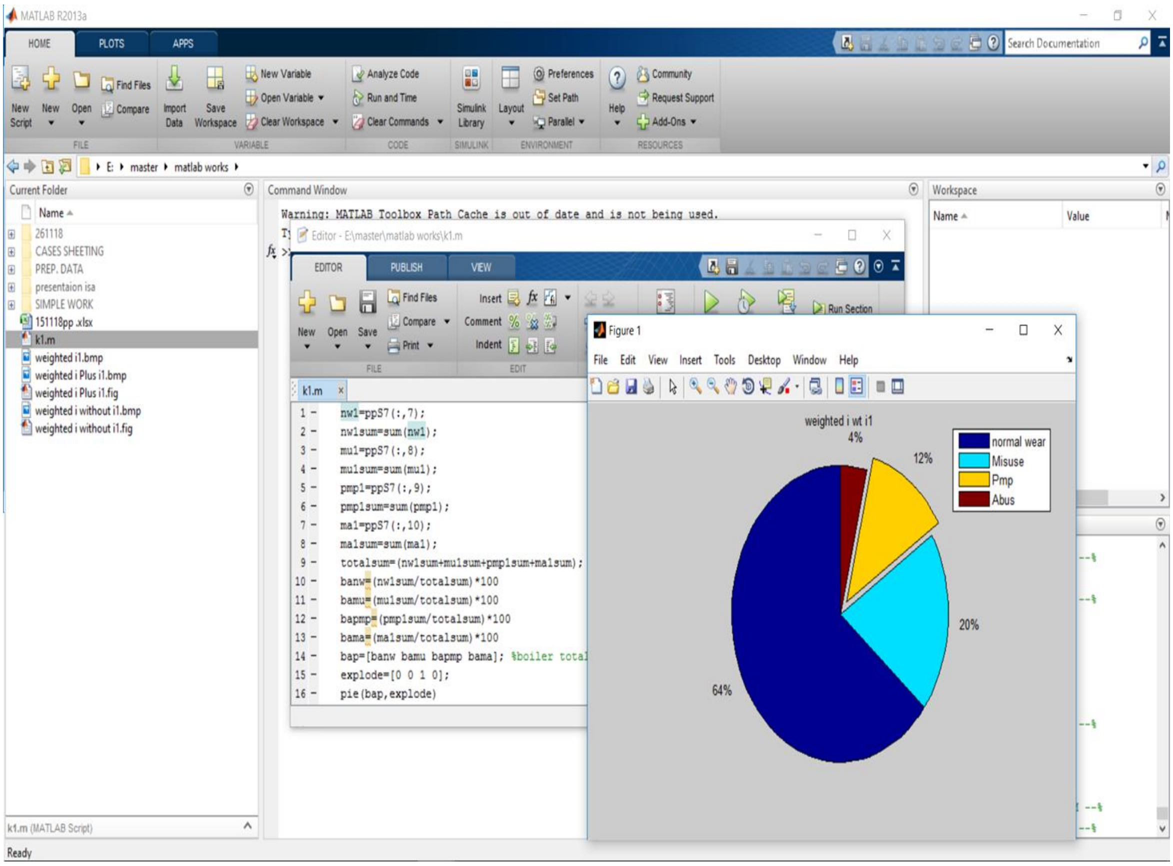
Its percentage of occurrence = 70% and its Equivalent weight = 0.25 then the weighted value = 0.7 x 0.25 = **0.175**

- For the electro-mechanical part "B"

Its percentage of occurrence = 70% and its Equivalent weight = 0.65 then the weighted value = 0.7 x 0.65 = **0.455**

4.5. DATA PROCESSING "II" :

The data sheet file is exported to Mat Lab program in order to be processed and executed through a pre-programmed M-file. The results are presented on Pi charts.

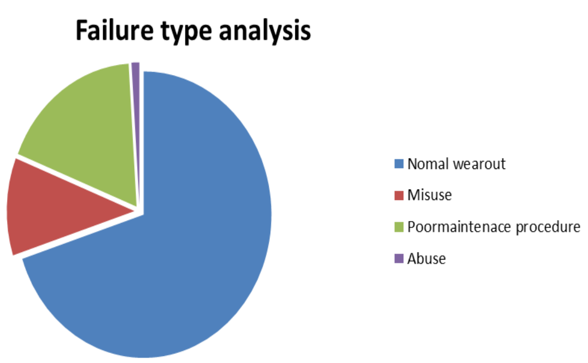


Presentation of the results on reports and Pi charts

5. RESULTS AND INTERPRETATION:

5.1

Failure type analysis				
Failure type	Normal Wear out	Misuse	Poor maintenance procedure	Abuse
Percentage	70%	11%	18%	1%



The above chart shows that 70 % of the total failures are caused by "normal wear out" which is expected at the end of the useful parts life-span under normal operating conditions. In the second rank comes the "Poor maintenance procedure" which scored 18 % from the total failures. Then the "Misuse "ranked the third place with 11%, finally abuse scored 1% from the total failures.

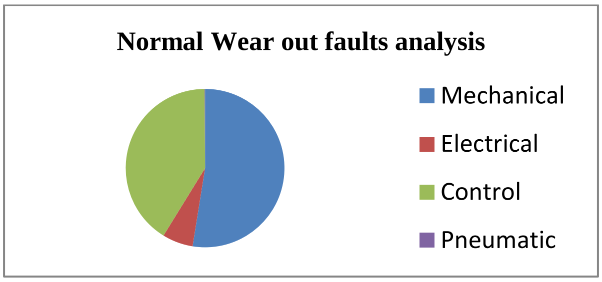
Misuse, Poor Maintenance Procedure and Abuse have few causes like: lack of knowledge, lack of experience, lack of training, technical disqualifications, limited ability to adapt with new working environment, etc. The above mentioned three causes account for 30% of the total failures, this percent can prevented by providing the followings:

- Maintenance system improvement.
- craftsmen training.
- Promotion of technical Knowledge acquirement by maintenance personnel.
- Meticulous supervision including (ICA) Immediate Corrective Actions towards any violations.
- improvement Professional Ethical protocols.
- Avoidance of personnel over working like in events of consecutive double shifting.

Having stated the above recommendations for the improvement of the state of art in the field of study and in similar fields, each type of failure causes is further analyzed in order to supply the user of this work with an extra tool of insight into the nature of the failures that affect the performance of the boilers.

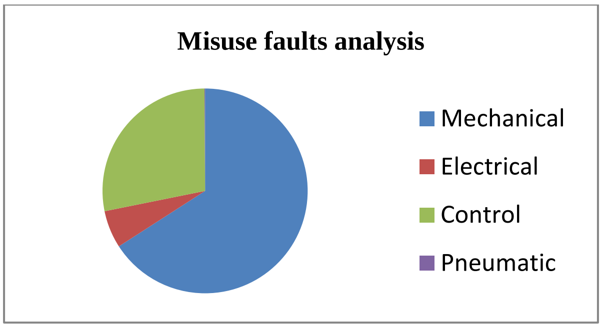
5.2

Normal Wear out faults analysis				
Type	Mechanical	Electrical	Control	Pneumatic
percentage	52.8%	6.2%	40.7 %	0.1%



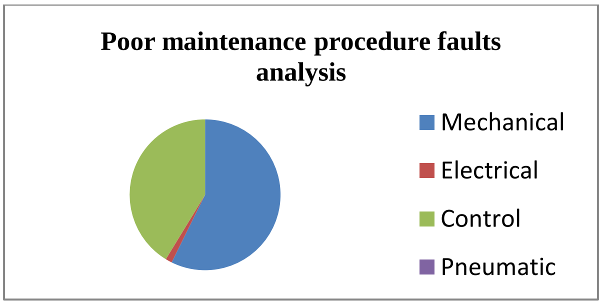
5.3

Misuse faults analysis				
type	Mechanical	Electrical	Control	Pneumatic
percentage	64.8%	6.1%	28.9 %	0.1%



5.4

Poor maintenance procedure faults analysis				
type	Mechanical	Electrical	Control	Pneumatic
percentage	57.2%	1.4%	41.2 %	0.0%



5.5

Abuse faults analysis				
type	Mechanical	Electrical	Control	Pneumatic
percentage	23.4%	21.3%	55.1 %	0.0%

7. Discussion

In this paper, the case of fire tube boilers was studied but the same algorithm may be applied on water tube boilers, which enlarges the area of application of this work.

There is a governing parameter namely the operating conditions which intensely affect the total number of failures of boilers; this parameter may be divided into a set of conditions like the quality of the water intake, the quality of the fuel, the level of expertise of the operators and/or the maintenance personnel. The improvement of these conditions may reduce the total amount of failures by a great factor.

8. Conclusion

This paper investigated the actuality in the field of operation and maintenance of fire tube boilers through the study of 40 real cases from Egypt. It was found that the field suffers from major losses due to failures that may be prevented by means of improvement of operation and of maintenance of these valuable applications. Given this fact it is concluded that the state of art of boilers profitability in Egypt as well as expectedly in most developing countries involve massive areas of potential improvement.

The authors made recommendations based on the results of the study and on field experience; these recommendations if followed are expected to decrease the amount of failures by 30%.

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Appendix I

		Boiler parts		"I"		new I weight Calculated Total Impact formula	failure mode Occ. % Normal wear	Misuse	Poor main. Proc.	Abuse	"I"	weighted value Normal wear	Misuse	Poor main. Proc.	Abuse
1	1	insulation	M	2,4	2)+	0.09	0.166667	0.166667	0.666667	0	2,4	0.015	0.015	0.06	0
2	2	smoke tubes up to 1	M	4		0.04	0.112676	0.873239	0.014085	0	4	0.004507	0.03493	0.000563	0
3	3	smoke tubes more 1	M	3		0.16	0.285714	0.696429	0.017857	0	3	0.045714	0.111429	0.002857	0
4	4	fire tube	M	3		0.16	0	0.111111	0.888889	0	3	0	0.017778	0.142222	0
5	5	barell	M	1		1	0.375	0	0.625	0	1	0.375	0	0.625	0
6	6	shells	M	3		0.16	0	0.873418	0.126582	0	3	0	0.139747	0.020253	0
7	7	hand hole gaskets	M	4		0.04	0.876333	0.089552	0.034115	0	4	0.035053	0.003582	0.001365	0
8	8	man hole gasket	M	4		0.04	0.93617	0.044917	0.018913	0	4	0.037447	0.001797	0.000757	0
9	9	chimney	M	1		1	0.5	0	0.5	0	1	0.5	0	0.5	0
10	10	stack damper	M	1		1	0.705882	0.176471	0.117647	0	1	0.705882	0.176471	0.117647	0
11	11	tube doors	M	1		1	1	0	0	0	1	1	0	0	0
12	12	doors fixers	M	3		0.16	0.533708	0.398876	0.067416	0	3	0.085393	0.06382	0.010787	0
13	13	door locks	M	4		0.04	0	0	0.714286	0.285714	4	0	0	0.028571	0.011429
14	14	fire side Door gasket	M	4		0.04	0.962667	0.008	0.029333	0	4	0.038507	0.00032	0.001173	0