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Process FMEA in a University Hospital: management of Occupational Risks in Boilers

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Abstract

This paper aims to identify the risks present in the flame tube boilers of one University Hospital using process FMEA tool. It was used an exploratory methodology of nominal qualitative type. On this basis, we proceeded with bibliographic analysis, methodologies, references, on-site visits, and studies of investments made in steam generators. We obtained as a result a dossier with information relevant to the identification of procedures that have higher incidence of risk in flame tube boilers.

Keywords: Risks. Steam Generator. Boilers. FMEA.

1 Introduction

The sharp industrial growth, resulting from technological advances, has developed several job opportunities, strengthening the competitiveness of organizations with the need to improve industrial processes that resulted in larger and more complex plants. This fact also increased pollution and industrial accidents that draw the attention of government entities (Moraes, 2010).

In this context, the improvement of the Work Security and Health (WHS) sector results on a reduction of risks of accident, leading to the preservation of health and improving the operating performance of employees. It also, enhances the company's image in the market, designing new growth opportunities (Oliveira, 2010). The growing concern about industrial safety in organizations tends to result in the reduction of labor risks intrinsic to the work environment and the operating procedures of the different activities. Work safety is related to the prevention of accidents and the preservation of workers' health. Therefore, its purpose is prophylactic in order to anticipate risks.

The term "risk" means the probability of a bad outcome, and "risk management" is the set of instruments that the organization uses to plan, operate and manage its activities in exercising the risk control function. Flamotube boilers are the most commonly used in small and medium-sized industries. This type of boiler is easy to operate, so most of the accidents generated are negligent. In addition many hospitals are used of flamotubular boilers because its cost of acquisition and operation is more advantageous to keep in operation the systems of autoclaves, laundry, among others. In view of this, the present article proposes to identify the hazards present in the operating phase of flame tube boilers of the University Hospital of Santa Maria (HUSM) with the use of *Failure Mode and Effects Analysis* (FMEA) tool. The justification for this work is based on the identification of improvements in controlling the process of HUSM's boiler's sector, seeking for the safety and physical integrity of employees.

1.1 Evolution of Prevention

The prevention of damage for the employees' work activities emerged and evolved after the First World War, with efforts focused on the study of diseases, environmental conditions, machinery and equipment layout. During this period, studies were developed to improve the understanding of the problem, propose methodologies and assess results. The engineer Helbert William Heinrich describes that there is 1 disabling injury for each 29 minor injuries and 300 accidents without injuries.

Extending these studies, the engineer Eduard Frank Bird Jr. analyzed accidents in 297 companies, which represented a sample of 21 groups of different industries, reporting a ratio of 1 disabling injury for every 10 minor injuries, 30 accidents with property damage and 600 incidents. In 2003, Marine showed that for every death there are at least 300,000 risky behaviors (Freibott, 2014). From this ratio, it is possible to conclude that actions should be directed to the base of the pyramid, not just to events that result in severe or disabling injury.

1.2 Risk Management in Boilers

Risk management can be defined as: identification, evaluation and ranking the priority of risks (Cagnin, Oliveira, Simon, Helleno, & Vendramini, 2016). The process of risk management starts primarily with the identification and analysis of risks of accidental losses that threaten the organization. The risk identification is the process by which the accident risk situations are analyzed continuously and systematically (Moraes, 2010). The analysis can be performed by means of technological, economic and social factors. Technological factors are related to the development of more complex processes. The economic factors are related to the increase of industrial plants' scale. The social factors comprehend the proximity of demographic concentration.

According to the Norm NBR ISO 31000: 2009, the term "risk" can be characterized as the effect (positive or negative) of uncertainty on determined objectives. Thus, risk analysis involves identification, recognition, evaluation and gradation of risks followed by controls in order to mitigate the probability of the causes occurrence and risk effects. The risk management process according to ISO 31000 as it is shown in Figure 1.

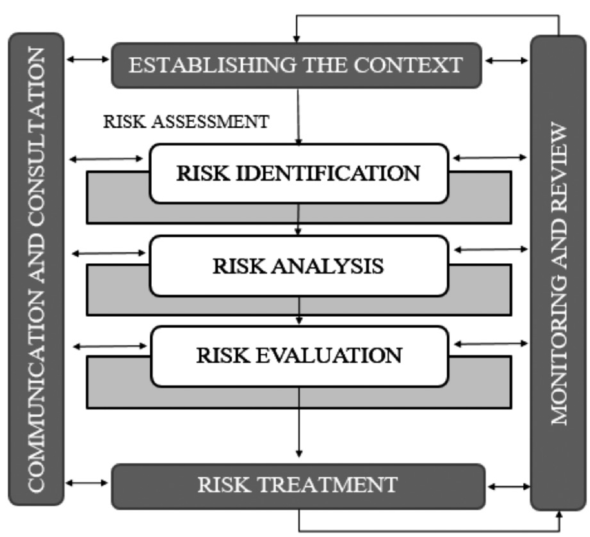

Figure 1: Risk management process
Source: ISO (2009).

Ruppenthal (2013) defines the risk management, in its turn, as a methodology that aims to increase confidence in the ability of an organization to predict, prioritize and overcome obstacles to achieve goals. Thus, comprises efforts in trying to eliminate, reduce, control or yet finance the risks, if economically viable. Therefore, it concerns the management of fault possibilities in order to prevent it from happening.

In this context, risk management is the systematic practice of selecting necessary actions to minimize or avoid the materialization of potential causes that can lead to the occurrence of accidents. Risks cannot be fully avoided, but can be minimized into tolerable levels set by the company or the process under analysis. For risk management, the problematic consists primarily in knowing and analyzing the risks and accidental losses that threaten the organization. This identification is the process by which the accident risk situations are analyzed continuously and systematically (De Cicco & Fantazzini, 2003; Moraes, 2010).

1.3 Management of Risk in Boilers

The NR 13 of the Ordinance 3.214/78 of the Ministério do Trabalho e Emprego (MTE), defines boilers as all the equipments that, simultaneously, generate and store water steam or other fluid (Brasil, 2017). The risk of accident of such equipment tends to increase as the material's allowable stress and wall thickness are reduced. The boilers are classified in the following categories: (i) A: the operating pressure is equal to or bigger than 1960 KPa or 19.98 Kg/cm²; (ii) B: the operating pressure is equal to or less than 588 KPa, or 5.99 Kgf/cm² and the inner volume is equal to or greater than 100 liters; and (iii) Class C: all those that are not included in the categories above. The boilers of category "A" provide the highest risks, while the ones in category "B" represent the lowest risks (Brasil, 2017). As for the type, the boilers can be classified into flame tube and water-tube. The flame tube ones, focused in this study, are characterized by internal circulation of the combustion gases in operation with liquid or gaseous fuels.

1.4 Flame tube boilers

The functionality of these boilers is restricted to the production of saturated steam. The work pressures are not high and possess limitations regarding the thickness of the outer wall of the side, once that the greater the thickness, the higher the pressure.

The flame tube boiler operation is characterized as simple, once it has few equipments to monitor the operation. However, this is the factor that favors the occurrence of accidents. According to Mariajayprakash and Sesnthivelan (2013) this type of boiler leads the accident statistics in the world, since it is common the presence of negligence in its operating processes and maintenance. Industrial systems are periodically subject to deterioration in function of its use and life cycle. Thus, the insertion of a maintenance policy becomes essential in organizations to mitigate problems (Dohi *et al.*, 2011). Maintenance can be defined as "actions required to maintain an operating system or restore it to a satisfactory condition for performing their duties"[1] (Dhillon, 2013).

In this context, there are four classifications for maintenance: (i) Corrective Maintenance: is the work done on a faulty machine or equipment in order to repair it (Aguiar, 2012). The Corrective Maintenance can be classified into: (i.i) corrective planned, when the repair is performed at a date after the failure, and (i.ii) corrective of emergency, in which the repair occurs immediately after the fault detection (Branco, 2008); (ii) Preventive Maintenance: it is the work performed to reduce failure or drop in performance according to a planning based on established time periods (Moraes, 2010); (iii) Predictive Maintenance: is the following or monitoring of the degradation conditions of a system (Aguiar, 2012; Branco, 2008); and (iv) Detective Maintenance: is the work done for protection or command systems to detect failures hidden from the employees of operation or maintenance areas (Moraes, 2010).

1.5 Failure Mode and Effect Analysis (FMEA)

FMEA represents the most popular approach for assessing the criticality level of the failures of products, processes or even complex systems (Ookalkar, Joshi, & Ookalkar 2009; Sawhney, Subburaman, Sonntag, Rao, Rao, & Capizzi 2010; De Souza & Carpinetti, 2014; Lolli, Gamberini, Rimini, & Pulga 2016). The method FMEA, has its first recorded use concept in 1949, from US military development in order to determine the effect of the occurrence of failure to systems and equipment. This method identify, systematically, potential failures in processes by defining the causes and effects, and from this, define actions to reduce or eliminate the risk associated with these failures (Marriott, Garza-Reyes, Soriano-Meier, & Antony, 2013; Aguiar, Salamon, & Mello 2014).

The authors Estorilio and Posso (2010), defines FMEA as a group of activities aimed at recognizing and evaluating the potential failure of a product/process and its effects. Accordingly, it is a tool that seeks to avoid, through analysis, the potential failures that may occur in the project, identifying actions that may eliminate or reduce the likelihood of a potential failure mode occurring and documenting the analysis process. Therefore FMEA is a reliable technique that aims to: (i) recognize and evaluate potential failures that may arise in a product or process; (ii) identify actions that could eliminate or reduce the chance of occurrence of such failures; and (iii) document the study, creating a technical framework that may assist in reviews and further development of the project or process (Devadasan, Muthu, Samson, & Sankaran 2003; Fogliatto & Ribeiro, 2009).

The FMEA is one of the important planning tools to analyze the cause and consequence of failure. During risk identification, risk events are recognized and the contingency plan is formulated by a team of experienced and qualified engineers to identify and classify the failures through risk priority (Lee, Yeung, & Hong, 2012). Its implementation can happen in project or process, this latter being the focus of the present study.

There are three stages that are very critical in the FMEA process to ensure the success of the analysis. The first stage is to determine the potential failure modes. The second stage is to find the data for occurrence, detection, and severity rankings. The third stage is the development of the control process based on the FMEA report (Teng & Ho, 1996; Teng, Ho, Shumar, & Liu 2006; Estorilio and Posso, 2010).

Teng *et al.* (2006) and Lolli *et al.* (2016) describe in studies that Process FMEA is analyzed with an orderly approach to formalize and document the reasoning of the team throughout the stages of planning and process improvement, helping to reduce the risk of failures. It evaluates the process requirements concerning the examination of all potential failures.

FMEA involves identifying each process step that may fail, then assigning rankings for occurrence probability, severity, and detectability. The "occurrence ranking" indicates how likely a failure is considered to be, and is related to the process capability indices. The "severity ranking" indicates the potential impact of a failure. The "detectability ranking" indicates howlikely it is that a failure can go undetected until its full impact materializes. The three rankings are then multiplied, and higher total scores indicate higher risk (Wang, Chin, Poon, & Yang, 2009; Kenchakkanavar and Joshi, 2010; Chuang, 2010; Nassimbeni, Sartor, & Dus, 2012; Pan & Chen, 2012). The process FMEA is shown in Figure 2.

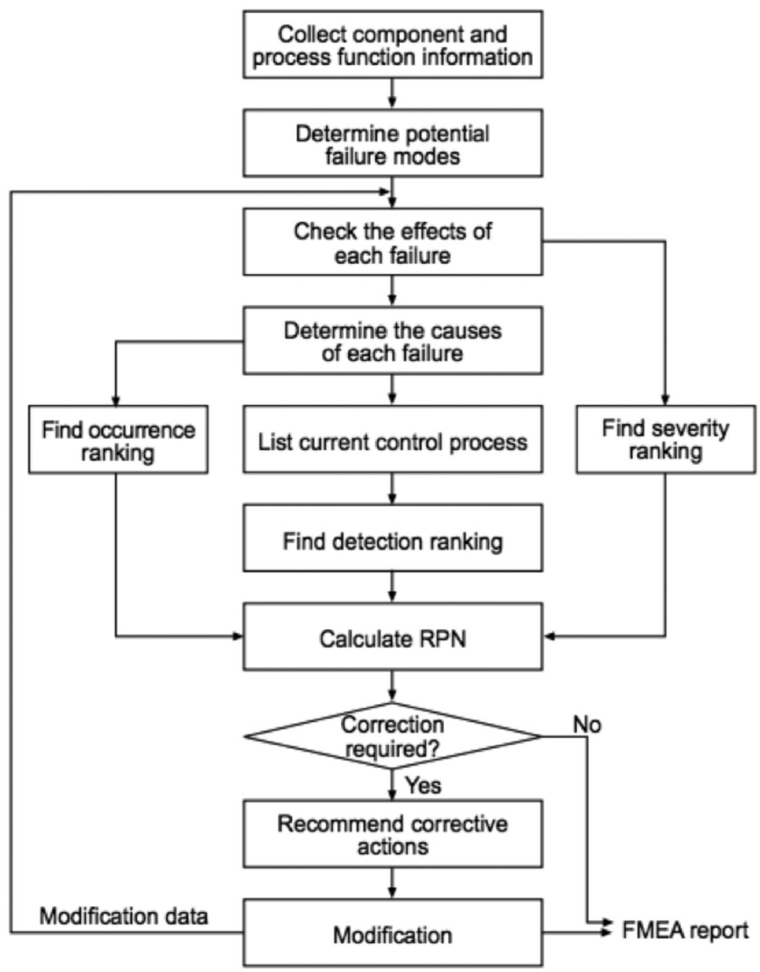

Figure 2: FMEA know-how fluxogram
Source: (Teng & Ho, 1996; Fogliatto & Ribeiro, 2009).

According to Fogliatto and Ribeiro (2009), for FMEA's monitoring is necessary to understand the technique as a dynamic document that should reflect the latest versions of the process, as well as the latest actions taken, including changes adopted after the production start. FMEA is applied to map the possible failure modes and effects from an item – in this case study, the flame tube boiler. In order to clarify the criteria for determining the indexes of occurrence (O), severity (S) and detection (D), Table I shows the indicators used in the application of FMEA.

Table I: Indexes of Occurrence (O), Severity (S) e Detection (D)

Occurrence Index		
Evaluation	Failure occurrence	Punctuation
Minimum	Very probable failures	1
Low	Failures rarely occur	2 to 3
Moderate	Occasional failures	4 to 6
Severe	Failures occur frequently	7 to 8
Very Severe	Almost inevitable failures	9 to 10
Severity Index		
Evaluation	Effect's Severity	Punctuation
Minimum	Failure that minimally affects the system's performance	1
Low	Performance drop	2 to 3
Moderate	Generates malfunction or performance drop	4 to 6
Severe	Equipment that does not operate without commiting security	7 to 8
Very Severe	Commits the operation's security	9 to 10
Detection Index		
Evaluation	Possibility of detection	Punctuation
High	High possibility of the controls detect this failure mode	1
Moderate	Controls can detect the failure mode	2 to 3
Small	Low possibility of the controls detect this failure mode	4 to 6
Very Small	Controls will probably not detect this failure mode	7 to 8
Remote	Controls will not detect this failure mode	9 to 10

Source: Adapted (Fogliatto and Ribeiro, 2009).

FMEA uses a Risk Priority Number (RPN), to assess the risk level of a component or process, which is obtained by multiplying three factors: probability/occurrence of the fault (O), severity of the fault (S) and probability of not detecting the failure (D) (Kumru and Kumru, 2013). A Pareto chart is generated based on their risk scores tabulated in descending order. This chart provides guidance for prioritizing risk response planning. The RPN pareto bar chart is plotted and contains values in descending order (Lee *et al.*, 2012).

2 Methods

The present work is categorized as an applied research. As for its goals, is characterized as an exploratory research. Thus, the method is characterized as a nominal qualitative case study, since the answers can't be sorted and seek to describe, decode and translate the issue focusing on processes under study. According of Yin (2010), the constructs in case study are considered valid when the researcher uses basic principles, as multiple sources of evidence and a database.

To describe the convergence and evidence of construct validity, an interview was conducted with the work safety engineer at the university hospital. In this interview were presented the plan of operation files of the boilers, the floor plans of the equipment, the hydraulic plant of the steam pipes that feed the hospital. In addition, a direct observation of the operation of the boilers was carried out. The investigation of the operation of the boilers was carried out in the three shifts of operation. After this stage, a meeting was scheduled with the boiler operators and the manager to investigate whether the method of operation used was the same for all Calderistas. As a result of this meeting it was found that each operator had a way of turning the boiler on and off. Thus, the authors, together with the boiler operators, through a brainstorming, have developed a standard procedure for turning the boiler on and off at the hospital. After these steps the FMEA technique of the process can be applied, therefore, it was performed, for the study, the identification of risks' factors present in the flame tube boiler's operating phase, focusing on the main risks noticed in workplaces. The application was done in a federal organization of the hospital sector located in Santa Maria, Rio Grande do Sul, Brazil.

The University Hospital of Santa Maria – HUSM was founded in 1970, recognized as a health reference for the central region of Rio Grande do Sul. It is an UFSM's organ that works as a school hospital with attention focused in developing education, research and public health assistance (Husm, 2014). The hospital serves a monthly average of 11,3 thousand specialized consultations, 4,6 thousand emergency consultations and effectuates approximately 760 thousand medical examinations and 10,8 thousand hospitalizations per year. It is the only hospital of the State's central region that fully serves the Sistema Único de Saúde[2] (SUS) (Husm, 2014).

HUSM possess two flame tube boilers, both manufactured in 1971. The boiler in analysis is a horizontal flame tube H-3N model, category B, with production capacity of 3.300kg.v/h, maximum allowable working pressure (MAWP) or permissible (MPWP) of 150 Lbs/pol^2 (10,55kgf/cm^2) and hydrostatic pressure of 225 Lbs/pol^2 (15,82kgf/cm^2) with vaporization area up to 100m^2.

The boilers sector is responsible for supplying steam to: laundry, autoclaves, kitchen, showers and more. This sector has five boiler operators that alternate with each other in a work schedule scheme that consists of two operators per scale. The shift begins at 6 a.m., and the system shutdown occurs at 10 p.m.

3 Results

Initially, it was identified a lack of standard procedure to the boiler's operation once the five operators use different procedures to operate the hospital's flame tube boiler. Accordingly, for apply the methods proposed in the study it was necessary to map the process for the steps to be focused on the boiler's risk study in order to establish an operation pattern. For the creation of these flowcharts it was used the *brainstorming* technique with the participation of the boiler's operators, the engineer of labor security and the researchers. It was also necessary to set one stage of the operating process to the study application. Therefore, FMEA was taken for the stages of starting up and shutting down the boiler. To give visibility to the failure causes in the boilers' sector it was elaborated a radar chart (Figure 3).

From the flowchart and the knowledge of the system operation it was started the application of FMEA (Table II) for the stage of starting up the boiler along with the proposition of the recommended actions for medium and high risks.

In order to apply the techniques in the shutdown of the boiler, the same procedures described in the boilers' starting up process were repeated. It was designed a radar chart of the causes of failures for the boiler's shutdown stage (Figure 4).

Table III shows the application of FMEA to the stage of shutting down the boiler and the proposition of recommended actions for medium and high risks.

3.1 Recommended Actions and Discussion of the results

The application of FMEA in the phase "shutdown of registers in the panel" pointed the highest score among the processes presented for the boiler's shutdown function. Thus, the following suggestions for improvement and recommendations for corrective/preventive actions were prepared: (i) implementation of a maintenance manual in order to measure the standard procedure to the process of anomalies' inspection; (ii) professional training through courses of boilers' operation and study of the procedure manual designed by the boilerman's team; and (iii) the

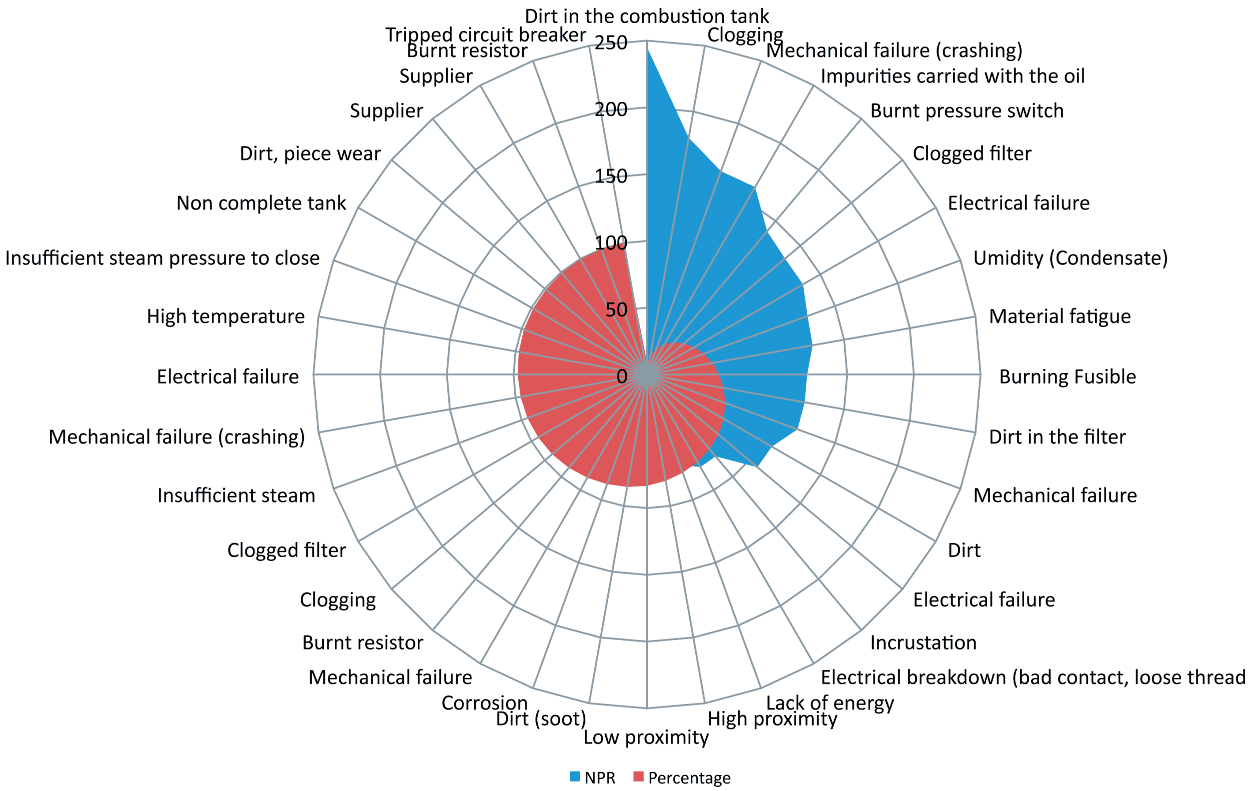

Figure 3: Failure causes in the boiler's starting up process
Source: Author.

adoption of instruments for easy identification of possible failures, such as *andon* or contact sensors for measuring wear.

The application of the technique resulted in the hospital improving its maintenance and safety processes in the operation of the boilers, as a standard operating procedure was inserted in the unit. In addition to the data from this study, the hospital provided a glossary of indicators, that is, the study data indicated that the managers and operators of the unit are the primary control and maintenance items in order to avoid failure and risks in the operation of the boilers. We obtained as a result a dossier with information relevant to the identification of procedures that have higher incidence of risk in flame tube boilers. Finally, the study presents to the other service operators that use this boiler model, a method to introduce the tool to analyze fault modes in processes. That is, this study may serve as a means of introducing the technique in similar units to which the study was applied, with the objective of mitigating the risk of accidents in boilers.

4 Conclusion

The use of FMEA methodology for the case study of the University Hospital of Santa Maria's flame tube boiler resulted in the identification of failure modes, effects and causes of the operating process. The application of FMEA aimed to holistically identify the possible faults in the system.

Thus, it was shown in this work, before the application of the methods and through the study

Table II: Spreadsheet of FMEA application in the boiler's starting up pr ocess

PROCESS FMEA										
Subsystem:				Shutdown of the flame tube boiler: HUSM's Case						
Manufacturer:		Ata Combustão Técnica S.A								Manufacturing Year: 1971
Model:		FTH, register number 2530				FMEA's Original Date: 11/11/2014				Review: 01/11/2014
Affected External Supplier:			Yes	X	No					Production Schedule: 3300 kg/h
Nº	Component	Function	Failure Mode	Failure Effect	Failure Cause	O	S	D	NRP	Recommended Actions
1	Control Cabinet	General control	No panel powering	Boiler does not come into operation	Burning Fusible	4	10	3	120	Corrective maintenance
					Tripped circuit breaker	1	5	1	5	There is not recommendation
2	Electrode of level control	Control of the boiler's water level	Insufficient water level	Boiler does not come into operation	Clogging	3	8	2	48	There is not recommendation
					Incrustation	2	8	5	80	Implementation of previous treatment of the water used in the process
			Excess of water level	Boiler does not come into operation	Burnt pressure switch	2	10	7	140	Implement conference procedures Predictive maintenance
3	Oil's temperature	Fuel (BPF oil)	Not in the ideal work temperature (70 °c)	Boiler does not come into operation	Burnt resistor	3	2	1	6	There is not recommendation
					Insufficient steam	5	7	1	35	There is not recommendation
			Pressure is not correct	Clogging of the oil network	Dirt in the filter	6	5	4	120	Creation of checklist Predictive maintenance
					Dirt in the combustion tank	7	7	5	245	Periodic inspection Preventive cleaning of the tank
4	Filters	Residual cleaning (piping)	Clogging of the fire control valve	Oil passage isufficient for combustion	Clogged filter	3	9	5	135	Periodic inspection Preventive cleaning of the filters Predictive maintenance
			Clogging of the solenoid valve	Boiler does not come into operation because there's oil passage	Clogged filter	2	6	3	36	
					Mechanical failure (crashing)	3	6	9	162	Preventive maintenance Implementation of an inspection procedure
					Electrical failure	3	7	1	21	There is not recommendation
5	Primary Air	Combustion	Temperature of non compliant oil	Oil cracking	High temperature	3	6	1	18	There is not recommendation
			Air contamination	Non stable flame	Umidity (Condensate)	8	8	2	128	Implementation of lubrefio for previous treatment of the combustor's incoming air
			Solenoid valve	Pulverization does not occur	Mechanical failure (crashing)	3	8	1	24	There is not recommendation
6	Secondary Air	Increase flame's intensity	Fan in operation at only one phase (energy)	Weak flame	Lack of energy	6	6	2	72	Andon's implementation Implementation of an automatic selector key (changes from the conventional network to the generator network)
7	Photocell	Open and close the oil passage	Detection of the flame	Impediment of the boiler's start	Dirt (soot)	6	10	1	60	There is not recommendation
8	Pilot Combustor	Start the burning (flame)	Lack of fuel	It's not possible to light up the flame	Non complete tank	1	10	1	10	There is not recommendation
			Clogging of the spray nozzle	There is no sparkle (does not catch fire)	Impurities carried with the oil	6	9	3	162	Periodic cleaning of the oil filters
			Grounded electrodes	There is no sparkle (does not catch fire)	Dirt	4	9	3	108	Implementation of a preventive maintenance manual
			Ignition system	It's not possible to light up the flame	Electrical failure	5	9	3	135	Preventive maintenance Implementation of an inspection procedure
9	Electrodes	Generate spark for combustion	Unregulated electrodes	Insufficient spark to ignite the fuel	High proximity	2	9	4	72	Implementation of a preventive maintenance manual
				There is no sparkle	Low proximity	2	9	4	72	Implementation of a preventive maintenance manual
			Oil's incrustation	There is no sparkle	Clogging	4	9	5	180	Andon's implementation Implementation of the cleaning of ducts with oil diesel
10	Pressure switch	On/off control source of maximum pressure or Flame's modulation	Stick the electrical contacts	The boiler does not power on	Electrical breakdown (bad contact, loose thread)	1	10	8	80	Preventive maintenance Implementation of an inspection procedure
			Hole in the diaphragm	Boiler does not start up and the pressure rises til the security valve's shooting	Material fatigue	2	9	7	126	Preventive maintenance Implementation of an inspection procedure
			Leak in the diaphragm		Corrosion	2	9	3	54	There is not recommendation
			Bad contact		Electrical failure	2	9	6	108	Preventive maintenance Implementation of an inspection procedure
11	Fire control valve	Restraing the oil passage according to the regulation, keep the oil pressure throu-gh regular return (high or low fire) by the motor brain	Valve dysregulation	Alteration of oil pressure, flow (more or less) or fully lock	Mechanical failure	3	6	3	54	There is not recommendation
12	Water inlet retainer valve	Let the water flow in only one way	Non closure of the valve	Return of boiling water with boiler's steam pressure, irreparable data to the water supply network	Dirt, piece wear	2	5	1	10	There is not recommendation
			Clamping		Insufficient pressure steam to close	2	9	1	18	There is not recommendation
			Valve's wear		Mechanical failure	4	6	5	120	Implementation of a preventive maintenance manual
13	BPF Oil	Combustion	Lack of fuel	Non existent process	Supplier	1	10	1	10	There is not recommendation
14	Diesel Oil	Lubrification and fuel for starting up the process	Lack of fuel	Non existent process	Supplier	1	10	1	10	There is not recommendation
15	Water	Vaporization	Cold water	Higher fuel expenditure	Burnt Resistor	3	6	3	54	There is not recommendation

Occurrence Index (O)		Severity Index (S)		Detection Index (D)		Risks (NRP)		Participants	
Evaluation	Punctuation	Evaluation	Punctuation	Evaluation	Punctuation	Evaluation	Punctuation	Name	Area
Minimum	1	Mininum	1	High	1	Low	1 to 70	João	Boilerman
Low	2 to 3	Low	2 to 3	Moderate	2 to 3	Medium	71 to 300	Thiago	Boilerman
Moderate	4 to 6	Moderate	4 to 6	Small	4 to 6	High	301 to 1000	Marcelo	Boilerman
High	7 to 8	Severe	7 to 8	Very Small	7 to 8			Ricardo	Boilerman
Very High	9 to 10	Very Severe	9 to 10	Remote	9 to 10			Marcos	Researcher

Source: Author.

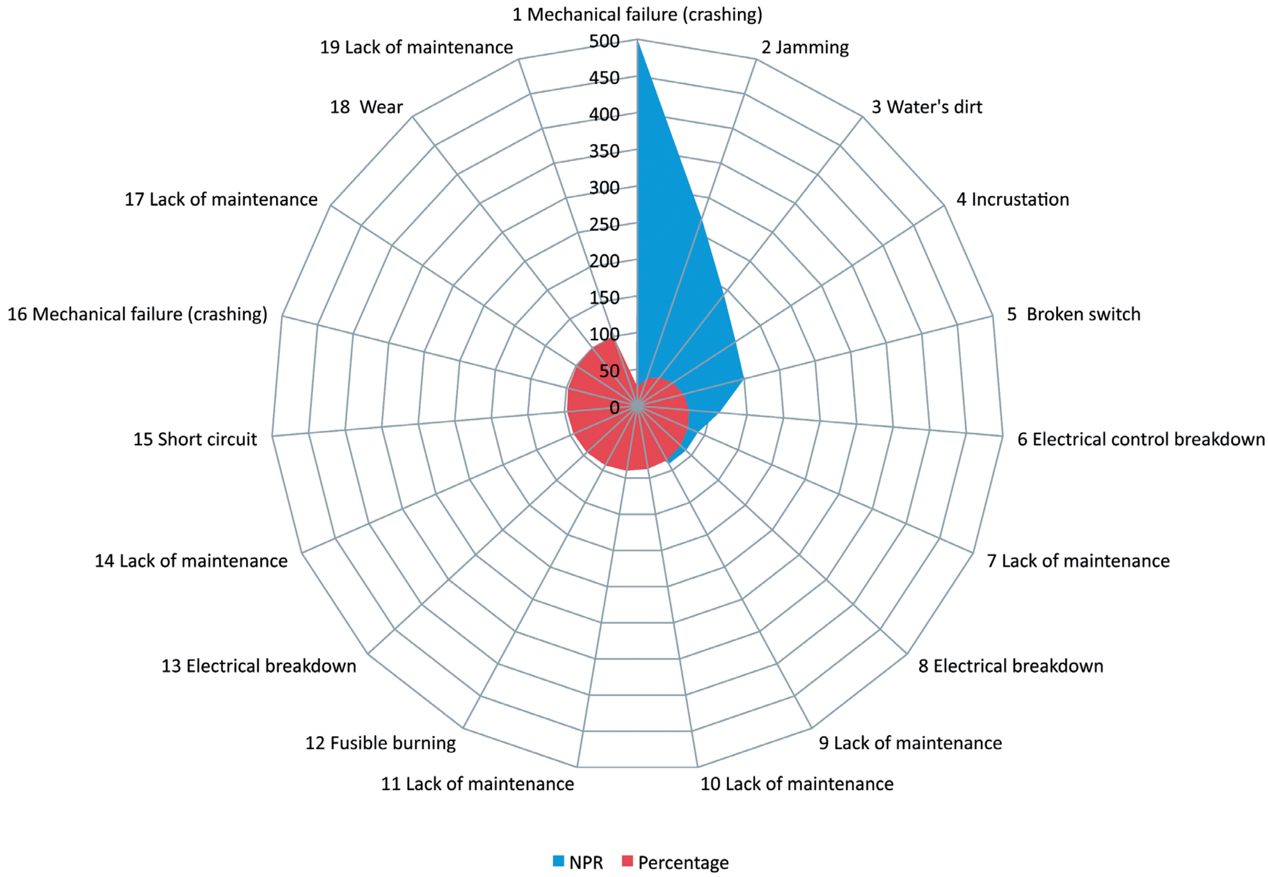

Figure 4: Failure causes in the boiler's shutdown process
Source: Author.

of the scientific literature, that the risks are likely to characteristics change in function of the organization performance environment and its operating characteristics. Therefore, the risks emerge from new corporate structures, per lack of equipment maintenance, and per technologies change without previous study of its impacts.

However, it may be concluded by the application that the sector under study has no operating and maintenance default of the boiler which in short results in a high possibility of failure in the system as a whole and catastrophic consequences in case come an explosion. At the same time, it was observed that the use of methods helps in understanding and identifying critical points as well as in proposing corrective measures or mitigation/ elimination of faults.

Notes

1 Translation made by the authors from material researched in portuguese.

2 Free translation: Unified Health System.

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Table III: FMEA application in the boiler's shutdown process

PROCESS FMEA

Subsystem: Shutdown of the flame tube boiler: HUSM's Case

Manufacturer: Ata Combustão Técnica S.A — Manufacturing Year: 1971

Model: FTH, register number 2530 — FMEA's Original Date: 11/11/2014 — Review: 01/11/2014

Affected External Supplier: Yes X No — Production Schedule: 3300 kg/h

	Component	Function	Failure Mode	Failure Effect	Failure Cause	O	S	D	NRP	Recommended Actions/ Corrective Measures
1	Pumping of petrochemical oil	Filling of buffer tanks	Pumb breaks	The tanks supply does not occur	Lack of maintenance	6	9	1	54	There is not recommendation
			Ducts' obstruction	The tanks supply does not occur	Incrustation	4	10	4	160	Checklist creation for components verification Implementation of tubes' periodic inspection Preventive maintenance
2	General Register of Steam	Close or open the steam passage in the pipes	Jamming	Interruption of steam supply	Lack of maintenance	2	10	1	20	There is not recommendation
3	Pressure Raises up to 9,5kg	Automatic desarmming	Automatic shutdown doesn't occur	No shutdown of oil and water pump	Electrical control breakdown	2	8	7	112	Preventive maintenance Implementation of the inspection procedure
			Security valve doesn't open	Explosion	Jamming	3	10	9	270	Daily verification of the valves operability Preventive maintenance
4	Key exchanges the combustor	Alternate the passage from BPF oil to disel or vice versa	Jamming	Interruption of the shutdown standard	Lack of maintenance	2	7	2	28	There is not recommendation
5	BFP oil heating shutdown	Allow the pipe washing with diesel oil	Electrical breakdown	Interruption of the shutdown standard	Fusible burning	3	5	3	45	There is not recommendation
6	Bypass	Change of diesel oil path (not to pass by the heater)	Jamming	Explosion	Lack of maintenance	3	10	3	90	Preventive maintenance in the registers
7	Pumps shutdown	Shutdown of the combustion pump	Pump breaks	Pressure rises until the automatic shutdown	Electrical breakdown	3	5	2	30	There is not recommendation
		Shutdown of the condensate's motor	Pump breaks	Flooding of the well of dirt condensate	Mechanical failure	4	7	2	56	There is not recommendation
		Shutdown of the boilers' pump	Pump breaks	No shutdown of the pump	Electrical breakdown	5	6	3	90	Preventive maintenance Implementation of the inspection procedure
			Pump breaks	No shutdown of the pump	Broken switch	5	6	5	150	Implementation of periodic inspection Implementation of the preventive maintenance manual (equipment's changeover time)
		Shutdown of the boilers' temperature controler	Fusible burning	No shutdown of the panel	Short circuit	6	2	2	24	There is not recommendation
8	Shutdown of registers in the frame	Water inlet	Breaking of the register's rod	Boiler's flooding	Wear	5	2	2	20	There is not recommendation
		Primary air	Solenoid valve	Non existent	Mechanical failure (crashing)	3	8	1	24	There is not recommendation
		Oil in the burning caisson	Solenoid valve	Creation of gases and retrocession	Mechanical failure (crashing)	5	10	10	500	Preventive maintenance Implementation of inspection procedure
9	Discharge of level bottle	Electrodes cleaning	Incrustation in the electrodes	Does not recieve signal from the water level	Water's dirt	3	8	8	192	Implementation of previous treatment of the water used in the process
10	Discharge of pressure valves	System's security	Jamming	System discharge does not occur	Lack of maintenance	3	10	3	90	Daily discharges in the level regulation tube Creation of the preventive maintenance manual
11	Closeing of oil general registers	Interrupt the oil passage	Registers' jamming	Non interruption of oil flow due to gravity on the network	Lack of maintenance	1	6	1	6	There is not recommendation

Occurrence Index (O)		Severity Index (S)		Detection Index (D)		Risks (NRP)		Participants	
Evaluation	Punctuation	Evaluation	Punctuation	Evaluation	Punctuation	Evaluation	Punctuation	Name	Area
Minimum	1	Mininum	1	High	1	Low	1 to 70	João	Boilerman
Low	2 to 3	Low	2 to 3	Moderate	2 to 3	Medium	71 to 300	Thiago	Boilerman
Moderate	4 to 6	Moderate	4 to 6	Small	4 to 6	High	301 to 1000	Marcelo	Boilerman
High	7 to 8	Severe	7 to 8	Very Small	7 to 8			Ricardo	Boilerman
Very High	9 to 10	Very Severe	9 to 10	Remote	9 to 10			Marcos	Researcher

Source: Author

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