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RISK ANALYSIS OF THERMOSYPHON ASSISTED DRYING AIR HEATING SYSTEM

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Abstract. *This work aims to identify risk possibility events with dangers and environmental aspects, whose occurrences could result in unwanted damage to people, plants, environmental and company's image during preparation, development, implementation and operation of a drying air heating system that will be mounted at Baldo S.A in Prudentópolis-PR This analysis involves risk identification present during system operation using: FMECA (Failure Mode, Effects and Criticality Analysis), FTA (Fault Tree Analysis), ETA (Event Tree Analysis), and CNEA (Causal Network Event Analysis) which allowed identifying main problems, causes, detection modes, and effects of failures that could happen during system operation, moreover, are given some recommendations that serve with preventive type of barriers such as the type of contingencies to minimize risk events during system lifetime.*
Keywords: *Risk analysis, two-phase thermosyphon, air heating system.*

1. INTRODUCTION

One of the basic principles that guide industry is a transformation of raw material into an elaborate product is operating costs reduction, without decreasing quality final product. In the case of *erva mate* mass production, the drying process optimization is indispensable, in this context the use of thermosyphon or heat pipe technology allows heat exchangers development that have a lot of advantages like (a) high thermal performance, (b) no sealing problems between air and combustion gases streams, (c) simple and robust construction minimizing problems with corrosion by combustion gases, (d) quickly maintenance tasks with high security level (VDI- GVC, 2010).

According to Dias (2013), risks associated to the potential to cause industrial damage and to health's worker, can be featured by the existence of physical, chemical, biological, ergonomic and mechanical agents. All of these agents are associated to a risk factor that expresses an occurrence probability of a determinate risk. Accidental risk is expressed in relation to the frequency or risk occurrence probability and its magnitude (CAPONI, 2004).

Two-phase themosyphon is a heat transfer device that consists of a metallic evacuated tube where a certain amount of working fluid is inserted. They are composed of three different regions: evaporator where heat is supplied, adiabatic section; this intermediate region may be small or even not existent, depending on the geometry of the device and the condenser where heat is rejected (Fig. 1). Thermosyphon heat exchanger basically consists of a thermosyphon tube bundle in cross flow. A hot gas stream flows through the external surfaces of the evaporators, while a cold stream flows through the condensers. The thermosyphon set removes heat from the hot stream and delivers it to the cold stream. Figure 2 shows the module configuration of thermosyphon heat exchangers (MANTELLI, 2013).

2. TECHNICAL SYSTEM

Erva – mate drying system is composed by a chamber called *barbaquá*, here drying process is performed. *Barbaquá* is composed by two metallic conveyor where *erva – mate* circulates in a cross flow process. Hot air from a heat exchanger is used for drying. Heat exchanger uses combustion gases from furnace, where firewood is used as combustible. This heat exchanger has four hot fluid passes (firewood combustion gases) which is not mixed and cold gas (drying ar) which is mixed. Figure 3, shows a heat exchanger scheme used to provide drying air to 120 [°C] at Baldo S. A. in São Mateus do Sul-PR which have similar characteristics to the one installed in Prudentópolis unit. A proposal for this work is to replace current heat exchanger (shell and tube) showed in Fig. 4 by a thermosyphon heat exchanger with similar characteristics to the one showed in Fig. 5. It is important to detach this technology was successfully used in Xisto refinery (SIX) in São Mateus do Sul, Paraná. Drying air heating system with new configuration can be divided into three subsystems: firewood feed system, furnace system and thermosyphon heat exchanger system as showed in Fig. 6.

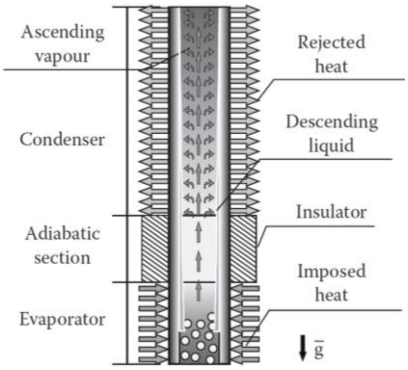


Figure 1. Two-phase themosyphon.

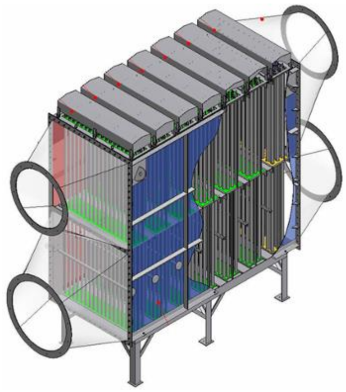


Figure 2. Thermosyphon heat exchanger.

Feed firewood system is composed by a feeder 1 which is manually operated and feeder 2 composed by a worm screw and a cone feeder which is fed manually. Furnace system is composed by combustion chamber, primary air feeder (primary blower) and the secondary air feeder. Finally heat exchanger system is composed by evaporator (carcass and exhaustion gases blower), condenser (carcass and drying air blower) and thermosyphon that connect the evaporator to the condenser. In Figures 7 -10 are showed studied technical system scheme. To understand how technical system works, it was done a simplified functional analysis and a decomposition functional analysis for drying air heating system, showed in Figure 11 and Figure 12, respectively.

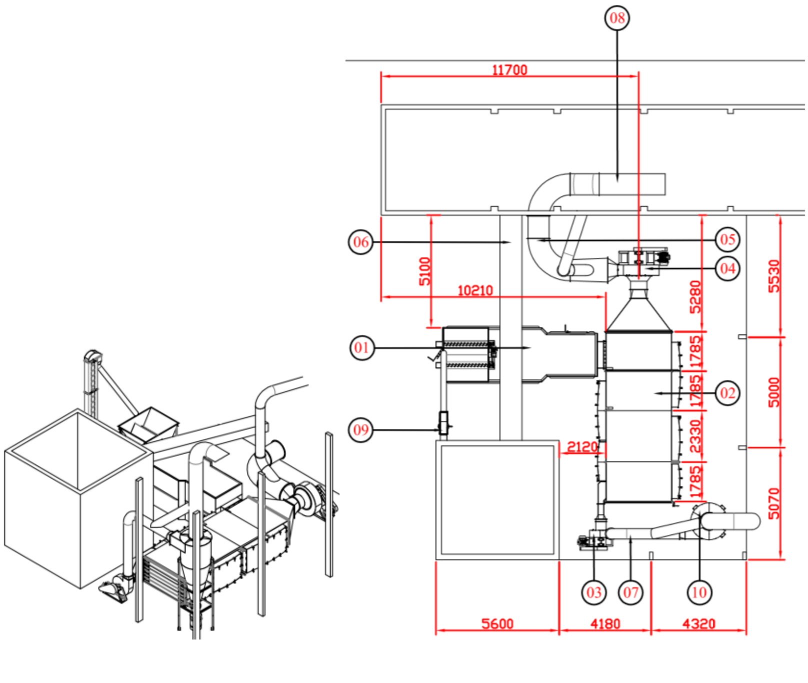


Figura 3. Current drying air heating system at Baldo S.A.
(1) Furnace, (2) Heat exchanger, (3) Combustion gases blower, (4) Drying air blower, (5) Tubing,
(6) Conveyor, (7) Tubing, (8) Dryer, (9) Conveyor and cone feeder, (10) Tubular cyclone. All dimensions in mm.

Figura 4. Current heat exchanger at Baldo S.A.

Figura 5. Thermosyphon heat exchanger.

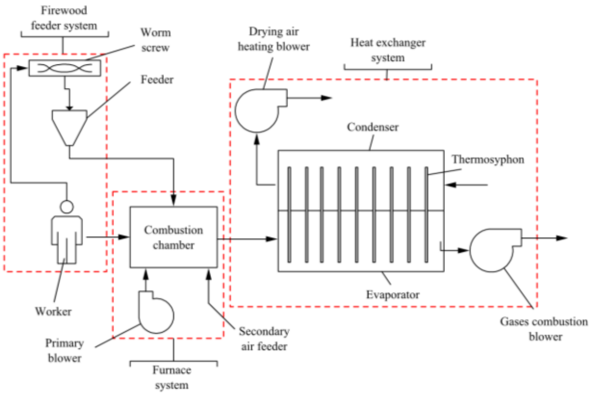


Figure 6. Assisted thermosyphon air heating system scheme.

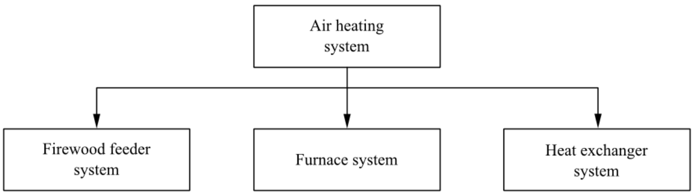


Figure 7. Air heating system scheme.

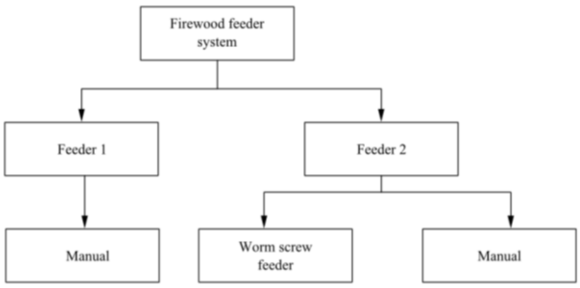


Figure 8. Firewood feeder system scheme.

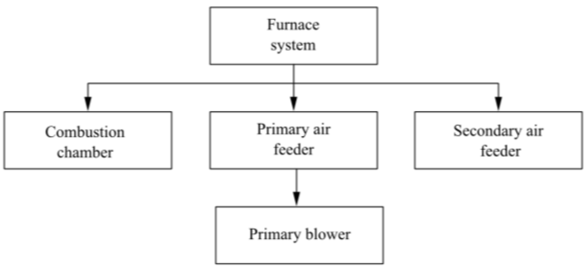


Figure 9. Furnace system division scheme.

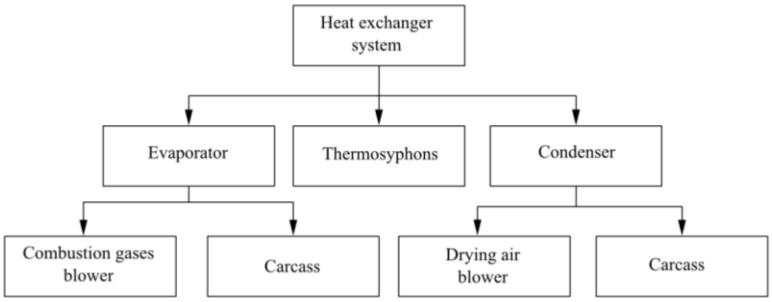


Figure 10. Heat exchanger system division scheme.

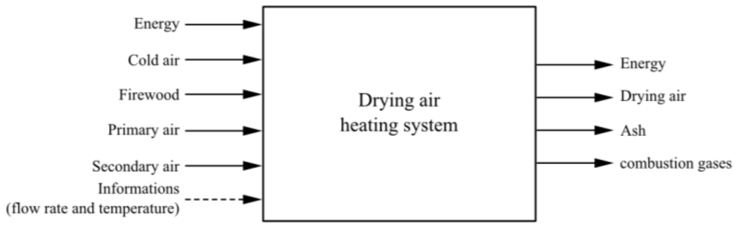


Figure 11. Simplified functional analysis of drying air heating system.

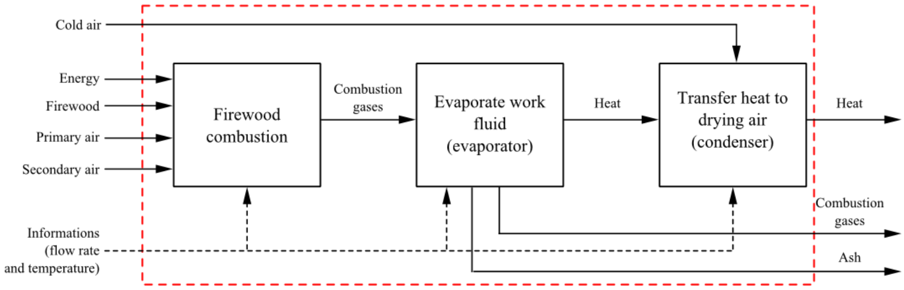


Figure 12. Decomposition functional analysis for drying air heating system.

3. RISK ANALYSIS OF TECHNICAL SYSTEM

The analysis performed in this work was split into three steps, the first one corresponds to the risk identification present during air heating system operation, in the second step is performed a FMECA analysis to identify failure effects severity of main components in air heating system. In third step are analyzed components that had higher severity in FMECA identifying principal causes and effects of failures, using analysis tools like FTA, ETA and CNEA.

3.1 Risk identification

Table 1 presents different risk associated with each of the different components that form subsystems of assisted thermosyphon air heating system.

3.2 FMECA

In this section is presented two risk analysis modes and criticity FMECA, to analyze failure in order to develop necessary knowledge to evaluate and guide actions for eliminating causes failure modes. Obtained results in FMECA analysis were developed by Mortean *et al.* (2015). For evaluating failure severity mode, occurrence probability, detection mechanisms are used SAE J1739/2002 standard.

Analyzing FMECA can be identified explosion failure as more critical in the system with severity of 10 and makes sense to carry out FTA analysis which is presented in section 3.3. Another critical item is combustion chamber, as showed "*in situ*" study of current drying air heating system used at Baldo S.A. Figure 13 presents equipment generated damage by thermal radiation on first tubes of shell and tube heat exchanger. It was observed that generated damage on heat exchanger tubes caused gas combustion leakage in temperatures greater than 700 [°C], generating high impact on security and functionality loss for a long period of time until normal restoration.

Table 1. Risk identification

System	Subsystem	Components	Risk
Feed system	Feeder 1	* Firewood * Combustion chamber gate	* Firewood inertia * Splinter wood * High temperature in the gate * Fire
	Feeder 2	* Conveyor * Cone feeder	* Firewood inertia * Conveyor inertia * Cinematic energy of conveyor * Cone inertia
Furnace system	Combustion chamber	*Firewood *Ash * Carcass	* High temperature * Thermal inertia * Fire
	Primary air feeder	* Primary blower * Tubing * Valves	* Electric shock * Cinematic energy of blower
	Secondary air feeder	*Tubing *Valves	* High pressure
Heat exchanger system	Evaporator	* Combustion gases blower * Carcass	* Electric shock * Cinematic energy of blower * High pressure * High temperature
	Condenser	* Drying air blower * Carcass	* Electric shock * Cinematic energy of blower * High pressure * High temperature
	Thermosyphon	* Tubo de aço Inox * Work fluid	* High pressure * High temperature

Figura 13. Generated failure by thermal radiation on heat exchanger tubes.

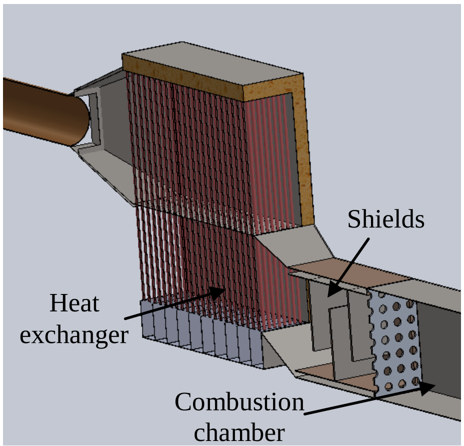


Figura 14. Shields to avoid thermal radiation damage.

One of the recommended solutions to avoid this risk is the use of shields to block emitted thermal radiation by high temperature combustion of firewood as showed in Fig. 14. Further analysis is presented in section 4.4 which were used ETA and CNEA techniques for raising a set of barriers for this event. It is important to say that projected shields fulfill three functions: 1) Block emitted thermal radiation by high temperature, in this case first holed plate can be changed periodically depending of damage level. 2) Physical shield for ash to prevent that particles go to inside of tube heat exchanger. 3) Homogenization of gases flow. To minimize this problem can be installed a shield with firebricks on furnace interior. This same shield will help in partial blocking of thermal radiation from flames and brazier in direction to heat exchanger. Figure 15 can be observed a sketch of this shield on furnace interior.

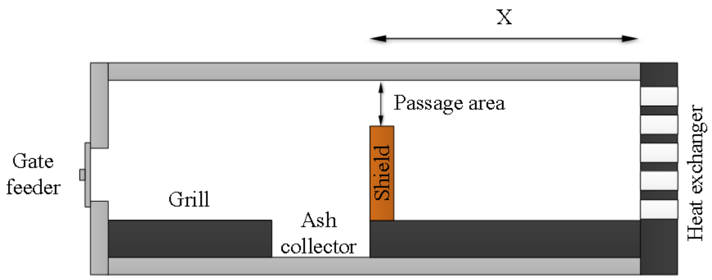


Figure 15. Localization sketch of shield on furnace interior.

3.3 FTA

In this section is performed an FTA analysis to effectively identify principal events that leading danger to transform in risk. Based on information obtained from FTA is possible to identify which are best decisions to employ and minimize failure generation.

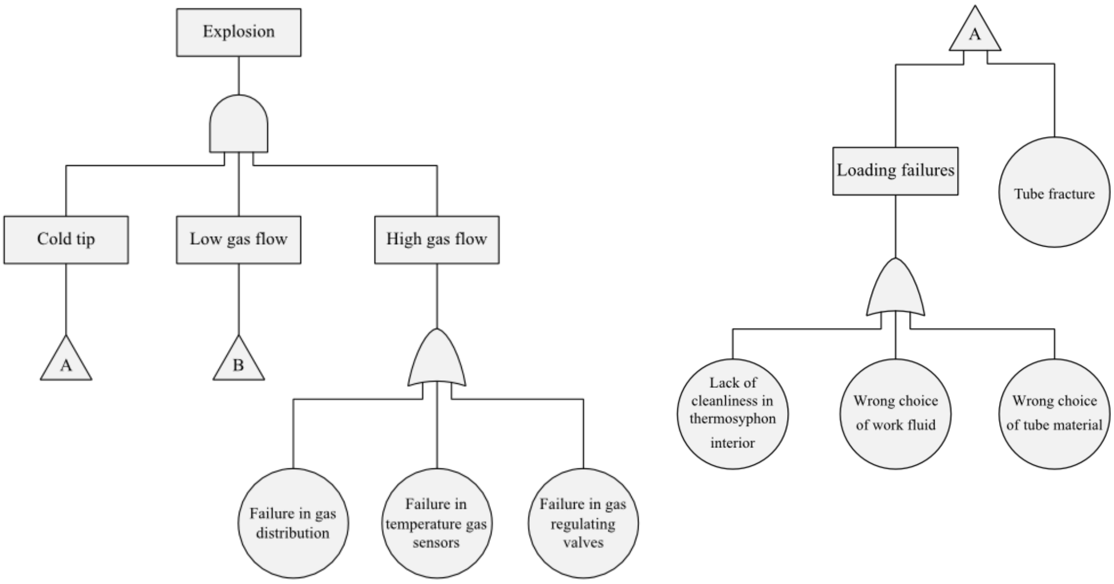
FTA is principally used with high NPR or for events when severity is high (9 or 10), because these events required a more efficient analysis method. Analyzing possible failures in heat exchanger, can be identified EXPLOSION as one of the more critical in system with severity of 9. Figure 16 presents FTA analysis for this failure, here is possible to observe a series of triggering events that would lead to this event type. It is important to highlight that for this analysis it was considered redundancy in drying air heating blowers with following causes bases / initial failure. Failure in gas distribution, temperature gas sensors, gas regulating valves, lack of cleanliness in thermosyphon interior, wrong choice of work fluid and tube material, tube fracture, blower electrical and mechanical failure, assembly equipment failure.

3.4 ETA E CNEA

Analyzing possible failure that can happen in combustion chamber (FMECA analysis) is identified that ‘fusion of first tubes of heat exchanger’ as one of the more critical in system because have a severity of 8 and NPR of 160 and it is necessary to carry out an more detailed study.

ETA was a first analysis developed where is identified different results for each studied case. One of the occurrence causes of ‘fusion of first tubes of heat exchanger’ is a failure on secondary feeder. If secondary feeder fails the conveyor system must stop automatically avoiding system superheating; if conveyor does not stop, the worker performs manual switching off; finally if manual switching off fails employ the shield barrier as showed in Fig. 12.

Table 2 presents events tree analysis ETA developed for ‘fusion of first tubes of heat exchanger’ event. It can be noted that two protection events (manual switching off and thermal radiation shield) are used to avoid accidents and used as barriers in causal chain.



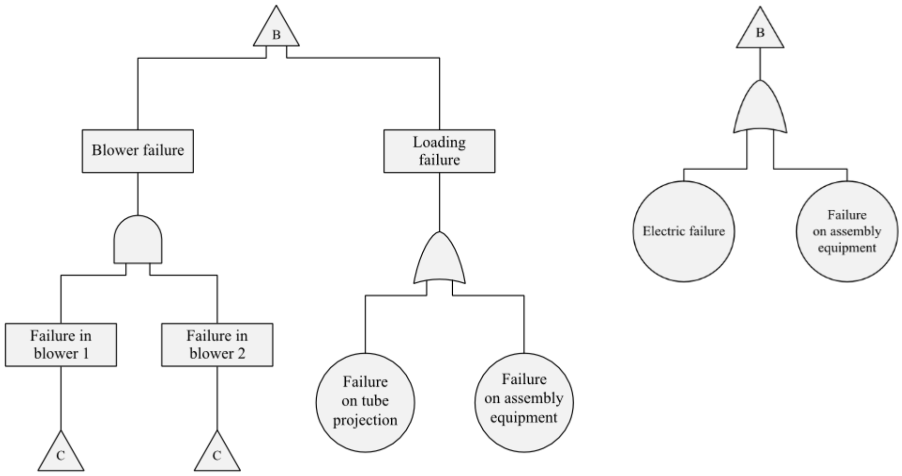
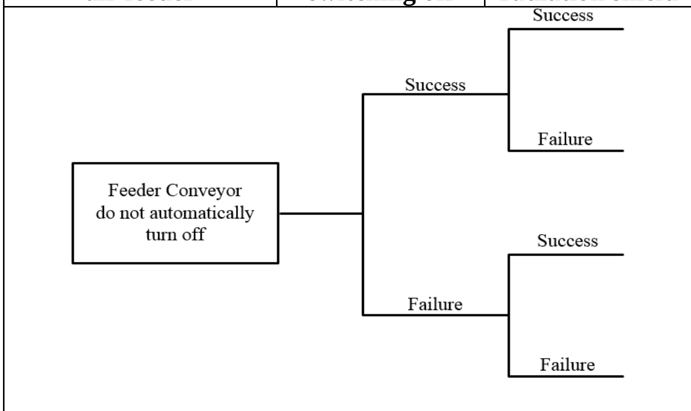


Figure 16. FTA of EXPLOSION failure in heat exchanger thermosyphon.

It is important to detach that once the event ‘fusion of first tubes of heat exchanger’ happens, failure equipment was generated and barriers approach must be used to mitigate event consequences in workers or in environment.

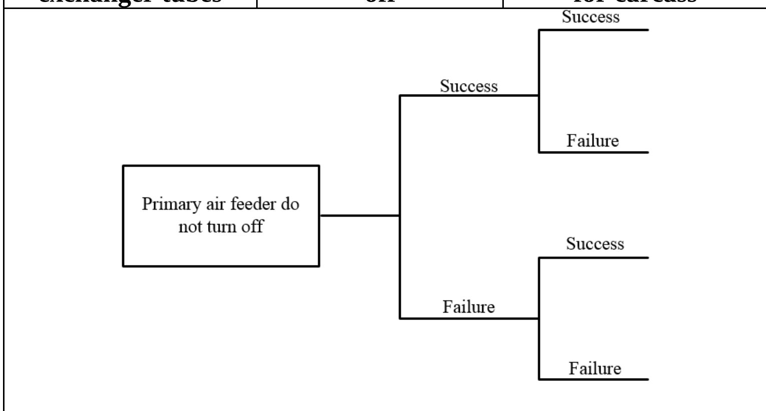
One of principal generated effects by ‘fusion of first tubes of heat exchanger’ event is leakage of combustion gases with temperatures greater than 700 °C, thus it is important to consider a number of measures to mitigate the risk generated by the event

Table 2. ETA performed for ‘fusion of first tubes of heat exchanger’ event.



Failure on secondary air feeder	**Manual switching off**	**Thermal radiation shield**	**Result for each scenario**
			No fusion of the first heat exchanger tubes
			No fusion of the first heat exchanger tubes
			No fusion of the first heat exchanger tubes
			Fusion of the first heat exchanger tubes

Table 3. ETA performed for damage to worker or environment.



Fusion of first heat exchanger tubes	**Manual switching off**	**External protection for carcass**	**Result for each scenario**
			No damage for worker or environment
			No damage for worker or environment
			No damage for worker or environment
			Damage for worker or environment

Table 3 presents ETA analysis performed to identify which scenarios would lead to damage to worker or environment once the event ‘fusion of first tubes of heat exchanger’ happens. In this analysis were considered three barriers to mitigate risk. First barrier is automatic switching off of primary air blower to avoid firewood combustion and leakage of combustion gases. In the case of not automatic switching off in primary blower, the worker must switching off manually and finally if manual switching off does not succeed it is consider an external carcass protection (evaporator inlet) that allows to protect workers.

To see more efficiently events, effects and barriers to be interposed for decreasing event probability or for avoiding effects was performed CNEA analysis for case presented in section 3 which is developed by Cisterna *et al.* (2015).

Observe that roots causes for occurrence of central event, in all cases were failures in organization administrative process, so were proposed additional barriers when implemented should minimize occurrence risk event and also it has been proposed a number of barriers that aim to mitigate the risk to workers or environment once analyzed main incident happened.

4. RISK ANALYSIS OF TECHNICAL SYSTEM

This study aimed to analyze risks associated to drying air heating system assisted by thermosyphon. The objective was to study risk that are associated for replacing current drying system of BALDO S.A. by a thermosyphon heat exchanger, this type of analysis it is necessary because it is a relatively drastic change in the operating system, thereby guaranteeing the safety of workers and the company as a whole.

With FMECA analysis were identified failures associated to each equipment, besides assisting in the assessment of severity involved in each failure and guide necessary actions to eliminate or mitigate failures.

Based on FMECA analysis was identified two major risks in change system, the first of which was thermosyphon explosion having a severity of 9, and the second was excessive combustion in the combustion chamber which results in the fusion of the first tube of heat exchanger (NPR risk of 180).

FMECA helped to identify the main causes of explosion, but was necessary further study and causes roots identification of failure to prepare ETA; listing the following causes bases / initial failure: failure in gas distribution, temperature gas sensors, gas regulating valves, lack of cleanliness in thermosyphon interior, wrong choice of work fluid and tube material, tube fracture, blower electrical and mechanical failure, assembly equipment failure.

The failure ‘fusion of first tubes of heat exchanger’ has a high NPR (180), it was necessary to conduct a more detailed study around this failure, for it was made an event tree analysis, ETA and then listing the different results for each studied scenario, and helping to identify and propose new barriers. Finishing study was conducted the CNEA identifying causes for this failure, barriers and consequences of this event, and propose new barriers to prevent and mitigate the consequences. With CNEA analysis can be seen that root causes for the occurrence of central event in all cases, were the failures in organization administrative process.

Erva – mate drying system, now have a risk analysis associated to the implementation of this new technology at BALDO S.A. to ensure safety for workers and company when the thermosyphon heating system will be implemented.

To ensure workers and company safety in thermosyphon heat exchanger operation could be suggested: 1) use of shields (holed plate) to block thermal radiation emitted by high temperature of gases combustion. 2) Installation of shield with firebricks on furnace interior to create a physical shield for ash to prevent those particles goes to inside of tube heat exchanger. 3) Temperature sensors in heat exchanger inlet to automatically switching on / off the primary air blower and worm screw feeder when gases temperature were higher than 750 ° C and lower than 700 ° C. 4) Firewood feeder through the worm screw feeder.

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