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Analysis of Root Causes of Fire in Coal Fired Power Plant Using FMEA Study Case Method at PT. PJB UBJOM PACITAN

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Abstract— **Fire is one of the highest risks in using coal as fuel for electricity generation. Coal fires often occur in the area of coal handling facilities and are caused by damage to equipment, accumulation of coal dust that has not been cleaned and burning coal itself. This study aims to find out how the application of the FMEA method for the analysis of the root causes of fires in the Coal Power Plant with a case study of the Pacitan steam power plant uses a quantitative approach to find the root cause for prevention by respondents from PT. PJB UBJOM PACITAN at manager and supervisor level. In applying FMEA, the severity, events, and detection is needed to produce risk level figures which will be used as a step in determining the priorities of the company's mitigation management. Based on this study, 15 types of equipment failures were found in the operational coal handling facility at PT PJB UBJOM PACITAN. By using the FMEA method, 6 types of critical failures can be found that require more attention, namely dust on coal which has the potential to cause self-ignition, self-ignition of coal in the area, hot surface, self- combustion in coal yards and perforated crushing bodies.**

Keywords—**Fire, Low Rank Coal, Coal Handling Facility, FMEA.**

I. INTRODUCTION

IN OPERATING a steam power plant using Low Rank Coal type coal, the company must carry out extra strict supervision of coal dust handling and self-combustion so that the operational process of the power plant in generating electricity can run safely and avoid the danger of accidents, such as fire. Fires in coal-fired power plants can be caused by equipment damage and accumulation of coal dust that has not been cleaned, which can lead to self-combustion. In an effort to analyze, evaluate and reduce the potential for fire accidents at coal-fired power plants, operational analysis of equipment at the Coal Handling Facility can be carried out.

The operational analysis of equipment in the Coal Handling Facility can be carried out with a risk assessment as a comprehensive risk management system used by the organization for the purpose of increasing the value of the company. Implementing appropriate risk management will have a major impact on all areas of work from operations, maintenance, and engineering. In terms of operation, operator anticipate that there will be no damage to coal handling equipment. Risk analysis is a series of processes carried out with the aim of measuring risk and evaluating risk. The purpose of risk evaluation is to understand the characteristics of risk so that risk will be more easily controlled [1]. The application of risk analysis in this case uses FMEA for each equipment to prevent operational failures and also causes fires because FMEA analysis involves a diverse team of people from different backgrounds (e.g. mechanics, instruments, electricity, and operations) with brainstorming methods, because this increases the likelihood that all failures will identified and effects will be estimated correctly. [2] The use of the FMEA method is used as a method to identify error modes, to assess the consequences of specific damage and to subjectively conclude risks and a number of priorities. FMEA is designed to: (1) fully identify potential failure modes and their causes, as well as the effects of failures on the system or end users, for certain products or processes; (2) assess risks associated with the modes, effects and causes of failure identified, and prioritize problems for corrective action; and (3) identify and take corrective actions to address the most serious problems. [3]

From the safety field data of PT. PJB UBJOM PACITAN which shows that there have been 192 incidents of self-combustion/fire that occurred during the period 2018 - April 2020 shown in Figure 1. This graph illustrates the importance of immediately measuring risks and mitigating to prevent self-combustion in coal handling areas of the facility.

PT. PJB UBJOM PACITAN is currently not doing any risk mapping for coal handling equipment operating in power plants. Coal handling facilities have a big role for power plants for reliability in the process of producing electricity. Then the focus of the study will be discussed by researchers relating to the Risk Assessment of the causes of fires in the operational equipment of the Coal handling facility. This Risk Assessment will be used as a reference for mitigation measures for Coal handling facilities.

II. METHOD

A. Coal Self-Combustion

Self-combustion also called self-combustion is one of the phenomena that occurs in coal when the coal is stored or stored storage / stockpile within a certain period [4]. Process self-combustion is a process self-heating or heating by itself that comes from oxidation or a chemical reaction of a mineral in the coal itself. Burning that happens on its own. Self-combustion on Stockpile is often the case and needs to get attention especially to large piles of coal. Coal will oxidize when it is exposed on the surface during mining, thus when the coal is deposited the oxidation process continues. The

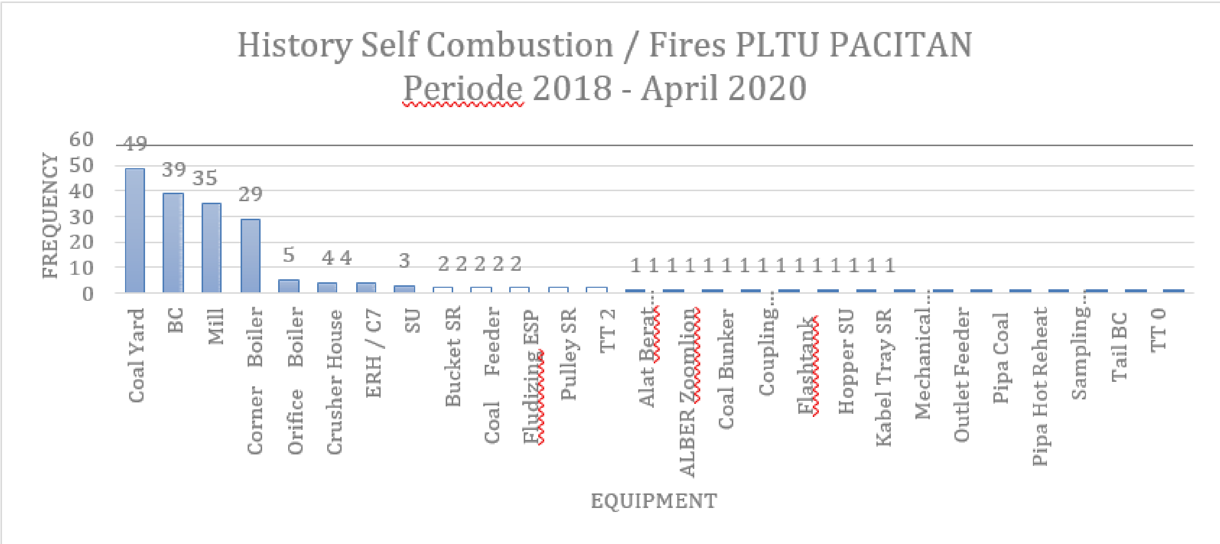

Figure 1. History of Self-combustion Coal Handling Facility.

Table 1.
Value of Occ, Sev, Det and RPN

Kode	Failure Mode	Occ	Sev	Det	RPN
F1	Coal is dusty	3,50	3,33	2,75	32,05
F2	Self-combustion on a barge	2,92	3,17	2,58	23,88
F3	Housekeeping not clean	2,25	2,67	2,58	15,50
F4	Self-combustion in the coal yard	2,92	3,08	2,50	22,48
F5	Dust Collector System is broken	2,00	2,33	2,67	12,44
F6	Fire Protection system isn't standby	2,33	2,17	2,50	12,64
F7	Dust Suppression System is broken	1,92	3,50	2,67	17,94
F8	Hot Surfaces	2,58	2,83	3,08	22,49
F9	Mechanical Spark	2,08	3,25	2,67	18,05
F10	Unlicensed Hot work	2,58	3,25	2,58	21,63
F11	Slip / Damage on Pulley	2,42	3,25	2,42	19,03
F12	Self-combustion in Bunker	2,42	3,00	2,50	18,15
F13	Chute Transfer Design	1,75	3,58	2,42	15,16
F14	Jogging Conveyor	1,75	2,50	3,25	14,22
F15	Hole at Body Crusher	2,50	3,75	2,17	20,34

coal oxidation reaction itself begins in the gas phase, so an oxidation reaction occurs exothermic between O_2 with flammable gases. If the oxidation reaction takes place continuously, the heat generated will also increase, so the temperature in the pile will also increase. This temperature increase is also caused by the circulation of air and heat in the pile is not smooth, so that the temperature in the pile will accumulate and rise until it reaches the point of combustion which can eventually cause the combustion process in the pile. The burnt reaction can be described as follows:

(1) Oxygen is absorbed by the carbon present in coal which then produces CO_2 and heat by the reaction equation:

$$C + O_2 \rightarrow CO_2 + heat \quad (1)$$

(2) Subsequent reactions produce CO and high temperatures, with the following reaction equation:

$$CO_2 + C \rightarrow CO + heat \quad (2)$$

There are two things that support the process of combustion in the embankment that is dependent on the reaction temperature and sufficient oxygen concentration. All types of coal have the ability to occur in the combustion process, but the time required and the amount of temperature required for the coal combustion process is not the same. For coal that has calories low requires shorter time and lower temperature compared to coal which has high calories. Development of coal heat type low rank coal which is caused by the oxidation process between O_2 and flammable gases such as: methane, hydrogen, carbon monoxide, which can result in the combustion process can be summarized as follows according to Mulyana Hana. [5]

1. At 37° C, the coal in the pile starts to oxidize slowly until the pile is 50 ° C.
2. Temperature 50° C, the oxidation process will increase according to the speed of coal temperature increase to a temperature of 100° C - 140°C.
3. At a temperature of 140° C, carbon dioxide and water vapor will decompose rapidly until a temperature of 230° C is reached.
4. Temperature 230° C, where this for the combustion stage occurs.
5. At temperatures above 350° C, coal will ignite and a coal combustion process will occur.

In addition, the content of flying substances contained in coal is closely related to the class of coal. Low grade coal (low rank coal) characterized by a high content of flying substances. Flying matter in coal consists of flammable gases (such as methane, hydrogen, hydrocarbons and carbon monoxide) and non-combustible gases (such as water vapor and carbon dioxide). Flying substances play an important role

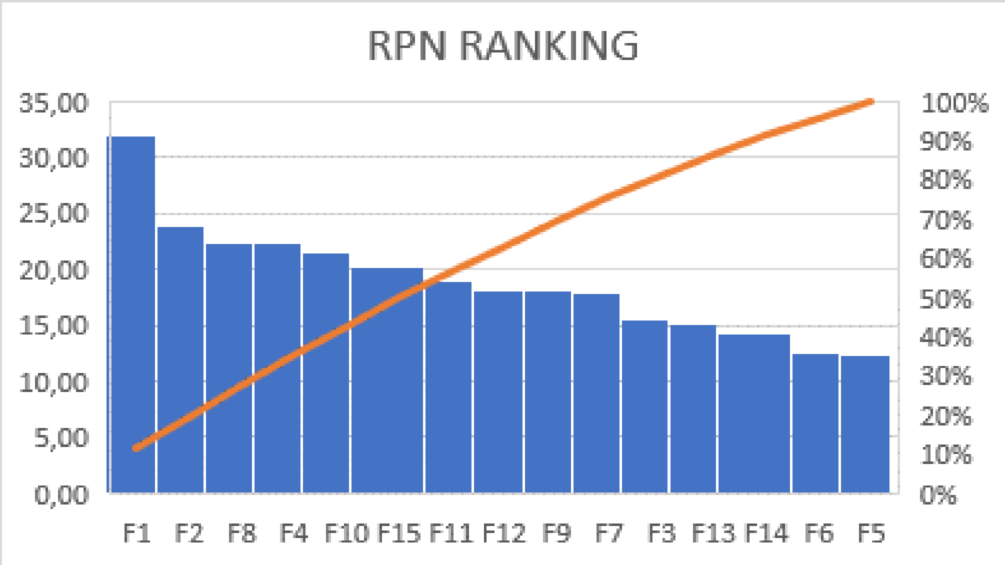

Figure 2. RPN Ranking.

Table 2.
Critical Risks based on FMEA

Kode	Failure Mode	Occ	Sev	Det	RPN
F1	Coal is dusty	3,5	3,33	2,75	32,05
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in initiating combustion because flying substances consist of flammable gases. So that the oxidation reaction occurs between flammable gases and oxygen and causes a combustion process. Coal varies greatly in its ability to react with oxygen; the ability of coal to oxidize will decrease with increasing coal grade.

This is due to the increasing grade of coal, because the combustion of a type of coal in a storage or storage is generally caused by two factors, namely air and heat, the prevention of burning can only be done if one of both of these factors are eliminated or eliminated through compaction in reducing the contact between coal particles and oxygen from the air. This needs to be done, especially for long-term stockpiling or storage Stockpile (for a stockpiling period of more than 3 months) to prevent the deterioration of the quality of the coal in addition to reducing the danger of the fire causing the fire. Compaction of coal deposits must be done systematically, that is done in layers by layer where each layer is spread evenly as thick as say 0.5 M to 1.0 M and immediately compacted with rubber-tired heavy mobile equipment, as loader than with bulldozers who generally use trucks, to prevent further destruction of coal particles.

B. Coal Handling System

Coal Handling Facility functions to handle starting from unloading coal from ships / barges (unloading areas), disposal / storage in stock areas or filling into bunkers used for combustion in boilers. Coal is obtained from the coal mine from the mine site to PT. PJB UBJOM PACITAN which is transported by barge to the coal pier. At Jetty, coal demolition is carried out using Ship Unloader. After unloading coal with the Ship Unloader is channeled into the coal yard using a Conveyor Belt. Conveyor Belt not only moves coal from the Jetty to the coal field, but moves coal from the loading and unloading area (Intake Hopper) to the Coal Bunker (power plant). In the implementation of the Coal Handling Facility, the main equipment needed is conveyor, reclaimer stacker, ship unloader, transfer tower, hopper, gate diverter, coal plough, and bunker / silo

III. ANALYSIS

This research uses a quantitative approach with in-depth interviews. The study was conducted at PT. PJB UBJOM PACITAN, in 2018 - May 2020. Data is collected at the Head Office of PT. PJB at Surabaya and PT. PJB UBJOM PACITAN. Requirements of respondents in this study were employees of PT. PJB UBJOM PACITAN with Manager and Supervisor levels and CHF experts who have the task of handling operations and maintenance in the Coal Handling Facility and found 15 respondents who meet these requirements. To determine the priority of a form of failure using FMEA, steps in Severity, Occurrence, Detection, and the final results of Risk Priority Number are needed. Severity is the severity or effect caused by the failure of the whole machine. Severity level consists of numbers 1 to 5 based on criteria from the Severity scale. Meanwhile, events are the level of frequency of damage or failure associated with the estimated number of cumulative failures due to specific causes of the engine. For FMEA systems and designs, the ranking of events taking into account the likelihood of occurring during the design period of a product Risk Priority Number (RPN) is a numerical rating of the risk of each mode or potential cause of failure, consisting of arithmetic products of three elements: Occurrence (Occ), Severity (Sev) and Detection (Det). After ranking, the Risk Priority Score (RPN) is calculated using the formula: occurrence is the level of frequency of damage or failure associated with the estimated number of cumulative failures due to a specific cause on the machine.

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$$RPN = Occ \times Sev \times Det \quad (3)$$

The higher the RPN value, the higher the risk of the event. This RPN figure is used to identify serious risks, as a guide for corrective action

IV.RESULT AND DISCUSSION

A. Result

Before determining the order of failure types, processes must occur in the area of PT. PJB UBJOM PACITAN power plant. Then using the FMEA method is used to determine the Critical Risk list for each coal handling facility. The determination of FMEA is based on the impact on the equipment, the likelihood of it happening, and whether the risk is known or not. The type of failure on mapped equipment was obtained from interviews with PT. PJB UBJOM PACITAN employees and questionnaires from experts PT. PJB UBJOM PACITAN Coal Handling Facilities Area. Fire Investigation Report data is also used for weighting. The report will find out how the impact of the fire that occurred in the area of coal handling facilities and the impact on the operations of PT. PJB UBJOM PACITAN unit. And found 15 types of failures that can cause self-ignition in the CHF area. In the next research phase using the FMEA method through questionnaire media will get a level of risk by tabulating all types of failures and combined with weights. In the questionnaire format, three ratings are determined that will determine the critical risk, namely the probability of the risk value (Occurrence), the impact due to risk (Severity), and the detection of risk (Detection). PT. PJB UBJOM PACITAN has its own standard to rank Severity and Occurrence, and this standard is used in this study.

Determination of OSD Occurrence, Severity, and Detection values to get the RPN value is done after the type of failure has been identified. To determine the value of using a questionnaire given to 15 (twelve) employees at PT. PJB UBJOM PACITAN with the minimum position of Supervisor whose filling is done through online brainstorming and the author actively explains the procedure to fill it. RPN values can be seen in Table 1.

Figure 2. shows sequential failure codes starting from the highest RPN value to the smallest value. Based on the risks that have been registered and the known value of each RPN, then the critical risk can be determined. Risk is categorized as a critical risk if it has an RPN value above the critical value. The critical RPN value is determined from the average RPN value of all risks.

$$\text{Critical Value of RPN} = \frac{\text{Total RPN}}{\text{Total Risk}} = \frac{286.02}{15} = 19.07$$

The RPN value of the fifteen risks above 19.07 which is a critical RPN value. Based on the critical RPN value above, 6 (six) critical risks are obtained. For these 6 types of risk can be seen in Table 2.

B. Discussion

From the results of the risk assessment based on calculations using the FMEA method, data obtained from 15 types of failures conducted by the study, which have a large risk there are 6 types of risks that require special attention to mitigation management so that the CHF area is always safe from the risk of self-ignition / coal fire.

1) Coal Risk Mitigation Many of Dusty

a. Coal dust from the Mine

Risk mitigation that can be done are:

1. Coal from the mine before shipping is carried out spraying with surfactant to prevent coal deformation. (Beamish and Smith) report other advantages of using antioxidant applications, namely less coal degradation, reducing dust problems, maintaining heating values, reducing the environmental impact and safety of gas emissions associated with hotspot development. [6]
2. Coal transportation is prioritized using boat types due to the location of power plants located in the south of Java where the sea waves are very strong and mining locations on the island of Borneo and on the island of Sumatra, resulting in a long coal shipping trip when using a barge type ship. Fast delivery duration can prevent coal deformation which causes dust.
3. Grab SU (Ship Unloader) has been equipped by the nozzle as a dust controller stating that with certainty pressure, efficiency increases when the design of the nozzle is very small to produce smoother mist. Soft fog is more effective in dropping small dust particles from the air. [7] So, by modifying a smaller nozzle it can produce a fog that can be more effective in controlling coal dust during the unloading process.

b. Coal Dust Mitigation at Yard

Risk mitigation that can be done are:

1. During the unloading process of coal from the Jetty to the coal field in a TT0 - TT2 conveyor belt a dust suppression system is installed which is mixed with surfactant. So that coal is emulated with a surfactant that can bind dust and protect coal from oxygen contamination so that during the transfer process on the conveyor dust contamination becomes much less and cleaner.
2. Implementation of coal use management in the coal yard area with the first in first out (FIFO) method in order to prevent coal deformation which can cause dust and even self-combustion.
3. Install a water spray / fogging jet system for coal wetting in the coal yard to keep the coal temperature at a stable temperature.
4. The process of loading coal from the coal yard is prioritized using a Stacker Reclaimer and then compacted using a Wheel loader by making a triangular shape of the coal pile terracing so as to avoid the wind gusts entering through the cavities of the coal pile cavities.
5. Install the auxiliary water fogging fan when loading using a wheel loader that can catch flying coal dust.

2) Coal Self-combustion on barges

Risk mitigation that can be done are:

1. According to Geijs et.al "Before coal disassembly is carried out it must be measured in coal temperature. And it will only be accepted for unloading if the loading temperature is not higher than 55 ° C based on the International Maritime Solid Bulk Cargo (IMSBC) CODE: Section 4 (protection fire). [6]
2. Self-combustion blackout with foam using a rod awl.
3. Monitor the temperature of the coal with thermal imaging points
4. Wetting with hydrant water for the coal area has a temperature> 55 ° C.
5. Shorten the ship berth time by speeding up loading time.

3) Hot Surfaces

Risk mitigation that can be done are:

1. Installation of heat insulation for areas that have hot surfaces.
2. Improvement with the addition or replacement of heat-resistant coatings on the Hot Surfaces with calcium silica material (existing glass wool material).

4) Self-ignition in coal yards

Risk mitigation that can be done are:

1. When loading coal from Jetty to the coal field in a TT0 - TT2 conveyor belt installed a dust suppressor system that is mixed with surfactants.
2. Arrangement according to the direction of the arrangement of coal yards in the form of a cone with the method compression.
3. Implementation of coal use management in the coal yard area with the first in first out method (FIFO).
4. Do a manual blackout whether the coal decomposes using an excavator later compacted. "Recirculating coal deposits by taking them and moving them through a reclamation system and conveyor can also be used as a method for removing heat" according to Anglo coal,
5. Extinguishing itself with foam using a stick awl.
6. Fire Fighting Cars use a mixture of water and foam.
7. Install a water spray / fogging jet system for coal wetting in coal meters for keep the temperature in the coal yard always stable.
8. Periodic monitoring of coal temperature checks the coal meter using imaging cameras thermal. Newcastle Coal states that "coal field observations are made when [6]:

a. <50 ° C makes scheduled observations (weekly).
b. 50-70 ° C daily observations and daily temperature measurements.
c. >70 ° C applies corrective action.

5) Damaged Dust Collector System

Risk mitigation that can be done are:

1. Filter preventive maintenance cleaning bags regularly.
2. Make modifications by installing dust bags to reduce wind speed and spread dust in the transfer point area. The core technology of filter cloth remains the bag itself, which acts as the matrix where the dust cake is formed. Several variables, including fabric, weaving finishing and construction affect the collection efficiency and filter life. [7]

6) Hole at Crusher Body

Risk mitigation that can be done are:

1. Repair by patching the crusher's body with holes, and still maintain the hot work procedure.
2. Redesigning the material body crusher upgrade
3. Installing a filter / gauze with material from iron that can capture coal material that has a size larger than the coal specifications to be processed by the crusher

Based on research activities, the research method and the results of the analysis of the risk of burning / fires that have been carried out as described above, are expected to be applied at PT. PJB UBJOM PACITAN which complements existing procedures or modifications and investments in equipment that can improve operational safety and other fields, such as maintenance and engineering. Some things that are recommended for the management of PT. PJB UBJOM PACITAN for the implementation plan includes:

1. Form a quick reaction team to blackout self-combustion/Fire
2. Program training by experts for the rapid reaction team and representatives from all departments involved in its application.
3. Propose a budget for the study and apply technical recommendations related to the modification of equipment or operational units to reduce the risk factors for own combustion / coal fire, one of which is:

a. Use surfactants in coal from the mine to be sent to power plant, so that coal is not easily oxidized with O2 so that coal deformation is not easy during the shipping process. Using surfactants for the dust collection system in the conveyor system when loading coal from the dock to the coal field
b. the coal yard to the bunker unit so that coal dust that is transported can be fastened properly with coal.

c. Installation of thermal imaging camera alarm detector coal yard system to detect spots that have the potential self- combustion coal yard by detecting changes in coal surface temperature automatically.
d. Installation of thermal imaging camera detectors and automatic suppression systems for conveyor area systems at TT 0 - TT 2 and BC 3 to secure the conveyor system by detecting coal hotspots that are transported through conveyor belts and can automatically spray directly so that coal that is self-igniting goes out and can enter the bunker safely.

V.CONCLUSIONS

Based on the results of data processing and analysis using the FMEA method of 15 types of equipment failures identified in the operation of coal handling facilities. 6 types of critical failures can be found that require more attention by management, namely coal dust which has the potential to cause ignition, self-combustion of coal in the barge, hot surface, self-combustion in coal yards and crushing bodies with holes. With the application of the FMEA method, PT. PJB UBJOM PACITAN can help minimize the risk of fire that could potentially occur in power plants to improve employee safety and coal handling facilities. Thus, the power generation process can run safely.

RECOGNITION

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