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ANALYSIS OF FIRE RISK ASSESSMENT IN THE PIPERACK AREA USING FISHBONE METHOD AND FAILURE MODE AND EFFECT ANALYSIS (FMEA) AT PT XYZ

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Abstract

As the industry in Indonesia develops, new challenges will arise in the field of occupational safety, especially in the field of fires and explosions. This problem comes from the problems of industrial productivity, employee safety, and welfare when carrying out duties. Fire risk is a work safety problem that often occurs in an industry. The pipe rack area at PT XYZ has a large potential fire risk due to the presence of flammable materials and sustainable production activities. The identification and analysis process regarding the causes of fire incidents is urgently needed to formulate preventive measures. By using the fishbone diagram analysis method, the root cause of potential fires can be identified and the Failure Mode and Effect Analysis (FMEA) method can be found out the value of the severity. The results of the study show that six basic causes affect the occurrence of fires. Through FMEA, several high-risk failure modes can be identified and prioritized as cracks in pipe joints in pipe fitting components. Recommendations for preventive measures include increasing occupational safety training, regular equipment maintenance, improving fire early detection systems, and implementing occupational safety standards.

Keywords: Fire Risk, *Piperack*, *Fishbone Diagram*, FMEA, Occupational Safety

Introduction

As the industry in Indonesia develops, new challenges will arise in the field of occupational safety, especially in the field of fires and explosions. This problem comes from the problems of industrial productivity, employee safety, and welfare when carrying out duties (Ririh, 2021). If this is not supported by good work ethics and safety, then negligence will arise at work. According to Law Number 1 of 1970 concerning work ethics, work ethics is a type of work that is not paid attention to and is not realized, which concerns a process that is developed from an activity and can result in losses to both human and material (Sinaga, 2021).

Occupational safety in the oil and gas industry is a major concern, especially in efforts to prevent accidents that can cause major losses, both in terms of human safety, asset damage, and environmental impacts (Saputra, Kusdarianto, & Samsinar, 2023).

One of the critical areas that requires risk management with a high level of precision is *pipe rack*. *Pipe Rack* It is the main distribution channel of fluids, be it crude oil, refined products, or gases, operating under high pressure and temperature conditions. This combination increases the potential for hazards such as leaks, explosions, and fires, which can trigger incidents with serious consequences (Faizal, 2024).

In an effort to manage risk effectively, risk analysis methods play an important role. Method *Fishbone* or a cause-and-effect diagram is used to systematically identify the root cause of a problem. By grouping the causes into categories such as people, methods, machines, materials, and the environment, the Fishbone diagram provides a comprehensive overview of the factors that affect the potential risk of fire (Ilmi, Juanda, & Islami, 2023).

After identifying the cause through *Fishbone* and methods *Failure Mode and Effect Analysis* (FMEA) is applied to further analyze and evaluate risks. FMEA is a quantitative-based method that evaluates each potential failure based on three main parameters, namely severity (*severity*), the possibility of occurrence (*occurrence*), and detection capabilities (*detection*). These three parameters are combined to determine *Risk Priority Number* (RPN), which gives priority to risks that require immediate mitigation actions (Khairansyah, Amrullah, & Qurratuláini, 2024).

By integrating these two methods, fire risk analysis becomes more directed, from root cause identification to risk priority evaluation and preparation of mitigation measures. PT XYZ, as a company engaged in the oil and gas sector, is committed to implementing appropriate risk management measures to ensure operational safety. This study was conducted to analyze the risk of fire in the area *pipe rack* PT XYZ uses the *Fishbone* and FMEA, so that it can provide data-based and targeted mitigation recommendations (Pardede & Tinambunan, 2022).

In addition, the importance of applying this risk analysis is not only related to the protection of company assets, but also to the workforce and the surrounding environment. By ensuring optimal risk management, PT XYZ can contribute to creating a sustainable workplace safety culture, while minimizing the potential negative impact of its operations on society and the environment (Rahmania, Muzakky, & Phuspa, 2024).

Research Methods

This study uses *Failure Mode and Effect Analysis* (FMEA) and *fishbone diagrams*. This research method aims to identify and analyze potential failures and their causes in a process or system, so that effective corrective measures can be taken to minimize risks. Using FMEA, researchers can evaluate the impact of each failure mode, while fishbone diagrams will aid in the visualization and mapping of the causes that contribute to the identified problems.

Fishbone Diagram

Fishbone diagram is an instrument used for the analysis of the causes of failure involving the relationship of several causal factors. The use of this method is to identify a number of potential causes of a failure so that it can determine control measures (Fajrin,

Suharto, & Rozi, 2019). The factors that affect a component failure are *man power, method, machine, materials, measurements, environment, maintenance and management* (Pušnik, Kous, Godec, & Šumak, 2019).

***Failure Mode and Effect Analysis* (FMEA)**

Failure Mode and Effect Analysis (FMEA) is one of the methods of analyzing the identification of failure modes of each component and determining the priority level of failure risk. FMEA uses 3 criteria to determine the Risk Priority Number *(RPN) value, namely the severity or damage (*severity*), the frequency of failures (*occurrence*), and the detection rate* (Khamid, Mulyadi, & Mukhtasor, 2019). The FMEA method aims to identify failure modes, their likelihood and influence on the system (Ebeling, 2019). From FMEA, *functions*, *function failures*, *failure modes*, and *failure effects will be found* (Moubray, 2001).

RPN Formula:

RPN = S ×O ×D ..... (1)

With

S = Severity

O = Occurrence

D = Detection

In determining the SOD value, you can see Table 1, Table 2, and Table 3[4].

Table 1. Severity Level

Value	***Criteria of Severity Effect***
1	No effect
2	There is no effect and workers are unaware of the problem
3	Not exist effect and workers realize there is a problem
4	Changes in functions and many workers realize that there is a problem
5	Subtract comfort Function of use
6	Loss comfort Function of use
7	Reduction of key functions
8	Loss of key functions
9	Security issues on key features and alerts are triggered
10	Safety issues and the engine does not work at all

Table 2. Occurrence Rate

Value	***Criteria of Occurrence Effect***
1	1 time in > 10000 hours of machine operation
2	1 time in 10000 hours of machine operation

3	1 time in 6000 hours of machine operation
4	1 time in 3000 hours of machine operation
5	1 time in 2000 hours of machine operation
6	1 time in 1000 hours of machine operation
7	1 time in 400 hours of machine operation
8	1 time in 100 hours of machine operation
9	1 time in 10 hours of machine operation
10	1 time in 2 hours machine operation

Table 3. Detection Rate

Value	***Criteria of Detection Effect***
1	Definitely detected
2	Highly detectable
3	Possibility detectable
4	Most likely to be found
5	Medium chance to find
6	Less likely to be detected
7	Highly unlikely to detect
8	Low probability and difficult to detect
9	The probability is very low and very difficult to detect
10	Undetectable

Results and Discussion

Fishbone Diagram

In this study, *Fishbone* Diagram was used to identify various causative factors that contributed to the fire in the *piperack* area of XYZ Refinery. Here are the results of the analysis of each category using *the Fishbone Diagram*:

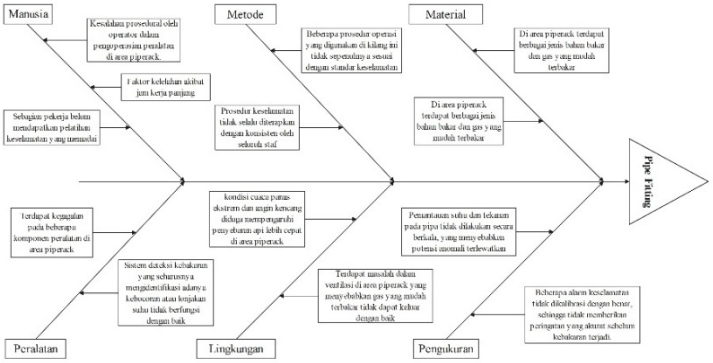

Figure 1 *Fishbone Diagram*

FMEA

Function	Failure Mode	Failure Effect	S	O	D	RPN
Pipe	Corrosion	Tool malfunction and leakage	9	5	3	135
	Clogged	Flow decline and pipe damage	7	4	4	112
Pipe Fitting	Loose connection	Leakage and pressure loss	8	6	4	192
	Joint cracks	Leaks in piping systems	7	5	5	175
Temperature Controller	Influence of environmental conditions	Non-conformity of temperature readings	9	4	3	108
	Calibration errors	Uncontrolled temperature	8	5	4	160
Pressure Controller	Electromagnetic interference	Pressure readings are constrained, making them inaccurate	7	3	2	44
	Over pressure	Pipe leaks that are not strong enough to withstand high pressure	10	4	3	120
Flow Controller	Fluid conditions are unstable	Reduced efficiency	8	3	3	72
	Over flow	Pipe leaks that are not strong enough to withstand high flow	9	5	3	135

Analysis results with the highest RPN value:

Function	Failure Mode	Failure Effect	S	O	D	RPN
Pipe Fitting	Joint cracks	Leaks in piping systems	7	5	5	175

DISCUSSION

Fishbone Diagram

Each *of the basic causes* of 6 factors that affect leaks in *pipe fittings* include:

People

Procedural errors were identified by the operator in the operation of the equipment in the *piperack area*. Some operators are reported not to fully comply with standard safety procedures, such as temperature and pressure monitoring procedures on pipelines.

It was found that some workers did not receive adequate safety training regarding handling emergency situations, which resulted in a slow response during fires. Fatigue factors due to long working hours also appear as a potential cause, which can affect the operator's level of vigilance in handling equipment.

Methods

Some of the operating procedures used in this refinery are not fully compliant with the recommended safety standards, especially related to routine monitoring and maintenance in the *pipe rack* area. This incident occurred in part because safety procedures were not always consistently implemented by all staff, such as the use of personal protective equipment (PPE) and periodic checks on critical equipment.

Materials

In the *piperack area* there are various types of flammable fuels and gases. At the time of the fire, it is suspected that there was an accumulation of flammable gases around *the piperack* which caused the intensity of the fire to increase. Research shows indications of the use of pipe materials that are not resistant to high temperatures or corrosion, leading to potential leaks and fires.

Machinery/Equipment ( )

There were failures in several equipment components in the *pipe rack* area, such as leaking valves and damaged pipes, which are suspected to be the initial source of the fire. Some equipment is known to have passed the recommended maintenance period. The fire detection system that is supposed to identify leaks or temperature spikes is not working properly, leading to delays in dealing with the fire.

Environment

At the time of the fire, extreme hot weather conditions and strong winds are thought to have affected the spread of the fire faster in the *piperack area*. There is a problem in the ventilation in the *piperack* area that causes flammable gases to not escape properly, increasing the risk of fire.

Measurements

Temperature and pressure monitoring in pipes is not carried out regularly, which leads to potential anomalies being missed. This inaccuracy of measurement results in a failure to detect critical conditions before an incident occurs. Some safety alarms are not properly calibrated, so they do not provide accurate warnings before a fire occurs.

From some of the factors above, equipment failure is one of the main causes of fires in *the piperack area*. In this case, the failure of the fire detection system and the leakage in the pipeline are technical factors that trigger the occurrence of the incident. Lack of

regular maintenance and inspections results in critical equipment not being able to function properly, especially in detecting and controlling emergency situations.

Recommendations

Based on the *Fishbone* Diagram analysis of fire incidents in the *pipe rack* area of the XYZ Refinery, several corrective and preventive measures can be implemented to improve operational safety and reduce the risk of future fires. The following are recommendations compiled based on the identified causative factors:

a. Revision and Enforcement of Safety Procedures
    1. Review Standard Operating Procedures (SOPs): Evaluate and update SOPs used in *pipe rack* areas, especially those related to operation, maintenance, and safety. Ensure the procedure meets the latest industry standards.
    2. Enforcement of Compliance with Safety Procedures: Strengthen oversight of employee compliance with existing SOPs. Conduct periodic safety audits to ensure that procedures are carried out consistently by all personnel.
    3. Increased Supervision: Increase the role of field supervisors in monitoring day-to-day activities, especially during high-risk critical operations.

b. Increased Safety Training and Awareness
    1. Periodic Safety Training: Conduct regular safety training for all employees, including training on the use of personal protective equipment (PPE), emergency response procedures, and how to identify potential hazards in the workplace.
    2. Emergency Response Simulation: Conduct periodic emergency response drills to test personnel readiness in response to emergency situations, such as fires, gas leaks, or explosions. These simulations can also help identify weaknesses in emergency procedures.
    3. Safety Awareness Increase: Create a safety campaign to raise awareness of all staff about the importance of occupational safety, including the installation of safety posters and regular counseling.

c. Routine Maintenance and Equipment Repair
    1. Schedule Preventive Maintenance: Implement a strict preventive maintenance schedule for all equipment in the *pipe rack area*, including valves, pipes, temperature sensors, and fire detection systems. Ensure that maintenance is carried out by trained and certified technicians.
    2. Material Quality Inspection: Review the quality of the materials used, especially pipe materials and other critical components. Choose materials that are resistant to high temperatures, corrosion, and extreme environmental conditions to reduce the risk of material failure.
    3. Replacement of Obsolete Equipment: Immediately replace equipment that is worn out or shows signs of damage, especially those related to safety systems such as sensors, alarms, and automatic fire extinguishers.

d. Improved Detection and Monitoring Technology
    1. Installation of More Advanced Fire Detection Systems: Install more sensitive fire detection systems, including gas, temperature, and pressure detection

sensors capable of detecting potential fires early. This system must be integrated with an alarm that can provide early warning to the entire refinery area.

2. *Real-Time Monitoring*: Use real-time-based monitoring technology to monitor critical parameters such as temperature, pressure, and fuel flow in the *pipe rack* area. The system must be equipped with automatic alerts in case of deviations from normal conditions.
3. Routine Calibration of Measuring Instruments: Ensure that pressure and temperature measuring instruments are calibrated regularly to ensure the accuracy of the data obtained, so that abnormal conditions can be detected faster.

e. Optimization of the Operational Environment

1. Ventilation System Repair: Improve ventilation in the piperack area to ensure that combustible gases do not accumulate. A good ventilation system will also help reduce the potential for fire to spread in the event of a fire.
2. Weather Factor Considerations in Surgery: Consider weather conditions when performing high-risk surgeries, especially on days with extreme temperatures or strong winds. Scheduling high-risk work must be adjusted to weather conditions to minimize risk.
3. High-Risk Area Control: Create a risk control zone in areas with a high potential for fire. Restrictions on access to such areas should be exercised only for qualified personnel who have received special training.

f. Periodic Measurement and Evaluation

1. Periodic Safety Audits: Conduct periodic safety audits to assess the effectiveness of the mitigation measures that have been taken. Identify weaknesses and immediately take corrective action to correct them.
2. Safety System Performance Evaluation: Evaluate the safety system thoroughly to ensure that all technologies and procedures used are running as expected. Use the results of this evaluation to update or improve the safety system.
3. Training Effectiveness Measurement: Review the effectiveness of the training that has been delivered by measuring employees' response to emergency simulations and their understanding of safety protocols.

g. Investment in Safety Infrastructure

1. Addition of Automatic Fire Extinguishers: Consider installing an automatic fire extinguishing system in the area *of the pipe rack*, such as *a sprinklers* or *deluge* system, which can work automatically if a fire is detected.
2. Upgraded Emergency Response Facilities: Provide additional facilities such as fire stations, portable fire extinguishers, and *easily accessible emergency escape routes*.
3. AI-Based CCTV Monitoring: Use CCTV monitoring systems equipped with artificial intelligence (AI) technology to detect abnormal activity that can lead to fire risks.

Based on the results of the FMEA analysis conducted on the fire incident at the PT XYZ piperack, it was found that the most significant failure mode was the joint crack in the *pipe fitting* component, with the highest RPN value of 175. This value reflects a combination of *Severity* (S) values reaching 7, indicating that the impact of leaks caused by joint cracks can have serious consequences, including potential fires and safety risks to workers and the environment. In addition, an *Occurrence* (O) value of 5 indicates that the possibility of joint cracks is quite high, which can be caused by various factors such as material wear, overpressure, or errors in the installation process. On the other hand, a *Detection* (D) value of 5 indicates that the challenge in detecting this problem before a failure occurs is considerable, perhaps due to a lack of adequate inspection or suboptimal detection technology.

Taking into account the high RPN value, it is important to further analyze the risks associated with this mode of failure. Potential accidents due to leaks may result in hazardous situations, including fire, explosion, or exposure of hazardous materials to workers. Additionally, the financial losses that may arise from leaks can be significant, including repair costs, lost production, and potential environmental fines. The environmental impact of chemical leaks is also a concern, as it can contaminate soil and water sources, having a long-term impact on local ecosystems. Additionally, fire incidents can damage a company's reputation, reduce customer and stakeholder confidence, and potentially affect stock values.

To address this problem, several mitigation strategies need to be implemented. First, companies should consider improving the quality of the materials used, by choosing materials that are more durable and in accordance with industry standards to reduce the likelihood of joint cracks. In addition, it is important to carry out a routine inspection and maintenance program, by carrying out periodic inspections of pipe joints to detect early signs of damage and implementing preventive maintenance that includes replacing components that show signs of wear.

The use of detection technology should also be considered, such as implementing pressure and flow sensors and *Internet of Things* (IoT)-based *monitoring* systems to detect leaks in real-time. In addition, employee training on correct installation techniques and how to detect problems in the piping system is essential to raise awareness about safety and emergency procedures related to leaks. Finally, companies need to develop and test emergency response procedures to deal with leaks or fires, as well as conduct regular simulations to ensure that all employees know how to react in emergency situations.

Conclusion

Based on the results of the analysis using *Fishbone Diagram* and FMEA on the fire incident in the *piperack* area of the XYZ Refinery, pipe fitting leaks are caused by various interrelated factors, including human error, inadequate procedures, materials that cannot withstand high temperatures, and failure of equipment and detection systems. These factors exacerbate conditions by reducing operator alertness, failures in routine maintenance, and a lack of effective detection technology.

As a follow-up, companies need to take corrective and preventive measures, such as updating safety procedures, increasing safety training and awareness, carrying out regular equipment maintenance, and improving fire detection systems and monitoring pipeline conditions. Improvements to the operational environment and periodic evaluations are also needed to prevent similar incidents in the future.

FMEA analysis also shows that joint cracks in pipe joints are a major failure mode with high risk that needs more attention. Longer-lasting material replacements, periodic inspections, and the use of advanced detection technologies such as pressure sensors and IoT will go a long way in identifying potential leaks early, minimizing fire risks, and maintaining the safety and sustainability of plant operations.

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