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Hazard identification with failure mode & effect analysis and fault tree analysis in the chemical industry

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ABSTRACT

Introduction: The possibility of system failure is something that can happen and can cause harmful effects on workers and the community around the factory. This is shown from the component failure data for the last five years. Components of the sodium silicate production system often fail especially the production pump component. Thus, this study is aimed to analyze the forms of failure, conduct a risk assessment, and determine the basic cause (cut set) of component failure for risk mitigation.

Methods: This was a cross-sectional study. This study was conducted in a company that has sodium silicate production (the company name is withheld). The data or sample that was collected was primary and secondary. FMEA was the next step after mapping the functional block diagram (FBD). Then from the results of the risk assessment on the FMEA, hazard identification was carried out using the FTA method to determine the basic cause (cut set) of component failure for mitigation. After that, the data was analyzed.

Results: This study found that the highest risk values were solvent tank leaks (with a risk value of 15) and production pumps that were not functioning (with a risk value of 20). The results of identification by using FTA to the peak incident of solvent tank leaks obtained 12 cut sets and a minimum of 2 cut sets, caused by the factor of poor maintenance and service life, in the pump production section received 7 cut sets and a minimum of 5 cut sets, caused by there was no supply factor of sodium silicate, bearing life, corrosion, irregular lubrication and short circuit.

Conclusions: Regarding this study, the hazard identification was sodium silica from X company, mainly caused by the dissolver tank leakage and production pump.

Keywords: Failure mode & effect analysis, fault tree analysis, FMEA, FTA, hazard identification.
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INTRODUCTION

The chemical industry certainly has relatively large potential hazards such as fire, explosion, and the release of toxic gases, even the combined effect of fire and explosion. The previous case in Bhopal, India, was one example of the chemical industry failure system that had a very wide impact. It caused about 4.000 fatalities, and 170.000 people were exposed to methyl isocyanate (MIC). This was caused by the high pressure in the tank, which was finally released into the air through the vent gas scrubber.[1]

The possibility of system failure is something that can happen and can cause harmful effects on workers and the community around the factory. This is shown from the component failure data for the last five years. Components of the sodium silicate production system often fail especially the production pump component.[2] Hazard identification was carried out to analyze the forms of failure and the risk of assessments and determine the basic causes (cut sets) of component failures for risk mitigation.[3] Thus, this study is aimed to analyze the forms of failure, conduct a risk assessment, and determine the basic cause (cut set) of component failure for risk mitigation.

To minimize the possibility of system failure in the chemical industry, we can use FMEA analysis. Failure Modes and Effects Analysis (FMEA) is a safety analysis widely used to evaluate the effects caused by different failure scenarios in each element or component. The FMEA is a methodical strategy for locating all potential system failures and identifying their root causes and effects. The distinct failures are ranked in order of severity (measured by severity criteria), occurrence (measured by occurrence criteria), and detection (measured by detection criteria) criteria.[4] Meanwhile, Fault Tree Analysis (FTA) is a systematic, deductive and logical risk assessment method. The FMEA results can be used for more detailed safety analyses such as FTA and event tree analysis.[3,5,6] Papadopoulos et al. (2004) proposed a method to develop FMEA results into a fault tree.[7] Although any FMEA recommendation results are difficult to carry out, especially when the frequency of use is high. In addition, linking FMEA data into a complex FTA process is also a challenge.[5,8]

METHODS

Study Design and Sample

This was a cross-sectional study. This study was conducted in a company that has sodium silicate production (the company name is withheld). The data or sample that was collected was primary and secondary. Primary data was obtained from direct observation and interviews with engineers, operators, and supervisors. At the same time, the secondary data was from process flow diagrams, MSDS, component failure data for the last five years, and other supporting documents.

Data Collection Procedures and Analysis

A functional block diagram was created to comprehend a system and depict the relationship between the system's constituent parts. After mapping the functional block diagram (FBD), FMEA comes next. Then, utilizing the findings of the risk assessment on the FMEA, hazards were identified using the FTA approach to ascertain the fundamental reason (cut set) for component failure for mitigation. After data processing was finished, data analysis was performed. The research was done using the outcomes of the data processing. If there are inconsistencies, suggestions for remedial measures might be made.

RESULTS

First disclosed in a functional block diagram that illustrates the relationships among the system's constituent parts, the plant or system under study was then identified.

Failure Mode and Effect Analysis Identification

Hazard identification is carried out using the FMEA method. We systematically identify potential hazards in the facilities or procedures of a process industry so that if there is a deviation, it can be seen whether the deviation can lead to an unwanted accident.

This method explains the sodium silica production system, its function, and the type of component failure. The risk value examination was reported in the FMEA table. The risk value was obtained from the multiplication of occurrence and severity. The occurrence and severity values are obtained from the risk matrix of X Company. Moreover, If the risk value was 12-25 belongs to the uncountable risk value. Thus, first of all, those risk values needed to be controlled. This study

Table 1. FMEA of sodium silicate production

No.	Component	Failure Mode	O	S	R
1	Gate Valve	The top of the gate valve is leaking	3	3	9
		Worn valve packing	3	3	9
2	Dissolver	The soldered wall is cracked	2	5	10
		Leak in the man hole	3	5	10
3	Ball Valve	Ball valve stuck	2	5	10
4	Pressure Gauge	Worn sock drat	3	3	9
		Pressure gauge is broken	2	3	6
5	Safety Valve	Safety valve fails to open when subjected to overpressure	2	5	10
		System leak on safety valve	2	5	10
6	Setling Tank	The tank wall has a leak	2	5	10
		Leak in the connection pipe connected to the tank	2	5	10
7	Indicator Level	The indicator sling is broken	3	3	9
		Corrosive indicator wheel	2	3	6
8	Filter Tank	Dirty sediment filter	5	2	10
9	Production Pump	Pump stuck or beeping	5	4	20
		Leak in seal	4	3	12
		Trip	4	4	16
10	Evaporator	Heating coil performance drops	2	2	4
11	Agitator	Motor stuck	3	3	9
12	Storage Tank	The tank wall has a leak	3	3	9
		Leak in the man hole	2	5	10
		Leakage of the connection pipe connected to the tank	3	3	9
13	Transfer Pipe	Leak in the pipe	3	3	9

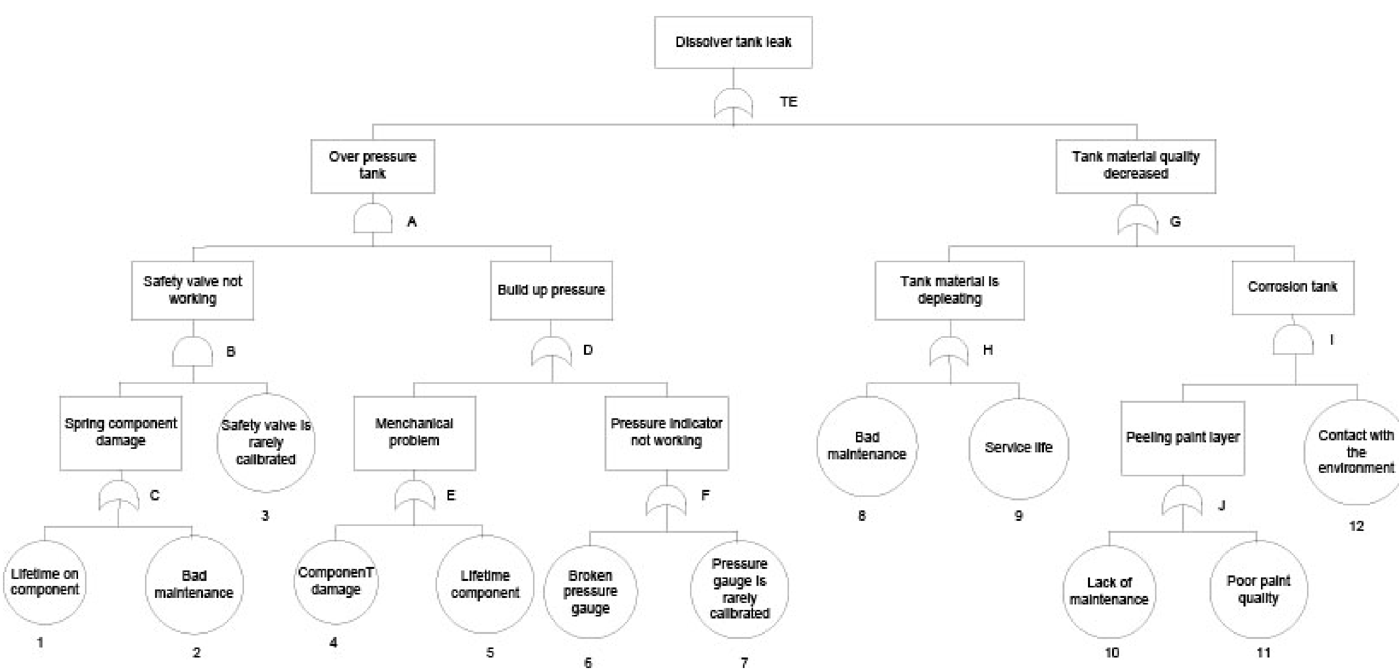

Figure 1. Fault tree analysis on dissolver tank leakage.

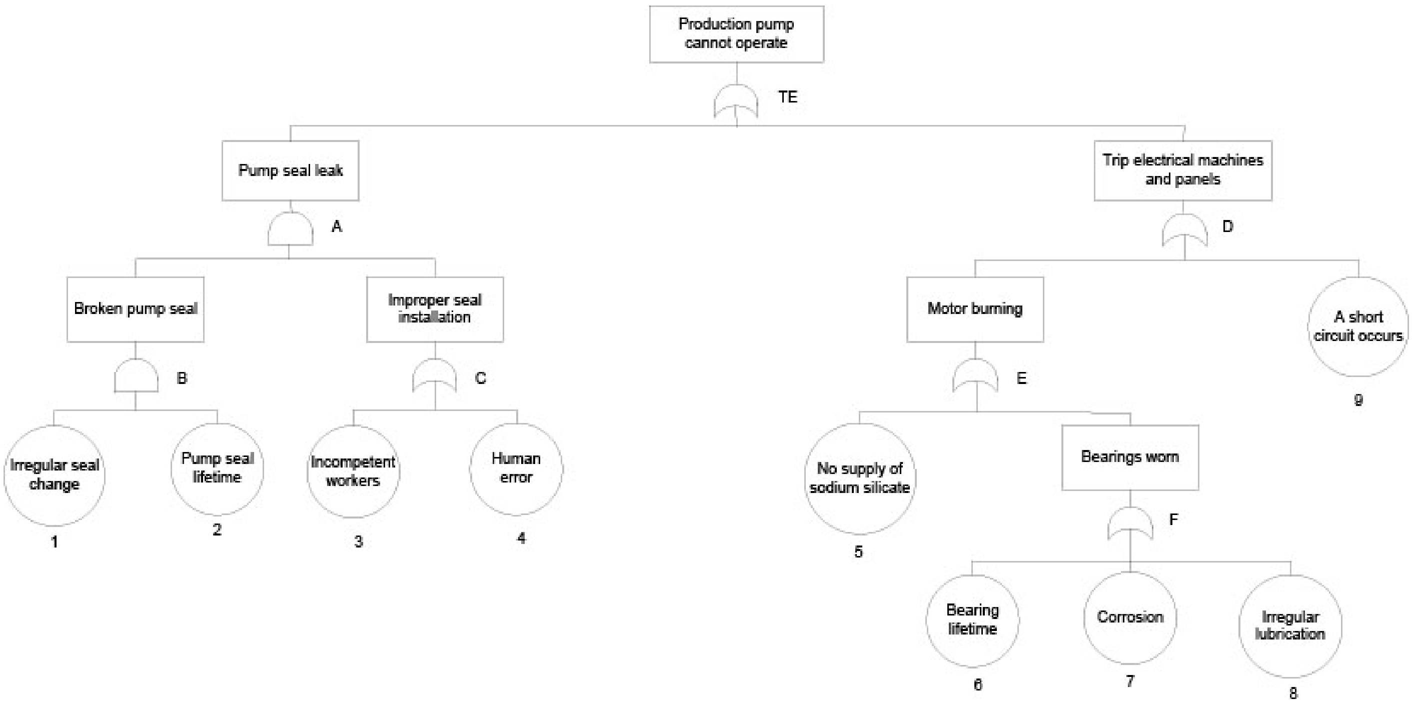

Figure 2. Fault tree analysis on production pump.

showed the highest risk value was dissolver tank leaks and the production pump not working. The following is Table 1 FMEA Sodium Silicate Production.

Fault Tree Analysis Identification

Fault tree analysis was used to find out the basic causes that occur as a main (Top Event). The selection of top events was obtained from a high-risk risk assessment. The cut set was determined to determine the combination of the basic causes that have been known from the FTA. In this study, the determination of the cut set was carried out using the Boolean algebra method. Boolean algebra is a mathematical method used to determine the cut set of FTA images. After knowing the basic causes of the failure, recommendations will be obtained for the failure so that it can be reduced and accidents can be reduced and improve a safe work environment. There was two FTA construction reported in this study. For the first FTA system, the leakage of the dissolver tan was obtained as the top event. The seconds were reported as the mall function of the production pump. Its problem also became the top event in this analysis. A detailed explanation of the FTA diagram of the leak of the dissolver tank and the production pump is shown in Figures 1 and 2.

According to Figure 1, the cut set calculation for the leak of the dissolver tank was:

TE = A + G
A = B . D
= (C.3). (E+F)
= (1+2).3 . (4+5) + (6+7)
= (1.3) + (2.3) . (4+5) + (6+7)
= (1.3.4) + (1.3.5) + (1.3.6) + (1.3.7) + (2.3.4) + (2.3.5) + (2.3.6) + (2.3.7)
G = H + I
= (8+9) + (J.12)
= (8+9) + (10+11).12
= (8) + (9) + (10.12) + (11.12)

After that, the twelve combinations of cut sets were obtained. The twelve combinations of cut sets such as cut set 1 (1,3,4), cut set 2 (1,3,5), cut set 3 (1,3,6), cut set 4 (1,3,7, cut set 5 (2,3,4), cut set 6 (2,3,5), cut set 7 (2,3,6), cut set 8 (2,3,7), cut set 9 (8), cut set 10 (9), cut set 11 (10,12), cut set 12 (11,12). The minimum cut set can be obtained from these calculations, such as the minimal cut set (8) and minimal cut set 2 (9).

Based on the FTA diagram above, the cut set calculation for the leak of the production pump is:

TE = A + D
A = B . C
= (1.2). (3+4)
= (1.2.3) + (1.2.4)
D = E + 9
= (5+F) + 9
= 5 + (6+7+8) + 9
= (5) + (6) + (7) + (8) + (9)

After that, the twelve combinations of cut sets were obtained. The twelve combinations of cut sets such as cut set 1 (1,2,3), cut set 2 (1,2,4), cut set 3 (5), cut set 4 (6), cut set 5 (7), cut set 6 (8), cut set 7 (9). From these calculations, the minimum cut set can be obtained, such as minimal cut set 1 (5), minimal cut set 2 (6), minimal cut set 3 (7), minimal cut set 4 (8), and minimal cut set 5 (9).

DISCUSSION

Regarding this study, we found that the highest risk value is dissolver tank leaks (has a risk value of 15) and the production pump not working (has a risk value of 20). The identification results using FTA for the top event of the dissolver tank leak obtained 12 cut sets and 2 minimum cut sets, namely poor maintenance factors and service life. On the production, the pump received 7 cut sets and 5 minimal cut sets, namely no sodium silicate supply factor, bearing lifetime, corrosion, irregular lubrication, and short-circuiting.

According to the hazard identification,

sodium silica from X company was mainly caused by the dissolver tank leakage and production pump. Ratriwardhani et al. reported that a study from X company had the highest risk value from dissolver tank leakage, the production pump not working. The tank component from the dissolver tank leakage has a slight possibility of leakage. Therefore, regular maintenance might be carried out once a month to check the material's condition and promptly make repairs if there are any indications of tank damage so that there is no leaking in the tank.[8] The adverse effects of sodium silica from dissolver tank leakage are strong irritants to the skin, eyes, and mucous membranes. It is also maybe toxic by ingestion.[9]

Not only the dissolver tank but the production pump also needs to be maintained regularly. Sodium silicate is transported or transmitted by the pump. There are several ways to support the pump properly, including performing routine maintenance on the pump's parts to prevent the pump from being damaged quickly, using a safety feature like the pump's thermal protector to avoid fatal damage like burning, tripping, and overheating of the motor body, and replacing pump parts that have reached their useful lifetime limit to prevent the pump from being damaged quickly and to save time on repairs.[8] The limitation of the study is the implementation of structural mitigation based on the smallest cut set combination. The study can only conducts in one place. Thus we could not evaluate other companies and their industry condition.

CONCLUSION

Regarding this study, the hazard identification was sodium silica from X company, mainly caused by the dissolver tank leakage and production pump. Risk mitigation is carried out in the form of structural mitigation. A suggestion to prevent system failure from probable threats is structural mitigation. Structural mitigation strategies include technological proposals, equipment upkeep plans, and other items relevant to the equipment.

AUTHOR CONTRIBUTION

In addition to conception and design, data analysis and interpretation, article drafting, critical article editing for significant intellectual content, final approval, and data collection and assembly, all authors have participated in this study process.

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CONFLICT OF INTEREST

None.

ETHICAL CONSIDERATION

This research was approved by the Health Research *Ethics* Committee of the Department of Public Health, Nahdlatul Ulama University Surabaya. Letter of exemption Ref. No. 22.37/HPZH.22/LL/2022.

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