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Environmental risk assessment of the waste incineration furnace of an industrial resin production plant in Takistan City, Qazvin province

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Abstract
This study aims to identify and assess the risks of the waste-burning furnace of the resin production factory in Takistan City, Qazvin province. Hence, Failure Mode Effect Analysis (FMEA) was used to identify possible risks and assess the risk's criticality. Then, based on the identified risks, a scenario was defined for the consequences of the selected scenario and analyzed using PHAST software. Accordingly, 15 risks were identified, of which 4 of them including the risks of Respiratory diseases caused by gas inhalation, poisoning due to working with chemical waste, explosion due to gas leakage and personnel health threaten due to leakage from chemical waste storage tanks were the most critical risks. On the other hand, carelessness in transportation, equipment use, falling parts, and noise pollution had the lowest risk. The consequences modeling of the selected scenario indicated that releasing the leaking material, spreads up to a height of 46 meters in the first seconds and affects a radius of more than 1.519.23 km^2 with a concentration of 1 ppm. It is suggested that the risks associated with the waste incineration furnace is identified and evaluated annually, and its control and management approaches are included in the list of factory rules.

Keywords: “Failure mode effect analysis”, “critical risks”, “environmental ma

Introduction

With the rise in population in contemporary societies, the necessity for adopting new technologies is more pronounced than ever before. While the advancement of new industries and technologies will undoubtedly enhance the well-being and quality of life for individuals, it also brings about potential risks in the fields of health, safety, and the environment [1].Simultaneously, the paint and resin industries, being among the most crucial sectors in the country, possess intricate supply chains. Consequently, due to the inherent uncertainty within this industry's supply chain, the management of risks and the mitigation of human-environmental risks become indispensable tools for effectively handling uncertainties. Risk management entails the process of identifying risk factors, evaluating them, and devising plans to minimize the adverse impacts associated with these identified risks [2]. Through the planning, organization, direction, and control of an organization's activities, risk management serves to mitigate the detrimental effects of accidents and new technologies on the performance, economy, and environment of human society. While it may not be feasible to completely eliminate human and environmental risks, they can be reduced to an acceptable or tolerable level [3],[4]. By establishing a systematic and continuous framework, risk management facilitates the identification, evaluation, elimination, control, prevention, reduction, and communication of risks. Consequently, decisions made within the risk management process are based on a comparison of the obtained results, which stem from risk assessment and the identification of risk levels [5],[6]. Various methods exist for identifying and evaluating risks. These approaches systematically analyze potential errors and mistakes that contribute to the occurrence of risks, as well as the probability of risk occurrence and its potential consequences [7].
Notable methods for risk assessment include hazard and operability study, failure mode and effect analysis, fault tree analysis, William Fine risk assessment, and similar approaches [8,9]. The failure mode and effect analysis method is a systematic and proactive approach in risk management that aims to control the risks associated with product design and production [10]. By identifying and evaluating potential problems and defects, this method helps prioritize and allocate resources to address the most likely and severe risks [11]. Originally developed by the US Army to classify failures based on their impact on mission effectiveness and personnel safety, this approach was later utilized in the Apollo space mission in 1960 and in evaluating and reducing risks in car models in 1980 [12],[13].In this approach, the identification, evaluation, and ranking of failure modes are conducted using risk priority numbers. These numbers are determined based on indicators such as probability of occurrence,

severity, and the capability of risk detection [13],[14]. In recent years, numerous studies have applied the FMEA method to various studies, including risk assessment in polymer pipe production lines [11], malt production processes [13], gas transmission lines [16], food supply chains [17], steel industries [18],[6], and underground mining [19]. This demonstrates the broad applicability of this approach in assessing safety, health, and environmental risks.

Therefore, the objective of this study is to evaluate the safety, health, and environmental risks associated with the waste-burning furnace in a resin production factory located in Takestan City, Qazvin province. By utilizing the failure mode and effect analysis method, the study aims to analyze the potential consequences and model the effects caused by these risks. Subsequently, management approaches will be developed to control and mitigate the identified risks in this specific factory unit.

Methodology

Industrial resins production factory with an area of 5.2 hectares is located in Qazvin province, Takestan city, central part, and Narje rural district. The waste incinerator is located near the southeast side of the factory. The capital of Qazvin province (Qazvin City) is 30 km to the northeast and the city of Takestan is 5 km from the furnace and is the closest urban center to the waste incinerator. The village of Kohak, at a distance of approximately 2 kilometers in the eastern location of the factory, is considered as the closest rural settlement center to this area [20].

This study is analytical cross-sectional research that was conducted for 4 months in the resin production plant by applying the approach of failure mode and effect analysis.

The first step of this approach is to prepare a list of the most important risks and hazards related to safety, health, and the environment.

In this study, after coordination with supervisors, all the necessary documents were prepared to identify potential risks. These documents include maps, descriptions of operations and systems, flow charts, piping diagrams and tools, technical specifications and descriptions of system components, properties of process materials, implementation methods, and operating instructions, diagrams of Logical devices (sensors and logical information), chart interlocks, fire, and explosion protection systems, physical and chemical characteristics of the materials used, especially hazardous materials such as acid and base, corrosion prevention and monitoring systems.

After preparing the documents, a team consisting of 5 experts in the field of environment, safety, and health, using brainstorming and Delphi methods, identified the most obvious and important risks related to the waste incinerator.

According to the evaluations provided by the risk assessment team, scores were assigned to each of the identified risks based on three factors: risk severity, probability of the risk occurrence, and the capability of risk detection. The obtained scores for the risk parameters are presented in Table 1[21].

Table 1- Ranking of the three factors affecting the risk levels

Probability of risk detection		Probability of occurrence		Intensity of risk	
Rank	Risk detection capability	Rank	Probable risk rates	Rank	Risk severity
10	Absolutely nothing	10	Once or more every day	10	Disastrous
9	very little	9	Once every 3 or 4 days	9	great important
8	insignificant	8	Once a week	8	Very important
7	Very low	7	Once a month	7	High significant importance
6	Low	6	Once every three months	6	Significant importance
5	Medium	5	Once every six months	5	important
4	Relatively high	4	Once every six months to a year	4	Medium importance
3	High	3	Every one to three years	3	little importance
2	Very high	2	Once every three to five years	2	Very little importance
1	Almost certain	1	Far from expected	1	Insignificant

The risk priority number was determined in the last step by multiplying the three values representing the probability of occurrence, severity, and detection capability for each of the identified risks within the Excel software.

$$RPN = Detection \times Occurrence \times Severity \quad (1)$$

Based on the risk priority number, the risk ranking levels can be categorized as follows:

1. The normal level is assigned when the numerical evaluation scores for all three factors are less than 6, indicating that no preventive measures are required.

International Journal of Innovation in Agriculture Sciences and Rural Development
Vol.5, NO.1 , P:34 - 42
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2. The semi-critical level is assigned when at least one of the three factors has a score higher than 6. However, the overall risk priority number remains low, indicating the need for preventive measures.

3. The critical level is assigned when two of the three investigated factors have scores higher than 6, resulting in a high-risk priority number. At this level, urgent and essential preventive measures are necessary [22]. Table 2 indicates the specific numerical range corresponding to each level of the risk number.

Table 2- Numerical range of different levels of risk number

symbol	Risk level	Risk priority number (RPN)
	50>	Low
	50-150	Medium
	150<	High

After the identification of the risks, the PHAST software was applied to model the potential consequences associated with these risks. Subsequently, the scenario was defined, and the necessary information required for inputting into the software was gathered. This information encompasses details about the waste incinerator as well as information pertaining to the environmental conditions.
The preheating operation tank had a temperature of 80 degrees Celsius, a tank pressure of 5.75-gauge bar (83.4 pounds per square inch), a cylindrical shape, a volume of 20 cubic meters, and a diameter of 0.24 meters. Atmospheric stability was determined using the Pasquiel distribution criterion [23].
Based on the data obtained from the closest weather station (Takestan weather station), the atmospheric stability in the study area was determined to be equivalent to D throughout both the day and night.
The meteorological data of the Takestan were extracted and used as follows.

Table 3- Meteorological information

Winter	Summer	Season
3.6	27	Average air temperature (°C)
57	36	average relative humidity %
4.2	3.86	Wind speed (m/s)
D	D	Degree of air stability

In this research, the selection of the preheated tank's activity scenario was based on several factors. Firstly, the tank's high volume of wastewater and the subsequent high probability of leakage were taken into consideration. Additionally, the study also focused on the environmental problems that arose as a result of this leakage and its impact on the mother plant.

Results Discussion

The results derived from the examination and inquiry conducted by the risk assessment team of the resin factory's waste-burning furnace indicate that there are a total of 15 instances of risk. These risks can be attributed to human errors, natural (environmental) factors, failure to comply with health and safety protocols, as well as other occurrences within this specific section of the factory (Table 4).

Table 4- The results of the evaluation of the safety, health, and environmental risks of the waste incinerator

Risk pri32ority number (RPN)	Capability of risk detection	Probability of occurrence	Ri4sk seve9rity	Foreseeable risk	Risks origin
24	4	2	3	Carelessness in transportation	Human errors
27	3	3	3	Carelessness in using equipment	
16	2	2	4	Falling equipment	
140	5	4	7	The electric shock when using equipment	
12	2	2	3	Floods and flooding	Natural factors
12	2	2	3	Earthquake	
168	4	6	7	Catching diseases caused by breathing exhaust gases from the oven	Failure to comply with health and safety
168	4	6	7	Poisoning due to working with chemical wastes	
42	3	2	7	Exposure to loud noises	

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112	4	4	7	Accidental use of defective equipment	
63	3	3	7	Air pollution is caused by the emission of polluting gases from process units (primary combustion furnace, chimney, etc.) including CO, Nox, and Sox	
128	2	8	8	Soil pollution caused by leakage of storage tanks	
32	2	4	4	Noise pollution caused by equipment in the operating phase, such as a diaphragm pump	
162	6	3	9	Explosion due to gas leak	Other cases
168	7	3	8	Leaking from chemical waste storage tanks and endangering the health of personnel	

In contrast, the findings indicate that 42.86% of low risks are associated with human errors, while natural factors and non-compliance with health and safety account for 28.57% each within these risk categories. 25% of the average risks fall under the classification of human errors, while the remaining 75% of these risks are attributed to the lack of adherence to health and safety protocols.

In terms of critical risks, half of them are associated with non-compliance with health and safety regulations, while the remaining half falls under the category of miscellaneous incidents. It is important to note that human errors and natural factors do not play a role in the emergence of these risks (Fig 1).

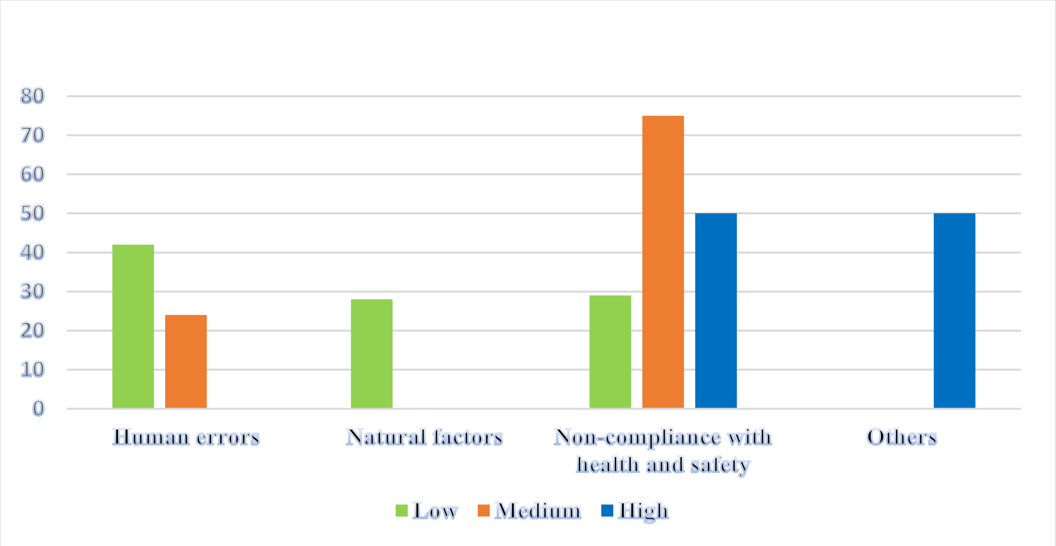

Figure 1- Comparison of the percentage of different levels of risk in each of the examined categories

Given that 4 out of the total 15 identified risks fall under the category of critical risks, it becomes imperative to implement corrective actions in order to mitigate these risks. Consequently, in order to minimize the likelihood of their occurrence, decrease the severity of their impact, and enhance the ability to identify high-risk risks, a set of solutions was proposed after consulting with experts and taking their opinions into account (Table 5).

International Journal of Innovation in Agriculture Sciences and Rural Development
Vol.5, NO.1 , P:34 - 42
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Table 5- Corrective measures taken to reduce the vulnerability of each risk

critical risks	corrective actions
Catching diseases caused by breathing exhaust gases from the oven	•Using suitable filter masks and monitoring how to use them
Poisoning due to working with chemical waste	•Installation of warning signs • Use of proper ventilation system in the environment • Compilation of executive instructions for basic maintenance and storage of chemicals in containers and warehouses equipped with safety systems
Explosion due to gas leak	•Complying with the necessary instructions to maintain the safety of workers and supervise them
Leaking from chemical waste storage tanks and endangering the health of personnel	•Periodic visits to chemical waste storage tanks to avoid the dangers that are occurring • Compilation of executive instructions for maintenance, repairs, and periodic inspection of all material transfer routes, pipes, and valve connection points.

After implementing the necessary corrective actions, experts assessed the magnitude of these risks and recalculated the risk priority number for each of them. Subsequently, these recalculated numbers were compared with the initial priority numbers (Figure 2).

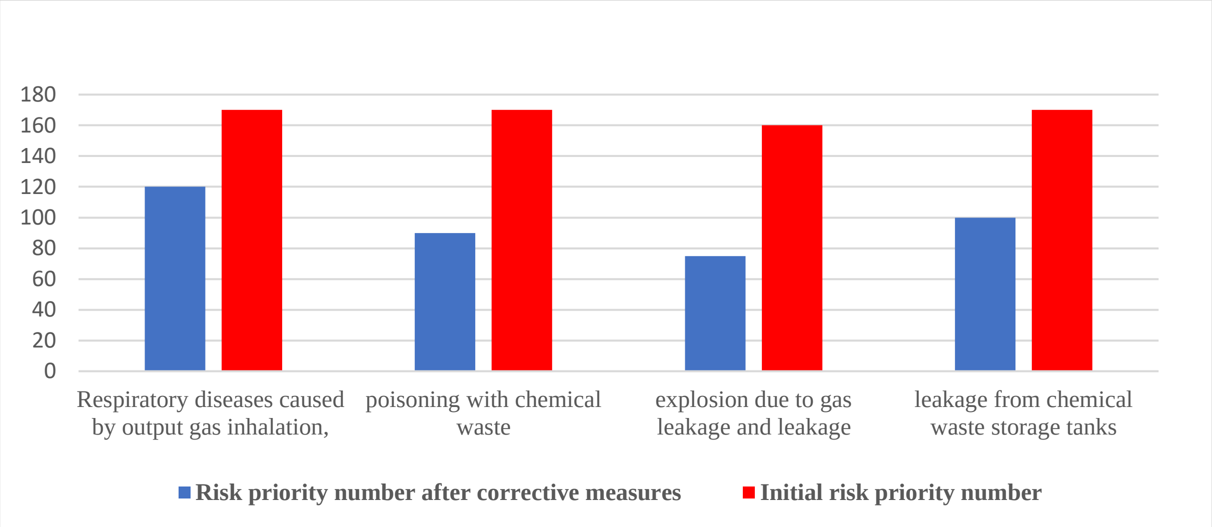

Figure 2- Comparison of the initial priority number and the priority number after corrective measures

Consequences of a tank leak
It is important to mention that all the results obtained through the utilization of PHAST software fall within the specified range, which is determined by the consistent weather conditions experienced during the summer season. The wind velocity measures 3.86 meters per second, while the weather remains stable, characterized by refreshing nights and a moderate breeze.

It is crucial to highlight that the elongation of the graph is attributed to the wind direction being taken into account.

Diagram A illustrates the correlation between the concentration of the substance being leaked and the time it takes for diffusion to occur. On the other hand, Diagram B depicts the concentration of the substance present on the Earth's surface. Lastly, Diagram C showcases the manner in which the substance diffuses from its surroundings.
In diagram A, it is evident that the concentration of the substance is remarkably high at the onset of the leak. Even within the initial seconds, the concentration will reach 400 ppm. On the other hand, diagram B illustrates that as the substance spreads across the

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earth's surface, specifically at a height of zero, the volume of dispersion or cloud mass will expand.
Diagram C indicates that when the material is dispersed through lateral forces and observed from a side perspective, the initial dispersion volume will be significant, causing the cloud mass to ascend to a height of 50 meters.

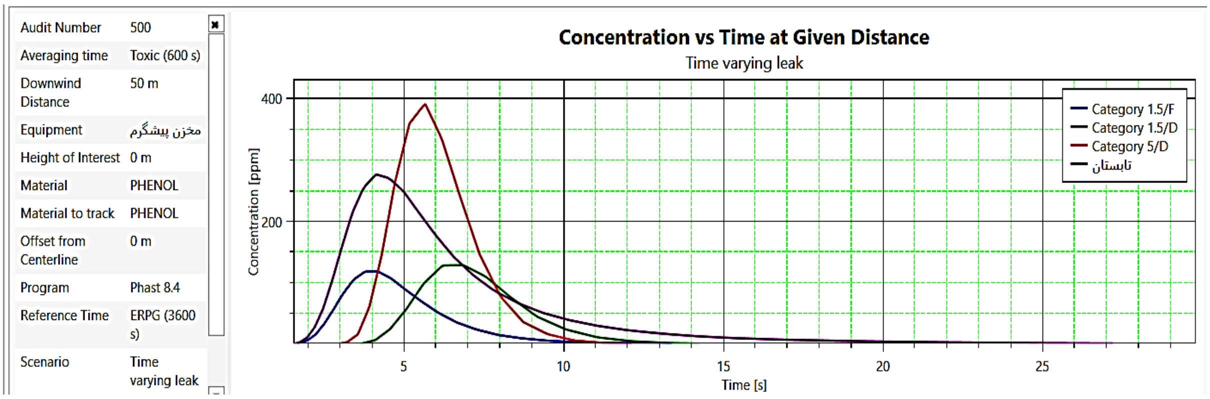

Figure 3- The relationship between the concentration of the leaking substance and the release time

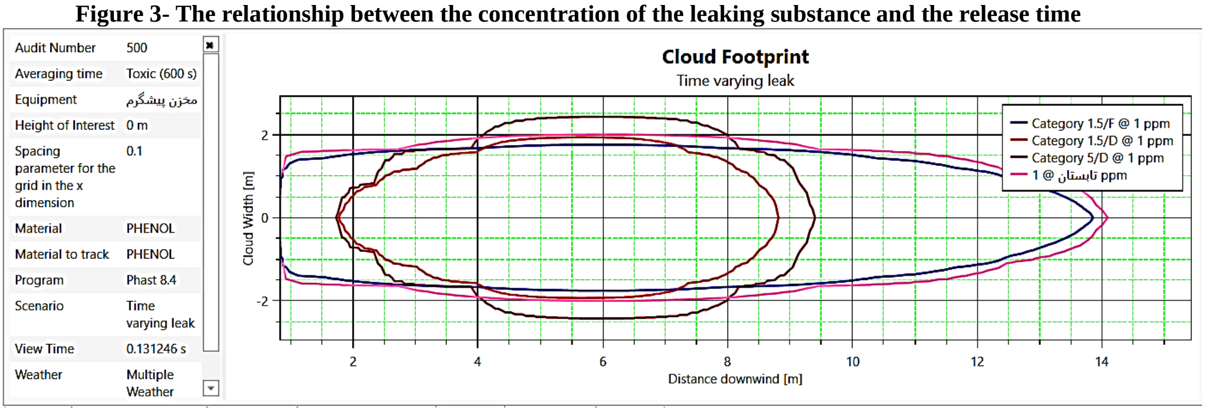

Figure 4- The concentration of the substance on the ground surface

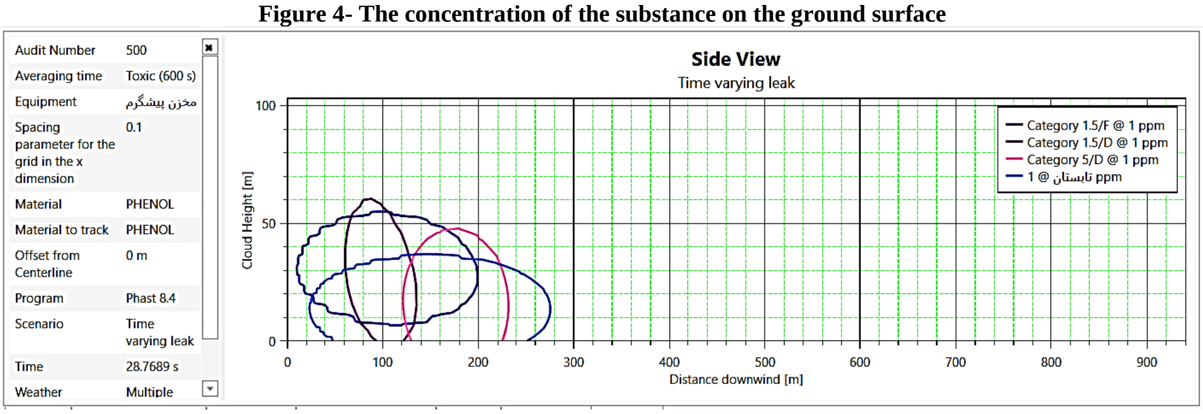

Figure 5- The leakage of the substance from the side

conclusion

According to the results, there are two categories of risks associated with the results. These risks include contracting diseases from inhaling polluted gases, being poisoned from handling chemical waste, experiencing explosions from gas leaks, and facing leaks from chemical waste storage tanks. Additionally, there is a risk of endangering the health of personnel. These risks are classified as critical and require immediate attention, as well as the implementation of preventive measures, in order to address non-compliance with health and safety regulations and other associated risks.

Based on the results, the risks identified and assessed in the waste-burning furnace unit of the resin production facility in Takestan City can be categorized as follows: 59% of the risks fall under the semi-critical risk class, 31% belong to the normal risk class, and the remaining 10% are classified as critical risks [24]. also evaluated the percentage of risks in the middle class for the risks of the casting furnace.
Furthermore, during the assessment of the casting furnace risks, the highest proportion of risks was found in the middle category. Out of the risks identified in three different classes - low (normal), medium (semi-critical), and high (critical) risks - 46.67% are

associated with non-compliance with health and safety protocols. Additionally, 26.67% of the risks are attributed to simple mistakes, while natural factors and other circumstances account for 13.33% of the identified risks.

In contrast to other types of errors, human errors are relatively more manageable. Consequently, the proportion of low-risk incidents within this category surpasses that of other categories, contradicting the findings of the study [25]conducted by Afshari et al. (2018). The researchers attribute the heightened risk of human error to factors such as stress, skill level, and job complexity among personnel.

Based on Figure 2, implementing corrective measures will result in the greatest reduction in explosions caused by leakage, while the decrease in respiratory diseases will be the least significant.

Based on this figure, it can be inferred that implementing corrective actions can significantly mitigate the risks associated with work-related activities and accidents in the environment. Various research studies in the field of risk assessment have also highlighted the significance of corrective measures in managing and minimizing workplace hazards, acknowledging their effectiveness in risk reduction [26], [27].

Based on Figure 2, it is evident that the implementation of corrective measures eliminates high risks from the risk scope and diminishes the level of risks to medium and low-risk risks. This clearly highlights the necessity of corrective measures in managing environmental risks within industrial projects.

According to the defined scenario regarding the chemical leakage from the tank and the outcomes of the modeling, the substance that is leaking will spread to a distance exceeding 1.5 kilometers with a concentration surpassing 1 ppm. Moreover, if the wind blows in a vertical direction, the radius of impact will extend beyond this measurement. Furthermore, the substance will continue to disperse up to a distance of 2 kilometers.

The leakage and release of the substance used in the preheater of the waste incinerator pose a significant risk due to its high toxicity. Therefore, it is crucial to address this issue promptly and with utmost care.

Meanwhile, it is crucial to implement precautionary measures to avert any potential tank leakage. Simultaneously, establishing a secure buffer zone around the reservoir and defining an acceptable risk boundary can significantly mitigate the likelihood of encountering severe risks [23].

The paint and resin industries, particularly the waste management sectors within these industries, encompass numerous environmental and safety hazards.

Based on the results of this research, the utilization of failure mode and effect analysis and the implementation of PHAST software prove to be effective methodologies in the identification and assessment of risks associated with industrial projects, specifically in resin industries. Furthermore, these approaches also facilitate the examination of the potential consequences that may arise from such projects.

However, offering remedial strategies is a valuable approach to risk management and mitigating the number of risks identified in these sectors. These measures can effectively eliminate high-risk hazards from the domain of risk and diminish their susceptibility to the level of moderate risks or even ordinary and typical risks.

Based on the results and assessments conducted in this research, by implementing the discussed approaches and implementing corrective actions, the level of risk associated with the identified hazards in the waste incineration furnace sector of the vineyard resin industries has been significantly diminished. These results demonstrate the effectiveness of the corrective measures in effectively managing the identified risks within this particular industry.

Hence, the utilization of PHAST software for assessing the impacts of chemical leaks from the waste incineration furnace is an appropriate approach to regulate the emission of pollutants within the authorized boundaries and thresholds. This software can aid in effectively handling the repercussions of material leaks from waste incinerators.

Ultimately, it is recommended that to effectively address the risks associated with waste incineration in resin industries, it is advisable to define multiple scenarios in future studies rather than just one. These scenarios should then be used to evaluate the potential consequences of various risks and establish appropriate management measures to mitigate them.

This proposal is not limited to addressing the risks associated with waste incinerators in the resin industry. It can also be utilized to assess the potential consequences of risks in various industries and projects, thereby mitigating the overall risk exposure resulting from industrial endeavors.

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