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Research article

Occupational health and safety in a hazardous waste disposal facility using Industry 4.0 technologies: A Fine Kinney risk analysis

Yasemin Demir*[1], Melike Ersoz[2], Huseyin Kurtulus Ozcan[3], Goksel Demir[1]

[1] University of Health Sciences, Hamidiye Faculty of Health Sciences, Occupational Health and Safety Department, 34668, Istanbul, Türkiye
[2] TC Demiroglu Bilim University, Faculty of Arts and Sciences, Department of Molecular Biology and Genetics, 34394, Istanbul, Türkiye
[3] Istanbul University-Cerrahpasa, Faculty of Engineering, Department of Environmental Engineering, 34320, Istanbul, Türkiye

Abstract

Considering the environmental and human health impacts of rapidly growing industries and the uncontrolled increase in the amount of waste they generate; hazardous waste disposal facilities play a critical role in protecting public health. Hazardous waste disposal facilities include various multidisciplinary systems such as landfills, biogas plants, laboratories, medical waste landfills, wastewater plants, and incineration plants. This study aims to examine each facility in a sample hazardous waste disposal facility in terms of occupational health and safety to identify risks, and to offer recommendations for solutions. The sample facility was visited, and each section was examined separately, and preliminary information was obtained using a checklist. In light of the preliminary information obtained, risk analysis was performed and the results were presented with recommendations. Fine Kinney Risk Assessment method was preferred because it is more comprehensive than other risk analysis methods based on probability and severity and can adapt to multiple disciplines. In addition, it is stated that automated processes within the scope of Industry 4.0 can have a positive impact on the prevention of occupational accidents by leading to a reduction in human work and thus a reduction in worker-waste contact. As a result of the risk assessment, 68 risks were identified in the facilities visited, most of which were substantial.

Keywords: *Fine Kinney; industrial revolutions; hazardous waste; occupational health and safety*

1. Introduction

The increase in hazardous waste, which has become a major problem all over the world, poses a threat to environmental health if it is disposed of uncontrolled, as well as a threat to public health and therefore worker health. It is accepted that the importance of the concept of hazardous waste management can be understood by looking at the laws and regulations that have come into force in recent years, especially in developed countries. The participation of the European Union (EU) member countries in the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal, which regulates the increase and disposal of hazardous wastes, which is considered a significant problem globally, has revealed that this issue is an important problem worldwide. Türkiye has internationally emphasized that it attaches importance to this issue by participating in this agreement in 1994 (Taser and Erdogan, 2010; Akkoyunlu et al., 2017).

In this period of accelerating industrial and technological progress, research into the management and disposal of hazardous waste is becoming increasingly important. The uncontrolled growth of fast-growing industries and the wastes

* Corresponding author.
E-mail address: yaseminin00@gmail.com (Y. Demir).
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generated by these industries pose serious risks to the environment and human health. At this point, the study and improvement of hazardous waste disposal facilities from an occupational health and safety point of view is of great importance (Gokcan et al., 2022; Harikaran et al., 2023). The process carried out by each facility presents different risks due to the nature of the work. For this reason, the study discusses in detail the operation and characteristics of each part of the facility, makes a risk assessment, and proposes solutions.

1.1. Concept of Industry 4.0

Industry 4.0 is considered to be the final point of industrial revolutions from the past to the present. The Fourth Industrial Revolution is one of the defining industrial and technological dynamics of today's working world. The First Industrial Revolution paved the way for mechanization and the widespread use of steam-powered machines, transforming an agrarian society into an industrial one. Then came the Second Industrial Revolution, when production processes became more automated, and productivity increased with innovations such as electricity and assembly lines. The Third Industrial Revolution led to a radical transformation of the business world with the spread of computers and digital technologies. Today, Industry 4.0 has led to significant changes in production processes with the combination of technologies such as digitalization, artificial intelligence, the Internet of Things, and automation (Celik and Can, 2019). This new industrial era aims to increase efficiency by making production processes more flexible and intelligent (Harmanci, 2024). Hazardous waste management facilities are an important example of the technologies used in Industry 4.0. While these facilities use technologies such as automation, artificial intelligence, big data analytics, and internet-connected devices to make production processes more intelligent, flexible, and efficient, they also create new types of risks in the area of occupational health and safety. These technologies, which form the basis of Industry 4.0, also have an impact on the risks and hazards faced by workers in hazardous waste management facilities. With the increase in human-robot interaction, the working conditions and safety requirements for workers are also changing. In this context, the impact of Industry 4.0 on occupational health and safety management in hazardous waste facilities should be closely examined. Traditional occupational safety methods and standards should be kept up to date to adapt to the new safety requirements brought about by Industry 4.0 (Caner, 2021; Oluk et al., 2023).

1.2. The concept of occupational health and safety

The needs of human beings have changed since the first day they appeared on Earth. The need for security is frequently encountered as one of the most basic needs. According to the Theory of Needs established by the American psychologist Maslow in 1943, human needs are defined as physiological needs, security needs, the need for belonging and love, the need for respectability, and the need for self-realization (Coban and Ozdemir, 2020). Given these needs in today's working world, it is considered the duty of occupational health and safety professionals to ensure that people who have to work and produce to sustain their lives are able to exist in the working environment in the best possible way, both physically and psychologically (Baskan Takaoglu et al., 2018; Oluk et al., 2022). According to the Occupational Safety and Health Law No. 6331, published in the Official Gazette in the year 2012, an occupational accident is defined as "an event that occurs in the workplace or as a result of the performance of work that causes death or mental or physical disability." Occupational health and safety is defined as the science of eliminating the health hazards and risks to which workers are or will be exposed during the performance of work because of the environmental conditions in the workplace, and reducing those hazards that cannot be completely eliminated because of the performance of work (Adsoy, 2020).

1.3. Concept of waste

The concept of waste was first legally defined in Environmental Law No. 2872, published in 1983, as "any substance that is generated, discarded or left in the environment as a result of any activity" in Türkiye. Furthermore, according to the "Waste Management Regulation" published in the Official Gazette in 2015, waste is defined as "any substance or material that is discarded or left in the environment by the producer or the natural or legal person who is in actual possession of it, or which is required to be discarded" (Aylanc, 2022).

1.4. Classification of waste

Waste is classified in the literature according to various criteria. These criteria include factors such as consumption habits, production processes, technical properties, chemical composition, physical properties, sources, origin, degree of hazard, and potential hazards (Tenikler, 2007). Waste interacts with the environment in which they are left, and as a result of this interaction, they can have positive or negative effects. It is possible to analyze waste in two groups as hazardous and non-hazardous according to their effects (Ercan, 2016).

Hazardous waste is defined as waste that has adverse effects on the environment and human health. These wastes present different hazards depending on their biological, chemical, and physical properties. For example, substances such as acids, lead, mercury, and arsenic compounds are included in this group. Hazardous wastes are substances that can be dissolved in water or transported in gaseous form, can be absorbed in the short term through respiration, digestion, or the skin, and can cause acute toxicity or chronic toxicity over time. These substances have carcinogenic or teratogenic effects and may pose a threat to the environment by inhibiting biological activities. Due to the negative effects of both human and environmental health effects, proper management of hazardous waste is important for the protection of the environment and human health (Durczak et al., 2024; Sikder et al., 2024).

Non-hazardous wastes are organic and inorganic wastes that are not considered harmful or hazardous wastes. Municipal solid wastes (MSW), food waste, cardboard, paper, ash, glass, plastic, and construction waste are included in this group. According to another definition, non-hazardous waste is waste that is not considered legally hazardous and can be recovered, stored, disposed of, or incinerated by separation within the scope of services provided by municipalities (Tenikler, 2007).

1.5. Waste management

In the Waste Management Regulation 2015, published in the Official Gazette, waste management is defined as "prevention of waste generation, reduction at source, re-use, separation according to its characteristics and type, accumulation, collection, temporary storage, transport, interim storage, recycling, recovery including energy recovery, disposal, monitoring, control, and post-disposal control activities." Waste management is a process that includes the collection, transport, recovery, disposal, and treatment of waste, as well as post-disposal site controls (Ercan, 2016).

The fundamental objective of the waste management hierarchy (Fig. 1) is to recycle and recover energy from waste materials in an optimal manner, while concurrently minimizing any potential risks to human health and the natural environment (EPA, 2020; Sahin et al., 2021).

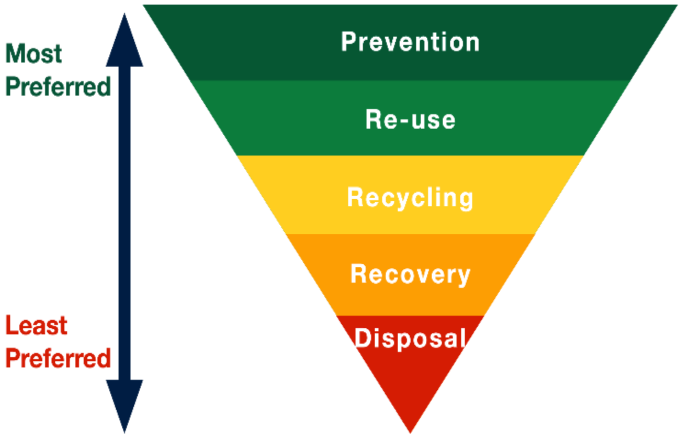

Fig. 1. Hazardous waste management hierarchy.

2. Materials and methods

The location of different hazardous waste disposal facilities in Türkiye, waste disposal and storage capacities, the number of waste disposal methods used in the facility, the operations carried out in other departments within the facility, the use of Industry 4.0 systems, and the size of the waste disposal capacity were taken as criteria for the selection of the facility to carry out the field study. Contact was established with the facility found suitable for the study. Prior to the risk assessment, the field study team obtained preliminary information by completing a checklist form. Subsequently, an inspection was conducted of the preceding accident reports of the enterprise, the occupational health and safety training documents of the employees, additional occupational health and safety forms, the control and maintenance documentation of the machinery and equipment utilized within the facility, the material safety data sheets and the preceding risk assessment reports.

The Fine Kinney method was employed as the risk assessment methodology (Kokangul et al., 2017). A risk assessment was conducted for each department based on the operations performed within the facility. The primary objective of conducting a risk assessment for each department individually is to ascertain the comparative risk and risk level between the departments and to mathematically quantify the extent to which the risks inherent to the nature of the operations performed affect the risk levels. A total of ten areas were examined in eight main sections and two sections within eight main sections at the facility in question. These areas included the site general area, the hazardous waste incineration plant and bunker area, the biogas plant, the landfill areas, the interim storage areas, the laboratory, the landfill leachate treatment plant, the medical waste plant, and the sterilization area.

The Fine Kinney risk analysis method is a qualitative risk assessment tool that enables the evaluation of past risk assessment data for enterprises and the current status of facilities following the implementation of corrective and preventive actions. The Fine Kinney method enables the attainment of more reliable and realistic results than those obtained through the use of other commonly employed matrix risk analysis methods. This is achieved by incorporating the probability and severity of damage, in addition to the frequency of exposure to hazardous areas or situations, into the risk score calculation (Oluk et al., 2023).

According to the Fine-Kinney Method, the risk level increases depending on three factors:

(P) Probability: The probability that the damaging event will occur.

(F) Frequency: The frequency of exposure to the harmful event.

(S) Severity: Possible consequences of the event.

For risk calculations, numerical values were assigned to these factors and the risk score was formulated by multiplying these values (Mogan and Gungor, 2023).

Risk=Probability x Severity x Frequency (Birgoren, 2017).

In accordance with the findings of the risk assessment and

Table 1
Probability, frequency, and severity grading according to the Fine Kinney method (Aker, 2020).

Probability Value	*Possibility (Probability of damage occurring)*	*Frequency Value*	*Frequency (Frequency of exposure to hazard over time)*	*Violence Value*	*Violence (Estimated harm to humans and/or the environment)*
10	Expected / Certain	**10**	Almost constantly, several times an hour	**100**	Multiple fatal accidents, environmental disaster
6	High, quite possible	**6**	Frequently, once or several times a day	**40**	Fatal accident, serious environmental damage
3	Possible	**3**	Occasionally, once or several times a week	**15**	Permanent damage, injury, job loss, environmental impairment
1	Low, but it is possible	**2**	Not often, once or a few times a month	**7**	Significant damage/injury, need for external first aid
0.5	Unexpected, but it is possible	**1**	Infrequently, a few times a year	**3**	Minor damage/injury, need for internal first aid
0.2	Unexpected	**0.5**	Frequently, a few times a year	**1**	Cheap bypass, no environmental damage

the established hierarchy of priorities, corrective measures are identified and implemented with respect to the identified hazards.

Table 2
Evaluation of the risk score according to the Fine Kinney method and the time allowed for correction (termination) (Aker,2020).

Risk Value	Risk Assessment Result	Time Allowed for Correction
400<R	Intolerable Risk The situation is reported to the employer as soon as possible so that he can take precautions.	In less than 1 month
200<R<400	Substantial Risk It should be improved in the medium term.	Within 1-3 months
70<R<200	Significant Risk It should be improved in the long term.	Within 6 months
20<R<70	Possible Risk It should be administered under supervision.	In 1 year
R<20	Insignificant Risk Prevention is not a priority.	Control

4. Results

Distribution percentages of the facility according to risk levels are given (Fig. 2). Of the risks identified;

1% at negligible (insignificant) risk level and with the explanation of "precaution is not prioritized",

18% with a possible (low) risk rating and the statement "should be implemented under supervision",

40% with the statement "should be improved in the long term (within 6 months)" in the degree of significant (medium) risk,

41% with the definition of "should be improved in the medium term (within 1-3 months)" in the substantial (high) risk rating and no extreme (intolerable) risk has been identified.

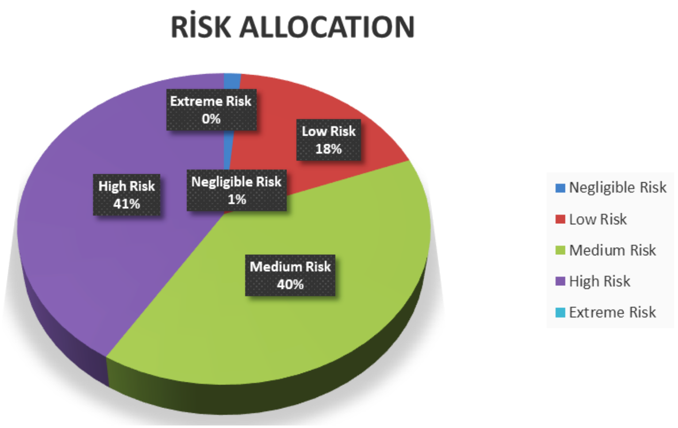

Fig. 2. Distribution of risk rating in general risk.

Of the 68 risks identified at the facility, only one was deemed to be insignificant, and this risk was observed to be present throughout the site. At the time of writing, the facility's open and closed areas are equipped with separate pedestrian and vehicle routes. Furthermore, the issue was communicated to facility personnel during occupational health and safety training sessions. It is evident that clear instructions are provided for employees and other individuals within the facility. It is prohibited for pedestrians to utilize other routes or traverse the facility except within the boundaries delineated on the accompanying map. Furthermore, the facility has developed a safety guide for third parties who will be entering the premises.

The guide contains a set of regulations and an explanation of the required standards of conduct within the facility. The speed limit within the facility is set at 20 km h^{-1}, and vehicles are positioned in a manner that does not impede emergency egress. A risk assessment of the facility identified that 25% of the risks that could potentially pose a hazard were associated with the acceptance of waste, 17% were linked to the hazardous waste incineration plant, 9% were related to the biogas plant, 8% were associated with the laboratory, 8% were connected to the wastewater treatment plant, 8% were linked to the medical waste plant, and 8% were associated with the interim storage facility. Upon examination of the risks identified through the risk assessment conducted at the facility, it becomes evident that there are potential hazards associated with vehicle accidents or the overloading of waste to vehicles during the acceptance of waste at the facility. In the present circumstances, it is evident that technical measures, such as protective railings against vehicle overturning, have been implemented to mitigate the risks associated with vehicle accidents at the facility.

Prior to entering the facility, vehicles loaded with waste are subject to inspection and weighing in accordance with the relevant licensing requirements. Only vehicles that meet the requisite standards are permitted to enter the facility. The studies conducted throughout the facility have revealed that landfill gases are kept to an acceptable level through the implementation of continuous monitoring for potential health risks, including eye irritation, respiratory tract irritation, and odor disturbances caused by ventilation conditions. Similarly, as gas is generated as a combustion byproduct in the hazardous waste incineration facility, the output gas is monitored and regulated through secondary measurements. The facility employs electrostatic filter units (ESF), which collect and remove particulate matter in the plant air and other particulate matter (PM) that may pose a health risk to employees and contribute to a pneumatic atmosphere due to the magnetic field within the units. Additionally, these ESF units regulate excessive heat and humidity. The personnel have undergone training on the potential hazards associated with chemical exposure and have been furnished with the requisite personal protective equipment. Furthermore, the facility is equipped with Material Safety Data Sheets (MSDSs) and emergency eye and body showers. Considering the aforementioned factors, while the potential consequences of the identified risks are deemed to be significant, the probability and frequency values are determined to be relatively low.

Consequently, these risks are classified within the probable risk group. A total of 22% of the risks identified at the facility are classified as significant and are distributed across the site, with 18% located in the hazardous waste incineration plant, 13% in the biogas plant, 13% in the bunker section, 9% in the waste leachate treatment plant, 9% in the medical waste plant, 4% in the acceptance of waste to the facility, 4% in the landfill facility, 4% in the laboratory and 4% in the sterilization section. Upon examination of the results of the risk assessment, it becomes evident that several significant risks are associated with chemical exposures and the performance of tasks in dusty environments during the processes of waste analysis and sampling. The frequency values were determined to be medium level since the employees in question perform these operations with greater frequency than other processes in the facility, namely individually. As a result, the risk scores were determined to be "significant risk," but not "substantial risk" or "intolerable risk." In the plant, the burner is designed to operate on fuels that do not result in higher emissions than natural gas. If the burner exceeds the range of 850°C or 1100°C at start-up or shutdown, it will not engage in combustion or chemical reactions that may occur due thigh-temperature operation during waste feeding in the hazardous waste incineration plant. In addition, unwanted combustion reactions are prevented by flap covers that are opened and closed during and after waste feeding in the bunker.

Therefore, although the severity of the risks arising from these processes is high, the probability and frequency values were determined at a low-medium level and a "significant risk" conclusion was reached. It was determined that 30% of the risks at the facility at the level of major risk were at the hazardous waste incineration plant, 19% at the landfill, 15% at the site, 7% at the biogas plant, 7% at the laboratory, 7% at the landfill leachate treatment plant, 7% at the bunker section, 4% at the medical waste facility and 4% at the interim storage facility. It was observed that the major risks were mostly due to the operations at the hazardous waste incineration plant, followed by the landfills and the site in general. The fact that the waste accepted before the waste feeding in the facility is in a mixture or that the content information is not clear, and the waste gives an unexpected reaction poses a threat to worker health. It is anticipated that this will result in an increase in the probability parameter in the risk rating. However, the facility currently categorizes mixed wastes with unclear content information as the most hazardous waste. Furthermore, it was observed that separate pools had been created for different waste types in order to prevent any potential reactions in the bunker area. Therefore, although the frequency of occurrence of this process and the potential damage that could result from an adverse event is classified as medium-high, the probability was determined to be low-medium, and the risk was determined to be a level that can be improved upon within a period of 1-3 months.

The incineration of hazardous waste is subject to continuous monitoring in the facility's control room, with subsequent measurements taken. The potential for explosive methane gas accumulation in the landfill areas within the facility, if uncontrolled, could result in significant adverse reactions. To mitigate this risk, methane drainage pipes have been installed between the waste mounds. This process prevents the accumulation of methane and allows the release of the gas into the atmosphere under favorable conditions. Ultimately, it has been observed that the facility is equipped with the necessary infrastructure to mitigate the risk of injuries that may arise from medical waste, particularly sharp or piercing medical waste. This includes the provision of appropriate-thickness bags to contain the waste and prevent injury.

Additionally, the facility has the necessary measures in place to protect against exposure to biological agents, which could result from such injuries. Furthermore, the necessary personal protective equipment has been made available for personnel working in this section. The existing protection measures have reduced the probability of occurrence of the risk in question. Physical risk factors, including noise, vibration, and ergonomic conditions, as well as risks associated with working at heights during maintenance and cleaning of machinery and equipment, are prevalent in the facility.

The facility has implemented personal protective equipment for the aforementioned risks, handrails to prevent falls, and areas made of noise-absorbing material. However, the ergonomic appropriateness of the office workers in the control room, who are constantly sitting and working with multiple screens, has been identified as a concern. It is therefore recommended that improvements be made within a period of 1-3 months.

5. Discussion

In this study, similarly, a risk analysis study was carried out in a hazardous waste disposal facility with a biogas plant, and the risk of exposure to biological and chemical agents arising from working with plant and animal wastes was determined in this facility, and in addition, solutions were offered for the risk of infection.

Risk assessment was carried out at three different hazardous waste disposal facilities using the SLRA method (Ercan, 2016). In the selection of the risk assessment method used in the study, it was stated that the SLRA method was preferred because it is simple and understandable, and it has the opportunity to evaluate the consequences of hazardous events, employee health and safety, and financial losses. In the study, risk assessments were made separately for the three facilities, and the existence of different risk types in facilities with similar operations was emphasized. 96 risks were identified in the first facility, 84 risks in the second facility, and 74 risks in the third facility. In the first facility, 30% of the total risks were due to hazardous waste disposal operations, 28% were due to site-wide risks, and interim storage of hazardous waste accounted for 17%, followed by waste analysis, waste entry, and other risks. It is stated that the significant risk difference of the risks in the first facility compared to the other facilities is due to the fact that energy production with biogas is also carried out in this facility.

In the second facility, the risks arising from the disposal of hazardous wastes are 33%, and general risks are 32%. Interim storage, analyzing the waste, entry of the waste to the facility, and risks in other facilities constitute the remaining risks. In the third facility, the number of risks is lower compared to the other facilities since there is no disposal by incineration. In this facility, general risks constitute 38%, followed by interim storage of hazardous waste, disposal, analysis, and other operations. For all three facilities, hazardous events that may occur, risk levels, and urgency definitions were specified, and solution suggestions were presented.

Yapici (2012) addressed the current situation of hazardous waste recovery and disposal facilities in terms of occupational health and safety by conducting field studies in a total of 15 facilities in Turkey. Within the scope of the research, exposure measurements, surveys, and general risk assessment of the facilities were carried out. Of the 15 facilities in the study, 2 are hazardous waste interim storage facilities, 5 are hazardous waste recovery facilities, 3 are packaging waste recovery facilities, 1 is end-of-life tire recovery facility, and 4 are cement factories. In the survey study, a questionnaire consisting of 10 questions was directed to 15 employees in each facility. The survey results were handled on a question basis, and the participation rate and answers for each question were expressed in graphs. According to the observations and survey results, it has been emphasized that the level of awareness of the workers working in these facilities is low in terms of occupational health and safety, the company management is insufficient to provide the necessary conditions for ensuring occupational health and safety, and occupational health and safety deficits in such facilities will indirectly cause environmental problems.

The previous study (Olcucu Sensoy, 2019) conducted a risk assessment of the potential hazards that may arise throughout the process, from the acceptance of waste to its disposal in a hazardous waste facility. It encompassed a comprehensive risk assessment across the entire facility, encompassing an in-depth evaluation of potential risk factors, occupational diseases, and biological factors. Furthermore, the significance of each risk factor was evaluated through a comparison of the 5x5 L-type matrix risk assessment method and the Fine Kinney method in risk assessment. Furthermore, the study revealed that a risk initially classified as category 1 in terms of importance according to the 5x5 L-type matrix method was subsequently categorized as category 3 when evaluated using the Fine Kinney method. It was highlighted that the incorporation of the frequency factor into the Fine Kinney method serves to reduce the degree of risk, contingent on the frequency with which the worker is exposed to the hazard in question.

Similarly, the Fine Kinney risk assessment method was selected for use in this study due to its incorporation of the frequency factor. Furthermore, it was emphasized in this study that the frequency of employee and work-related hazard exposure contact is included in the risk rating compared to other risk assessment methods, which will result in more accurate and healthier results.

A study (Mogan and Gungor, 2023) conducted an analysis of asbestos, a substance that is commonly found in residential, occupational, and industrial settings, including power plants, mines, and other structures. Asbestos is classified as a hazardous waste material. The potential risks associated with asbestos removal were evaluated using the 5x5 L-type matrix method. The evaluation yielded the following results: quarantine installation and dismantling, asbestos dismantling, post-dismantling hygiene works, and waste storage, and works were classified as high-risk. Ultimately, the engineering measures proposed were determined through the application of the risk control hierarchy. It was concluded that the most effective protection method is personal protective equipment.

A risk assessment was conducted by Demirel and Sert (2018) using the Preliminary Hazard Analysis (PHA) method in a plastic recycling plant that accepts waste from a variety of industrial sources, including the textile, automotive, machinery, and chemical industries. The plant handles a range of materials, including hazardous chemicals contaminated with plastic packaging and raw materials obtained from high-density polyethylene preparations. The PHA method was selected due to its ability to predict potential occupational safety deficiencies in a system prior to the occurrence of an accident. The risk assessment of the facility resulted in the categorization of risks into three groups: A-B, B-C and C-D. It was concluded that 49% of the identified risks require a review of the protection measures and practical solutions, 43% require a review of the protection measures and their implementation in the facility, and 8% can be continued with the existing protection measures.

A study examines hazardous waste management (HWM) in Turkey and highlights significant shortcomings in current practices, such as the dominance of landfilling over recycling and incineration. It notes that while incineration can detoxify hazardous waste, it poses health risks due to emissions. The study emphasizes the importance of accurate data collection, facilitated by a web-based monitoring system for hazardous waste tracking. It identifies the Marmara Region as the highest generator of hazardous waste and calls for improved administrative capacities, industry training, additional disposal facilities, and heightened public awareness. The article concludes with recommendations for enhancing HWM practices in alignment with European Union standards (Akkoyunlu et al., 2017).

Yildirim (2023) compared different risk assessment methods to provide a suitable working environment in terms of occupational health and safety in biogas production facilities. The advantages, disadvantages, and success rates of the risk assessment methods were analyzed. The study sought to answer the question of which risk assessment method is most appropriate for biogas plants. As a result of the evaluations, it was found that the FMEA (Failure Mode and Effects Analysis) method had the highest success rate for biogas plants. The Fine Kinney risk assessment method was ranked second. Although the L-Matrix method appears to be analyst-friendly, it is recommended that it is used in combination with other methods as it carries the risk of making mistakes that can lead to major accidents and occupational illnesses, and this method ranked third in terms of success rate. The X Matrix method was considered to have the lowest success rate due to the need for 5 years of accident history data and low scores in other criteria.

Another recent study conducted that the occupational health and safety of a solid waste facility in Gumushane Province was analyzed using the Elmeri method (Kulekci and Guvendi, 2024). The solid waste management process includes the stages of waste collection, transport, sorting, recycling, and disposal. In the study, the hazards that may occur in these processes (cutting, poisoning, fire risk, etc.) were identified and the risk levels were assessed. A total of 494 observations were made, of which 239 showed correct safety behavior, and 255 showed incorrect behavior. The highest safety index was calculated for the waste collection day shift at 57.2% and the lowest for the waste sorting day shift at 29.3%. The study draws some conclusions and recommendations based on the findings. Safety indices were generally lower for night shifts, and additional safety measures were recommended in this area. It also highlighted the need to improve tidiness and cleanliness standards, provide training on vehicle safety, and raise awareness of industrial hygiene issues. It is stated that the study should be considered as part of the continuous improvement process and that the implementation of the recommendations will increase the safety of employees.

6. Conclusion and recommendations

The findings of the study indicate that the Fine Kinney method is well-suited to the operations of hazardous waste disposal facilities. Furthermore, the Fine Kinney method also evaluates the hazard exposure of the employee due to the frequency of the operation, thereby providing more reliable results than other common risk analyses. Autonomous machines with self-control processes in the facility are programmed to cease operation or to initiate emergency measures automatically when they exceed the predetermined range values for their operations. This situation confers advantages in terms of occupational health and safety, as it reduces human-machine contact and the risks associated with human error.

In the study, the risks identified for each department in the plant were analyzed based on the processes of that department. The highest-scoring risks identified throughout the facility were those pertaining to the hazardous waste incineration plant and landfill areas. The list was subsequently followed by that of the medical waste disposal plant and the biogas plant. The principal risks identified in this study are as follows: exposure to biological and chemical agents resulting from the disposal of contaminated waste; work machine accidents caused by waste acceptance and stacking operations; noise and vibration exposure; ignition of waste in hazardous waste incineration plants due to reaction or ignition sources; pneumatic gas exposure; toxic effects of harmful gases released after incineration and disposal; and odor exposure. No level of risk has been identified that could be considered "intolerable" in any part of the plant. This is due to the fact that, even when the severity value is determined to be high in risk assessments, the probability or frequency values are given a low rating as a result of the existing protection measures that have been put in place.

In conclusion, the study entitled "Occupational Health and Safety in a Hazardous Waste Disposal Facility Using Industry 4.0 Technologies: Fine Kinney Risk Analysis", The current occupational health and safety standards of the facility have been revealed by the Fine Kinney risk assessment method. This method offers to handle many disciplines at the same time and can adapt to many industries. It is therefore able to obtain healthier results since the parameters that make up the method include the frequency parameter compared to other risk analysis methods based on probability and severity. Furthermore, the study has shown that industrial machines with self-managing processes within the scope of Industry 4.0 provide advantages in terms of occupational health and safety. It is anticipated that the study will make a substantial contribution to the existing body of literature on the interaction between occupational health and safety and Industry 4.0 in the context of hazardous waste disposal.

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