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ORIGINAL RESEARCH PAPER

Implementation of Analytical Hierarchy Process to Prioritize Health, Safety and Environment Risks of Hydrocarbon-Rich Sludge in South Pars Gas Complex-First Refinery, Iran

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ABSTRACT

Risk management embarrasses processes aimed at reducing the hazardous effects of an activity through informed actions to predict and prevent unwanted events. Oil sludge disposal is an integral activity in gas refineries, which, if not implemented safely, can impose environmental pollution, health risks and huge cost. The present applied, cross-sectional, analytical survey aimed to identify and prioritize Health, Safety and Environment (HSE) risks of hydrocarbon-rich sludge in South Pars Gas Complex-First Refinery, Iran. The statistical population included HSE experts and managers of the studied refinery, selected by purposeful sampling (n=31). By reviewing the literature and collecting available information on the technical and process properties of waste management in the studied refinery, the relevant risks were identified using Failure Modes and Effects Analysis (FMEA). Delphi technique was used to qualitatively analyze risks and achieve group knowledge. The probability of risk occurrence was determined by performing analytical hierarchy process (AHP) and pairwise comparisons using Expert choice software. Data analysis revealed 17 environmental (n=7), health (n=4) and safety (n=6) risks. Based on the results, the highest risk priority was "Accumulation of radioactive materials deposited on the internal surfaces of pipes, valves, pumps, heat exchangers, tanks, boilers and other equipment and the risk of these materials being dangerous for human health", which were in the health risk category. The lowest priority was the risk of "Contamination of the lands of the gas refinery with burnt oils, catalytic beds, hydrocarbon sludge, amine sludge, soda sludge and refinery sludge".

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1. Introduction

The oil industry generates large amounts of oily sludge during various stages of oil and gas treatment, such as extraction, transportation, storage, and refining (Hu et al., 2015; Jalilzadeh Yengejeh et al., 2017). The sludge generated in the refinery depends on the processing design, crude properties and oil storage system (Tabari, et al., 2021; Hu et al., 2013).

Oily effluent generated by gas refineries is a refractory waste characterized by a stable water-oil emulsion of water, solids, petroleum hydrocarbons (PHCs), and metals (Abbaspour et al., 2013; Mazlova and Meshcheryakov, 1999). The presence of toxic organic substances and heavy metals such as lead, copper, mercury, nickel and zinc has caused oil sludge to be considered as hazardous waste; storage and disposal of oil sludge in conventional landfills is not allowed (Jalilzadeh Yengejeh et al., 2014; Roudneshin and Azadeh, 2019). Improper disposal or insufficient treatment of oily sludge can pose serious threats to the environment and human health (Liu et al., 2009; Zhao et al., 2019). The activities of gas refining industry potentially pollute the environment due to their technological nature, and if their environmental consequences are not taken into account, huge cost must be spent to fix the damages caused by not paying attention to such problems. Hence, gas refineries already have a strong commitment to reducing their associated waste (Tabari et al., 2020; Masoumi et al., 2020) . Recognizing, preventing and controlling environmental pollution can help improve the generation process and increase productivity in the long run. Therefore, we find out that industrial progress and development programs in the gas industry, despite all the benefits for humans, have been the source of many risks and hazards. Accordingly, to achieve and confirm the appropriate environmental yield, these industries need to control the consequences of their activities on the environment according to their policies and goals (Hajizadeh, 2013; Khajeh Hoseini et al., 2021; Hoseini et al., 2022).

Risks are an inherent part of all industrial projects and their complete elimination is impossible (Jabraeil Nejad and Fataei, 2015). Although the effective management of risks can reduce their impact in achieving project goals (Hassanpour Kourandeh and Fataei, 2013; Fataei, 2020), there is a possibility of their occurrence at least in one of the dimensions of the project such as scope, time, cost or quality. Therefore, risk identification, analysis and prioritization can play a significant role in the success of industrial projects (Ravan Nakhjavani and Fataei, 2015; Cheraghi, et al., 2018).

Numerous national and international studies have been conducted regarding the identification and management of environmental risks in oil and gas refineries. For example, Roudneshin and Azadeh (2019) introduced a new multi-objective fuzzy model to optimize oil sludge management considering health, safety and environment (HSE) parameters and resiliency indicators in a gas refinery. They presented a new mathematical model by improving the solved epsilon constraint and using data envelopment analysis (DEA) method for oil sludge management in gas refinery. Their results showed that the existing uncertainty has changed the solution space in the problem. In addition, environmental impacts can be reduced by maximizing economic performance. The changes in demand alter the restrictions related to demand, and thus the Pareto optimal solution changes. The results of this research were confirmed by the judgments of experts in the refinery. It was shown that the integrated mathematics of this study would lead to 19% and 12% improvement of environmental costs and safety factors, respectively. Vazdani et al. (2018) applied the Failure Modes and Effects Analysis (FMEA) model to evaluate the HSE risks of gas condensate storage tanks of Parsian Gas Refining Company, Iran. The Delphi technique identified 17 risks, of which 12 were environmental risks and 5 were health and safety risks. Based on analytical hierarchy process (AHP), the greatest environmental risk was related to fire caused by intentional and terrorist factors, which is due to the sensitive position of this country in the region. In the health and safety sector, the highest risk was related to inhalation of vapors during repairs due to not observing safety precautions and not using personal protective equipment. Jalili Ghazizadeh et al. (2017) conducted a research entitled "Environmental risk assessment in gas refineries by combination of indexation method and multi criteria analysis approach" in South Pars gas refinery project phases 22, 23 and 24. Thus, some criteria were determined as project risks and then classified based on the recipients, including humans and the land and sea environment. The results showed that the greatest risk of the project was caused by air pollution in emergency situations, followed by the explosion in the platform and leakage from the gas tanks in the next step. Saeedi et al. (2017) presented a model to check the risk of process operation in oil and gas refineries and used Fuzzy Logic System (FLS) for risk modeling. Using the Delphi technique, 26 asset failures were identified in the gasoline plant of the oil refinery. The fuzzy risk results showed that three failures had a semi-critical level and 23 other failures were non-critical. In both conventional and fuzzy RBM methods, some condenser failures had the highest number of risks and some pumps were prioritized to have the lowest number of risks. Branco et al. (2012) assessed the level of carbon risk in selected groups of several companies. In this study, the positive and negative properties of the effects of the carbon risk level for each company were obtained by the AHP method. The results revealed the compatibility of active and passive companies in minimizing carbon risk to save energy consumption and budget indicators. They also discussed some of the pros and cons of using AHP to quantify the impact of carbon-dependent companies on climate and policy. In a research, Yang et al. (2011) prioritized environmental issues in oil and gas operations using the combined method of fuzzy inference system (FIS) and AHP. Such a hybrid approach not only does not fail in the above constraints, but also serves as a powerful tool for prioritizing environmental issues in G00 operations.

Gas refineries are among the most important industrial waste production centers in Pars Special Economic Energy Zone. Incorrect planning regarding the formulation of the refinery waste management system and related risks management leads to the occurrence of various pollutions in this region. Mass production of industrial waste such as molecular sieves, catalysts, hydrocarbon-rich sludge, limited space for waste storage in the refinery, risk of waste production, exceeding the standard limit of exhaust gases from sulfur recycling units and the absence of a supplementary treatment system for refinery effluents, in addition to damaging the environment, can seriously threaten employees in the long run. Therefore, preventing the occurrence of occupational accidents and diseases and also environmental problems and enjoying a healthy environment requires the establishment and exploitation of a suitable system for managing macro risks and institutionalizing this system in management and operations (Jafarnia et al., 2018). The ranking of risks is considered a key part of the risk management process, so that the ranking determines the superiority of each risk versus other risks and therefore helps the decision-maker to plan the degree of allocation of available resources to deal with each risk. With regard to the introduction, and that one of the important environmental problems in South Pars Gas Complex-First Refinery, Iran, is the unwanted by-products and hydrocarbon-rich sludge at the end of the monoethylene glycol (MEG) recycling process, condensate stabilizers and industrial wastewater treatment, and considering that the only solutions used so far to get rid of this problem in this complex have been chemical neutralization methods, sludge burial and burn pit, which themselves are the source of irreparable damage to the region's environment and people's health, the present study was conducted with the aim of identifying the HSE risks of hydrocarbon-rich sludge in South Pars Gas Complex-First Refinery and prioritizing the occurrence of risks using the AHP method.

It is worth mentioning that, among the various methods used to identify and analyze the risks of oil and gas industries, this technique is more accurate and correct than other risk assessment methods due to the probability of risk detection. It can be used to identify potential failure modes, determine their causes, evaluate their effects on system performance, and is effective in determining ways to reduce the probability of occurrence and consequences and increase the ability to detect failure modes (Nami et al., 2017). However, it also has shortcomings, such as the fact that the exact determination of risk factors is often difficult, and the risk factors are not weighted in the calculation of Risk Priority Number (RPN) and have the same value ((Hosseinzadeh, 2017). Therefore, the present study was conducted with the aim of identifying the HSE risks of hydrocarbon-rich sludge in South Pars Gas Complex-First Refinery, and the AHP method was used to reduce the limitations of the FMEA method for prioritizing the probability of risk occurrence

2. Materials and Methods

2.1. Introduction of the area under study

Pars Special Economic Energy Zone was established in October 1988 under the supervision of Pars Oil and Gas Company in order to provide suitable conditions for foreign direct investment in oil, gas, petrochemical and related industries. This region has the privilege of "Special Economic Energy Zone" and has also obtained other special privileges that go beyond "Special Zone". This region with an area of 140 square kilometers is located on the coast of the Persian Gulf, in front of Bahrain and Qatar, and is about 100 kilometers away from the South Pars gas field, the largest gas field on the Iranian side of the Persian Gulf (www.spgc.ir). South Pars Gas Complex (SPGC) is located in Asaluyeh and Kangan counties of Bushehr province in Iran, next to the coast of the Persian Gulf, consisting of 24 gas phases, which are phases 1 to 10 and 15 to 21 in site 1 (Asaluyeh) and phases 11 to 14, phase 19 and phases 22 to 24 in site 2 (Kangan). First Refinery is the title of the first refinery among South Pars gas refineries, where the phase 1 development plan has been implemented.

The marine facilities of this phase are located at a distance of about 105 km from the coast, including two production platforms with 12 wells, a processing platform, a residential platform, a burner, an 18-inch pipeline to transfer gas from the production platforms to the processing platform, a 32-inch submarine pipeline to transfer gas and gas condensate to land and a 30-inch pipeline to export gas condensate.

The coastal facilities of this phase include units for receiving and separating gas and gas condensate, sweetening, dehumidification, removal of mercaptan, regulation of dew point and density of gas for transmission and recycling, as well as sulfur granulation, which was handed over to Petropars in February 1998 to carry out the project and was put into operation in November 2005.

South Pars Gas Complex was established in 1998 to exploit the development phases of the South Pars gas field. The South Pars gas field is one of the largest gas resources in the world, located on a joint border between Iran and Qatar. Gas reserves in this sector owned by Iran are 14 trillion cubic meters of gas along with 18 billion barrels of gas condensate.

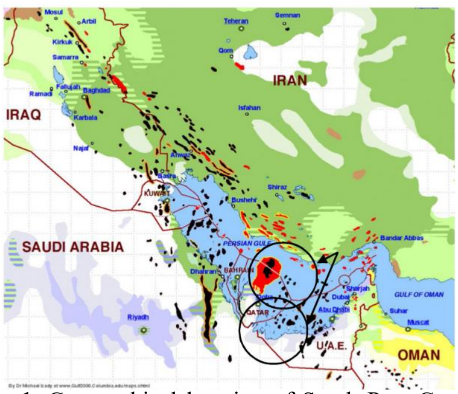

Figure 1. Geographical location of South Pars Gas Complex-First Refinery, Iran

2.2. The study design

The current research is applied in terms of purpose, analytical-cross-sectional in terms of nature and survey in terms of method, which was carried out in the period of 2020-2022.

The statistical population of this research was made up of experts in the field of environment and HSE, whose number was five people in the qualitative risk identification and analysis department and 31 people in the quantitative risk analysis, who were selected by a purposeful sampling method from the experts and executive directors of the studied refinery with more than 10 years of work experience. In addition to the managerial position, people were selected based on their knowledge, experience and expertise and interest in participating in this study. In the risk identification and qualitative analysis department, all five experts were HSE and environmental experts with more than 10 years of experience and had a master's degree and were managers of the studied refinery. The participants in the quantitative risk analysis section consisted of 30 experts and managers of the studied refinery, five managers with a PhD degree in the API unit with 13 years of work experience and 12 experts and managers with a master's degree with 15 years of work experience in the interaction unit, and 13 experts with a bachelor's degree in the sulfur recycling unit, desalination unit and the tank unit with more than six years of work experience.

2.3. The study methodology

The research was carried out in four main steps as shown in Figure 1

First step: library and field studies about the risks of hydrocarbon-rich sludge in the studied refinery

In addition to library studies, the review of documents and the use of statistics and quantitative and qualitative information in relation to the technical and process properties of the gas refining industry, sludge generation, waste management and pollution emission in the gas refinery (such as information related to refinery projects, specified requirements and obligations, checklist of previous projects, recorded risks and existing reports, statistics of incidents and exposure to frequent risks in the past, statistics of health damages, environmental costs caused by project activities, the type and quantity of effluents in different units of the refinery and their collection and storage mechanism, health care and their management mechanism in the complex, etc. ...) and completing the information by field studies, the required information of waste management was extracted in the gas refinery.

Second step: Identifying and classifying the hydrocarbon-rich sludge in the studied refinery

In order to investigate the hydrocarbon-rich sludge generated in the studied refinery, after studying the P&ID, PFD maps and field visits to the various units of the refinery with the assistance of the operation, engineering and HSE units, checklists related to the volume of hydrocarbon-rich sludge were prepared and completed. In the neutralization ponds, catch pit and storm basin, the sludge mainly contains hydrocarbon compounds. Hydrocarbon-rich sludge was identified and classified in accordance with existing laws, regulations and standards for refinery sludge management based on the Basel Convention, domestic waste management laws, including the Executive Regulations of the Waste Management Law approved by the Council of Ministers in 2006 (Environmental Protection Organization and Waste Management Organization) and the rules in the Environmental Protection Agency (EPA).

Fourth step: Quantitative risk analysis by combining FMEA and AHP Methods

Additionally, by completing FMEA worksheets and quantifying risks, the HSE aspects were identified based on the multiplication of Severity (S), Occurrence (O) and Detection (D). The identified risks were placed in the FMEA worksheet and evaluated by experts in the HSE and the Environment, Engineering and Operations and Refinery Operation Units.

RPN (Risk Priority Number) = S×O×D

Then, the results were analyzed by Excel software (Fataei et al., 2013). It should be noted that due to the shortcomings of the FMEA method and often difficult in determining the risk factors and that the risk factors are not weighed in the calculation of RPN and have the same value ((Hosseinzadeh et al., 2017), the present study used the AHP method to solve the deficiencies of FMEA, to determine weight for risk factors and to prioritize risk. A pairwise comparison matrix was formed for weighting in the AHP technique, and the weighting operation was carried out using Expert Choice software. After determining the importance coefficient of risk factors for the identified risks, RPN was calculated and accordingly the risks of hydrocarbon-rich sludge in the studied refinery were prioritized.

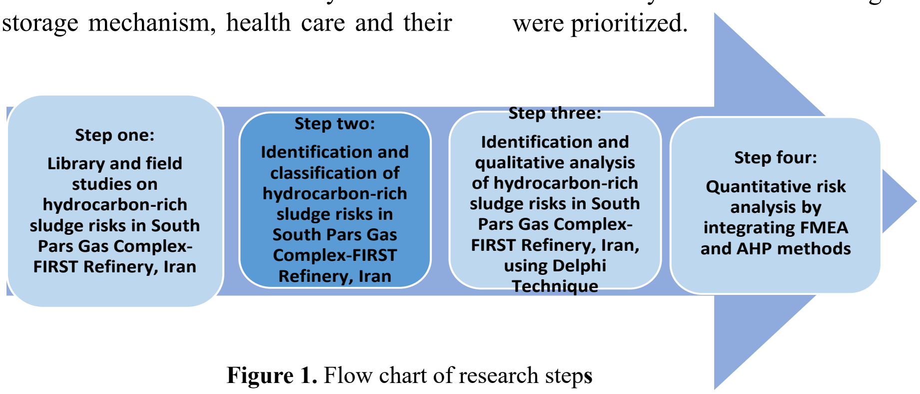

Figure 1. Flow chart of research steps

3. Results

The present study aimed to assess environmental, health and technical-safety risks related to hydrocarbon-rich sludge at South Pars Gas Complex-First Refinery, Iran. Thus, we examined the sources and volume of hydrocarbon-rich sludge generation in the study area. The sources of these types of sludge generated in different units of the studied refinery include Gas Receiving Stations (GRS), 2100 Slug Catcher, 8100 Gas-Condensate Reservoir, 3100/3200 Gas Condensate Stabilization, 4100/4200 Gas Sweetening, 5100/5200 Gas Dehydration, 6100/6200 Sulfur Recycling, and Gas odorization. The results of the current study presented unit 8100 as the highest sludge producer and units of 4100, 4200, 5100 and 5200 as the lowest sludge producer.

Table 1. Comparison of the results of the consensus indices of the three rounds of Delphi

Type of risk		Risks	Kendall rank correlation coefficient		
			Delphi R-1	Delphi R-2	Delphi R-3
Environment	R1	Annual release of high volume of carbon dioxide and sulfur dioxide into the environment	0.275	0.587	0.787
	R2	High volume of sludge stored in the burn pit, where there is a possibility of leakage and soil and groundwater contamination	0.225	0.504	0.731
	R3	High volume of waste resulting from storage and refining of hydrocarbon-rich sludge produced in the studied refinery	0.347	0.497	0.767
	R4	Absence of a supplementary treatment system for the refinery effluents	0.272	0.536	0.827
	R5	Contamination of the lands of the gas refinery with burnt oils, catalytic beds, hydrocarbon sludge, amine sludge, soda sludge and refinery sludge	0.213	0.500	0.722
Health	R6	Potential possibility of natural radioactivity pollution in burn pit	0.084	0.628	0.787
Technical-Safety	R7	Failure to comply with the rules related to the design, construction and emptying of pits	0.438	0.606	0.818
Environment	R8	Risk of soil pollution due to the storage of hydrocarbon-rich sludge produced in the studied refinery in the burn pit due to the presence of some aliphatic and aromatic hydrocarbons.	0.227	0.612	0.832
	R9	Risk of groundwater pollution due to sludge leakage after storage in burn pit	0.108	0.697	0.909
Health	R10	Direct contact of workers with sludge during collection, discharge, repair and washing of equipment	0.300	0.496	0.973
	R11	Accumulation of radioactive materials deposited on the internal surfaces of pipes, valves, pumps, heat exchangers, tanks, boilers and other equipment and the risk of these materials being dangerous for human health	0.238	0.559	0.817
	R12	Development of respiratory problems for the staff supervising the operation and the staff of evaporation ponds	0.310	0.663	0.874
Technical-Safety	R13	Failure to comply with HSE environmental standards during the management of hydrocarbon-rich sludge produced in the studied refinery	0.207	0.638	0.833
	R14	Failure to supply equipment and quality control systems, personal protective equipment	0.258	0.663	0.874
Technical-Safety	R15	Ignoring the costs of storage and refining of hydrocarbon-rich sludge produced in the studied refinery	0.156	0.377	0.788
Technical-Safety	R16	No recognition of the risks resulting from hydrocarbon-rich sludge produced in the studied refinery and related activities	0.179	0.603	0.782
Technical-Safety	R17	Political and economic sanctions and difficulty in providing the equipment needed for the refinery	0.225	0.559	0.808

3.1. The results of three Delphi rounds

In the risk identification section, after reviewing the literature and reported scientific results and collecting information on the technical and process properties of the studied industry in relation to the management of hydrocarbon-rich sludge in the gas refinery, the Delphi

Table 2. Quality indicators of identified risks and their acceptance level with partial least squares regression

Type of risk	Risks	Cross-validation	Composite Reliability	Average variance extracted
		Acceptance level		
		≥0	>0.7	>0.5
Environment	Annual release of high volume of carbon dioxide and sulfur dioxide into the environment	0.233	0.763	0.705
	High volume of sludge stored in the burn pit, where there is a possibility of leakage and soil and groundwater contamination	0.007	0.711	0.588
	High volume of waste resulting from storage and refining of hydrocarbon-rich sludge produced in the studied refinery	0.117	0.731	0.567
	Absence of a supplementary treatment system for the refinery effluents	0.109	0.709	0.544
	Contamination of the lands of the gas refinery with burnt oils, catalytic beds, hydrocarbon sludge, amine sludge, soda sludge and refinery sludge	0.121	0.781	0.601
Health	Potential possibility of natural radioactivity pollution in burn pit	0.137	0.812	0.549
Technical-Safety	Failure to comply with the rules related to the design, construction and emptying of pits	0.094	0.863	0.628
Environment	Risk of soil pollution due to the storage of hydrocarbon-rich sludge produced in the studied refinery in the burn pit due to the presence of some aliphatic and aromatic hydrocarbons.	0.142	0.726	0.719
	Risk of groundwater pollution due to sludge leakage after storage in burn pit	0.109	0.805	0.746
Health	Direct contact of workers with sludge during collection, discharge, repair and washing of equipment	0.098	0.811	0.605
	Accumulation of radioactive materials deposited on the internal surfaces of pipes, valves, pumps, heat exchangers, tanks, boilers and other equipment and the risk of these materials being dangerous for human health	0.083	0.793	0.581
	Development of respiratory problems for the staff supervising the operation and the staff of evaporation ponds	0.109	0.755	0.763
Technical-Safety	Failure to comply with HSE environmental standards during the management of hydrocarbon-rich sludge produced in the studied refinery	0.081	0.812	0.699
	Failure to provide equipment and quality control systems, personal protective equipment	0.113	0.783	0.713
Technical-Safety	Ignoring the costs of storage and refining of hydrocarbon-rich sludge produced in the studied refinery	0.152	0.771	0.633
Technical-Safety	No recognition of the risks resulting from hydrocarbon-rich sludge produced in the studied refinery and related activities	0.173	0.809	0.581
Technical-Safety	Political and economic sanctions and difficulty in providing the equipment needed for the refinery	0.086	0.829	0.662

Table 3. Worksheet of health, safety and environment risks caused by sludge generated in South Pars Gas Complex-First Refinery, Iran, based on the FMEA method

Type of risk	Risks	Occurrence (O)	Severity (S)	Detection (D)	Risk Priority Number	Degree of risk
Environment	Annual release of high volume of carbon dioxide and sulfur dioxide into the environment	0.114	4	4	0.824	M
	High volume of sludge stored in the burn pit, where there is a possibility of leakage and soil and groundwater contamination	0.102	4	4	1.632	H
	High volume of waste resulting from storage and refining of hydrocarbon-rich sludge produced in the studied refinery	0.072	4	4	1.152	H
	Absence of a supplementary treatment system for the refinery effluents	0.219	3	2	1.314	H
	Contamination of the lands of the gas refinery with burnt oils, catalytic beds, hydrocarbon sludge, amine sludge, soda sludge and refinery sludge	0.101	3	2	0.606	M
	Risk of soil pollution due to the storage of hydrocarbon-rich sludge produced in the studied refinery in the burn pit due to the presence of some aliphatic and aromatic hydrocarbons.	0.086	2	2	0.344	M
	Risk of groundwater pollution due to sludge leakage after storage in burn pit	0.046	3	2	0.276	M
Health	Potential possibility of natural radioactivity pollution in burn pit	0.075	3	2	0.45	M
	Direct contact of workers with sludge during collection, discharge, repair and washing of equipment	0.042	3	2	0.252	M
	Accumulation of radioactive materials deposited on the internal surfaces of pipes, valves, pumps, heat exchangers, tanks, boilers and other equipment and the risk of these materials being dangerous for human health	0.044	2	2	0.176	M
	Development of respiratory problems for the staff supervising the operation and the staff of evaporation ponds	0.042	1	1	0.042	L
Technical-Safety	Failure to comply with the rules related to the design, construction and emptying of pits	0.058	3	2	0.348	M
	Failure to comply with HSE environmental standards during the management of hydrocarbon-rich sludge produced in the studied refinery	0.376	3	3	3.384	H
	Failure to supply equipment and quality control systems, personal protective equipment	0.120	3	2	0.72	M
	Ignoring the costs of storage and refining of hydrocarbon-rich sludge produced in the studied refinery	0.116	3	2	0.696	M
	No recognition of the risks resulting from hydrocarbon-rich sludge produced in the studied refinery and related activities	0.096	3	2	0.576	M
	Political and economic sanctions and difficulty in providing the equipment needed for the refinery	0.093	2	2	0.558	M

H: High, **M:** medium, **L:** Low

technique was employed to detect the HSE risks caused by the sludge generated in the studied refinery, the results of which are shown in Table 1.

The results of three Delphi rounds on environmental and health risks caused by sludge (Table 1) showed the final consensus on 17 risks, including seven environmental risks, four health risks and six technical-safety risks.

According to Table 1, in the second round, more than 50% of the members chose 17 influential factors in environmental and health risk management (with an average of more than 3.5) as their first priority risk. The standard deviation of members' responses about the importance of risks in the third round significantly decreased compared to the previous rounds. Kendall rank correlation coefficient for members' responses regarding the importance coefficient of risks in the third round was 0.579(Fataei and Alsheikh(2009). Kendall rank correlation coefficient for the order of effective risks identified in the third round increased by 0.165 compared to the second round, indicating a significant growth of consensus among panel members in two consecutive rounds (Fataei et al., 2022).

Since the Kendall rank correlation coefficient for the responses of the experts about the importance coefficient of risks in the third round expressed a strong consensus and in some cases very strong among the panel members, and considering that the results in the fourth round of Delphi showed a very slight difference with those in the third round, the implementation of Delphi rounds was halted.

The results of the validity and reliability of the risks identified in the Delphi technique are displayed in Table 2. The results of Composite Reliability (CR) with Partial Least Squares (PLS) regression when CR is greater than 0.7 and also CR is greater than Average Variance Extracted (AVE) indicate that there will be convergent validity. Therefore, the reliability and validity of 17 identified environmental and health risks caused by the sludge generated in the studied refinery were confirmed based on the analytical reasoning of the open system.

3.2. The results of quantitative risk analysis of sludge generated in the studied refinery based on FMEA method

Table 3 shows the results of the risk analysis based on the FMEA method.

According to Table 3, among the HSE risks, four items were classified as high risks (H), and 12 items as medium (M) risks, and "Development of respiratory problems for the staff supervising the operation and the staff of evaporation ponds" was positioned in the acceptable and low risk (L).

In the continuation of the discussion, the graphs related to the probability of occurrence, the severity of effect and extent of contamination (the probability of detection) for the HSE risks in the studied refinery are presented, described and compared.

3.3. Probability of occurrence

It is only by reducing the causes of each risk that one can hope to reduce the probability of risk occurrence. Figure 2 shows the numerical probability of occurrence of health and environment risks in the studied refinery based on the FMEA method. Regarding the probability of risk occurrence among the studied risks, "Failure to comply with HSE environmental standards during the management of hydrocarbon-rich sludge produced in the studied refinery" accounted for the highest weight (0.376), and the risks of "Direct contact of workers with sludge during collection, discharge, repair and washing of equipment", and "Development of respiratory problems for the staff supervising the operation and the staff of evaporation ponds" had the lowest weight (0.042). Among the risks with low probability of occurrence, the risk of "Accumulation of radioactive materials deposited on the internal surfaces of pipes, valves, pumps, heat exchangers, tanks, boilers and other equipment and the risk of these materials being dangerous for human health" were in the next categories with a probability of 0.044 (Figure 2), and "Risk of groundwater pollution due to sludge leakage after storage in burn pit" with a probability of 0.046 were in the next rank (Figure 2).

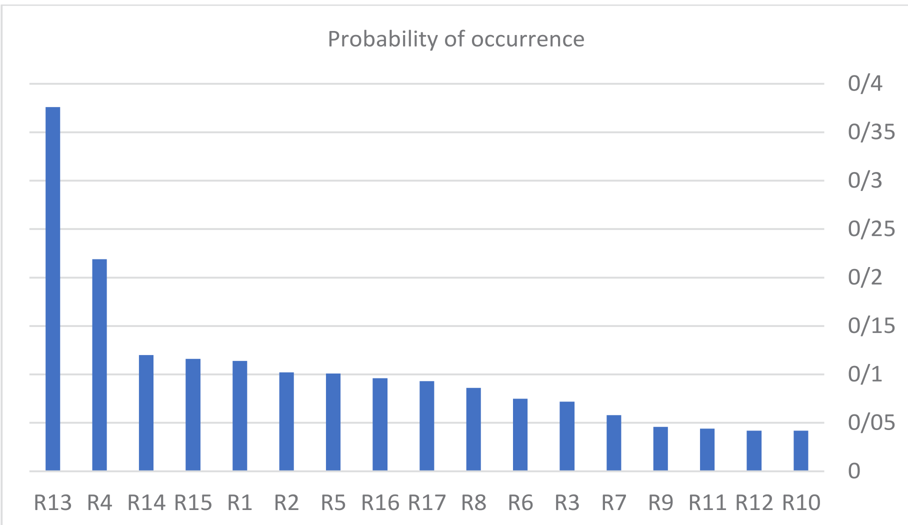

Figure 2. Probability of occurrence of health, safety and environment risks caused by South Pars Gas Complex-First Refinery, Iran

3.4. Severity of risk effect

Severity has been compared to the effect of HSE risks caused by sludge generated studied refinery (Figure 3). In terms of the severity of risk effect, the risk of "Development of respiratory problems for the staff supervising the operation and the staff of evaporation ponds" had the lowest severity with the number of 1, and the risks of "Annual release of high volume of carbon dioxide and sulfur dioxide into the environment", and "High volume of sludge stored in the burn pit, where there is a possibility of leakage and soil and groundwater contamination", as well as "High volume of waste resulting from storage and refining of hydrocarbon-rich sludge produced in the studied refinery" with the number 4 had the highest severity of risk effect so that there is a possibility of cracking in the walls and floor (Figure 3).

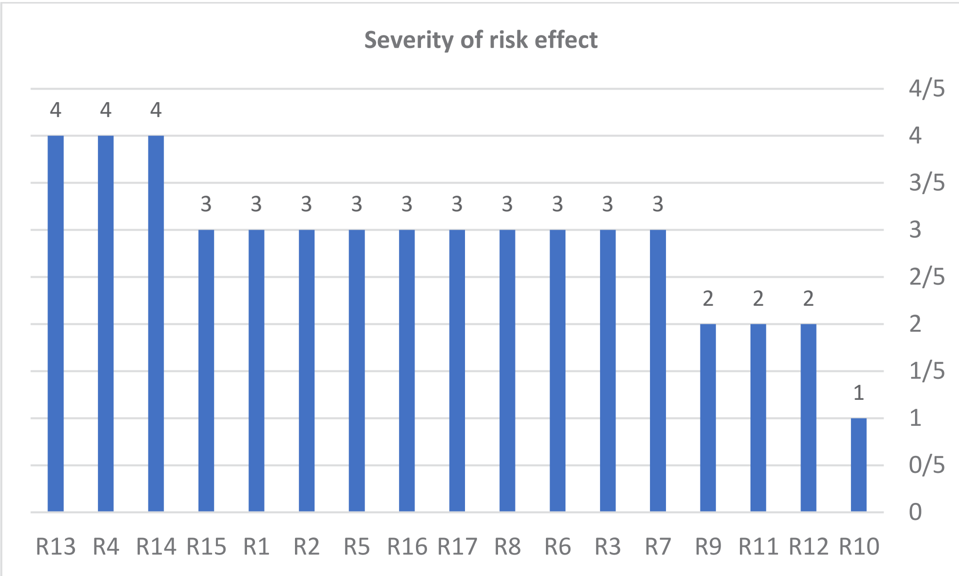

Figure 3. Severity of health, safety and environment risks caused by sludge generated in South Pars Gas Complex-First Refinery, Iran

3.5. Extent of contamination (Probability of detection)

The risk of "Development of respiratory problems for the staff supervising the operation and the staff of evaporation ponds", based on Figure 4 that shows the probability of detection of HSE risks, had the lowest extent of contamination (0.042) among the studied risks. The highest risk number belonged to the risk of "Failure to comply with HSE environmental standards during the management of hydrocarbon-rich sludge produced in the studied refinery" with a number of 3.384, which puts it in the high risk category (Figure 4).

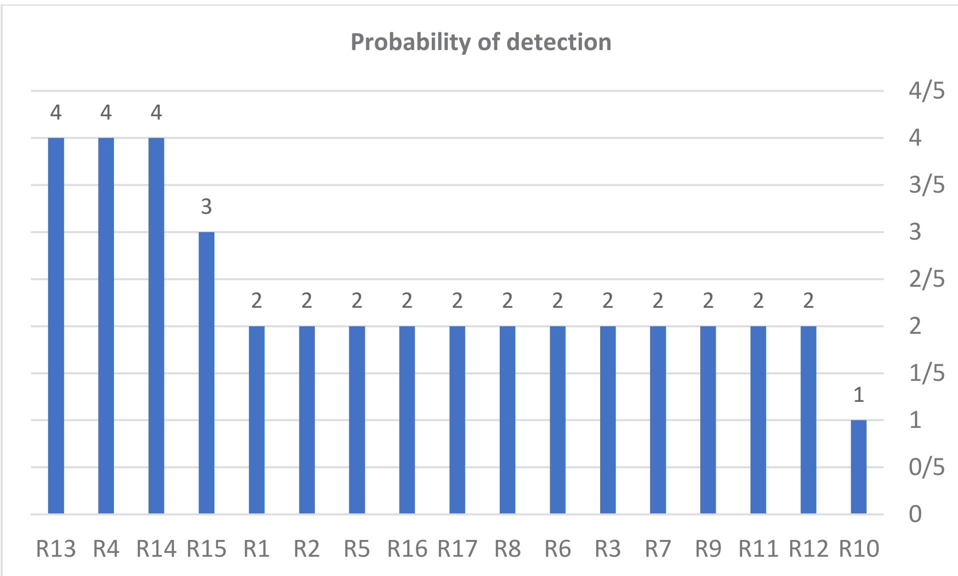

Figure 4. Probability of detection of health, safety and environment risks caused by sludge generated in South Pars Gas Complex-First Refinery, Iran, based on FMEA method

3.6. Estimating the relative importance of criteria (probability of risk occurrence) based on the AHP technique

The relative weight of each risk for the probability of occurrence is shown in Table (4) and the comparison of weights in Figure 5. As mentioned, in the FMEA method, it is often difficult to accurately determine the risk factors, and the risk factors are not weighted in the RPN calculation

Table 4. The weight of each of the risks caused by the hydrocarbon-rich sludge generated in South Pars Gas Complex-First Refinery, Iran, for the probability of occurrence based on the AHP technique

Type of risk	Risks	Weight	Rank in group	Rank in total	Probability of occurrence
Environment	Annual release of high volume of carbon dioxide and sulfur dioxide into the environment	0.030	7	13	0.114
	High volume of sludge stored in the burn pit, where there is a possibility of leakage and soil and groundwater contamination	0.0433	4	10	0.102
	High volume of waste resulting from storage and refining of hydrocarbon-rich sludge produced in the studied refinery	0.0432	5	11	0.072
	Absence of a supplementary treatment system for the refinery effluents	0.024	8	15	0.219
	Contamination of the lands of the gas refinery with burnt oils, catalytic beds, hydrocarbon sludge, amine sludge, soda sludge and refinery sludge	0.010	9	17	0.101
	Risk of soil pollution due to the storage of hydrocarbon-rich sludge produced in the studied refinery in the burn pit due to the presence of some aliphatic and aromatic hydrocarbons.	0.075	1	5	0.086
	Risk of groundwater pollution due to sludge leakage after storage in burn pit	0.033	6	12	0.046
	Potential possibility of natural radioactivity pollution in burn pit	0.060	2	7	0.075
Health	Direct contact of workers with sludge during collection, discharge, repair and washing of equipment	0.012	3	16	0.042
	Accumulation of radioactive materials deposited on the internal surfaces of pipes, valves, pumps, heat exchangers, tanks, boilers and other equipment and the risk of these materials being dangerous for human health	0.15	1	1	0.044
	Development of respiratory problems for the staff supervising the operation and the staff of evaporation ponds	0.130	2	2	0.042
Technical-Safety	Failure to comply with the rules related to the design, construction and emptying of pits	0.050	3	8	0.058
	Failure to comply with HSE environmental standards during the management of hydrocarbon-rich sludge produced in the studied refinery	0.050	2	9	0.376
	Failure to supply equipment and quality control systems, personal protective equipment	0.070	1	6	0.120
	Ignoring the costs of storage and refining of hydrocarbon-rich sludge produced in the studied refinery	0.030	1	14	0.116
	No recognition of the risks resulting from hydrocarbon-rich sludge produced in the studied refinery and related activities	0.090	1	4	0.096
	Political and economic sanctions and difficulty in providing the equipment needed for the refinery	0.1	1	3	0.093

and have the same value (Hosseinzadeh, 2017). Therefore, the present study tried to solve this problem while using the AHP method by performing the pairwise comparison matrix to weight the probability of risk occurrence and accordingly prioritize the risks in the relevant group (environment, health or technical-safety) and determine the assigned rank compared to all 17 risks. Based on Table (4), the investigation of the risks caused by hydrocarbon-rich sludge in the studied refinery showed that the risk of "Accumulation of radioactive materials deposited on the internal surfaces of pipes, valves, pumps, heat exchangers, tanks, boilers and other equipment and the risk of these materials being dangerous for human health" with a weight of 0.15 ranks first in all identified risks. The risk of "Contamination of the lands of the gas refinery with burnt oils, catalytic beds, hydrocarbon sludge, amine sludge, soda sludge and refinery sludge" with a weight of 0.010 had the lowest degree and 17th rank. The results of the prioritization of risks in each group revealed that, in the environment group, "Risk of soil pollution due to the storage of hydrocarbon-rich sludge produced in the studied refinery in the burn pit due to the presence of some aliphatic and aromatic hydrocarbons" with the rank one took the most weight. In the health group, the risk "Accumulation of radioactive materials deposited on the internal surfaces of pipes, valves, pumps, heat exchangers, tanks, boilers and other equipment and the risk of these materials being dangerous for human health" had the highest weight both among its own health risks and among all 17 risks with rank one. In the technical-safety risk group, the risk "Political and economic sanctions and difficulty in providing the equipment needed for the refinery" has been assigned the first rank.

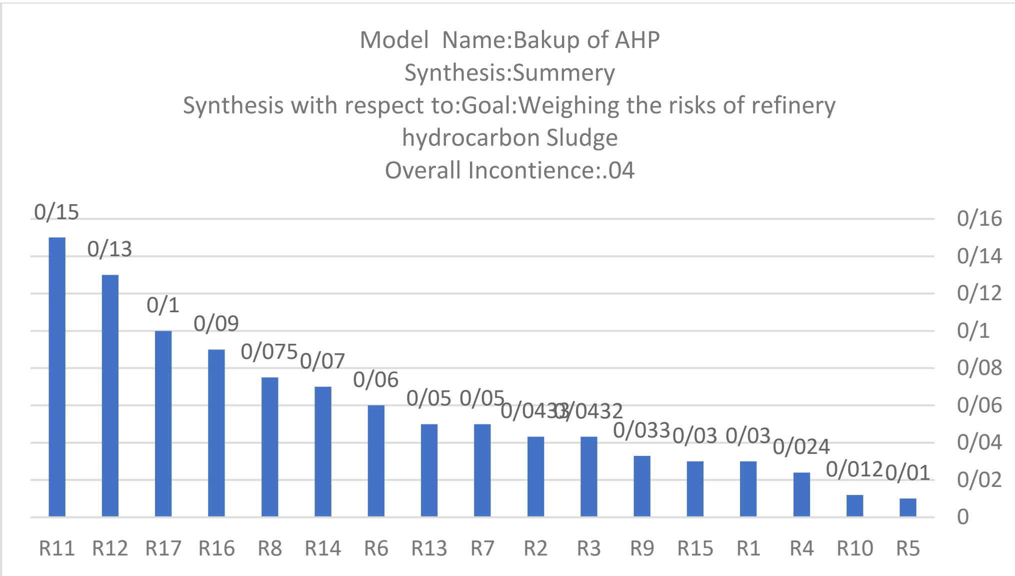

Figure 5. Weighting of risks caused by hydrocarbon-rich sludge generated in South Pars Gas Complex-First Refinery, Iran, using Expert Choice software

4. Discussion

Gas refineries are among the most important industrial waste production centers in Pars Special Economic Energy Zone. Incorrect planning regarding the formulation of the refinery waste management system and related risk management leads to the occurrence of various pollutions in this region. One of the main environmental problems in South Pars Gas Complex-First Refinery, Iran, is the unwanted by-products and hydrocarbon-rich sludge at the end of the monoethylene glycol (MEG) recycling process, condensate stabilizers and industrial wastewater treatment, and the only solutions used so far to get rid of this problem in this complex have been chemical neutralization methods, sludge burial and burn pit, which themselves are the source of irreparable damage to the region's environment and people's health; hence, the present study was conducted with the aim of identifying the HSE risks of hydrocarbon-rich sludge in South Pars Gas Complex-First Refinery and prioritizing the occurrence of risks using the AHP method.

In this study, data analysis revealed 17 environmental (n=7), health (n=4) and safety (n=6) risks. Based on the results, the highest risk priority was related to "Risk of soil pollution due to the storage of hydrocarbon-rich sludge produced in the studied refinery in the burn pit due to the presence of some aliphatic and aromatic hydrocarbons ", followed by "High volume of sludge stored in the burn pit, " in the second place. The lowest priority was related to "Risk of contamination of the lands of the gas refinery with burnt oils, catalytic beds, hydrocarbon sludge, amine sludge, soda sludge and refinery sludge". In a study by Amanatyazdy and Moharamnejad (2013) entitled "Environmental Risk Management of Fire in Oil Warehouses and Storage Tanks", fire caused by intentional and terrorist factors with the RPN of 720 was identified as the highest risk in tanks, in line with the present study. Wang et al. (2013) conducted Fuzzy Fault tree analysis for fire and explosion of crude oil tanks and found fire and explosion as the most common incidents in refineries, in agreement with the present study. Nojumi et al. (2019) identified eight main factors affecting crisis management, including leadership and management, human factors, organizational culture, organizational agility, organizational systems, regional infrastructure, production continuity and continuous monitoring. Their data analysis revealed that human factors had the greatest impact on the structure of crisis management predictors. These results were confirmed by our findings. In a research by Bahrami et al. (2018), among 15 risks identified in the petrochemical complex with the opinions of experts, the highest fuzzy-based RPN was related to noise pollution (0.75) in the health sector, falling from a height (0.75) in the safety sector and reducing ecological resources (0.613) in the environment sector, which have differences with the present research.

In our study on health risks, "Potential possibility of natural radioactivity pollution in burn pit" had the highest coefficient of importance. As mentioned, six risks were investigated in technical-safety category. Based on the obtained results, it can be seen that "Political and economic sanctions and difficulty in providing the equipment needed for the refinery" was in the first place, and the risk of "No recognition of the risks resulting from hydrocarbon-rich sludge produced in the studied refinery and related activities" was in the second place. In addition, the risk of "Ignoring the costs of storage and refining of hydrocarbon-rich sludge produced in the studied refinery" was the least important and ranked last.

The results obtained from the risks caused by hydrocarbon-rich sludge in the studied refinery showed that the risk of "Accumulation of radioactive materials deposited on the internal surfaces of pipes, valves, pumps, heat exchangers, tanks, boilers and other equipment and the risk of these materials being dangerous for human health" with the first rank in all the investigated risks had the greatest weight (0.15).

Based on the results obtained in the current research and the most important risks identified, the following measures are suggested in order to reduce these risks:

1- The pollutant emission of the refineries mainly depends on the settings and operation of the facilities, so that the pollution caused by this refining industry depends on the design and operational processes. Therefore, regular maintenance of equipment, replacement of old parts, paying attention to the quality of the equipment and adjusting the functional conditions, and providing and using the appropriate equipment for waste treatment and processing, as well as taking into account the appropriate environmental and protection guidelines, should be prioritized by oil company managers (Aitani, 2004; Festus M. Adebiyi., 2022).

2- Due to the fact that the financial credit and budget are vital items for the implementation of goals, after the primary planning and provision of the necessary budget resources, in case of a possible gap, income-generating strategies with less financial burden should be put in priority for implementation so that other strategies can be implemented by the obtained financial resources. Oil refineries, like gas refineries, cause environmental threats with the waste produced (Bayram et al., 2015; Liu et al., 2013; Festus M. Adebiyi., 2022). Therefore, in order to implement the management plan to reduce these environmental risks, South Pars Gas Complex-First Refinery needs specialized management for regular interaction with other organizations in order to effectively implement, especially the reduction of semi-solid wastes such as sludge. Therefore, it is suggested that a specialized and experienced management group should be selected, which includes the expertise of HSE, air pollution and environmental management.

3- The operation of recycling hydrocarbon materials resulting from the recycling of hydrocarbon-rich sludge to the production and processing cycle of hydrocarbon materials is suggested to be carried out with the efforts of the employees of South Pars Gas Complex Refinery.

4- The basic management of hydrocarbon-rich sludge, which is in the category of special wastes, should be done in such a way that they are recycled before disposal. The main process used to manage hydrocarbon-rich sludge is lime stabilization, which is contrary to environmental requirements. Therefore, it is necessary to replace this method with environmentally friendly solutions. One of the basic ways that should be considered before incineration is the extraction of recyclable waste materials by existing technologies.

5- If the recycled water from the sludge dehydration process is used in industry and agriculture, the resulting hydrocarbon materials must be returned to the cycle of production and processing of hydrocarbon materials after increasing the required additives. In addition, the residual solid waste, which constitutes a very small percentage of waste, can be used in the production of bitumen and bitumenous waterproofing; by doing this process, the volume of waste will reach almost zero and will have positive environmental and economic effects.

5. Conclusions

Data analysis revealed 17 environmental (n=7), health (n=4) and safety (n=6) risks. Based on the results, the highest risk priority was "Accumulation of radioactive materials deposited on the internal surfaces of pipes, valves, pumps, heat exchangers, tanks, boilers and other equipment and the risk of these materials being dangerous for human health", which were in the category of health risks. The lowest priority was the risk of “Contamination of the lands of the gas refinery with burnt oils, catalytic beds, hydrocarbon sludge, amine sludge, soda sludge and refinery sludge".

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