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Original Article

Environmental Risk Assessment of a Hydrocracker Unit in Abadan Oil Refinery Using the EFMEA Analysis

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Abstract

Background: The aim of risk assessment is to use a rational method to analyze risks and to identify the possible hazards and outcomes for people, equipment, materials, and the environment.
Methods: The criteria and indices for assessing the environmental, health, and safety risks of the hydrocracker unit were determined by a Delphi questionnaire in this study. Then, an Environmental Failure Mode and Effects Analysis was applied to evaluate, score, and rank the risks based on their probability of occurrence, severity, probability of detection, extent of pollution, and potential of recycling.
Results: According to the results of the Delphi process, 19 out of the 22 items were identified as the main criteria in the environmental, health, and safety risk evaluation of the hydrocracker unit at the Abadan Oil Refinery. However, the results indicated that 67% of the risks associated with the life cycle operation were low while 33% of them were high in terms of intensity. In contrast, 75% of the risks associated with control room operators were low and 25% were high in terms of intensity. On the other hand, 64, 7, and 29% of the risks associated with the activities of site employees were low, moderate, and high in terms of intensity, respectively, while the corresponding figures were 14, 29, and 57% in the case of risks associated with repairs.
Conclusion: Based on the results of techniques of environmental failure modes and effects analysis (EFMEA) and Delphi, appropriate methods can be used to identify and reduce risks in similar industries.
Keywords: Environmental health risks, Pollution, EFMEA method, Risk, Hydrocracker unit

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Introduction

Natural resource exploitation is among the influential and prominent factors in the economic and industrial development of countries.[1] Population growth and overexploitation of natural resources for the sake of global economic development have caused many environmental challenges.[2] Thus, despite solving a huge portion of the problems in communities, industrial development has created many environmental risks and hazards.[3-6] Risk assessment is a logical technique used to evaluate risks and is concerned with the identification of risks and their potential consequences for individuals, equipment, materials, and the environment.[7] Risk assessment provides invaluable data for decision-making aimed at risk mitigation, environmental improvement, hazardous facilities, planning for emergencies, acceptable risk level, audit and maintenance schemes for industrial facilities, etc.[8-10]

Natural resource exploitation is one of the influential and prominent factors in the economic and industrial development of countries.[11] Population growth and the overexploitation of natural resources for the sake of global economic development have led to numerous environmental challenges.[12] Therefore, despite solving a significant portion of the problems in communities, industrial development has also created many environmental risks and hazards.[13-16] Risk assessment is a logical technique used to evaluate risks and is concerned with identifying risks and their potential consequences for individuals, equipment, materials, and the environment.[17] Risk assessment provides invaluable data for decision-making aimed at risk mitigation, environmental improvement, hazardous facilities, emergency planning, determining acceptable risk levels, and establishing audit and maintenance schemes for industrial facilities, among other things.[18-25]

Risk evaluation is one of the primary pillars of Health, Safety, and Environment (HSE) management systems and focuses on identifying, evaluating, and controlling hazardous factors that impact the HSE of industrial workers.[26] Risk assessment provides vital data for decision-making aimed at mitigating risks, improving the environment, managing hazardous facilities, emergency planning, determining acceptable risk levels, and establishing audit and maintenance schemes for industrial facilities, among other purposes.[27]

Refining plants have made significant technological advancements in recent decades, but this progress has also brought about increased workplace risks and hazards, resulting in substantial financial losses for the industry.[28] To address these hazards, an effective management system is necessary to mitigate risks, ensure employee safety and well-being, and safeguard the environment. It is of utmost importance to prioritize safety and implement measures such as accident analysis, hazard identification, and risk assessment in the oil and gas industries. These industries are particularly prone to accidents like explosions and fires due to the nature of their processes and materials used. For instance, the fire incident at the UMM SAUD Refinery Plant in Qatar in 1977 resulted in seven fatalities, 12 injuries, and financial damages of US$ 210.8 million, while the gas explosion at the ABQAIQ Refinery Plant in Saudi Arabia in 1978 caused no casualties but led to financial losses of US$ 148.9 million.[29] Therefore, emphasizing safety and implementing measures such as accident analysis, hazard identification, and risk assessment are crucial in preventing accidents. Gas leaks in the gas path flanges and the associated fire and explosion hazards can have detrimental effects on water, soil, and air pollution throughout the lifecycle of these plants.

Failure modes and effects analysis (FMEA) is a widely utilized technique for system safety analysis. It was initially introduced in the late 1950s by an engineer and served as a dependable method for evaluating the safety of military systems. Since then, its applications have significantly expanded.[30] This quantitative analysis technique examines a system or sub-system to identify potential faults in its components and assesses the potential impacts of these faults on other parts of the system.[31] On the other hand, environmental failure modes and effects analysis (EFMEA) is a qualitative approach employed during the product development process to identify and prioritize significant environmental factors in a timely and efficient manner.[32] Consequently, this study aimed to assess the safety, health, and environmental risks associated with the hydrocracker unit in the Abadan oil refinery plant using EFMEA.

Materials and Methods

The operations conducted within the hydrocracker unit at Abadan oil refinery encompass life cycle operations, control room operator duties, on-site staff activities, and maintenance tasks for the hydrocracker unit.

This study, utilizing a descriptive-cross-sectional approach, aimed to identify and assess safety, health, and environmental risks within the hydrocracker unit of the Abadan oil refinery plant through EFMEA. The EFMEA analysis was utilized to precisely evaluate occupational hazards and implement hazard mitigation measures in accordance with the severity of identified risks. The rationale for utilizing this approach is rooted in its extensive utilization within the realm of quality engineering and management tools in our country, as highlighted by Darvishi et al.[32] This technique involves assembling a team composed of a safety expert, plan executor, production supervisor, and technical expert, as well as collecting data to carry out occupational safety analysis. Jobs necessitating such analysis are selected based on their accident history and the hazards associated with each job. Subsequent to a safety evaluation that considers observations, documents, preliminary investigations, and hazard checklists, the most suitable candidates for occupational safety analysis are prioritized for evaluation. Hazard identification is accomplished through the implementation of EFMEA. The execution and implementation of this method necessitate collaboration within a professional HSE committee to identify hazards and assess risks. Consequently, in the current study, the hazards present on the site were identified by recruiting one professional health expert, two environmental health experts, two safety experts, and one master of industrial engineering. Risks were then ranked and evaluated in terms of intensity, occurrence probability, detection probability, pollution scope, and recycling possibility, utilizing the expertise of the professionals and standard tables employed in EFMEA. Subsequently, risk classification was performed, categorizing the hazards into low, moderate, and high risks, and corresponding measures were taken accordingly.

Results and Discussion

The hydrocracker unit at Abadan oil refinery involves various activities, including life cycle operation, control room operators' tasks, site staff activities, and hydrocracker unit repairs. During the analysis, a total of 34 risks associated with these activities were identified. The evaluation of these identified risks, including their probability, intensity, detection probability, and Risk Priority Number (RPN), is discussed in the following section.

Life Cycle Operations

The risk evaluation of life cycle operations in the hydrocracker unit at the Abadan refinery plant, as shown in Table 1, revealed that the highest risk priorities were attributed to gasket failure, valve control failure, and path (pipe) perforation. These specific risks were identified as having the greatest potential impact and were thus given the highest priority for mitigation and management.

Control Room Operators

The results of the risk assessment for control room operators in the hydrocracker unit of the Abadan refinery plant have been presented in Table 2. The findings highlight that the highest priority risk was associated with the potential technical failure of certain alarms, leading to the non-transmission of control room alarms.

Staff Activities in Open Sites

Results of site staff activities' risk evaluation in the Abadan refinery plant's hydrocracker unit indicated that failure to use personal protective gear had the highest risk priority (Table 3).

Maintenance

According to the findings presented in Table 4, the maintenance risk evaluation conducted at the hydrocracker unit of the Abadan refinery plant revealed that the failure to utilize personal protective gear was assigned the highest priority in terms of risk.

The risk level and index for each activity were determined according to Table 5 using the statistical technique of confidence intervals. Mean risk priorities and their standard deviation were initially calculated in SPSS to establish the confidence interval. The results indicated that risks scoring above 37.72 would be classified as high, risks scoring below 30.73 would be classified as low, and risks falling between these two values would be considered moderate. Based on this classification, control plans and mitigation measures were initially developed for high-level (H) risks in order to reduce them to moderate-level (M) and low-level (L) risks. Subsequently, control plans were designed for moderate-level (M) risks with the objective of reducing them to low-level (L) risks through the implementation of control methods and continuous monitoring.

As Table 6 demonstrates, 67% of the risks in life cycle operations were at low levels while 33% were at high levels.

Table 1. Risk Evaluation of the Activities Performed in Life Cycle Operations in the Abadan Refinery Plant's Hydrocracker Unit

Activity	Risk	Possibility	Intensity	Possibility of Not Being Discovered	RPN
Control room operators	Due to the occurrence of technical defects in a number of alarms, signals related to the control room are not sent.	5	4	3	60
	Problems in communicating in a timely and appropriate manner with other departments.	3	5	4	60
	Lack of timely tracking and follow-up of pressure increase failure, which is followed by fire and leakage of toxic substances.	4	4	3	48
	The gas leak test is performed late or incompletely.	5	3	2	30

Table 2. Risk evaluation of Control Room Operators in Abadan Refinery Plant's Hydrocracker Unit

Activity	Risk	Possibility	Intensity	Possibility of Not Being Discovered	RPN
Control room operators	Due to the occurrence of technical defects in a number of alarms, signals related to the control room are not sent.	5	4	3	60
	Problems in communicating in a timely and appropriate manner with other departments.	3	5	4	60
	Lack of timely tracking and follow-up of pressure increase failure, which is followed by fire and leakage of toxic substances.	4	4	3	48
	The gas leak test is performed late or incompletely.	5	3	2	30

Table 3. Risk Evaluation of Site Staff Activities in the Abadan Refinery Plant's Hydrocracker Unit

Activity	Risk	Possibility	Intensity	Possibility of Not Being Discovered	RPN
Fields employee	Contact noise	3	5	4	60
	Contact with particles	4	4	3	48
	Slipping on a surface contaminated with substances	3	4	3	36
	Material leakage and overflow	5	3	2	30
	Falling from a height	5	3	2	30
	Falling into the vents and grooves of the floor	5	3	2	30
	cutting the wire	5	3	2	30
	Traffic through the stairs	3	3	2	18
	Chemical spillage	4	3	2	24
	Material leakage from tanks	4	3	2	24
	Leakage of materials from connections and pipes	4	3	1	12
	Falling tools and hitting people	4	3	2	24
	Failure to use personal protective equipment	5	5	4	100
	Contact with power lines	5	4	3	60

As Table 7 demonstrates, 75% of the risks in control room operators were at low levels while 25% were at high levels.

As Table 8 demonstrates, 64% of the risks in sit staff activities were at low levels while 29% were at high levels.

As Table 9 demonstrates, 75% of the risks in repairs were at low levels while 25% were at high levels.

Analysis of occupational safety during repair operations identified the primary occupational hazards, encompassing risks associated with lifting heavy components, chemical spills, falls from elevated areas, electrical hazards, cable damage, personnel falls, and inadequate use of personal protective equipment. These findings align with similar studies.[7,30,33] Loss and damage encompass broad concepts that can be defined from various perspectives. Each industrial unit faces diverse hazards and unique damages influenced by its processes, operational conditions, materials, equipment, personnel, location, urbanization geography, and other parameters. The hydrocracker unit at the Abadan oil refinery experiences the highest operational pressure among all units. Hydrocarbon cracking in the presence of hydrogen demands exceptionally high pressure due to the nature of the hydrocracking process. Operating under such pressure is highly sensitive, significantly increasing the risk of leaks. The operational sensitivity is particularly heightened at this pressure, coupled with extremely high temperatures and the presence of hydrogen, placing this unit in a distinctive position in terms of operational considerations.

Activities performed in the hydrocracker unit at the Abadan oil refinement plant include the life cycle operation, control room operators, site staff activities, and hydrocracker unit repairs. In the life cycle, hydrogen gas and feed mix and enter the catalyst reactor after being heated up and reaching the desired temperature for reaction, where desulfurization, denitrogenation, and hydrocracking reactions occur in contact with catalysts (alumina-silica-based catalyst with molybdenum and nickel metals) present in this unit. After passing through the reactor and undergoing the mentioned reactions, inlet feed enters the separation tower where various products (crude gasoline, liquefied gas, kerosene, gas oil, and oil cut) are produced and separated. The catalyst in the unit is designed based on the primary product obtained in the unit and could be either amorphous or a molecular sieve.

Table 4. Risk evaluation of maintenance in the Abadan refinery plant's hydrocracker unit

Activity	Risk	Possibility	Intensity	Possibility of Not Being Discovered	RPN
Repairs	Carrying heavy parts	3	4	3	36
	Chemical spillage	5	4	3	60
	Falling from a height	5	4	3	60
	Electric shock during operation	5	4	3	60
	Cable rot and split	4	3	2	24
	Fall of personnel	5	3	2	30
	Failure to use personal protective equipment	5	5	4	100

Table 5. Safety, Health, and Environment Risk Indices in the Hydrocracker Unit of the Abadan Oil Refinement Plant

Indices	
Number	34
Average	34.23
Standard deviation	20.99
Risk index	30.73-37.72

Table 6. Risk Levels of Life Cycle Operations

Activity	Risk	Risk Level	Consequences	Appropriate Response to Risk
Production cycle	Gas leakage in the flanges of the gas path and the possibility of fire and explosion	L	Air pollution, land pollution, water pollution	Using a gas detector near the furnace
	The possibility of fire due to leakage from the flanges or a perforated layer on the gas path from the part of the separation vessel (cow drum) to the furnaces.	H	physical injury	Continuous checking of the furnace by operation personnel - replacement of faulty gaskets and finally shutdown of the unit in emergency mode
Consumption cycle	Gasket failure, valve control failure, punctured paths (pipes)	H	physical injury	Continuous checking of the furnace by operation personnel - replacement of faulty gaskets and finally shutdown of the unit in emergency mode
Waste cycle	A lot of noise from burning gas in the furnace	H	hearing damage	Using the phone
	Gas leakage from the flange and the possibility of fire and explosion and creating fear	L	physical injury	Furnace air or furnace oxygen adjustment and intake adjustment (furnace suction) - Burner adjustment (furnace torch)
	Consumption of resources, raw materials and energy	L	Depletion of natural resources	Visiting and regulating the working conditions of the furnaces and proper insulation of the paths
	Energy consumption and use of fossil fuel (natural gas)	L	Depletion of natural resources	Visiting and regulating the working conditions of the furnaces and proper insulation of the paths
	Energy waste and increased fuel consumption	L	Depletion of natural resources	Visit and take out of service if there is a lot of leakage
	Petroleum waste	L	Depletion of natural resources	Visiting and take out service if there is a lot of leakage

Table 7. Risk Levels of Control Room Operators

Activity	Risk	Risk Level	Consequences	Corrective Actions
Control room operators	Due to the occurrence of technical defects in a number of alarms, signals related to the control room are not sent.	H	Physical injury	Continuous periodic visit, timely replacement of parts
	Problems in communicating in a timely and appropriate manner with other departments	H	Physical injury	Communication and continuous exchange of information with colleagues
	Lack of timely tracking and follow-up of pressure increase failure, which is followed by fire and leakage of toxic substances	H	Physical injury	C.RO training for management and start-up
	The gas leak test is performed late or incompletely	L	Physical injury	Communicate with the site operator and get the necessary information about the situation

Table 8. Risk Levels of Site Staff Activities

Activity	Risk	Risk Level	Consequences	Corrective Actions
Fields employee	Contact noise	H	Hearing damage	Preparing and using a suitable protective phone and rotating work shifts if possible
	Contact with particles	H	Lung damage	Implementation of routine inspection programs, use of personal protective equipment
	Slipping on a surface contaminated with substances	M	Contusion	Leveling the uneven surfaces of the training course (slipping, falling and sliding), holding first aid courses
	Material leakage and overflow	L	Burn	Implementing routine inspection programs, strengthening and implementing the CLEAUP program, installation and automatic notification of leakage, use of personal protective equipment
	Falling from a height	L	Death	Providing and equipping work environments with the risk of falling from a height with appropriate protective equipment, holding long-term and short-term training (TBM) before starting work
	Falling into the vents and grooves of the floor	L	Injury	monitoring and inspecting the environment before starting work, use of protective equipment and tools
	cutting the wire	L	Death	Ensuring that the wires are healthy before performing the operation. Continuous monitoring and inspection
	Traffic through the stairs	L	Injury	Installing protection and painting it, holding training courses to familiarize with the dangers of the work environment and safety signs. Work environment discipline
	Chemical spillage	L	Skin damage	Implementation of routine inspection programs, reinforcement and implementation of CLEAUP program, installation and automatic notification of leakage, use of personal protective equipment in acute cases
	Material leakage from tanks	L	Soil pollution	Implementation of routine inspection programs, reinforcement and implementation of CLEAUP program, installation and automatic notification of leakage, use of personal protective equipment in acute cases
	Leakage of materials from connections and pipes	L	Soil pollution	Implementation of routine inspection programs, reinforcement and implementation of CLEAUP program, installation and automatic notification of leakage, use of personal protective equipment in acute cases
	Falling tools and hitting people	L	Injury	Monitoring the safety and security of work during implementation, use of hats, shoes, and appropriate safety clothing. Availability of first aid kit
	Failure to use personal protective equipment	H	Physical injury	Provision of personal protective equipment, training personnel and monitoring their use
	Contact with power lines	H	Death	Preparation and use of insulated shoes, rubber gloves and ensure that the power supply is disconnected before starting the operation

The results indicated that 67% of the risks associated with the life cycle operation were low while 33% of them were high in terms of intensity. Also, 75% of the risks associated with control room operators were low and 25% were low in terms of intensity. Moreover, 64%, 7%, and 29% of the risks associated with the activities of site employees were low, moderate, and high in terms of intensity, while the corresponding figures were 14%, 29, and 57% in the case of risks associated with repairs, respectively, which is consistent with other studies.[15,33] The occurrence of accidents in technological systems and industrial facilities highlights the significance of continuous progress in safety research, encompassing safety standards, modification of safety evaluation methods, and identification and evaluation of the role of factors involved in safety. Managers of industrial facilities and technological systems typically aim to identify the factors that led to an incident after it occurs. Managers of industrial facilities and technological systems typically aim to identify the factors that led to an incident after it occurs.[34,35] As a result, the study and identification of risk factors, along with their prioritization, play a prominent role in this industry.

Conclusion

The present study aimed to identify and evaluate risks associated with various activities through occupational safety analysis. Risk levels were calculated based on

Table 9. Risk Levels of Repairs

Activity	Risk	Risk Level	Consequences	Corrective Actions
Repairs	Carrying heavy parts	M	Injury to the spine	Not working for a long time in one mode, rotating shift work if possible
	Chemical spillage	H	Death	Education, using a full face mask
	Falling from a height	H	Death	Providing and equipping work environments with the risk of falling from a height with appropriate protective equipment, holding long-term and short-term training (TBM) before starting work
	Electric shock during operation	H	Death	Disconnection of electricity while doing work, preparation and use of insulated shoes, rubber gloves
	Cable rot and split	L	Muscle damage	Using the right raw materials, Implementing routine inspection programs, Using personal protective equipment
	Fall of personnel	L	Death	Providing and equipping work environments with the risk of falling from a height with appropriate protective equipment, Holding long-term and short-term training (TBM) before starting work
	Failure to use personal protective equipment	H	physical injury	Providing personal protective equipment, training personnel and monitoring

parameters such as risk intensity, probability, and scope of risk. Control measures were proposed using the evaluation code assigned to each risk. EFMEA analysis facilitated the clarification of required training for personnel, development of standard occupational instructions, and identification of causes for safety, health, and environmental risk levels in the hydrocracker unit at the Abadan oil refinery. Occupational safety analysis of life cycle operations revealed tangible hazards, including gas leaks in gas pipe flanges and risks of fire and explosions. Control room operators faced safety risks such as technical failures in alarms, hindering their transmission to the control room. Site staff activities posed risks such as contact with noise and particles, slipping on surfaces with spilled substances, falling from heights, and more. Moreover, the ranking of risks in life cycle operations highlighted gasket failure, valve control failure, and path (pipe) perforation as the highest risk priorities. Similarly, technical failure in alarms ranked highest among risks for control room operators. The ranking of risks in site staff and repair activities in the hydrocracker unit of the Abadan oil refinement plant indicated potential issues, with the sentence incomplete and requiring additional information.

Authors' Contribution

Conceptualization: Ali Mahdavi, Katayoon Varshosaz.
Data curation: Ali Mahdavi, Katayoon Varshosaz.
Formal analysis: Ali Mahdavi.
Investigation: Ali Mahdavi, Katayoon Varshosaz.
Methodology: Ali Mahdavi, Katayoon Varshosaz.
Project administration: Katayoon Varshosaz.
Software: Ali Mahdavi.
Supervision: Katayoon Varshosaz.
Validation: Ali Mahdavi, Katayoon Varshosaz.
Visualization: Ali Mahdavi, Katayoon Varshosaz.
Writing–original draft: Ali Mahdavi, Katayoon Varshosaz.
Writing–review & editing: Katayoon Varshosaz.

Competing Interests

The authors declared no conflict of interest.

Ethical Approval

There were no ethical considerations to be considered in this research.

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