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Original Article

Quantitative Evaluation by Protection Layer Analysis (LOPA) for Equipment in Imam Khomeini Petrochemical Aromatic Unit

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Abstract
Background: In the petrochemical industries, accidents are generally catastrophic which endanger human, environment and economic. In the industries, there is a wide range of flammable and toxic substances that affect health and safety of workers. They have also adverse effects on society. Numerical risk and impact assessment as well as design for protective layers against catastrophic events are necessary for designing process units.
Methods: First, the occupational-process and environmental safety hazards were measured by hazard and operability (HAZOP) and environmental failure mode and effects analysis (EFMEA) techniques. Then, the risk was assessed using the layer and operability analysis (LOPA) method.
Results: The results showed that a total of 50 safe and health items and 37 environmental risks were identified by HAZOP and EFMEA methods in Imam Khomeini Petrochemical Aromatic Unit. There were 17, 19 and 14 items with low, medium and high level risk, respectively.
Conclusion: This study showed that the LOPA method is more comprehensive than hazard identification methods for the analysis of protective layers. The important actions were blockage of the excess gas to the flare and release the H2S gas. Also, evaluation of the environmental aspects of aromatic unit activities showed that air pollutant production in the power supply unit, waste disposal of reactor tank, waste disposal of condensate tank and reactor fire and explosion were at a high level risk.
Keywords: Risk assessment, Imam Khomeini Petrochemical, FUZZY method, LOPA method, BOWTIE

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Introduction

Safety is assumed to be a necessity for survival and stability. It is also a foundation for purposive production and development. One of the most essential and technical requirements for all industries is the identification sector for hazards and risk quality analysis as well as risk omission, correction, control, and survey. The medium and high level risks will be explored for quantitative risk assessment after identifying hazards and determining the quality of risk.[1]

Risk and impact assessment along with the design of protective layers against catastrophic events are of the requirements for design of the process units. Without risk assessment, we cannot have acceptable safety for the start-up and operation of process units.[2]

Petrochemicals are of special importance in terms of safety. The results of past accidents have shown that accidents in the industries are generally catastrophic which have adverse effect on human, environment and economic.[3] In the industries, there is a wide range of flammable and toxic substances that affect the health and safety of workers. They have also adverse effects on society. Reducing the risk to an acceptable range needs to technical and organizational requirements.[4]

This research aimed to evaluate the equipment risk of the aromatic petrochemical unit in Imam Khomeini Port using the layer of protection analysis method, which is a semi-quantitative risk assessment method and used after the hazard identification techniques.[5] This method allows the user to determine the risk of various hazards using the severity and probability of an event incident. In this method, the process risk is reduced to the acceptable level of the organization according to the safety integrity level (SIL). Also, this method can determine the level of safety integrity for safety precision of instrument systems or equipment that have safety functions under critical conditions without using time-consuming techniques. Also, the documentation process can be carried out simultaneously. This technique is a powerful tool for evaluating the existing status of the protective layers of the process. Therefore, with the implementation of layer and operability analysis (LOPA), the efforts to reduce the higher risk and produce a logical framework for allocating resources and controlling the risks are created effectively.[6]

The general objective of present study was risk assessment of equipment in Imam Khomeini (RAH) Port Petrochemical Complex. In line with the general objective, the following minor objectives were also assessed:

- Identification and classification of risk in the aforementioned petrochemical equipment
- Evaluation and analysis of independent protective layers used for reduction of risk in the petrochemical equipment
- Specifying reduced risk at different layers using the LOPA-Fuzzy method in the petrochemical complex;
- Measuring the control, reduction, and possible removal of risks in the petrochemical complex

In this regard, there are some examples of academic projects, published papers and books. One of the domestic-related backgrounds in this field is the risk assessment conducted by Taghani and Hoseini in refinery structures located in the South Pars zone. They identified hazards and the risks caused by construction of a refinery complex using failure mode and effects analysis (FMEA).[7] Protective layers analysis using LOPA technique and determination of SIL process in octanizer (continuous catalytic reforming) unit of gasoline production complex in Isfahan Oil Refinery Company was proposed by Baharlouei et al.[8]

Cialkowski conducted some studies using protective layer analysis as a multipurpose tool to solve team problems.[9] Risk assessment of LNG combustion terminal using LOPA-Fuzzy technique' was used in the studies. Also, advanced management was applied by Renjith and George. In this study, protective layers for risk assessment were used in LNG burning terminals.[10]

Materials and Methods

The statistical population of this study was the aromatic unit of Imam Khomeini Petrochemical Complex in Mahshahr, and the sample comprised of total equipment in units of this complex.

In this study, we used librarian method and different basic investigations of environmental and safety activities as well as risks in the petrochemical sector.

Also, the comments by experts and specialists concerning local and regional visits and the acquisition of information about the petrochemical position were used in this study. The related risk factors and their importance level were identified in third step. The risks-related parameters were also determined according to the indicators derived from assessment method. The risk assessment matrices in the HAZOP method were utilized in the occupational hazards section. environmental failure mode and effects analysis (EFMEA) technique was also used for evaluation of environmental aspects. Eventually, event occurrence scenario assessment was implemented using the LOPA technique to extract scenarios based on order of preference risks.

Process of Hazard Identification by HAZOP Method

HAZOP technique is a systematic method to identify operational risks and problems in the system. This technique is often utilized in chemical industries. The risk level of identified hazards was measured using probability of occurrence which is ranged between 1-6. and become greater if the probability rises. Also, the effect of intensity varied from 1-9 in which the effect is reduced based on the order of numbers according to equation 1. Finally, the ranking of hazards were three classes of risks (high, medium, and low).[11]

$$Risk = Occurrence\ probability * Intensity\ of\ occurrence * Discoverability \quad \text{Eq. (1)}$$

Environmental Hazard Identification by EFMEA Method

In order to identify and determine weights of environmental dimensions in the aromatic unit, EFMEA technique considering discretion and routine of the petrochemical safety group and environmental aspects (qualitative and different units and scales) was adopted.

Given the designated characteristic, the samples were scored by a number between 1 to 5 (i.e., from the lowest to the highest). Similarly, the same score is given to the probability of occurrence scale. The numbers 1 and 5 represent the highest and the lowest mode of occurrence probability, respectively. The numbers between the range (1-5) are also considered as characteristics of contamination range or potential recycling.[12]

Risk Assessment Using LOPA

LOPA technique has an unfavorable consequence based on HAZOP mining. The intensity of this consequence is approximated. Then, primary events are characterized by the consequences. Table 1 presents the repeatability of primary events. Afterwards, the severity and probability of the scenarios are determined. The probability of occurrence varies from 1 to 7 in this technique, where 7 is the highest probability. The classification of intensity is also ranged from 1 to 7 by which the effect on personnel exposed to the environmental factors is classified. Tables 2 and 3 present severity and probability classifications, respectively. In the LOPA method, the independent protective layers and their probability

Table 1. Repeatability of Initiating Events in LOPA Method

Repeatability	Event	Level
Less than 10^{-4} per year	Defects or a series of defects with a very small probability of occurrence in the working life of the unit, such as: defects of three or more process equipment, human error, sudden failure of a task or defect of process containers	Low
Between 10^{-4} to 10^{-2} per year	A defect or a series of defects with a very small probability of occurrence in the working life of the unit, such as: double defects in tools or valves, a combination of precision tool defects and human error, defects in pipelines or small process connections	Medium
More than 10^{-4} per year	The occurrence of defects is reasonably expected during the working life, such as: process leaks, defects of valves and tools, and human errors that can lead to material release	High

Table 2. Classification of Severity in LOPA Method

Classification of Injuries and Deaths	Subgroup	Description	Severity
Little or no injury, no wasted time	Staff	Very Low	1
No injury, danger or inconvenience to the public	Society		
Recordable event without notice to the agency	Environment		
A minor overhaul of equipment with an estimated cost of less than $100 000 and no loss to production	Facilities		
Little or no injury, no wasted time	Staff	Low	2
No injury, danger or inconvenience to the public	Society		
Recordable event without notice to the agency	Environment		
A minor overhaul of equipment with an estimated cost of less than US$ 100 000 and no loss to production	Facilities		
Only one injury, not too serious, a possible waste of time	Staff	Medium	3
Complaints of smell or noise from the public	Society		
A publication that causes a warning to the agency.	Environment		
Damage to some equipment with an estimated cost of more than US$ 100 000 and with minor loss of production	Facilities		
One or more severe injuries	Staff	High	4
One or more minor injuries	Society		
A significant release with a serious impact on the environment	Environment		
Major damage to the operation area with an estimated cost of more than US$ 1 000 000 and some loss to production	Facilities		
Death or permanent disabling injury	Staff	Very High	5
One or more severe injuries	Society		
A significant release with a serious impact on the environment and possibly an immediate or long-term impact on health	Environment		
Major or general destruction of the operation area with an estimated cost of more than US$ 1 000 000 and significant losses to production	Facilities		

Table 3. Probability Impacts in LOPA Method

	Possibility
1×10^{-6} to 1×10^{-7}	1
1×10^{-5} to 1×10^{-6}	2
1×10^{-4} to 1×10^{-5}	3
1×10^{-3} to 1×10^{-4}	4
1×10^{-2} to 1×10^{-3}	5
1×10^{-1} to 1×10^{-2}	6
1×10^{-1} to (stronger)	7

of failure defect are determined for each initial cause at the next step. Then, the risk classification is determined. Tables 4 and 5 represent the classification of risks.[13] At the end, the risks are reduced by adding more independent protective layer or using other risk reduction options (e.g., redesign process) based on the given results. The results derived from this technique in chemical industries may show that this technique is an effective tool for determining SIL using process safety engineers.[14]

Table 4. Risk Classification in LOPA Method

Description	Risk Classification
Acceptable (no action required)	1
Acceptable (no action required)	2
Acceptable (no action required)	3
Acceptable (no action required)	4
Acceptable (no action required)	5
Optional (evaluation of proposals)	6
Optional (evaluation of proposals)	7
Optional (evaluation of proposals)	8
Undesirable (risk control measures must be taken within a certain period of time)	9
Undesirable (risk control measures must be taken within a certain period of time)	10
Undesirable (risk control measures must be taken within a certain period of time)	11
Unacceptable	12
Unacceptable	13

Table 5. Risk Category in LOPA Method

Frequency		Severity				
		Cat1	Cat2	Cat3	Cat4	Cat5
		Negligible No Losses	Minor Lost Day Work	Medium Injury	Major Disabilities	Catastrophic Fatalities
Cat7	Very frequent	Ta 7	Tna 14	Na 21	Na 28	Na 35
Cat6	Frequent	A 6	Ta 12	Tna 18	Na 24	Na 30
Cat5	Probable	A 5	Ta 10	Tna 15	Tna 20	Na 25
Cat4	Occasional	A 4	Ta 8	Ta 12	Tna 16	Tna 20
Cat3	Remote	A 3	A 6	Ta 9	Ta 12	Tna 15
Cat2	Improbable	A 2	A 4	A 6	Ta 8	Ta 10
Cat1	Eliminated	A 1	A 2	A 3	A 4	A 5

Na, non acceptable; Tna, training needs analysis; Ta, tolerance accpetable; A, acceptable

Results and Discussion

The results include the following points:

- Extraction of distinct Health, Safety and Environment (HSE) using HAZOP and FMEA
- Planning of event occurrence scenarios based on risk origin, initial risk factors, risk consequences, current controls and suggested controls
- Assessment of event occurrence scenarios based on the LOPA technique.

The results were derived from HSE risks in the aromatic unit by the HAZOP technique which showed that 17 identified risks (34%) were at a low level, 19 risks (38%) were at a medium level, and 14 risks (28%) were at a high level.

The foremost identified processes were operational tasks in the feed tanks and products site, pumping of flammable materials, operation/stop of unit implementation under emergent conditions, blockage of the path for surplus gases toward flare, entry of individuals into reactor No 101, repairing operations (overhaul) in a power substation, operation at height over the scaffold, entry into closed tank and vessel, the release of H_2S gas due to disruption in the disposal of reactor effluent, the release of H_2S gas due to interruption in the recycled gas flow to stripper, release of H_2S gas caused by a flash drum of sour water, H_2S leakage due to disruption in sulfiding flow in hydrodesulfurization (HDS) process, and interruption in the suction unit for gases in the reactor.

The results derived from the assessment of environmental aspects (i.e., activities of the aromatic unit at Imam Khomeini Port Complex) using the EFMEA technique indicated that among 36 identified risks, 23 risks (66%), 9 risks (26%), and 3 risks (8%) were at high, medium and low levels, respectively. The most important environmental dimensions were production of air pollutants in the unit of power supply, disposal of wastes from reactor tanks, disposal of effluents from tanks, condensate, fire, and explosion in reactor

Event Scenario Planning

The scenarios were planned after identifying and assessing HSE risks in the aromatic unit.

According to the suggested method by Bahr and Boyle, identifying distinct HSE risks include the cases for which the preference number is at least at medium level or the intensity of their occurrence is at a maximum level.[15,16] As a result, among 50 studied health and safety (HS) risks (28 cases with 36 environmental aspects), 12 cases were extracted for scenario-planning.

In order to plan for scenarios based on the suggested technique, the studied variables including event origin, occurrence scenario, event consequences, current controls, and necessary controls were investigated.[17]

The analysis of occurrence of HS events (Table 6) indicated that 7 HS scenarios (25%) were at an acceptable level without revision; 8 HS scenarios (29%) were at an acceptable level with revision; 9 HS scenarios (32%) were at an unacceptable level with medium priority, and 4 HS scenarios (14%) were ranked at unacceptable level with immediate priority. Similarly, for the scenarios of environmental events (Table 7), 4 environmental scenarios (34%) were ranked at an acceptable level without revision; 1 scenario (8%) was at an acceptable level with revision, 3 scenarios (25%) were at unacceptable level with medium priority, and 4 scenarios (33%) were at unacceptable level with immediate priority.

Conclusion

The aromatic unit is one of the important units located in the petrochemical complex in Imam Khomeini Port. The performance of different equipment (e.g., tanks, furnace, turbine and reactor) are directly related to accidents and environmental aspects.

The current study aimed to identify and evaluate

Table 6. Assessment Results Using LOPA Technique for Health and Safety (HS) Scenarios in Aromatic Unit

Row	Scenario	Class of Intensity	Frequency	Class of Frequency	Risk Level	Criterion for Acceptance of Risk Scenario
1	Spraying of chemicals due to leakage from pipelines of materials	2	0.0121	Cat.6	Tna14	Unacceptable- medium priority
2	Fire of chemicals in operational site	4	0.01102	Cat.6	Tna18	Unacceptable- medium priority
3	Explosion of tanks in operational site	5	0.00005	Cat.2	Ta10	Acceptable by revision
4	Leakage of chemicals caused by EDC injection	2	0.9789	Cat.6	Ta12	Acceptable by revision
5	Fire and explosion due to pumping of flammable materials	3	0.2211	Cat.6	Tna18	Unacceptable- medium priority
6	Fire and explosion due to operation/stopping implementation of unit under emergent conditions	3	0.17989	Cat.7	Na21	Unacceptable- immediate priority
7	Fire caused by hydrogen leakage from Dew Point device	1	0.0211	Cat.6	Ta7	Acceptable by revision
8	Spraying of materials in the process of injection of Javelle water substances	2	0.07999	Cat.6	Ta12	Acceptable by revision
9	Noise due to operation of compressors	1	0.1	Cat.7	Ta7	Acceptable by revision
10	Contact to H2S gas upon entry into reactor	3	0.00101	Cat.5	Tna15	Unacceptable- medium priority
11	Contact to aromatic materials during routine operation	2	0.08	Cat.6	Ta12	Acceptable by revision
12	Fire and electrification during repairing operations (overhaul) in substation	4	0.01879	Cat.6	Na24	Unacceptable- immediate priority
13	H2S gas leakage at Zone 100	4	0.0899	Cat.6	Na24	Unacceptable- immediate priority
14	Leakage and inhalation of argon gas for personnel in control room	2	0.08	Cat.6	Ta12	Acceptable by revision
15	Fall from the high point during operation over the scaffold	3	0.07	Cat.6	Tna18	Unacceptable- medium priority
16	Respiratory problems under restricted conditions	3	0.063	Cat.6	Tna18	Unacceptable- medium priority
17	Pouring of chemicals during discharge and loading operation on solvent barrels	2	0.0411	Cat.6	Ta12	Acceptable by revision
18	Release of H2S gas due to disruption in disposal flow of reactor effluent	4	0.0709	Cat.6	Na24	Unacceptable- immediate priority
19	Release of H2S gas due to flow of recycled gas to stripper	4	0.0087	Cat.5	Tna20	Unacceptable- medium priority
20	Release of H2S gas due to flash drum of sour water	3	0.0077	Cat.5	Tna15	Unacceptable- medium priority
21	Leakage of H2S gas caused by interruption in sulfiding flow in HDS	2	0.077	Cat.6	Ta12	Acceptable by revision
22	Interruption in suction unit of gases in reactor	2	0.191	Cat.7	Tna14	Unacceptable- medium priority

EDC, ethylene dichloride

Table 7. Assessment Results Using LOPA Technique for Environmental Event Scenarios in Aromatic Unit

Row	Scenario	Class of Intensity	Frequency	Class of Frequency	Risk Level	Criterion for Acceptance of Risk Scenario
1	Surplus wastewater during effluent treatment	5	0.9089	Cat.7	Na35	Unacceptable- immediate priority
2	Propagation of gases resulted from burning by combustion operation in furnace	3	0.089	Cat.6	Ta18	Unacceptable- medium priority
3	Surplus wastewater in operation of cooling tower (4&6)	2	0.098	Cat.6	Ta12	Acceptable by revision
4	Propagation of gases resulted from burning of extra gases in torch	4	0.79	Cat.7	Na28	Unacceptable- immediate priority
5	Production of air pollutants caused by power supply in unit complex	3	0.07	Cat.6	Na21	Unacceptable- immediate priority
6	Disposal of recycling tanks of reactor effluent	3	0.07	Cat.6	Tna18	Unacceptable- medium priority
7	Spill-over of effluent from condensate tanks	2	0.4	Cat.7	Tna14	Unacceptable- medium priority
8	Fire and explosion of reactor	4	0.06	Cat.6	Na24	Unacceptable- immediate priority

HSE accident occurrence scenarios of equipment in the aromatic unit of Imam Khomeini Port using the LOPA technique in 2020.

The results of this study showed that 50 safety and health risks and 37 environmental aspects were identified by HAZOP and EFMEA techniques in the aromatic unit of the petrochemical complex in Imam Khomeini Port. Among these risks, 17 were identified at the low level, 19 at the medium level, and 14 at the high level.

Based on the method used in this study, among 50 HS risks, 28 cases and 37 environmental items, 12 aspects were extracted for scenario planning.

Given 6 different scenarios, the release of H_2S gas was determined as the foremost identified risk caused by equipment in the aromatic unit. Hydrogen sulfide is toxic at high dosages which causes a range of acute, chronic and carcinogen effects at lower doses. The factors involved in this scenario were non-observance of safety protocol accuracy in the reactor and tanks, not using reagents, weak isolation of equipment and lines, and rising pressure at flow pipelines.

Another important identified HS scenario was the fire and electrification during operational works. Two important factors in electrification accidents were poor internal coordination and not using personal protection equipment. Based on the type of high voltage installation power used in the complex, the accident would result in serious damage or death.

Fire and reactor explosion, typically caused by electrical connections or leakage of oil derivatives, include some scenarios related to occurrence of emergent conditions and accidents. Although these scenarios acquired the least score regarding occurrence probability and frequency, due to very high intensity, they need to effective safety management.

Analysis of distinct environmental scenarios showed that surplus wastewater during effluent treatment with the priority of NA35 was the most important environmental aspect in running processes at the aromatic unit of Imam Khomeini Port. Some reasons for occurrence of this aspect are non-separation of water and oil, lack of regulation of Skimmer Line and non-performance of treatment process on surplus wastewater. Gas propagation resulted from the burning of surplus gases in torch and the contamination caused by the operation of boilers (steam pots) for the generation of electrical energy are another important environmental aspects that led to the dissemination of air pollutants and greenhouse gases.

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Competing Interests

The authors declared no conflict of interest.

Ethical Approval

All ethical principles were considered in this article.

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