original article

The application of the Layer of Protection Analysis (LOPA) in Sour Water Refinery Process

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ABSTRACT

Aims: The objective of this study was to analyze major accidents take place in sour water refineries, and to assess the adequacy of safeguard layers in the system. Also it has been provided safety recommendations in regarding to our analysis.

Materials and Methods: Using the layer of protection analysis (LOPA), the role of protective layers in controlling the potential risks in Sour Water Recycling Unit is determined and required recommendations to reduce risk are provided.

Results: This study showed that there are 49 high risk areas in Sour Water Recycling Unit. Moreover, Excessive flow rate in pipelines, Excessive temperature, Reverse flow, H_2S leakage, Flow interruption, and Corrosion are the main identified hazards.

Conclusion: It can be conclude that the effectiveness of protective layers is not enough and additional protective layers are required to improve the process safety system. Furthermore, LOPA is an improved technique when use the output of hazard and operability study (HAZOP) and it has some advantages due to its semi-quantitative nature in estimating hazards.

Key words: LOPA, protective layer, risk, sour water

INTRODUCTION

Significant changes have been taken place in materials, processes and activities in the chemical industries, especially in oil and gas field over the past fifty years. According to recent surveys conducted by the General Inspector Organization of the Center for Strategic Studies, oil and gas industries have been announced as an infrastructure to the country development and achievement of the objectives of the country's development plan without the proper use of such resources seems to be unfeasible. Vast potential of Iran oil and gas reserves and significant economy conservation in this part necessitates more investment priority in this industry to authorities since the South Pars Gas Field in Assaluyeh region (having over 14 trillion cubic meters gas reserves -about 4% of total world gas reserves) is located in the country's priority development projects.[1] On the one hand number of refineries and their products have been increased and accordingly enlarged the number of people employed in these industries and communities around them are exposed to higher risks. Precise determination of direct and indirect costs of accidents in such industry is difficult and

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demands therefore for more investment for safety in oil and gas industry compared to other industries.

Analysis and identifying the hazards as well as dangerous parts of the refinery units in order to prevent the occurrence of catastrophic events are so important, therefore, hazards identification and risk analysis shall reveal deviations, so that strategies to eliminate them can be offered.[1,2] According to recent surveys conducted by the General Inspector Organization of the Center for Strategic Studies, oil and gas industries have been announced as an infrastructure to the country development so the proper use of such resources seems to be vital. The number of refineries and their products have been increased and accordingly enlarged the number of people employed in these industries are exposed to higher risks. Precise determination of direct and indirect costs of accidents in such industry is difficult and demands therefore for more investment for safety in oil and gas industry compared to other industries. Incidents in the chemical processes that lead to the occurrence of environmental catastrophes made human experts to estimate the frequency and potential outcomes of these events through probability approaches and thereby making it possible to control the frequency and severity of the hazards. This is one of the applications for risk assessment.[3] Risks, in any project, are the probability of upcoming events or conditions that may occur with negative consequences on future goals and affect projects objectives. So the risk identification and determination of positive & negative consequences on projects is very important. Nowadays the use of risk assessment methods in different industries is growing. Such methods are used for identifying, controlling and reducing the risks of consequences. Each of industries depending on their needs can benefit from various risks identification and assessment methods. Moreover, it is possible to integrate several risk assessment methods in the process to have a comprehensive assessment.[4] In the present study, the results of Hazard & Operability Study (HAZOP)[5,6] that have been prioritized based on severity and probability were integrated as input to LOPA scenarios in which each scenario in the framework of LOPA spreadsheet are analyzed semi-quantitatively.[7] The LOPA technique was introduced as a tool that potentially can carry out an assessment of barriers and the protection required in the chemical and refinery process. Basically LOPA is a simplified form of semi-quantitative assessment. Depth and hardness of the protective layers are tested and their effects are calculated to quantify appropriately the nature and severity of risk.[8] Literatures have shown that conducting LOPA from the results of HAZOP has many merits outweigh carrying out them separately. LOPA results will help to identify the best safeguards for refinery process.[7,9] The study showed that the LOPA technique was introduced as a tool that potentially can carry out an assessment of barriers and the protection required in the process. Furthermore, it is used to determine the acceptable or tolerable risk and Target factor as well as development of potential scenarios of existing dysfunctional protective layer.[9] This study also emphasizes on the role of human factors and human failures with application of the LOPA framework in the refinery process.[10] In order to reduce the process safety dependence on human, the application of the safety instrumentation system (SIS) and the Inter lock system has been reviewed.

MATERIALS AND METHODS

What is Layers of Protection Analysis (LOPA)?

The semi-quantitative Layers of Protection Analysis (LOPA) method used for the identification and analysis of the safeguards that consider as independent protection layers was first utilized in a chemical process in 1993 during the development of Safety Integrity Level (SIL) for electronic & electrical safety systems.[3,11] This method is used as an effective tool in process risk assessment in recent years. It allows user to determine the risk of several serious incidents using potential incidents and severity. Using various risk reduction methods may help a user to reduce overall risk and risk mitigation for the different protective layers. If further reduction in safety measures in the system under study is required after the process design, one can utilize one of the major changes in process control systems, alarm devices, describing the duties and responsibilities, installation of emergency valves or systematic safety instructions and then may calculate the overall safety level of the system to reduce risks. Besides, such procedure answers to questions arise about the number and strength of the protective layers in the system using following responses: Providing semi-quantitative results based on the risk status, reducing individuals' motivation effects and preferences in decisions and judgments, clarification and stabilization of the measures taken and protective potential in a system, documentation based on decisions exploitation of comments made by personnel who work in a specific process unit. LOPA, could be implemented at each stage of the lifecycle process or equipment installations especially in the following cases: In the stage of a conceptual design process, in the design process, when the process flowchart is completed, in periodically and intermittently stages, when the process starts when utilization of new equipment in system requires risk assessment due to added equipment to the system, when the human reaction & responses to emergencies as a risk reducing factor in the analyzed process.[12] The first step in LOPA analysis is outlining a scenario which will be considered as Impact Event in the LOPA column. After that, a benchmark, The LOPA Target Factor, for measuring the gap between existing situation to the acceptable one (tolerable level of risk) is required. Senior management is able to evaluate the results of the LOPA by this benchmark. Such criteria is defined as LOPA Safety Target Factor based on objectives such as extent of damage and human injuries, environmental damage and losses, financial losses or a combination of them.[12]

Application of LOPA in this study

In this investigation using LOPA, Sour Water Recycling Unit has been analyzed. This division separates sour and acid gases from water consumed in different parts of the refinery. There are always risks threatening this key unit due to the processes and large volumes of flammable gases and compounds. This unit is feed by a regular flow of acidic water from glycol recycling (MEG Regeneration) as well as temporary flow from several parts including condensate stabilization, ethane recycling, Fuel Gas and industrial Waste Effluents Disposal. In order to separate acidic and sure gases, mainly H2S and SO2, all collected water shall go through the Stripper Tower Process. This Process is based on Reboilering Ttechnique.[13] In our study, we created a small team including the experinced operators and enginers in the Sour Water Recycling Unit.

For performing LOPA in this process, firstly, all documentation including reports, HAZOP analysis, defects etc were reviewed. Then, results of a qualitative HAZOP study that had been done before in the process has been utilized, as each end consequence, with high potential risk, present each LOPA scenarios The main LOPA scenarios were defined as LOPA Target Factor were the extent of human injuries, environmental damage, financial losses and the combinations of them. According to Iranian national regulatory, safety, health and environmental losses should be mitigated. LOPA Target Factor has been assigned the code 5 and probability to fail on demand (PFD) regarded 1×10^{-5} in this study. After that, the initiating causes for the deviations and risk potential were identified and listed by the team members. We have also determined the probability and frequency of the initiating causes. Subsequently, regarding to the safety, health, environmental and economic impacts, the consequence of the identified hazard scenario was estimated. Once the frequency and severity of the risks were obtained, we used a risk matrix to evaluate the hazard levels and to realize the necessity of extra Independent Protection Layer (IPL) for further risk reduction. Safety levels in the SIL for the process equipment are identified with the scores of 1 to 4 in a way the greater score of SIL, the higher risk level and require outstanding levels of safety. Finally, the list of IPL for mitigating initiating causes was provided and the practical recommendations have been suggested.

RESULTS

Due to the characteristics of the study process, HAZOP study is used as input to qualitative study of LOPA. Then through reviewing process and preliminary studies and data & documents gathering policies regarding the company's senior management guideline, the level of acceptable risk and risk tolerance were compared to each other using existing tables, and code 5 determined as the corresponding LOPA Target Factor and corresponding PFD 1×10^{-5} regarded as acceptable risk level. Our finding revealed 49 high-risk areas in which 20 points required revision [Table 1]. The study showed that major hazards in this unit are due to (a) Excessive flow rate in pipelines (b) Excessive temperature (c) Reverse flow (d) H_2S leakage (e) Flow interruption and (f) Corrosion, each of which may start a chain of events with wide consequences. Total PFD of the protective layers in BPCS equipment, alarms and other control devices is recorded as reduced probability in Table 1. New protective layers for those that their PFD were more than LOPA target factor (10^{-5})/yr are proposed as corrective recommendations which are shown in Table 1. These suggestions are adapted from these four main groups' recommendations as independent protective layer (IPL): (a) human reactions/responses (b) passive protective layer (c) interactive protective layer and (d) Safeguards which the latter usually are not considered as independent protective layers. 50% of all 20 suggestions involve independent protection layers using SIL code that 60% of these cases were assigned to SIL1 and remaining 40% were assigned to SIL2. However, SIL3 and SIL4 were not suggested at any case.

90% of the suggested protection layers were IPL of which 15% are among the human reactions, 40% assigned to passive protective layers, 30% are active protection layers and remaining 15% are Safeguards.

DISCUSSION

LOPA methodology is used as a tool in order to assess the role and function of protective layers to prevent the possible scenarios in a process. The significance of this point is independency of protective layers and states that an independent layer should be able to prevent the development of an potential scenario, whether the event is started or not and should be independent of other layers function. In our study, independent layers were concentrated upon and where a protective layer singly could not control events, it is considered as a safety guards. It could be pointed out besides maintaining an active independent role for layers, this study emphasize on the appropriate and effective reaction of human by recommendations such as procedures and more importantly trained operators.[14] Therefore, human reaction during 10 minutes are recommended in 15% of suggestion for corrective action as the same as safeguards. The role of human, training and procedures have been evaluated as important, so 35% of the proposed protective layers are assigned to controls which were related to the human factor. Although in some studies proposed that instrumented equipments such as safety instrumentation system (SIS) and the Inter lock should be used in chemical process to reduce dependences on human factors, in refineries, considering its situation, it is not possible to eliminate the role of human.[15] Some studies suggested the application of LOPA risk assessment technique on reactive chemicals, automated response equipment such as safety instrumentation system (SIS) and the Inter lock system are suggested in addition to reducing

Table 1: LOPA spreadsheet related to analysis of hazardous areas and required protection layers

Action Ref.	Mitigated likelihood	LOPA Target Factor	Required Mitigation	ACTION		$PFD_{(avg)}$	SIL of IPL	Notes
				Description	Type			
109^{-04}	10^{-3}	10^{-5}	10^{-2}	Open Vent	IPL	1×10^{-2}	2	
109^{-11}	10^{-4}	10^{-5}	10^{-1}	Human Action With 10 Minutes Response	IPL	1×10^{-1}	NA	NA = Not SIL is Required
109^{-12}	10^{-4}	10^{-5}	10^{-1}	Underground Drainage System	IPL	1×10^{-2}	NA	
109^{-16}	10^{-4}	10^{-5}	10^{-1}	Human Action With 10 Minutes Response	IPL	1×10^{-1}	NA	
109^{-16}	10^{-4}	10^{-5}	10^{-1}	Normal Testing and Inspection	Safe Guard	1×10^{-1}	NA	Safeguard not Consider IPL
109^{-20}	10^{-3}	10^{-5}	10^{-2}	Human Response to BPCS Indications	IPL	1×10^{-1}	NA	
109^{-20}	10^{-3}	10^{-5}	10^{-2}	BPCS	IPL	1×10^{-2}	1	
109^{-21}	10^{-4}	10^{-5}	10^{-1}	Relief Valve	IPL	1×10^{-2}	NA	
109^{-22}	10^{-4}	10^{-5}	10^{-1}	Basic Process Control System	IPL	1×10^{-2}	NA	
109^{-23}	10^{-4}	10^{-5}	10^{-1}	Normal Testing and Inspection	IPL	1×10^{-2}	1	
109^{-26}	10^{-3}	10^{-5}	10^{-2}	Basic Process Control System	IPL	1×10^{-2}	2	
109^{-26}	10^{-3}	10^{-5}	10^{-2}	Procedures /Normal Testing and Inspection	IPL	1×10^{-1}	NA	Safeguard not Consider IPL
109^{-28}	10^{-4}	10^{-5}	10^{-1}	Open Vent (no valve)	IPL	1×10^{-2}	2	Only selected pump trips.
109^{-29}	10^{-3}	10^{-5}	10^{-2}	Relief valve	Safe Guard	1×10^{-1}	NA	Safeguard not Consider IPL
109^{-30}	10^{-4}	10^{-5}	10^{-1}	Basic Process Control System	IPL	1×10^{-2}	NA	
109^{-31}	10^{-4}	10^{-5}	10^{-1}	High alarm added	IPL	1×10^{-1}	1	
109^{-32}	10^{-3}	10^{-5}	10^{-2}	"Inherently Safe" Design	IPL	1×10^{-2}	2	Off spec material containing H2S goes to atmospheric chamber
109^{-43}	10^{-3}	10^{-5}	10^{-2}	High and low flow alarms shall be added	IPL	1×10^{-1}	1	It needs High and low detectors
	10^{-3}	10^{-5}	10^{-2}	Procedures /Normal Testing and Inspection	Safe Guard	1×10^{-1}	NA	Safeguard not Consider IPL
109^{-47}	10^{-4}	10^{-5}	10^{-1}	check valve	IPL	1×10^{-2}	1	It needs High and low detectors
109^{-56}	10^{-3}	10^{-5}	10^{-2}	"Inherently Safe" Design	IPL	1×10^{-2}	2	

dependences on human factors in process safety. However considering existing situation in refineries it is not possible to eliminate the role of human resources and it is required to pay more attention to improve their role effectively.[9] LOPA method and consequently the present study cannot provide anyone with facilities required for mapping and simulation of possible events while in a research, methods and strategies to compensate these deficiencies are provided.[16] Due to direct interference of staffing & human resources on risk assessment and method novelty, acquiring team-work skills reviewing accuracy and precision of results is very important and therefore the calibration and evaluation process is also important.[17]

LOPA is not capable for defining failure causes take place between an independent protection layer and the next layer.[13] For example it is inefficient in describing blockage that might be occurred in the pipes and is regarded as the limitations of this method.[18] Another distinction of the present study compared to other ones is that there are a few researches carried out using this method for risk assessment of refineries and platforms & offshore structures. Therefore, it would be difficult to make a strong conclusion regarding to the analysis which has been done by LOPA.

LOPA method is a better technique compared to other methods such as HAZOP analysis regarding risk assessment system and has the advantages due to its semi-quantitative nature in estimating the standard deviation as a feature, however since this method is recently developed, operators or users are required to acquire enough experiences and skills in its application. Besides, determination of LOPA Target Factor is a function of the conditions of the organization standards and generalization of criteria from one organization to another one involve its own complexities, especially because of relationship between objective occurrence frequency and the severity of the incidents.[18,19] Due to financial and time constraints of the present study it was not possible to examine the impact and effectiveness of corrective actions while it should basically be monitored and evaluated using schedule and operational impact of proposed actions. In most of example case studies, the researchers had hardly the opportunity to monitor and evaluated proposed actions.[20-26] There are not any previous records and enough information in order to realize the environmental changes impact of various scenarios on determination of target factor as well as the level of severity and consequences considering environmental issues and makes clear the need for research in this regard.

CONCLUSION

It can be conclude that the identification of initiating causes for the deviations by LOPA via defining the main scenarios could, precisely, assess and criticize the process of Sour Water Recycling. This technique can be, therefore, considered as an effective method for mitigation the risk levels especially when use the output of HAZOP as a main LOPA scenarios.

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