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Risk Assessment Study for LPG Storage and Handling System of Heat Treatment Plant.

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***Abstract*— Risk Assessment is one of the key tools used by process industries worldwide. Process industries development is inevitable for any countries economy. New process, products thus results in new hazards and risk to human beings. In this paper risk assessment of an LPG storage bullet of a heat treatment process plant is carried out which is located in a cluster of industrial area. The hazard identification are carried out systematically and various maximum credible accident scenarios are identified which had potential to impact offsite consequence. These scenarios are further modeled in sophisticated risk assessment software and results are compared with the accepted international criteria. Based on the results the safety precautions are developed and these results are used for future land usage planning and layouts. This papers review the overall QRA (Quantitative Risk Assessment) methodologies applied in process industries and software's used to do this QRA studies, the results and how the risk criteria adopted to evaluate ALARP risk level.**

***Keywords*— Accident scenarios, Risk analysis, Hazard identification, Risk criteria, QRA**

I. Introduction

Petroleum products are preferable among all other fossil fuels by industry and as well as domestic. Liquefied petroleum gas (LPG) is one of the widely used gas in industries for various applications such as heating, furnace, boilers etc. LPG is stored as liquid under pressure in storage tank. LPG is stored in portable cylinder as well as in bulk quantity. When industrial belts are developed in rapid growth due to industrialization, huge quantity of LPG gas is stored by these industries. Bhopal disaster in 1984 and Piper alpha oil rig catastrophe in 1988 are examples of lack of safety standards and practices results in serious accidents, loss of lives and property. Risk assessment study is to guide engineering solutions, design safety, emergency preparedness and planning etc. [1]. So the process industry safety to consider more important during design phase. Great importance has to be given during this stage to enhance the plant safety. [2]. Risk analysis is a methodology developed in middle of 1970 to take care of process industry by the loss prevention in process industries. [3].

LPG is a highly flammable gas which results in fire and explosion in case if it leaks during the unloading or loading process and from the storage container. The various fire and explosion scenarios associated with LPG are jet fire, pool fire, flash fire, Confined vapour cloud explosion (CVCE), unconfined vapour cloud explosion (UVCE) and Boiling liquid expanding vapour cloud explosion (BLEVE). In LPG storage system fire and explosion accidents are happened due to leakage from tank or pipelines. [4]. QRA is used for different purposes it is one of the most important risk management program. [5]

Process description:

LPG is used in boiler, furnaces and various heat treatment applications. The heat treatment plant uses LPG as a fuel for heating purpose. The LPG is received through road tankers and unloaded in two LPG bullet capacities of approximately 20 Metric tonnes. The LPG bullet is operated at 4 Bar and 28^{0}C temperature. LPG bullet storage yard consists of road tanker unloading bay, unloading pipelines, hoses and associated valves & fittings. The LPG road tanker is unloaded using LPG vapour by pressurization method. The LPG vaporizer is installed in the downstream and supply of gas to the plant.

The LPG bullet is provided with safety and fire protection system such as LPG detection and warning system, fire hydrants, automatic water monitor, bund, static electricity holder, safety relief valve, burst disc, level indicator, flameproof electrical appliances etc

II. Risk Assessment Methodology

Risk assessment is defined as a mathematical function of the probability and consequence of an incident [6]. The target of risk assessment is to identify potential accidents, analyses the causation and evaluate the effects of the risk reduction measures. Risk assessment is broadly classified as qualitative and quantitative methods. The following Table 1. Show the various tools used as qualitative as well as quantitative in process safety design studies.

TABLE 1
QUALITATIVE AND QUANTITATIVE TOOLS

Qualitative	Quantitative
Checklist	Fault tree analysis
Site survey	Event tree analysis
Site inspection	Probalistic risk assessment
Safety audit	Quantitative risk assessment
Site observation	
HAZID	
What if	
HAZOP	

Layer of protection analysis (LOPA), Failure mode effect analysis (FMEA) are called semi quantitative analysis tools. LOPA is lies in between HAZOP and Quantitative Risk Assessment in terms of rigorousness. [7]. In QRA studies initial hazard identifications are carried out by qualitative tool and to find frequency of failures, estimating risks quantitative tools are used. The selection of risk assessment qualitative or quantitative or semi quantitative is based on the purpose of study is depends on many factor such as the design stage or operational stage or expansion of the plant, legal requirement and usage of the results. Quantitative Risk Assessment is carried out to find the risk in numerically. Quantitative method is identifying the risk from the hazards and assesses the risk level using different modeling according to the risk involved. The quantitative tool such fault tree and event tree is used to quantify the risk [8].This method consists of probability and consequence analysis and risk evaluation.

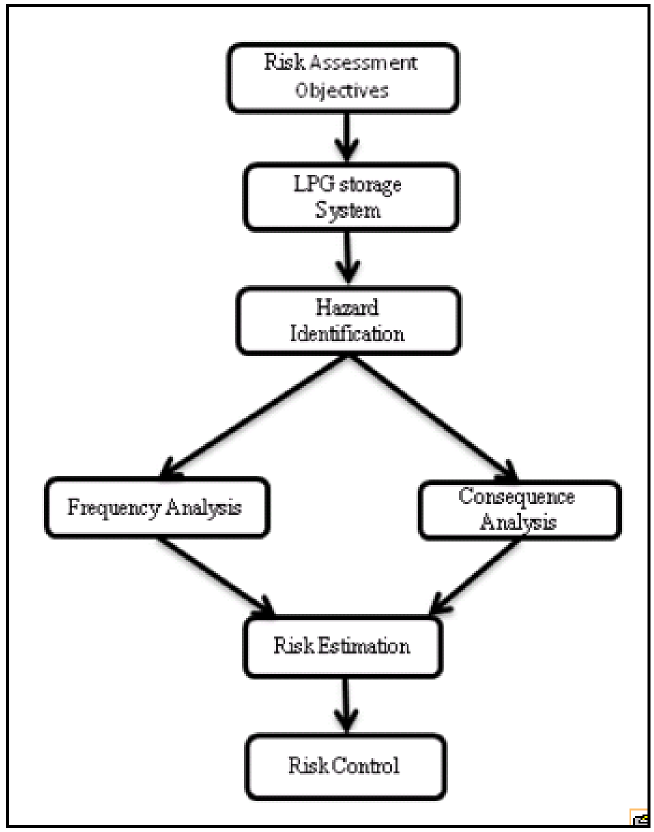

Fig.1: Typical QRA flow diagram

Typical QRA methodologies are in use today, the World Bank guideline, Dutch purple book, and CCPS guideline etc. The results of QRA are normally presented as individual risk graph or individual risk contours and F & N Curve.

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It is concluded that a QRA can be a useful tool, for example in land use planning. Quantitative risk assessment is very important in risk management and is being used in assessing risk of urban pipeline carrying natural gas and it is used to improve the safety level [9]. Typical quantitative risk assessment flow diagram is followed systematically in this study has shown in Fig. 1. [7] [10].

A. Hazard identification:

Hazard identification is the first key step in risk assessment study. Hazards are identified in the LPG plant, its inventories like quantity used and its composition, operating temperature and pressure of the process, storage condition etc. The site visits are carried out and verified the flow diagram, and process & instrumentation diagrams and discussion with plant operator, manager etc. The HAZID study is conducted with appropriate check list which covers all inclusive hazards. The HAZID study gives the possible LPG leaks and various fire and explosion scenarios. Based on the nature of hazard and consequence, the significant scenarios are indentified to carry out QRA study. The selected hazards incident scenarios are taken to further modelling.

B. Scenarios selection:

The various incident scenarios are considered for QRA study is listed in Table. 2.

TABLE 2
SCENARIOS SELECTED FOR ANALYSIS

- LPG unloading line leakage
- LPG unloading line catastrophic failure
- LPG bullet leakage
- LPG bullet catastrophic failure
- LPG vaporizer catastrophic failure

C. Consequence analysis:

Consequence analysis is carried out based on the source model. How the materials are discharged such as from pipeline or tank and the type of failure etc. Then based on source model the fire and explosion outcomes are carried out based on the ignition probability. Usually the event trees are used to identify the different event outcomes from any leakage scenario.

The jet fire (immediate ignition), vapour cloud fire (flash fire), pool fire (delayed ignition), vapour cloud explosion (delayed ignition-explosion), toxic cloud (no-ignition), safe dispersion are the outcome cases of any leak of hazardous material leakage. [9]. All these steps are covered by the modeling software during the analysis.

Consequence analysis depends upon various parameters. The dominant parameters such as released volume, release rate, release direction, probability of ignition, time of ignition, and events associated with ignitions are considered. [11]. A typical example of accident scenarios for LPG storage bullet catastrophic failure and various outcomes are analyzed using event tree is shown in the Fig. 2.

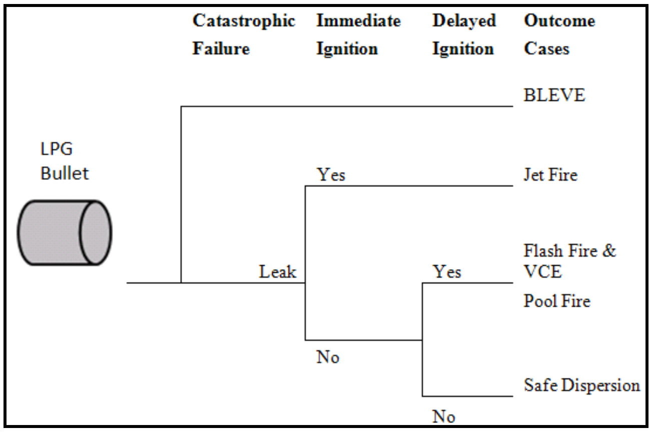

Fig.2: Consequence analysis-typical incident outcome from LPG tank.

The magnitude of each outcome cases are evaluated by the PHAST software 6.5 model and their results are given in various graphs. The hazards associated with jet fire, flash fire are producing toxic gases and in addition to that thermal radiation emission. [12].

Catastrophic rupture of vessel or pipe produces a massive release of LPG into atmosphere results in explosion such as BLEVE if immediately ignited. If the ignition got delayed results in pool fire, flash fire, confined vapour cloud explosion and unconfined vapour cloud explosion depends up on the confinement.

D. Weather conditions:

The wind speeds, wind direction, relative humidity, solar radiation, outside temperature are the important parameter effects the dispersion of leakage gases. The site metrological data's are collected from the metrological station situated at the location. The analyses are carried out mainly for weather classes such as 1.5 D, 1.5 F and 5 D cases etc.

III. RESULTS & DISCUSSION

The over pressure from explosion and heat radiation intensity from fire and explosion as considered as criteria for assessing the effects towards humans and structures.

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Over pressure had created more damage to people, equipment, assets from the past vapour cloud accidents. [13].

A. Overpressure due to LPG pipeline catastrophic failure

TNT equivalent method is used to calculate the explosion over pressure. In this method the same mass TNT is considered for modelling. Here LPG pipeline catastrophic failure leads to different fire scenarios such as pool fire; explosion etc. depends up on the ignition. The Fig.3 shown the overpressure developed due to explosion.

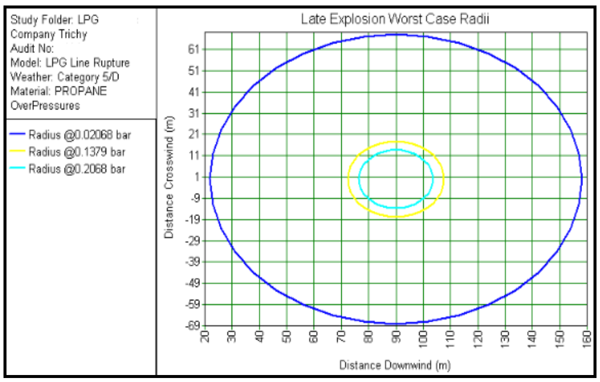

Fig.3: Concentration of LPG based on Flammability values in ppm.

TABLE 1
OVER PRESSURE AND DISTANCE IN DOWN WIND

Overpressure	Unit	Maximum Distance (m)		
		Category 1.5/D	Category 5/D	Category 1.5/F
0.02068	bar	1027.79	1045.74	1002.04
0.1379	bar	311.667	335.557	311.605
0.2068	bar	256.996	284.776	259.211

The Table 1 describes the model output for different wind stability classes and over pressure distance in meter. From the analysis approximately 300 meter distance contour, the glass and repairable damage may occurred to people due to this scenario.

B. LPG concentration contour around LPG storage tank failure.

The LPG tank failure caused sudden dispersion of gases to the surroundings. Depends up on the wind stability class and wind speed, solar intensity, ground condition the concentration may vary.

The software models the output to specific wind class stability and contour is made based on the concentration levels. The various level of concentration interested is drawn as a footprint in Fig.4. The distance from the point of release 38 m and 143 m are falling in flammable range to the downwind direction. Based on the LFL level distance the selection of electrical equipment's, avoiding ignition sources are to be decided.

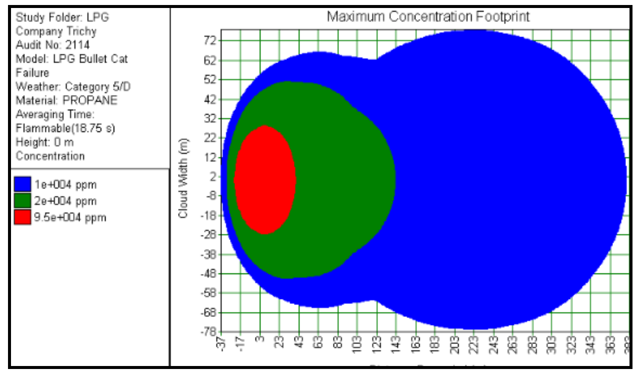

Fig.4: Concentration level footprint of LPG based on downwind distance.

C. Radiation Heat intensity due to catastrophic failure of LPG bullet

Sudden failure of LPG tank results in spillage of liquid petroleum gas and immediate ignition results in fire ball. This is one of the common accident scenario based on previous LPG accident history. The Fig. 5 shows the heat radiation flux based on down wind direction.

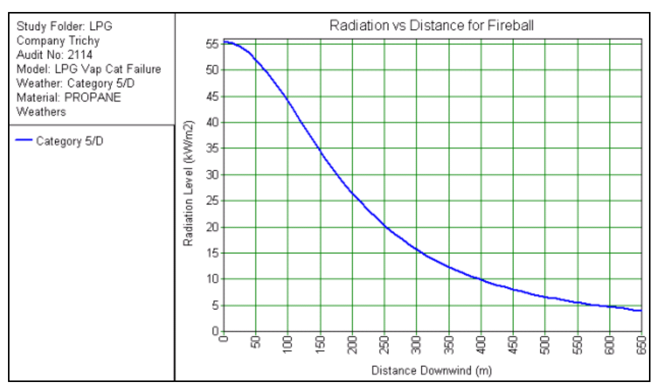

Fig.5: Heat radiation flux with respect to downwind distance.

The maximum heat radiation flux due to explosion reached 56 KW/m^2 at the source as per the chart. The Table 2 illustrates the distance and various heat intensity levels.

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TABLE 2
HEAT RADIATION FLUX WITH RESPECT TO DOWN WIND.

Scenario	Maximum distance affected by the radiation level (in meter)				
	4.0 KW/m^2	9.5 KW/m^2	12.5 KW/m^2	25.0 KW/m^2	37.5 KW/m^2
Catastrophic Failure of tank	*550*	*400*	*350*	*200*	*120*

D. Frequency Estimation

Risk estimation involves the quantitative evaluation of likelihood of an undesirable event and as well as the consequence i.e the damage caused to life, property, environment etc.

The sudden and accident leakage of tank or pipeline or catastrophic failure can happen due to failure of any component in the system. The failure probability of the system is depends up on the individual components. The fault tree and event tree techniques are used to find failure probability. Nuclear power plants, aerospace industries are using these powerful tools to predict the failure rates. [1]. HSE UK-OREDA, Dutch Purple book, CCPS are composed generic failure data database for various components, equipments etc. So far in Indian condition there is generic failure data database is not developed. It is a common practice to select failure data from the internationally recognised failure database for risk assessment. The Table 3 show a typical assessment of frequency for pipeline leak outcome scenario.

TABLE 3
TYPICAL FREQUENCY ESTIMATION.

Leak Size	Frequency	Scenarios	Immediate	Delay	Probability	Outcome Frequency
Pipeline Small	2.300.E-05	Jet Fire	0.0045		0.0045	1.03.E-07
		VCE	0.9855	0.01	0.0098	2.26.E-07

Bayesian network analysis is one of the statistical tools to find the failure rate of components from generic failure data. Bayesian theory the judgement of the analyst is suggested to represent the uncertainty in the analyst's assessment. [14]

From combining the consequence analysis and frequency analysis the risk contour is established and the risks are plotted in map. The risk to the individual are represented as risk contour and called as individual risk. Individual risk contours connects the same risk level in a geographical map. [2] The risk to the people surrounding the facility are represented by F and N curves and called as societal risk and. [10] These risk levels are depends up on many factor such as input data, methodology followed, process condition, meteorological data, generic frequency data and modelling software, assumptions made etc. [10].

These values are compared with risk acceptance criteria and based on them, the control measures and mitigation measures are developed. The HSE-UK recommended a risk acceptance criterion for acceptable societal risk is $1 * 10^{-6}$. From this assessment the effects are within the plant premises and not have effect on offsite. Acceptable level of risk for people employed in plant is higher than people offside the plant.

IV. RISK CONTROL MEASURES

Based on the risk assessment study and the results the following are to be adopted further to the design requirements to mitigate the risk. Release containment and suppression system, fire containment and suppression system, explosion relief, containment and suppression system are the possible measures suggested as control & mitigation for prevent accidents by the previous researchers.[13] Correct and careful risk analysis is needed to develop and implement a safety management system for complex chemical plant. [15] The following conclusion and recommendation were made based on this study.

- Increase the number of LPG detectors in the unloading area, valves and installation in vaporiser area etc
- Prevent ignition sources around the LPG storage and associated areas such as explosion proof electrical equipment's and installations and flame proof trucks etc.

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- The heat intensity at a distance of 550 meter approximately reaches 4 KW /m2 for LPG tank catastrophic failure sufficient to cause pain to personnel is likely. During LPG transfer operation restricted number of operational team to be allowed and plan the land use surrounding to this facility accordingly.
- The shock wave pressure of 0.2 Bar reaches approximately 40 m contour for pipeline rupture scenario with late ignition. From this serious effects are result from shock wave in explosion which to be considered during new facility around.
- LPG warning signs to be provided around the storage facility such as highly flammable, no smoking etc.

V. CONCLUSION

In this work Quantitative Risk Assessment of LPG storage bullet and its handling system is analysed. From the consequence analysis it was found that jet fire, pool fire, VCE, BLEVE are the potential scenarios. The frequency analysis for a leak and probability of ignition is used to find the overall outcome failure frequency. From the analysis the individual risk is acceptable level and all the effects are within plant premises.

Provided safety and fire protection system in the plant are adequate and well maintained to take care in case of any emergency. The consequence analysis results such as the over pressure distance and radiation intensity is to be used for future planning of facilities adjacent to the storage. The emergency preparedness plan especially the off site plan need to be studied and frequent mock drills are to be conducted regularly. More accurate models such as CFD are to be used considering all the wind conditions and for accurate results. Computer modelling used to assess the safety distances are varies however available data are to be further verified by field work to increase the reliability.

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