Fire, Explosion and Dispersion Modelling of Automatic LPG Distribution System of High Rise Building Apartment

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Abstract

LPG is a common fuel used in industries and as well as for domestic purpose. LPG stored in bullets and small cylinder in commercial and domestic purpose. But in recent developments LPG is stored in bulk quantities in high rise apartments and supplied directly to individual homes. It calls for LPG bullets or stored in apartment buildings and loading and unloading of huge quantities in this buildings. In this paper an attempt is made to do a risk assessment study is carried out of a LPG storage, handling and use in a high rise building apartment. The different hazardous scenarios are considered and various initiating event and failure of piping and storage vessel are identified for this study. The consequence models such as Jet Fire, Flash Fire, BLEVE, UVCE and frequency of failure of various LPG system components are established to assess the risk for different scenario. The analysis is done by a leading software tool PHAST. The risk is calculated for the LPG automatic distribution system based on safety zone and the safety distances are assessed based on thermal radiation and over pressure. Based on the results of this analysis, the existing control measures are evaluated and recommendations are suggested to improve the safety and fire protection system of the apartment building.

Keywords: BLEVE, Consequence Flash Fire, Model, Jet Fire Risk, Unconfined Vapor cloud explosion etc

I. INTRODUCTION

LPG means Liquefied petroleum gas which is stored and handled under pressure. This LPG stored in huge quantities in LPG bullet or storage tanks. [8] LPG is a popular and automotive fuel all over the world and LPG is plenty available in oil and gas industries. However LPG is substantially used in industry, commercial and domestic purpose. The LPGs are stored in huge quantity in storage tanks either in above ground or underground. [1]

Accidents such as Bhopal Gas disaster (1984), Piper alpha(1988), SEVESO (1976), have created major impact on to the people, environment and society. This accident could have been avoided if the basic safety and fire precautions are followed. [7]

The use of quantitative risk assessment study is to improve the safety system in an industry. The Risk assessment study is being popular in now a day for the design of oil and gas installation and even it is mandatory requirement by the government in few countries. [5]

Risk Assessment is the study to identify the hazard and analysis the hazard and evaluate the risk and control measures for any oil, gas and process plant. In this research one of the case study it is applied for an automatic LPG storage and distribution network of a high rise apartment building.

A. Process Description:

LPG is stored in underground storage tank in the apartment building. The LPG supply lines are connected from storage tank to individual apartments. The supply lines are laid through the vertical shaft and individual floors connected to the houses. A separate LPG meter and detector is fitted in the individual house. The individual house owner use the LPG fuel depending upon their requirement and pay as per the meter reading.

LPG in the storage tank is filled by LPG supplier through tanker and unloaded to the underground storage tank. The risk assessment study is carried out during unloading of the tanker operation.
The following assumptions are made for this analysis.

**B. Assumptions:**

1) Surface roughness : 0.1
2) Release source : 1.5 m (case 1-outdoor pipeline rupture)  
                     : 12 m (case 2-Indoor pipeline rupture)
3) Atmospheric stability class : 5D and 2F
4) Discharge coefficient : 0.7 (Two phase)
5) Pipeline dispersion / release : 10 min
6) Solar radiation : 1 Kw / m²
7) LFL criteria : 40 and 50 and 100 %
8) Thermal Radiation criteria : 6.0, 12.5, 25, 37.5 KW / M²
9) Over pressure radius : 0.02, 0.04, 0.08, 0.17, 0.26, 0.5 bar

**C. Weather Data:**

1) Atmospheric temperature : 38 C
2) Humidity : 74 %
3) Wind speed : 5 km / hr (Day) and 2 km / hr (Night)
4) Wind direction : North East.

The fig. 2 shown unloading operation of LPG from road tanker to underground storage tank of the apartment building.
II. PREVIOUS RESEARCH

Robert E. Melchers et al. (2001) conducted a study of LPG automatic refueling facility. In this study Jet fire, pool fire, flash fire, unconfined vapor cloud explosion (UVCE), boiling liquid expanding vapor explosion (BLEVE) are considered different scenarios.

HAZOP study is used to found the possible lease of LPG from the storage and handling system. Gas and liquid leak from various scenarios results in fire and explosion. [8]

S.I Suddle et al. (2006) modelled the LPG explosion modelling during the transportation and consequence effects on motorway and office buildings. How the structural elements are to be designed and separation or spanning of buildings are established based on the modelling results.

Albrecht Michael Birk (2013) pointed out in his study that how large LPG sphers are engulfed with fire and carried out the failure analysis and results of BLEVE based on accident happened in Japan in March 2011.

Storage of hazardous materials are poses major threats to adjacent populated areas. [10] F.Rigas carried out a study on major hazards analysis for populations adjacent to chemical storage facilities. The study uses thermal radiation, overpressure intensity were used for assess the safety distance. BREEZE software is used to model the different scenarios of fire, explosion and dispersion.

1) Objectives of This Work:

In this study the research is carried out to obtain the following objectives

1) To identify the various outcome scenarios in case of LPG leaks from the storage tank / tanker or any LPG distribution supply lines.
2) To analysis the different causes for LPG leakage using fault tree analysis and evaluate the event frequency or failure data
3) To carry out the consequence analysis or physical effects modeling using software for various LPG leak scenarios and establish the safety distances / safe zone
4) To review the existing safety and fire protection system and emergency preparedness plan for the high rise building and suggest recommendations if any.

III. RESEARCH METHODOLOGY

The research methodology is followed in this study based on the following steps.

1) Site visits and observation
2) Supervise / monitoring LPG handling system.
3) Data collection
4) Modeling with sophisticated risk assessment software
5) Review the system and suggest recommendations
6) Preparation of report

The main objectives of risk assessment study is to identify the potential hazards, assess the risk from the individual scenarios and evaluate the risk control measures to reduce the risk to people, plant and environment. Risk is the product of frequency of hazardous event and consequence of the hazardous event. In Quantitative risk assessment study the frequency of the various hazardous event and respective effects such as fatalities, damages are calculated.

The major steps involved in typical risk assessment process are shown in fig. 3.
Many risk assessment methodologies are adopted by different oil and gas companies. [4] The study is compared four quantitative risk assessment approach for LPG storage plant. QRA approach of France, QRA approach United Kingdom-HSE, QRA approach Wallonia-FPMs and QRA approach the Netherlands-RIVM method are applied in a LPG depot of unloading area and their outputs are studied. It is common all the risk assessment methods evaluate the risk on individual as well as societal risk. Quantitative risk assessment (QRA) also sometime called probabilistic risk analysis (PRA) and it is used by many countries. [18]

LPG-18 study briefed about the QRA is not considering sufficiently / limitations omission of possible causes of risk due to incomplete analysis of mechanical and engineering sources of plant failure.

Hazard identification is the principal step in any risk assessment. According to IS 15656:2006 the hazard identification are classified as comparative and fundamental method. The following Table-I shows the hazard identification methods.

| Table - 1
Hazard Identification Methods |
<table>
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<tbody>
<tr>
<td><strong>Comparative Methods</strong></td>
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<tr>
<td>Check list</td>
</tr>
<tr>
<td>Safety Audit</td>
</tr>
<tr>
<td>Hazard Indices</td>
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<tr>
<td>Preliminary Hazard Analysis</td>
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<tr>
<td><strong>Fundamental Methods</strong></td>
</tr>
<tr>
<td>What-if Analysis</td>
</tr>
<tr>
<td>Failure Modes and effects analysis</td>
</tr>
<tr>
<td>Hazard and Operability Study</td>
</tr>
</tbody>
</table>

Comparative methods are using standards and evaluate the actual site condition. But the fundamental methods are systematic way carried out by team of experts do brainstorming and identify the hazardous scenarios. In this LPG handling system in the high rise apartment building hazard identification is carried out based on checklist and hazard and operability study. For each LPG leak various incident outcomes are derived from by event tree techniques. The following four scenarios are considered in this study.

**A. Possible Hazardous Scenarios:**

1) Catastrophic LPG Tanker failure  
2) Unloading Hose Line rupture  
3) LPG distribution Supply line rupture – Indoor  
4) Catastrophic underground tank failure
IV. FREQUENCY ESTIMATION

The frequency of hazardous event is depends up on many factor. Failure frequency of pipelines, valves, components, storage tanks, design, construction, maintenance and ignition probability in case of leaks. IS 15656:2006 explained that the fault tree and event tree techniques shall be used for hazard analysis. Fault tree is identifying the various basic events that lead to an accident event and Event tree analysis used to find different accident scenarios from an initiating event. But the standard not briefed how to estimate or evaluate the frequency of failure. Usually the component failure frequencies are derived from historical accident or failure experiences or theoretical modelling. The leak frequency data and various failure hole sizes are assumed based on the study requirement. The generic failure frequency or historical frequency is used for establishing the risk.

Failure frequency data for cylinders, piping, valves, connections and other components were taken from either historic data or standard failure data base. [17] The failure data base such as Rijmond study (COVO.1982) HSE-UK, OREDA reliability dataset, Dutch Purple Book (RIVM,2009), CCPS (2000), Lees (Mannan, 2005) are used by QRA consultant and analyst for their studies. This produces sensible risk results even though lead to highly uncertain estimation. The data are not collected in standard manner and some data are provided in high estimates. [15] These failure data are usually called generic frequency data.

A. Failure Analysis Techniques:

The theoretical modeling or techniques are used to find failure data are listed in below,

1) Fault tree analysis
2) Event Tree analysis
3) Layer of Protection analysis
4) Fuzzy Fault Tree Analysis
5) Baysean Network
6) Modification factor with basic frequency data / historical data.

After Piper Alpha accident the investigation team suggestion to UK HSE to develop a leak frequency data set for UK sector North Sea installation. HSE UK collected the data in a systematic manner using forms and the Hydrocarbon release database (HCRD data base) is generated.

V. CONSEQUENCE MODELING

Consequence of an hazardous condition varies by many factor. The leakage of LPG may be from tanker or unloading pipeline or underground tank or distribution supply line etc. The availability of ignition source, timing of ignition and metrological condition such as wind speed, direction, day or night time also influence the dispersion hence affects the consequence.

In general the following are the different consequences occur in case of any LPG leakage from the system.

1) Jet Fire
2) Pool Fire
3) Flash Fire
4) Confined or Unconfined Vapor cloud explosion
5) BLEVE

Usually the event tree analysis technique is adopted to establish different accident scenarios in risk assessment. It is a very effective logic tree technique and displays the hazardous condition in graphical form.

A. Jet Fire:

Jet fire is a scenario the leakage occurred from a hole in a tanker or pipeline in particular direction and immediately it catches fire.

B. Pool fire:

The leakage of LPG from the tanker or pipeline spread like a pool on ground and immediately catches fire then pool fire occurs. But LPG rapidly flashes to vapor in the atmosphere.

C. Flash fire:

The released LPG gas is not ignited immediately then the gas is dispersed according to wind direction and mixing with air. If the mixture is in flammability range and ignited later this flash fire occurs.
D. Vapor Cloud Explosion:

The released LPG gas is not ignited immediately and mix with air and exploded in later period. But the explosion may happen sometimes confined or unconfined. Due to the LPG property the gas is drifted in low lying areas and makes confinement. So that explosion produces overpressure surround the ignition source.

E. BLEVE:

Catastrophic loss of LPG tank due to any reason results in huge quantity of LPG is release to atmosphere or any external fire make failure of LPG tank. Due to the sudden vaporizing of / boiling of LPG gas and immediate ignition results in fire Ball, This is called Boiling liquid expanding vapor explosion and very serious in nature produce high over pressure and physical fragments. Hence BLEVE is a dangerous phenomenon.

In this study Event tree analysis is used to identify the various incident outcomes for each scenario and modeling are carried out for all incident outcomes and the safety distance and various outputs are established using PHAST software. The table II and III is used for assessing the overpressure and thermal radiation effects and it is compared with the output values.

### Table - 2
**Overpressure Level And Its Effects**

<table>
<thead>
<tr>
<th>S.No</th>
<th>Pressure Level</th>
<th>Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.5</td>
<td>Partial demolition of houses, Made uninhabitable</td>
</tr>
<tr>
<td>2</td>
<td>3.5</td>
<td>Steel frame buildings distorted and pulled away from foundation.</td>
</tr>
<tr>
<td>3</td>
<td>7.0</td>
<td>Loaded train cars overturned.</td>
</tr>
<tr>
<td>4</td>
<td>10.0</td>
<td>Probable total building destruction; heavy machine tools moved and badly damaged</td>
</tr>
<tr>
<td>5</td>
<td>15-30</td>
<td>Range for 1-99% fatalities among exposed populations due to direct blast effects.</td>
</tr>
</tbody>
</table>

### Table - 3
**Thermal Radiation Level And Its Effects**

<table>
<thead>
<tr>
<th>S.No</th>
<th>Radiation Level</th>
<th>Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.6</td>
<td>Will cause no discomfort for long exposure.</td>
</tr>
<tr>
<td>2</td>
<td>4.0</td>
<td>Sufficient to cause pain to personnel if unable to cover the body within 20 seconds</td>
</tr>
<tr>
<td>3</td>
<td>9.5</td>
<td>Pain threshold reached after 8s.</td>
</tr>
<tr>
<td>4</td>
<td>12.5</td>
<td>Minimum energy required to piloted ignition of wood, melting of plastic tubing, 50% damage level.</td>
</tr>
<tr>
<td>5</td>
<td>25</td>
<td>Minimum energy required to ignite wood at indefinitely long exposure.</td>
</tr>
<tr>
<td>6</td>
<td>37.5</td>
<td>Sufficient to cause damage to process equipment and death to humans.</td>
</tr>
</tbody>
</table>

**VI. RESULTS AND DISCUSSION**

From the analysis the LPG tanker car failure releases the LPG up to 1150 meter distance concentration. Due to fire ball the radiation level reaches 45.9 kw/m2. The intensity of the fire ball radiation is felt near facilities if the downwind direction on south side. Few graphs of some incident outcomes are shown in Fig. 4, 5, 6 respectively.
F. LPG Tanker Catastrophic Failure:

The figure displayed the various concentrations of LPG gas and its dispersion. The concentration level is shown in red, green, and blue color depends up on the concentration level. For example the color red is maximum concentration level spread across a 50 meter surrounding from leak source.

Radiation level from various fire and explosion scenarios are give effects to people especially the operators, and people living in the accommodation and surrounding people around the facility and people using in the express way at the time of accident. The table-3 mentioned the various level and its effects. These values enable to decide what kind of protective clothing to be worn by the operator and allowing any activity nearby while unloading of LPG etc.
VII. CONCLUSION

A detailed hazard identification technique is used for this LPG automatic distribution system of high rise building is studied. This study recognizes the hazardous scenarios which are effect the accommodation and it’s surrounding other facilities. Comprehensive check list indices method is used for hazard identification and which enhances the process of identifying accident scenarios. Consequence analysis such as fire, explosion and dispersion of LPG gas models are carried out by sophisticated software which is available in market. These modeling give the vulnerable zone around the facility based on the thermal intensity and overpressure effects. These results are used for further land use planning or providing adequate protection for existing facilities. From the analysis it is found that the tanker unloading operation is one of the critical activity and fire & explosion vulnerable zone effects up to the distance of 1500 m. The risk suggested risk reduction measures are to be implemented to manage or control the hazard and risk from the unloading of LPG tanker operations. However the limitation of frequency assessment is important in risk assessment studies and how to obtain reliable frequency is a key. Based on the fire, explosion modeling the safe zone contour are established, so that it will helpful to plan any land use planning and set a layout of other buildings adjacent to the existing apartment building.

REFERENCES