Estimating Societal Consequences of a Major LPG Release Incident from a Tank Wagon

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Abstract
Not so long ago, an incident of major LPG release occurred near Panoli Railway station in Gujarat. The release took place from the top dome connection of one of the wagon of a goods train, which was temporarily stationed and was waiting to pass through. The release did not cause fire or explosion and no one was injured except disruption of traffic through this busy route. However, catastrophic consequences would have caused, if the released LPG found an ignition source causing fire and explosion. The paper, in fact, tries to figure out the probable consequences that would have caused to the public in the event of a fire or an explosion and gives an ordinary estimate of potential loss of lives, injuries and property damage. Three scenarios were discussed namely, a major LPG release causing toxic consequences to the nearby public, a fire and a vapour cloud explosion with potential consequences (societal risk) estimated. US EPA's ALOHA dispersion modeling software was used and the consequence effect distances with impact area contours were plotted on GIS enabled MARPLOT software. The lethal and non-lethal effects on the nearby people were estimated using three Levels Of Concern (LOCs) and number of people that would have been likely be affected is estimated based on the 2011 Census data of incident area. The LOCs for LPG release (toxic effects) are estimated using Acute Emergency Guidelines Limits (AEGLs) concentrations of LPG (Butane). The LOCs for Fire impacts are estimated using different percentages of LEL concentrations, whereas, for blast effects due to vapour cloud explosion are estimated using overpressure criteria.
The results show that in case of LPG dispersions without fire, at least 2 persons are likely to face lethal injuries within an impact area of 0.005 sq.km, 5 persons to suffer irreversible health effects within an area of 0.013 sq.km and 8 persons is likely to suffer minor reversible health complications within an area of 0.021 sq.km. Further, had the LPG leak caught fire, the likely consequences would have been such that 2 persons would have faced lethal injuries due to acute respiratory problems within an area of 0.006 sq.km, 3 persons suffered irreversible health effects with severe respiratory symptoms within 0.008 sq.km and 13 persons would suffer reversible health effects with minor respiratory symptoms within 0.034 sq.km. Similar consequence effect distances have been estimated for vapour cloud explosion scenario also. The incident at Panoli Railway station has brought out the likely consequences of a major LPG release in a station area with many people around. A BLEVE (Boiling Liquid Expanding Vapour Explosion) would have been the worst in terms of societal consequences. A proper risk assessment therefore would help in focusing on issues related to hazmat transportation through railways and in enhancing the capabilities of railways towards adequate emergency response.
Keywords: LPG, ALOHA, LOC, Risk

1. Introduction

An incident of major LPG release occurred near Panoli Railway station in Gujarat. Total geographical area of Panoli industrial notified area is the smallest city by area in the sub district. As per 2011 census, the area is having Population density of 401 persons per km^2 [1].The ambient conditions usually prevailing in the area are as follows: Temperature: Max 45°C; Min 21°C. Annual Average Rainfall: 670mm and Relative humidity: 48%. The predominant wind direction: SW – NE as per India Meteorological Department (IMD).

The release took place from the top dome connection of one of the wagon of a goods train, which was temporarily stationed and was waiting to pass through. The Mumbai-Delhi Rajdhani Express was delayed for 6 hrs. due to the incident. The platforms were evacuated and no smoking order was imposed. The release did not cause fire or explosion and no one was injured except disruption of traffic through this busy route. However, catastrophic consequences would have caused, if the released LPG found an ignition source causing fire and explosion.

1.1. LPG Wagon Details

Usually a rake consists of 44 gas containers. Each LPG tank wagon is18.93 m long and 2.4 m in diameter. The volumetric capacity of each tank wagon is 79.48 Cu.m, The liquid filling lines, vapour return line and associated valves (including safety relief valves) are placed in a dome on the top which are the probable source of leakages, either due to malfunctioning of the valves or faulty operation during loading in loading bay inside the refinery.

2. Methodology

In fact, 3 scenarios were discussed and consequences (societal risk) estimated. The scenarios are 1) a major LPG release causing toxic consequences to the nearby public, 2) fire and its potential consequences on people and 3) a vapour cloud explosion and its lethal and non-lethal effects.

ALOHA dispersion modeling software [2] was used for the above scenarios and the consequence effect distances with impact area contours were presented in GIS enabled MARPLOT software. The lethal and non-lethal effects on the nearby people following the scenarios mentioned were estimated using three Levels Of Concern (LOCs) and number of people that would have been likely be affected is estimated based on the 2011 Census data of Panoli area. Meteorological conditions considered are wind speed and direction, stability class, ambient air temperature and the height to the bottom of any inversion.

The LOCs for only LPG (taken as Butane) release ‘not on fire’ are estimated using Acute Emergency Guidelines Limits (AEGLs) concentrations of LPG, namely AEGL-3 (lethal concentration), AEGL-2 (Irreversible health effects) and AEGL-1 (Temporary Reversible health effects) [3, 4, 5]. The LOCs for Fire impacts are estimated using LEL, 60% of LEL and 10% of LEL concentrations. Whereas, for blast effects due to vapour cloud explosion are estimated using overpressure criteria, namely 8 psi (heavy destruction to buildings), 3.5 psi

(serious injuries) and 1 psi (glass shattering). Besides plotting on GIS enabled MARPLOT are having 3 distinct colours indicating 'Red zone,' 'Orange zone' and 'Yellow zone' according to the increasing order of effect distances and the decreasing order of seriousness of consequences.

Societal consequences in terms of injuries and fatalities to the public present inside the various impact zones are estimated according to the following equation:

$$R_s = I_{zone} \times P_d \quad \text{.... (1)}$$

R_s = Societal Risk
I_{zone} = Impact zones Area (Red, Orange and yellow)
P_d = Population density

3. Results & Discussions

The results, as an output of ALOHA dispersion modeling for all three scenarios, earlier mentioned, are presented below and the different 'Threat Zones' are superimposed in the affected area on the MARPLOT. Further, the impact area and the likely consequences (fatalities or injuries) within various threat zones are estimated.

SITE DATA:
Location: PANOLI, INDIA
Building Air Exchanges Per Hour: 0.53 (unsheltered single storied)

CHEMICAL DATA:
Chemical Name: BUTANE CAS Number: 106-97-8 Molecular Weight: 58.12 g/mol
AEGL-1 (60 min): 5500 ppm AEGL-2 (60 min): 17000 ppm AEGL-3 (60 min): 53000 ppm
LEL: 16000 ppm UEL: 84000 ppm Ambient Boiling Point: 31.1˚ F
Vapor Pressure at Ambient Temperature: greater than 1 atm
Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

ATMOSPHERIC DATA: (MANUAL INPUT OF DATA)
Wind: 2 meters/second from sw at 3 meters
Ground Roughness: open country Cloud Cover: 3 tenths Air Temperature: 30˚ C
Stability Class: D (user override) No Inversion Height Relative Humidity: 25%

SOURCE STRENGTH:
Leak from short pipe or valve in horizontal cylindrical tank
Flammable chemical escaping from tank (not burning)
Tank Diameter: 2.4 meters Tank Length: 18.93 meter Tank Volume: 85.6 cubic meters
Tank contains liquid Internal Temperature: 30˚ C
Chemical Mass in Tank: 48.3 tons Tank is 90% full
Circular Opening Diameter: 2 inches
Opening is 0.24 meters from tank bottom
Release Duration: ALOHA limited the duration to 1 hour

Max Average Sustained Release Rate: 5.65 kg/sec (averaged over a minute or more)
Total Amount Released: 20156 kg.
Note: The chemical escaped as a mixture of gas and aerosol (two phase flow).

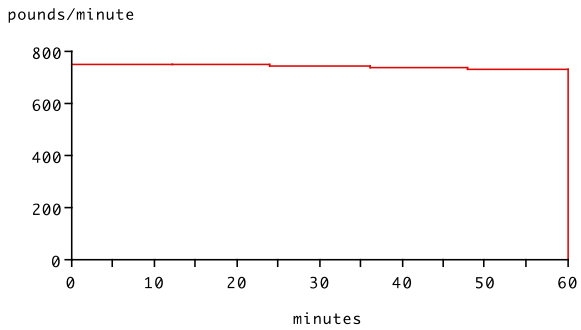

Fig.1 Source Strength Graph

3.1 Scenario-1: Toxic Dispersion & Effect Distances

THREAT ZONE:
Model Run: Heavy Gas
Red : 42 m --- (53000 ppm = AEGL-3 [60 min])
(Note: Threat zone was not drawn because effects of near-field patchiness make dispersion predictions less reliable for short distances).
Orange: 70 m --- (17000 ppm = AEGL-2 [60 min])
Yellow: 123 m --- (5500 ppm = AEGL-1 [60 min])

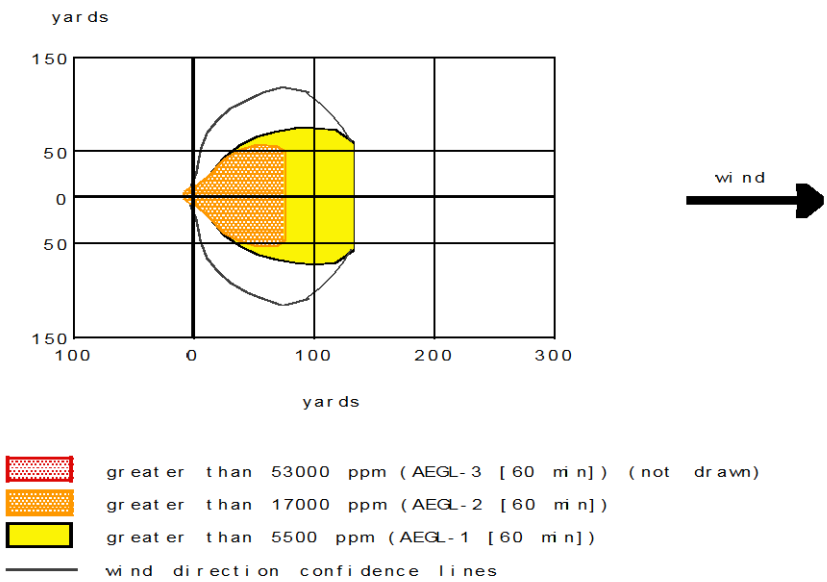

Fig.2: Consequence Effect-distances of LPG release 'without fire

3.1.1 Estimates of Consequences

Red Area (AEGL-3): 0.005 km^2
Societal Risk (Red Area): 0.005 x 401 = 02 persons

Orange Area (AEGL-2): 0.013 km^2
Societal Risk (Orange area): 0.013 x 401 persons = 5 persons

Yellow Area (AEGL-1): 0.021 km^2
Societal Risk (Yellow Area): 0.021 x 401 = 8 persons

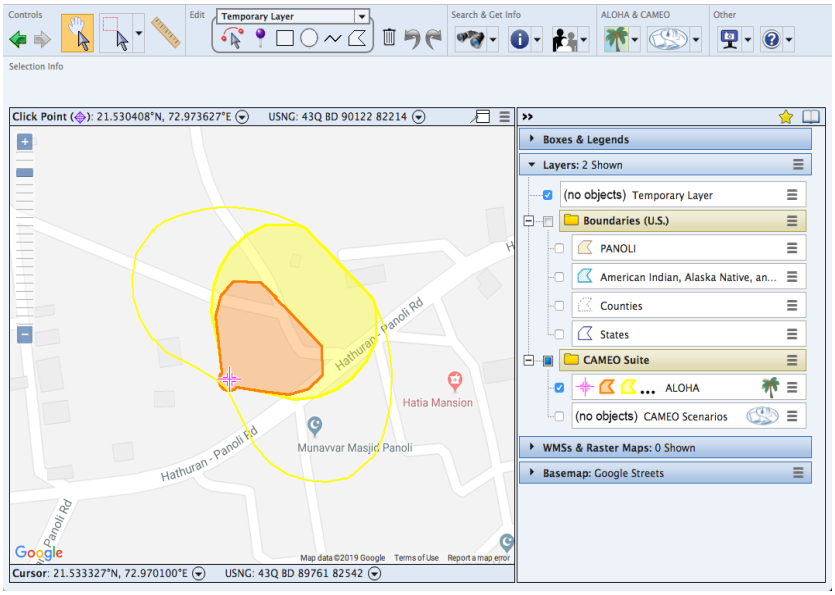

Fig.3: 'Impact Zone Diagram' for the release in the incident area

Hence, in case of LPG dispersions without fire, at least 2 persons are likely to face lethal injuries within an impact area of .005 sq.km, 5 persons is likely to suffer irreversible health effects within an area of 0.013 sq.km and 8 persons will suffer minor reversible health complications within an area of 0.021 sq.km.

3.2 Scenario-2: Flammable Effects from release associated with fire

THREAT ZONE:
Threat Modeled: Flammable Area of Vapor Cloud
Model Run: Heavy Gas
Red : 73 m --- (16000 ppm = LEL)
Orange: 92 m --- (9600 ppm = 60% LEL = Flame Pockets)
Yellow: 235 m --- (1600 ppm = 10% LEL)

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3.2.1 Estimates of Consequences

Red Area (100% of LEL): 0.006 km^2
Societal Risk (Red Area): 0.006 x 401 = 2 persons

Orange Area (60% of LEL): 0.008 km^2
Societal Risk (Orange area): 0.008 x 401 persons = 3 persons

Yellow Area (10% of LEL): 0.034 km^2
Societal Risk (Yellow Area): 0.034 x 401 = 13 persons

Hence, had the LPG leak caught fire, the likely consequences would have been i) 2 persons to face lethal injuries due to acute respiratory problems, ii) 3 persons to suffer irreversible health effects with severe respiratory symptoms and iii) 13 persons to suffer reversible health effects with minor respiratory symptoms.

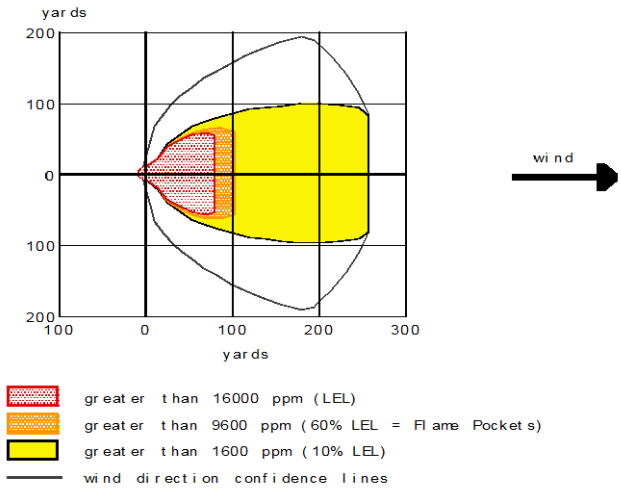

Fig.4: Consequence Effect-distances of LPG release associated with fire

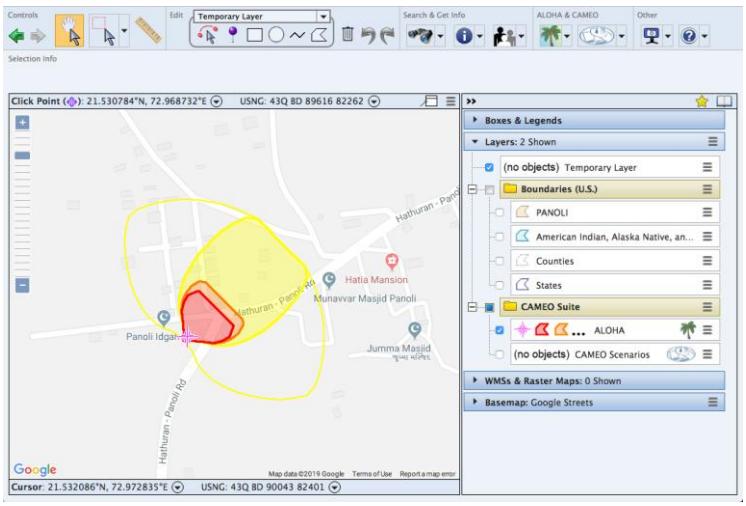

Fig.5: 'Impact Zone Diagram' for the scenario (fire) in the incident area

3.3 Scenario-3: Blast Effects Estimates from Vapour Cloud Explosion

THREAT ZONE:
Threat Modeled: Overpressure (blast force) from vapor cloud explosion
Type of Ignition: ignited by spark or flame
Level of Congestion: congested
Model Run: Heavy Gas
Red : LOC was never exceeded --- (8.0 psi = destruction of buildings)
Orange: 78 m --- (3.5 psi = serious injury likely)
Yellow: 121 m --- (1.0 psi = shatters glass)

3.3.1 Estimates of Consequences

Red Area (8 psi heavy destruction): LOC never exceeded
Societal Risk (Red Area): No person likely to be exposed to this concentration.
Orange Area (3.5 psi, serious injury): 0.003 km^2
Societal Risk (Orange area): 0.003 x 401 persons = 1 person

Yellow Area (1 psi, shatters glass): 0.021 km^2
Societal Risk (Yellow Area): 0.021 x 401 = 8 persons

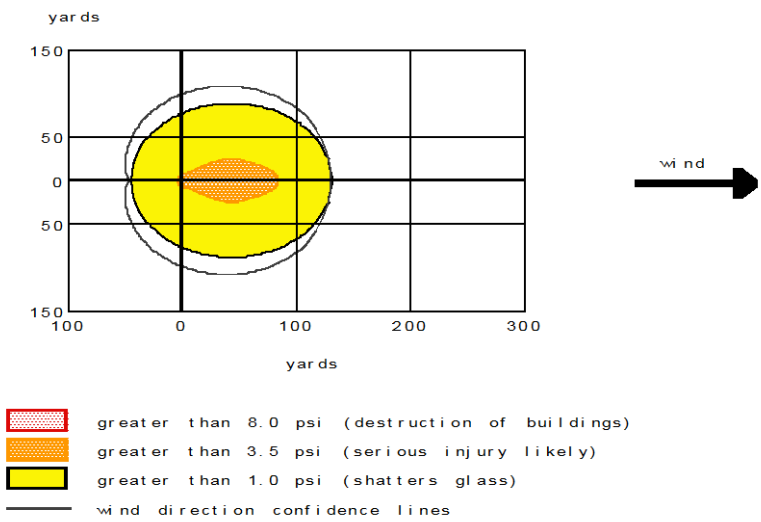

Fig.6: Consequence Effect-distances of LPG release causing vapour cloud explosion

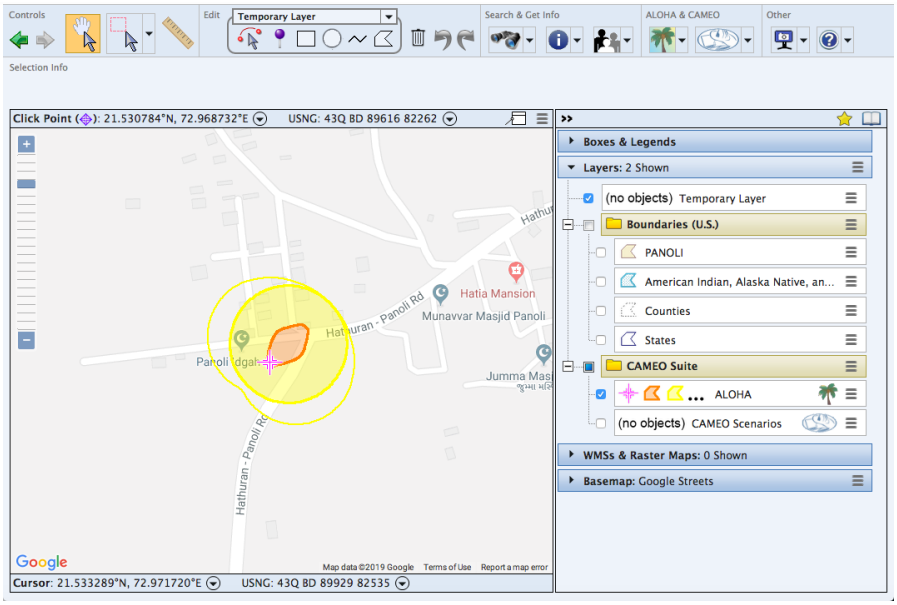

Fig.7: 'Impact Zone Diagram' for the scenario (blast effect) in the incident area

Hence among people in the station area, serious bodily injuries are likely to at least one person in the vicinity. Other minor injuries are likely within 120 m of the vapour cloud explosion site wherein at least 8 persons will suffer minor injuries.

Conclusion

The incident at Panoli Railway station is an example of what would have happened if the released LPG is not capped in time and if it had involved in a fire or a vapour cloud explosion. The consequence of a BLEVE would have been still worst. Railway authorities took timely action to inform oil marketing companies and fire brigades and loud speaker announcement made not to use mobile phones in the vicinity. Also, societal risk would have been higher as compared to the scenarios mentioned. Hence, a proper risk assessment should be the scientific way to estimate the potential loss of lives and properties and the information should become the part of local emergency management planning for proper response by first responders and of the evacuation planning of surrounding population to safety. Sensitization of people is also essential for controlling any such mishaps in future.

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