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[1]Manish Dubey

[2]Dr. Mohammed Ali

Predictive Modeling of Gas Leak Threat Zones in City Gas Distribution Network Using Aloha

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Abstract: - Natural gas is indispensable for urban energy supply in major Indian cities, transported through intricate pipelines that pose inherent risks such as gas leaks. This paper employs historical accident data and the Areal Locations of Hazardous Atmospheres (ALOHA) software to predict gas leak threat zones at pressure reduction stations. Methodologies include scenario selection, condition analysis, and accident modeling using ALOHA, focusing on jet fires. This paper also emphasizes the influence of environmental factors on fire characteristics and thermal radiation distances. The results underscore the criticality of stringent installation standards and effective emergency responses in mitigating gas leak risks. Recommendations are provided for enhancing safety measures and emergency preparedness in city natural gas distribution network.

Keywords: Natural gas, gas leak, ALOHA software, predictive modeling, urban safety, City gas distribution network, fire scenarios, and emergency preparedness.

1. Introduction

Natural gas, primarily composed of methane, is an efficient and environmentally friendly fuel widely used in urban areas of India, including Mumbai, Delhi, Lucknow, Surat, Hyderabad, etc. It is transported through intricate pipeline networks categorized into gathering, transmission, and distribution pipelines. In India, natural gas is transported at high pressures and undergoes multiple pressure reductions at regional regulator stations before reaching end users.

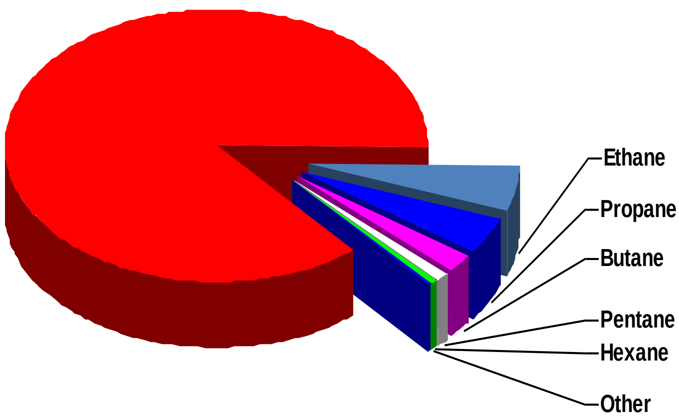


Figure No. 1- Composition of Natural Gas

Natural gas, known for its efficiency and environmental friendliness, is widely utilized in homes, businesses, and industrial sectors in Mumbai. It is transported through either pipeline in its gaseous form or by tankers as liquefied natural gas (LNG). Delivering natural gas to end users involves a complex pipeline network, which is divided into three categories:

1. **Gathering Pipelines**: These pipelines transport gas from the production sites, or wellheads, to collection plants.
2. **Transmission Pipelines**: These pipelines carry natural gas from collection plants to facilities for refinement, processing, storage, and further distribution.

[1]Ph.D. Scholar, Mechanical Engineering Department, Oriental University, Indore, Madhya Pradesh, India

[2]Professor, Mechanical Engineering Department, Oriental University, Indore, Madhya Pradesh, India

3. **Distribution Pipelines**: These pipelines deliver natural gas from transmission pipelines directly to consumers in residential and commercial areas.

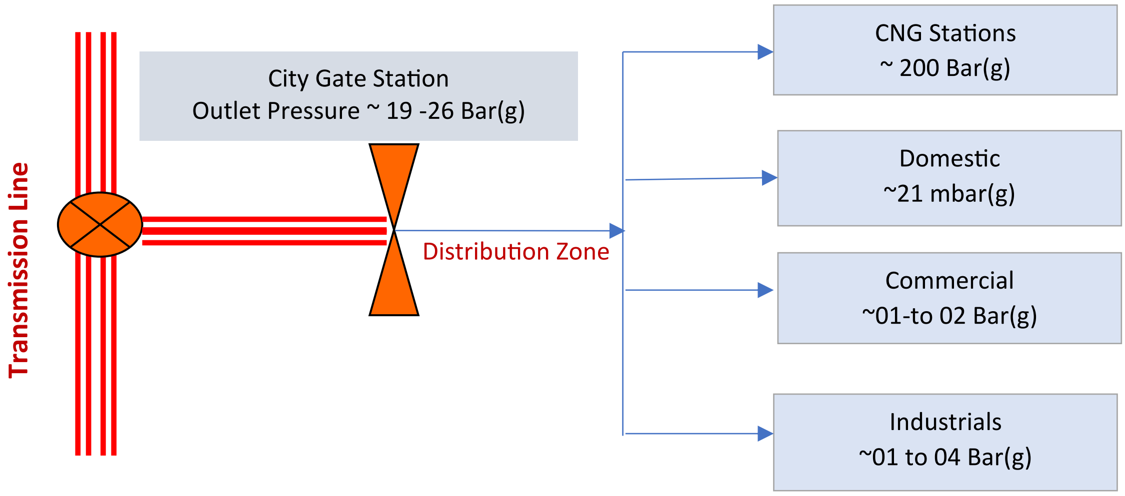


Figure No. 2-City Gas Distribution Network

In India, natural gas is transported between cities at high pressures (35–75 bar) through steel transmission pipelines. At main pressure reducing stations (RMS) near cities, the pressure is reduced to 20–40 bar or 12–19 bar, depending on the distribution network. The gas is then directed through steel distribution lines to regional regulator stations within the city. At these stations, the pressure is further decreased to approximately 1–4 bar for industrial use, 1–2 bar for commercial use, 200 bar for CNG stations, and 21 mbar for domestic use. It is then delivered to residential service boxes via polyethylene pipelines (63 to 125 mm in diameter) buried at a depth of 0.8–1 meter. At the service boxes, the pressure is further reduced to 21–300 mbar, based on the building's usage needs.

Despite the benefits, the transportation of natural gas via pipelines poses significant risks, including potential gas leaks that can result in severe environmental and public safety hazards. Various accident data from different sources reveals that accidents, even in companies with robust safety records, can cause substantial economic losses and fatalities. These incidents underscore the importance of accurately predicting gas leak threat zones to enhance safety measures.

This paper aims to utilize historical accident data and ALOHA software to predict gas leak threat zones in metro cities of India. By developing a predictive model, the research seeks to improve public safety and mitigate risks associated with natural gas city distribution networks.

2. Materials and Methods

Accident outcome modeling predicts the impact of hazardous substance releases, focusing on emissions, fires, explosions, and toxic dispersions. The methodology for modeling gas leaks at a gas pressure reduction station includes four stages:

- Scenario Selection: Choose gas leak or fire scenarios for hot and cold seasons, then simulate and examine them.
- Condition Analysis: Investigate variable conditions like weather and substance emissions, considering both seasons.
- Accident Modeling: Use ALOHA software to model scenarios and map the impact of material toxicity and fire for each season.
- Damage Assessment: Assess damage based on modeling results and provide safety recommendations, considering seasonal variations.

This approach helps understand and mitigate gas leak and fire consequences, enhancing safety and preparedness.

ALOHA is a computer-based modeling tool which helps emergency responders and planners to assess hazards and risks from accidental releases of hazardous substances. ALOHA estimates how these substances disperse in the atmosphere, predicts their impact on health and the environment, and guides emergency response actions. It is used for planning, decision-making, risk assessment, and mitigation efforts, helping to determine evacuation zones, shelter-in-place recommendations, and the need for protective measures. This tool is essential for emergency management agencies, industrial facilities, and other stakeholders in emergency response planning and preparedness.

In this paper, ALOHA software is utilized for hazard modeling of city gas distribution network.

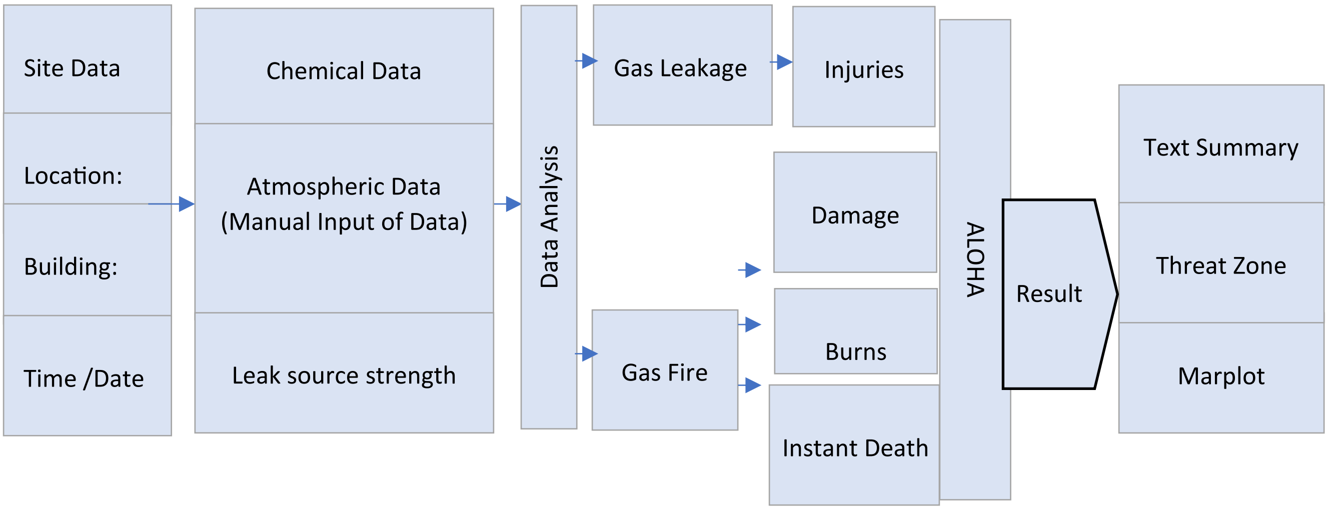


Figure No. 3- Flow Chat of ALOHA

In Jet Fire Modeling the calculation of release rates, estimate flame characteristics and assess thermal radiation levels are done. The threat zones are evaluated, where fire hazards exceed safety thresholds, considering human exposure, structural damage, and environmental impact. Visualization and reporting are done through MARPLOT for Visual Map.

To enter information into the ALOHA software, follow these steps:

Step 1: - Identify Location and Timing: Determine the city, specific site location, longitude, latitude, elevation, and the date and time of the chemical release.

Step 2: - Select Relevant Chemical: Choose the appropriate chemical from ALOHA's database. For example, methane with properties such as a molecular weight of 16.04 g/mol, LEL of 50,000 ppm, UEL of 150,000 ppm, and a boiling point of -258.7°C for precise modeling of dispersion and hazards.

Step 3: - Input weather conditions including wind speed, wind direction, ground roughness, air temperature, stability class, cloud cover, humidity level, and inversion height to ensure accurate assessment.

Step 4: - Enter Leak Source Strength: Provide leak source details like pipe diameter, pipe length, pipe roughness, hole area, pipe pressure, pipe temperature, release duration, and release rate for precise modeling of the leak source strength.

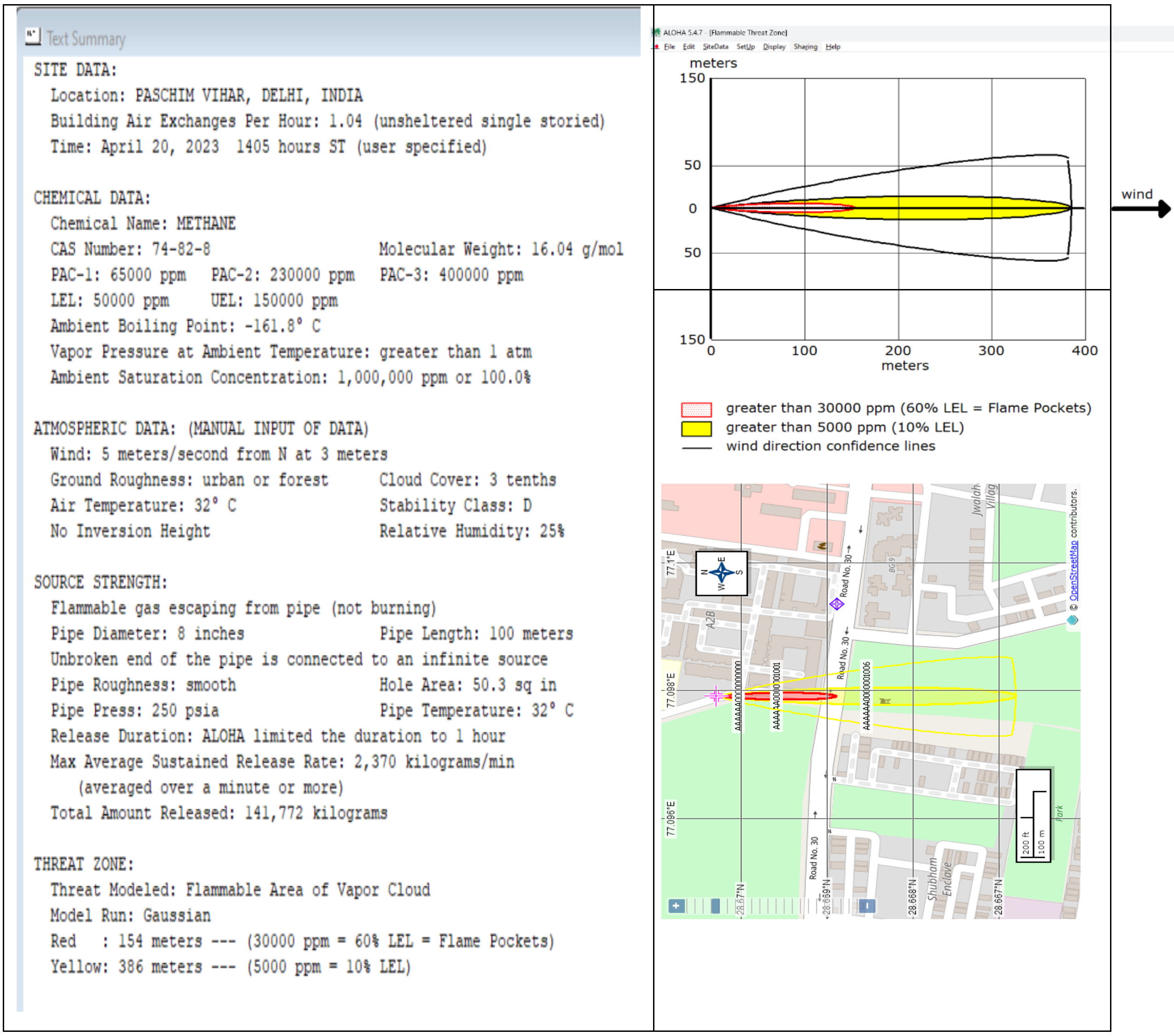
3. Results and Discussions

The work considers three major imaginary scenarios in different cities of India.

Scenario No.: - I

On April 20, 2023, at 14:05 hrs, a fire outbreak occurred in Paschim Vihar, Delhi, India, following a gas leak from a faulty installation of a commercial gas distribution pipe carrying PNG (pressure between 0.1 to 0.2 Bar(g)). The incident took place at an unsheltered single-story building. The CGD company responded promptly to the leak report, arriving by 14:20 hrs to find the leak originating from an 8-inch diameter, 100-meter long MDPE pipe damaged during third-party excavation. Atmospheric conditions at the time included a wind speed of 4.2 m/s from the east, partly cloudy skies, a temperature of 28.4 °C, and 45% humidity. The pipe, with a smooth surface and a hole area of 50.3 square inches, was pressurized at 250 psia and 32°C.

Modeling studies conducted for pipe lengths ranging from 25 m to 1000 m showed a non-linear decrease in threat distances with increasing pipe length, stabilizing for longer distances. This scenario provides critical data for ALOHA software to analyze the impact of gas leaks and subsequent jet fire risks under similar environmental conditions. It underscores the importance of adhering to stringent installation standards and maintaining emergency readiness to mitigate such incidents in urban areas.


Text Summary

SITE DATA:
Location: PASCHIM VIHAR, DELHI, INDIA
Building Air Exchanges Per Hour: 1.04 (unsheltered single storied)
Time: April 20, 2023 1405 hours ST (user specified)

CHEMICAL DATA:
Chemical Name: METHANE
CAS Number: 74-82-8 Molecular Weight: 16.04 g/mol
PAC-1: 65000 ppm PAC-2: 230000 ppm PAC-3: 400000 ppm
LEL: 50000 ppm UEL: 150000 ppm
Ambient Boiling Point: -161.8° C
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: 5 meters/second from N at 3 meters
Ground Roughness: urban or forest Cloud Cover: 3 tenths
Air Temperature: 32° C Stability Class: D
No Inversion Height Relative Humidity: 25%

SOURCE STRENGTH:
Flammable gas escaping from pipe (not burning)
Pipe Diameter: 8 inches Pipe Length: 100 meters
Unbroken end of the pipe is connected to an infinite source
Pipe Roughness: smooth Hole Area: 50.3 sq in
Pipe Press: 250 psia Pipe Temperature: 32° C
Release Duration: ALOHA limited the duration to 1 hour
Max Average Sustained Release Rate: 2,370 kilograms/min
(averaged over a minute or more)
Total Amount Released: 141,772 kilograms

THREAT ZONE:
Threat Modeled: Flammable Area of Vapor Cloud
Model Run: Gaussian
Red : 154 meters --- (30000 ppm = 60% LEL = Flame Pockets)
Yellow: 386 meters --- (5000 ppm = 10% LEL)

Figure No.4 Text Summary, Threat Zone and Visual site map of gas leakage in city1

Scenario No.: -II

On April 10, 2023, a jet fire erupted in Andheri, Mumbai, India, caused by a gas leak from a gas company's 32 mm MDPE pipeline that was damaged during excavation work by the electrical department. The incident occurred at around 17:45 hrs during the digging of a pit to install a dismantled electrical pole. The damaged pipeline, 8 inches in diameter and 100 m in length, was under pressure of 250 psi and 32°C. The leak originated from the pipe, which had faulty installation under high air exchange conditions of 15 m² per hour in an unprotected single-story building. The fire was triggered by an electrical short circuit at 12:30 hrs on the same day. The supervisor immediately reported the damage to the MDPE pipe to the emergency contact number, prompting the O&M team to reach the site. They successfully stopped the gas flow and repaired the damage by 20:30 hrs. This incident underscores the critical importance of vigilance during excavation activities to prevent damage to the gas pipeline and highlights the need for robust installation practices and emergency preparedness to minimize the risk of jet fire in urban environments

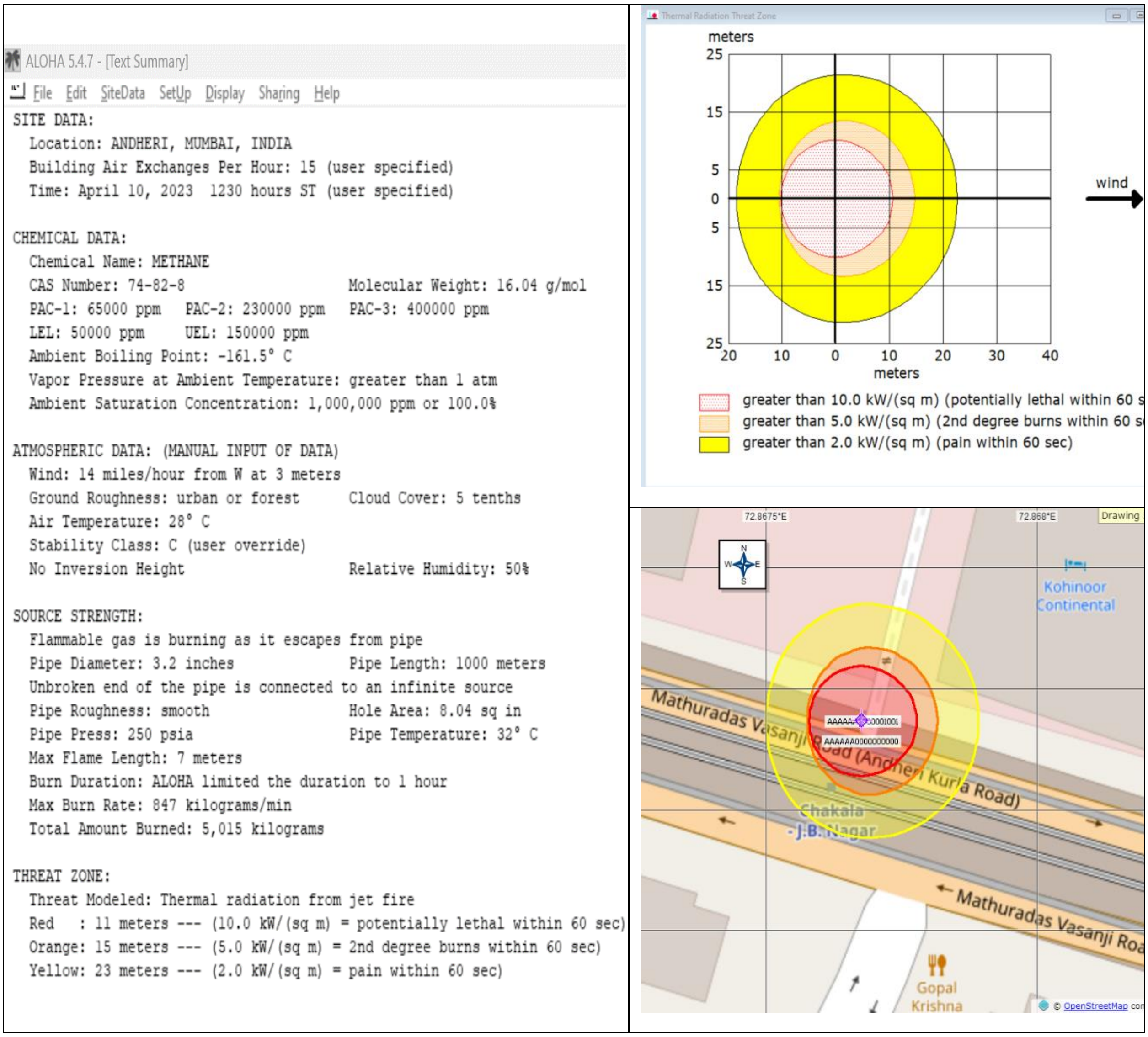


Figure No.5 Text Summary, Threat Zone and Visual site map of gas leakage in city2

Scenario No.: -III

On June 15, 2023, at 05:54 hrs ST, a jet fire erupted on a highway in Surat City, India, due to a gas leak from a 63mm diameter pipeline. The pipeline, spanning 1000 meters in length, was under a pressure of 19 bar and had a hole area of 3 square centimeters, caused during open trenching for water pipeline installation by the Water Department. The incident was promptly rectified by 11:15 AM. The unbroken end of the pipeline was connected to an infinite source, exacerbating the fire. With smooth pipe roughness, the pipeline was pressurized at 150 psia and maintained a temperature of 42°C. The resultant fire reached a maximum flame length of 15 meters. This scenario occurred in a sheltered, double-storied building environment in Surat, with a low air exchange rate of 0.65 exchanges per hour.

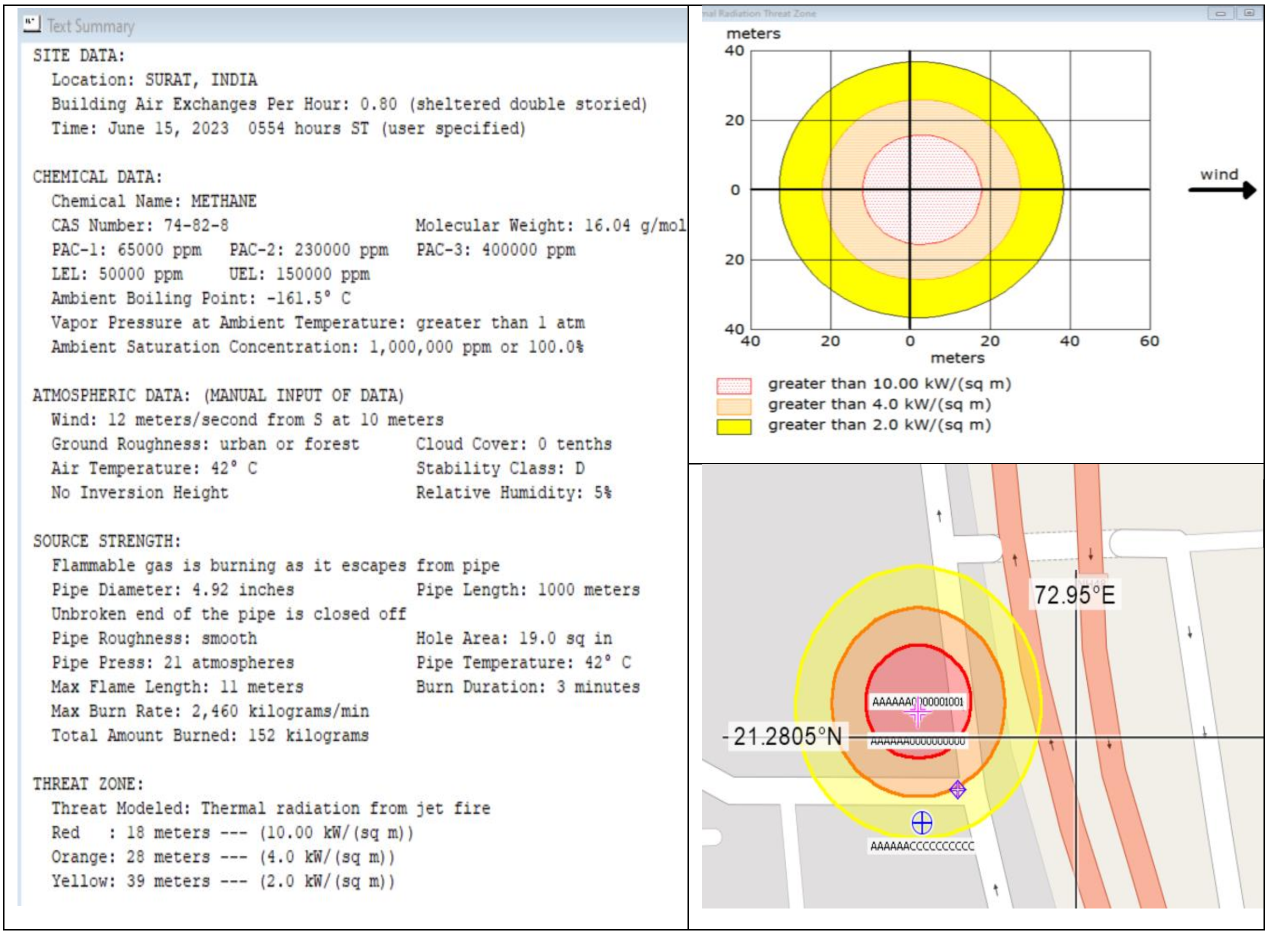


Figure No.6 Text Summary, Threat Zone and Visual site map of gas leakage in city3

Table No.1 Details of Input data for 3cities.

Aspect	Scenario-I	Scenario-II	Scenario-III
Date	April 20, 2023	April 10, 2023	June 15, 2023
Time	14:05 hrs	17:45 hrs	05:54 hrs
Location	Paschim Vihar, Delhi,	Andheri, Mumbai,	Surat, Gujarat
Incident	Fire outbreak due to gas leak	Jet fire due to gas leak	Jet fire due to gas leak
Pipeline Diameter	8 inches	8 inches	63 mm
Pipeline Pressure	0.1 to 0.2 Bar(g)	250 psi	19 bar
Hole Area	50.3 square inches	50.3 square inches	3 square centimeters
Pipe Temperature	32°C	32°C	42°C
Environmental Conditions	Wind speed 4.2 m/s, partly cloudy, 28.4°C, 45% humidity	High air exchange (15 m² per hour), unprotected building	Sheltered double-storied building, low air exchange (0.65/h)
Cause of Leak	Faulty installation and third-party excavation	Damage during excavation by electrical department	Open trenching for water pipeline installation

Results of the Scenarios:

In three scenarios, the threat zones for gas leaks and fires were modeled by considering the gas leak, location information, atmospheric conditions, and leak source strength. Table 2 shows the results for each scenario in the three different cities.

Table No.2 Result of fire scenario for 3cities.

Scenario	Emission Data			Risk Area of Thermal Radiation (kW/sq.m)		
	Maximum flame lengt (meters)	Burning Speed (kilograms/min)	Total amount of burning (kilograms)	**10**	**4**	**2**
Scenario-I	100	2,370	141,772	30	39	74
Scenario-II	7	32.3	845 kilograms	11	15	23
Scenario-III	11	2,460	152 kilograms	18	28	39

4.Discussion

The use of ALOHA for modeling jet fires provides valuable insights into the hazards associated with gas pipeline operations. However, it is essential to consider the limitations of the software, such as the reliance on simplified models and assumptions. The accuracy of the results depends on the quality of the input data and the specific conditions of each scenario. Therefore, it is recommended to use ALOHA in conjunction with other tools, expert knowledge, and site-specific data for a comprehensive assessment.

The use of ALOHA software provides valuable insights into the hazards associated with fire scenarios in city gas distribution systems. Limitations include assumptions in modeling techniques and the need for accurate input data. Recommendations include combining software modeling with expert knowledge and real-world validation to enhance hazard assessments and emergency preparedness.

5.Conclusion

This paper illustrates the effective use of the ALOHA software in predicting gas leak threat zones within urban environments in cities across India. By simulating scenarios such as jet fires in cities like Mumbai, Delhi, and Surat, we have highlighted the significant factors influencing fire characteristics and thermal radiation distances. MARPLOT is utilized to visually map the threat zones predicted by ALOHA, offering a clear visualization of potential hazards and concentration estimates at specific locations. Our findings underscore the critical role of accurate environmental data and proactive emergency preparedness in mitigating the risks associated with natural gas distribution networks in these urban centers. Recommendations from this research stress the importance of stringent installation standards and swift emergency response strategies to enhance public safety and protect infrastructure. Moving forward, continued utilization of advanced modeling tools like ALOHA will be essential for strengthening the resilience of city gas distribution systems against potential hazards. Therefore, preparing emergency response plan as part of this research will be instrumental in reducing the adverse effects of toxic and hazardous substance releases. For further research, incorporating an explosion scenario alongside modeling various scenarios simultaneously can provide additional.

References

[1] Joe, Y.-D.; Ahn, B.J. (2022) Analysis of Hazard Area Associated with Pressure Natural-Gas Pipeline. J. Loss Prev. Process Ind. 15, 179–188.

[2] Vairo, T., Pontiggia, M., Fabiano, B. (2021) Critical aspects of natural gas pipelines risk assessments. A case-study application on buried layout. Process Saf. Environ. Protect. 149, 258–268.

[3] Rajeev, K., Soman, S., Renjith, V.R., George, P. (2019) Human vulnerability mapping of chemical accidents in major industrial units in Kerala, India for better disaster mitigation. Int. J. Disaster Risk Reduct. 39, 101247.

[4] Gupta, P., Thein Zan, T.T., Wang, M., Dauwels, J., Ukil, A. (2018) Leak detection in low- pressure gas distribution networks by probabilistic methods. J. Nat. Gas Sci. Eng. 58, 69–79.

[5] Silva, E.C. (2017) Accidents and the technology. J. Loss Prev. Process. Ind. 49, 319–325. Tseng, J.M., Su, T.S., Kuo, C.Y., 2012. Consequence evaluation of toxic chemical release by ALOHA. Procedia Eng. 45, 384–389.

[6] Azari, P.; Karimi, M. (2017) Quantitative Risk Mapping of Urban Gas Pipeline Networks Using GIS. Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci. 2017, XLII-4/W4, 319–324.

[7] Liu, D., Wei, J., (2017) Modelling and simulation of continuous dense gas leakage for emergency response application. J. Loss Prev. Process. Ind. 48, 14–20.

[8] Praveen Patel and Nagendra Sohani (2015) Hazard Evaluation using Aloha Tool in storage area of an oil refinery, IJRET: International Journal of Research in Engineering and Technology, Vol. 04, 203-209.

[9] Vianello, C.; Maschio, G. (2014) Quantitative Risk Assessment of The Italian Gas Distribution Network. J. Loss Prev. Process Ind., 32,5–17.

[10] Nolan, D.P. (2014) Handbook of Fire and Explosion protection Engineering Principles: for Oil, Gas, Chemical and Related Facilities. William Andrew.

[11] Hans Pasman and Genserik Reniers (2014) Past, Present and Future Quantitative risk assessment and the incentive it obtained from land use planning. Journal of loss prevention in the process industries, 28, 2-9.

[12] Rathnayaka, S., Khan, F., Amyotte, P. (2012) Accident modeling approach for safety assessment in an LNG processing facility. J. Loss Prev. Process. Ind. 25 (2), 414–423

[13] Shao, H., Duan, G., (2012) Risk quantitative calculation and ALOHA simulation on the leakage accident of natural gas power plant. Procedia Eng. 45, 352–359.

[14] Gang Dong, (2010) Evaluation of hazard range for the natural gas jet released from a high-pressure pipeline: A computational parametric study Journal of Loss Prevention in the Process Industries, 23, p.522-530.

[15] Robert E. Melchers and William R. Feutrill (2001) Risk Assessment of LPG automotive refueling facilities, Reliability Engineering and System Safety, Vol. 283-290.