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Integrated Approach for Natural Gas Accidental Release: Simulation and Cost Estimation

Amir Naveed[a]*, Muhammad Noman[b], Muhammad Arif[a], Amina Rahat[c], Muhammad Sadiq[d], Muhammad Asif[e] and Fatima Umul Baneen[f]

[a]Center for Advance Studies in Energy Engineering, University of Engineering and Technology, Peshawar, KPK, Pakistan

[b]Department of Chemical Engineering, University of Engineering and Technology Peshawar, KPK, Pakistan

[c]Food and Nutrition, College of Home Economics, University of Peshawar, KPK, Pakistan

[d]Department of Mechanical Engineering, UET Peshawar, KPK, Pakistan

[e]Department of Electronics, University of Peshawar, KPK, Pakistan

[f]Lahore Medical and Dental College, Pakistan

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Abstract. Accidental release of natural gas from the distribution lines poses a big challenge to pipeline operators. This accidental release causes shocking accidents and also a major economic loss due to the flammability and dispersed nature of the released natural gas. The current study presents detailed data of losses caused by various gas incidents of a gas company and identifies potential threat zones offered by pipeline networks. Potential threat zones of thermal, toxic, flammable and overpressure for serious health impact and economic damage are also identified in case of accidental release of natural gas. A simulation was done for different diameter pipelines, having different pressure and temperature parameters for certain geographic networks of distribution pipelines. This enables natural gas companies to analyze the impacts of each phase of the events and to utilize their resources with the greatest success of the defense conservation and emergency response system.

Keywords: simulation, natural gas, accidental release

Introduction

Distributing of natural gas to customer contain installation and maintenance of complex piping systems largely affected by their respective operating pressure and temperature (Ahmed and Kabir, 2021). Pipelines are considered to be the most economical and effective way of transportation for a flammable substance like natural gas. Pipeline operators and regulatory authorities in many countries are not following the standard operating procedures (SOP) during operation and handling to keep natural gas distribution lines safe (Ikealumba *et al*., 2016). Due to this lack of expertise and unavailable hazards point management, there is the ever-present threat of accidental release of natural gas due to interference with the integrity of pipelines (Yafei *et al*., 2014). A large number of fatalities, property and human losses occur when accidental fire, explosion and toxic dispersion certainly happen. A suitable plan of risk analysis is progressively important in the gas pipelines transmission, thereby reducing the hazards. Over time in a growing community important issues of gas pipelines like under and upper ground construction of buildings arise which need special attention of regularities that how to plane gas distribution to enhance safety factors and control accidental losses. Therefore, it is important to carry out comprehensive risk estimation in terms of cost and simulation of accidental release from the natural gas pipelines (Shao and Duan, 2012). Various risk estimation and modeling simulation software are available for locating potential hazardous in distribution lines.

Amongst these software ALOHA Simulator (areal locations of hazardous atmospheres) is the one, which is applied to enhance safety factors for gas pipeline companies during the distribution of gases (Park *et al*., 2004). Modeling software ALOHA is utilized for mapping various accidental releases of certain geographic pipeline networks. This forecasting and mapping of possible hazards will assist the emergency planners and first responders to stay prepared more effectively for dealing with the accidental release (Stephens, 2000). The current study is focused on employing ALOHA to simulate and predict the potential threat zones for serious

*Author for correspondence;
E-mail: amirkhattak@uetpeshawar.edu.pk

health effects and economic damage. This research work also assesses the impact of each incident category to improve the means of safety and help in devising effective preventive maintenance programs.

Materials and Methods

Risk estimation. Fatalities, injuries and losses of property occur when gas pipelines are broken (Jo and Ahn, 2003). In safety planning and management, risk estimation is a very important fundamental safety factor in a gas pipeline network. The term risk refers to the combination of the likelihood of incidences of a hazardous event and the severity of consequences caused by the event (Park *et al*., 2004).

Total risk = Total cost (Rs/year) .... (1)
Risk (Rs/year = Consequence (Rs/event) × frequency (event/year) .... (2)
Cost (Rs/year) = Risk total = $\Sigma Cs \times Fs$ .... (3)

The term risk is highly dependent on the cost of each incident borne by the distribution company. Total cost is related to the cost of maintenance or repair, material loss, damage of humans and building and supply interruption (Jo and Crow, 2008; Mannan, 2005).

C total = C material loss + C human fatality/Injury + C repair .... (4)

In this work, a case study of a local company of natural gas distribution in Pakistan for the years of 2011, 2012 and 2013 in a certain geographic network is carried out. The average cost of natural gas was considered 2.8652 US dollars/MCF. The case study was done for the different categories of losses that heavily impact on company economy *i.e*. material losses, destruction of building, human juries, fatality and maintenance cost. From the Table 1, material loss during the unsafe act is heavily dependent on the total cost.

Incident frequency evaluation. In this research project, the name of the incident is the unintentional discharge of natural gas into the gas distribution lines. The gas supply to the pipelines is organized into three separate phases by the size of the leak described in Table 2.

Incident is caused by many reasons but we considered following causes *i.e*. Incident due to 3rd party excavation works, incident due to construction defects, incident due to corrosion defects in the pipeline, incident due to ground movement like flood, landslide etc. Incident because of warm tape made by error, incident due to designing error, maintenance and lightening etc. The frequency of incidents is founded from incident statistics of gas pipeline companies and the survey of gas leakage detection (GLD) natural gas pipeline of the unnamed gas company in the north of Pakistan for certain geographic networks in the year 2011, 2012 and 2013. The probability of ignition for small, large leakage and rupture is taken from ECIG group report 2011 (Jo and Ahn, 2005) and shown in Table 3.

Consequence evaluation. Accidents in gas distribution system always results in gas release and fire eruption. Consequences of such accidents will be identified from the rate analysis of the gas release and fire analysis of the accident. Further, they will be analysed in terms of their release scale (small or large) and nature of the pipeline rupture. Gas emissions analysis will be available at each stage of the incident. In the event of a split, the

Table 1. Cost analysis for different losses categories

Classification of losses	Cost (US dollar)
Physical loss	10081755.22
Cost of construction, human casualty/ injury	249355.71
Cost of Overhaul	37.91
Total	**10676844.46**

Table 2. Release of natural gas in different dimensional pipelines

Gas release from different pipe size	Measurements
Small scale leak (Pinhole/crack)	Pipe with less diameter with hole of equal or less to 5mm.
Large scale release	Natural gas pipe with the (Hole) diameter of 30mm and smaller.
Rupture	Pipe with similar hole to the pipeline diameter.

Table 3. Distribution of incident per cause and ignition probabilities

Dimensions of leakage	Ignition possibilities (%)
Small scale leak	5
Large scale release	3
Rupture	14

gas discharge will be found in the 2011, 2012 and 2013 natural gas pipeline company statistics (US dollar/event). With smaller discharges and larger discharges, gas extraction data will be available in the gas leak detection study (GLD). The cost of repairing the site renovation for each case of minor leaky pipe damage, large scale disassembly and cracking will be estimated from real-time costs. Figure 1, shows that external interferences are the biggest threat to pipeline safety which are causing a major gas release followed by construction defects and corrosion defects. It also shows that major loss to natural gas operator is due to large-scale release which will be controlled in preventive maintenance program by reducing their response time.

In this research work, the study of cases of accidental loss due to third party interference, material failure, pipe corrosion, ground movement due to nature, accidental hot tape and other small losses compared to small, large pipe and snatching. For small scale pipe leak, In the year of 2011, 2012 and 2103 number of accident was calculated in the range of 5902, total volumetric losses of gas was calculated 6583912 MCF and total cost of all these losses were calculated 18865989.15 US dollar. While for large pipe, in the year of 2011, 2012 and 2013 number of the accident was 3000 in number, volumetric loss of gasses from a large pipe is 20736000 and the total loss in the term of cost is 59438188.80 US Dollar. The number of incident, volumetric loss and their financial impact for the year of 2011, 2012 and 2103 for the ruptures is 35, 131903 and 378108.26 US dollars, respectively as shown in Fig. 1.

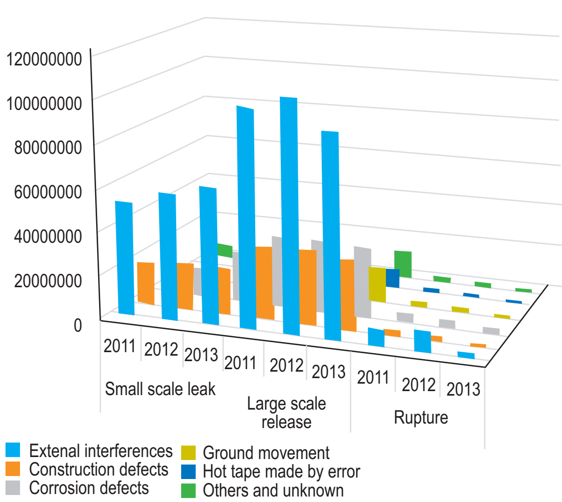


Fig. 1. Comparative cost and accidental analysis of 2011, 2012 and 2013.

Accidental release modeling. In modeling non-routine accidental releases, we know that it is limited duration release e.g. rupture of a gas pipeline. Due to this limitation, accidental releases are not well understood. Accidental release involves immediate health effect such as injury, fatality and property loss such as building or equipment damage (Han and Weng, 2010). ALOHA simulator is use for dispersion modeling of non-routine or accidental release (Han and Weng, 2011). The term ALOHA is stand for "area locations of hazardous atmosphere" developed by US agencies of environmental protection and emergency response division. ALOHA is an air purifier designed to measure the hazardous conditions of chemical emissions and to measure the underlying causes (Slavounos and Rigas, 2006). ALOHA can model many hazards such as radiation, toxins, burns and excess stress and map out the threatening areas in sequence the threat of heat, toxic hazard, the burning threat and the extremely threatening area (Zhenghua and Jianhua, 2012). In ALOHA the graphical interface is used for data entry and the results are shown in diagrams as steps in Fig. 2. Results are summarized in the text. ALOHA is designed to provide close proximity to threatening levels associated with chemical spills and emissions. Below are the details needed to build an ALOHA model for a specific project.

Input parameters. Enter site details by entering the city name, date and time of the chemical release that is taking place; select the chemicals considered in the ALOHA chemical library; describe the atmospheric conditions and the gravity of the soil in the excavation area; Select the source by specifying which mode the chemical escapes (e.g., leaking liquid in the tank); Identifying areas of threat, to assess whether the risk

Table 4. Pipeline diameter, length and approximate operating pressure

Pipeline diameter (Inches)	Length (Km)	Approx pressure (Psia)
18	13	100
16	32	90
12	26	80
10	28	70
8	133	60
6	382	60
4	1032	60
2	1552	60
1	2424	60

(toxicity, heat, radiation and excessive pressure) has exceeded the level of concern (LOCs) or not.

Results and Discussion

The accidental consequence calculation for gas pipelines and other dangerous equipment's within the range of city through ALOHA is shown in Fig. 6 and Fig. 7.

The impact and proliferation of threatening environments can be easily mimicked using ALOHA mimics (Shu-Jiao *et al*., 2013). As mentioned before the publication of ALOHA is one of the most powerful tools in emergency response planning in the event of an accident (Hasan and Ahmed, 2000). This section will explain how it is used to identify.

This section will explain how it is used to identify various threats to the natural gas pipeline. ALOHA will identify the most threatened areas in red, orange and yellow according to the level of concern (LOCs) selected by default, with red representing the worst-case scenario, and the threatened orange and yellow areas representing areas that reduce risk (Brito *et al*., 2009; Jonkman *et al*., 2003; Rnaldo *et al*.,1998). Below the Fig. 4 & 5 show potentially dangerous areas in hot, toxic, flammable and over pressure areas in the event of cracks, large discharges and small leaks. The threat area is where ALOHA predicts that the level of risk will exceed your level of concern (LOC) sometime after the initial release. ALOHA can model multiple hazards (toxicity, heat, radiation or excessive pressure) and the type of LOC will choose by accident.

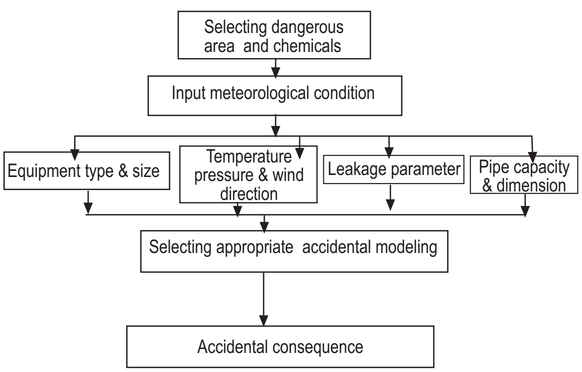
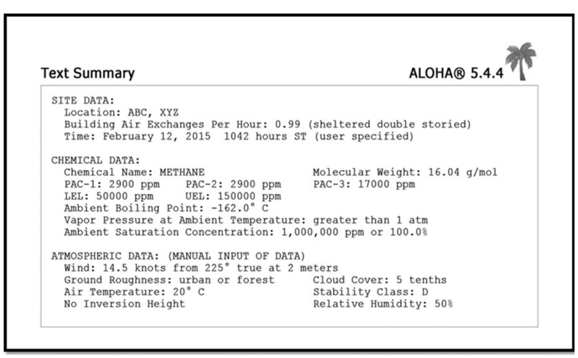


Fig. 2. Process schematic of consequences calculation through ALOHA.



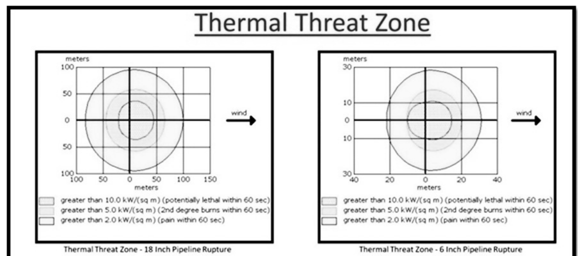
Text Summary ALOHA® 5.4.4

```
SITE DATA:
  Location: ABC, XYZ
  Building Air Exchanges Per Hour: 0.99 (sheltered double storied)
  Time: February 12, 2015  1042 hours ST (user specified)

CHEMICAL DATA:
  Chemical Name: METHANE                    Molecular Weight: 16.04 g/mol
  PAC-1: 2900 ppm    PAC-2: 2900 ppm        PAC-3: 17000 ppm
  LEL: 50000 ppm     UEL: 150000 ppm
  Ambient Boiling Point: -162.0° 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: 14.5 knots from 225° true at 2 meters
  Ground Roughness: urban or forest         Cloud Cover: 5 tenths
  Air Temperature: 20° C                    Stability Class: D
  No Inversion Height                       Relative Humidity: 50%
```

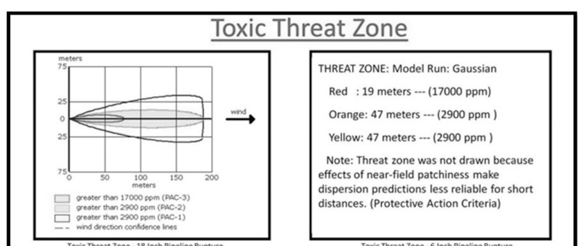
Fig. 3. Text summary of input parameters to ALOHA software.



THERMAL THREAT ZONE

	Release level	Pipe Diameter (Inches)									Radiation Intensity
		18	16	12	10	8	6	4	2	1	
Red zone (Meters)	Rupture	45	43	31	26	21	15	10	10	<10	(10.0 kW/(sq m) = potentially lethal within 60 sec)
	Large Scale	10	10	10	10	10	10	10	10	<10	
	Small Scale	Less than 10 meters									
Orange zone (Meters)	Rupture	66	62	44	36	29	20	13	10	<10	(5.0 kW/(sq m) = 2nd degree burns within 60 sec)
	Large Scale	10	10	10	10	10	10	10	10	<10	
	Small Scale	Less than 10 meters									
Yellow zone (Meters)	Rupture	100	95	68	56	44	31	20	10	<10	(2.0 kW/(sq m) = pain within 60 sec)
	Large Scale	16	16	16	16	16	16	15	10	<10	
	Small Scale	Less than 10 meters									

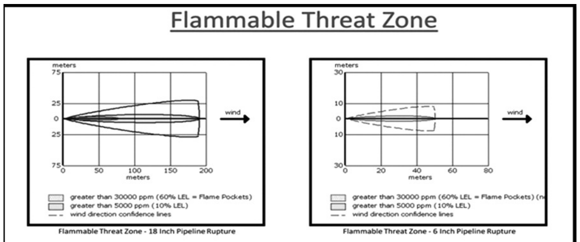
Fig. 4. Thermal threat zone probabilities of the natural gas pipeline.



TOXIC THREAT ZONE

	Release level	Pipe Diameter (Inches)									Concentration
		18	16	12	10	8	6	4	2	1	
Red zone (Meters)	Rupture	73	66	44	35	27	19	11	<10	<10	(17000 ppm = PAC-3)
	Large Scale	20	20	20	20	20	20	16	<10	<10	
	Small Scale	Less than 10 meters									
Orange zone (Meters)	Rupture	179	161	108	86	65	47	26	<10	<10	(2900 ppm = PAC-2)
	Large Scale	50	50	49	49	48	48	39	<10	<10	
	Small Scale	Less than 10 meters									
Yellow zone (Meters)	Rupture	179	161	108	86	64	47	26	<10	<10	(2900 ppm = PAC-1)
	Large Scale	50	50	49	49	48	48	39	<10	<10	
	Small Scale	Less than 10 meters									

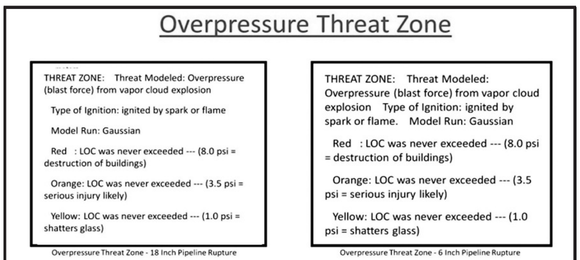
Fig. 5. Toxic threat zone accident probabilities of the natural gas pipeline.



FLAMMABLE THREAT ZONE

	Release level	Pipe Diameter (Inches)									Concentration
		18	16	12	10	8	6	4	2	1	
Red zone (Meters)	Rupture	77	70	47	38	28	20	11	<10	<10	(30000 ppm = 60% LEL = Flame Pockets)
	Large Scale	22	22	22	22	21	21	17	<10	<10	
	Small Scale	Less than 10 meters									
Yellow zone (Meters)	Rupture	191	172	116	92	69	50	28	11	<10	(5000 ppm = 10% LEL)
	Large Scale	53	53	53	52	52	52	41	11	<10	
	Small Scale	11	11	11	11	11	11	11	10	<10	

Fig. 6. Flammable threat accident probabilities of the natural gas pipeline.



OVERPRESSURE THREAT ZONE

	Release level	Pipe Diameter (Inches)									Pressure
		18	16	12	10	8	6	4	2	1	
Red zone (Meters)	Rupture	LOC was never exceeded									(8.0 psi = destruction of buildings)
	Large Scale	LOC was never exceeded									
	Small Scale	LOC was never exceeded									
Orange zone (Meters)	Rupture	LOC was never exceeded									(3.5 psi = serious injury likely)
	Large Scale	LOC was never exceeded									
	Small Scale	LOC was never exceeded									
Yellow zone (Meters)	Rupture	LOC was never exceeded									(1.0 psi = shatters glass)
	Large Scale	LOC was never exceeded									
	Small Scale	LOC was never exceeded									

Fig. 7. Over pressure accident probabilities of the natural gas pipeline.

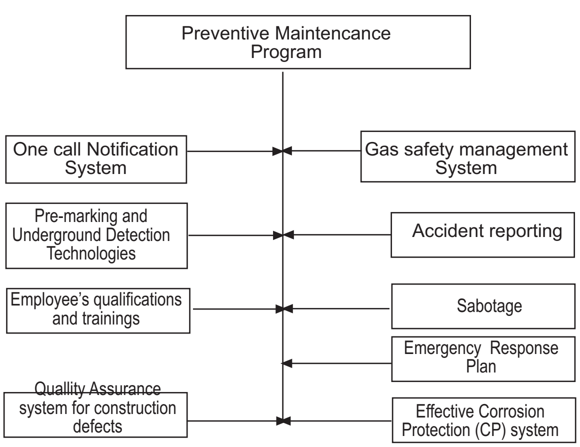


Fig. 8. Preventative maintenance program.

The dashed lines in Fig. 4 along both sides of the threat zone represent uncertainty in the wind direction. The wind rarely blows constantly from any one direction. As it shifts direction and blows released chemicals in a new direction. The wind direction confidence lines around the threat zone enclose the region within which is about 95% of the time, the chemical cloud is expected to remain. The lower the wind speed, the more the wind changes direction, so as to wind speed decreases, the wind direction confidence lines become farther apart.

Preventive maintenance program. To control the effect of accidental emissions of natural gas, the respondent should immediately manage to evacuate nearby personnel to leave the area discharged by accident. Emergency measures should be taken immediately to eliminate the risk as soon as possible. Major emergency measures include limiting the availability of hazardous materials, closing the source of fire-fighting equipment, isolating the hazardous area at the scene of an accident such as a walk made based on a similar risk simulation as described in Fig. 8. In this way, emergency and response planners deal with the huge success of accidental extraction of natural gas from a pipeline (Marco *et al*., 2012; Jonkman *et al*., 2003; Rnaldo *et al*., 1998) as described in Fig. 5.

Conclusion

It has been concluded that the increase in the number of users and enhanced suburbanization of land from which the gas distribution pipes are routed, produced big problems for gas pipeline operators. The proliferation of cities in countries where pipelines are distributed, as well as an increase in the number of users of underground pipelines, has created difficulties for the supply of natural pipelines. In this study, a method was developed to analyze the cost of incidents incurred by a person using natural gas as a result of accidental removal of a pipe. The high impact of external disturbances followed by corrosion and structural degradation under scores its importance to plumbers and authorities. Risk areas provided by this accidental release are assessed with the ALOHA modeling software. Creating an accidental discharge map for a specific country pipeline network has been developed. A conservation plan is put in place to address major threats to the safety of the natural gas pipeline to meet the gas company's objectives. The ALOHA footprint described in this application is a very useful tool in emergency response planning in the event of an accidental release. The results allow you to take the necessary emergency response actions during an emergency.

Conflict of Interest. The authors declare that they have no conflict of interest.

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