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Study of the Analyzing the Effect of Releasing LPG in the Environment with Different Wind Velocity Using ALOHA

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ABSTRACT

LPG gas is one of the substances with a high potential for environmental harm that is now widely employed in industry and other applications. In this study, the ALOHA model was utilized with varied wind speeds to assess the impact of releasing LPG into the environment, which causes a negative effect on human health. The purpose of this study is to show the toxic and flammable area of the affected area from the released LPG vapor cloud. The red zone (AEGL-3) of the toxic and flammable vapor cloud from the released gas remains constant with increasing ambient wind velocity for each LPG property (propane (C_3H_8), butane (C_4H_{10}), and isobutene (C_4H_{10})). The yellow zone (AEGL-1) of the toxic vapor cloud from the released propane (C_3H_8), butane (C_4H_{10}), and isobutene (C_4H_{10}) gas ranged from 25–30 m, 21–33 m, and 21–33 m, whereas the orange zone (AEGL-2) ranged from 11-15 m, 11–17 m, and 11–17 m. The flammable vapor cloud from the released propane (C_3H_8), butane (C_4H_{10}), and isobutene (C_4H_{10}) gas ranged from 49-54m, 45-64m, and 43-60m, respectively, for the yellow zone (AGEL-1) while in orange zone (AGEL-2) 19-22m, 18-28m, and 16-26m. On the other hand, the orange zone (AEGL-2) is a little bit decreasing with increasing wind speed. But yellow zone (AEGL-1) is more decreasing than the red zone (AEGL-3) and orange zone (AEGL-2). The flammable area of the isobutene (C_4H_{10}) is decreased than the *propane* (C_3H_8) and butane (C_4H_{10}). This study may be considered for future risk assessment in LPG plants with varied ambient wind speeds for minimizing the potential impact of LPG release.

Keywords: LPG, Safety, Explosion, Risk Assessment, ALOHA.

1. Introduction

LPG is a popular and commonly used household fuel that is supplied and stored under pressured conditions in a refrigerated form inside a pressure vessel in petroleum storage and distribution plants. LPG composition varies from country to country owing to purification processes such as crude fractionation, cracking, hydrogen processing, and refining. A variety of vessels like road tankers, rail wagons, and spheres or bullets are utilized for the storage and transportation of LPG [1]–[3]. LPG is a combination of C_3 and C_4 hydrocarbons that is an environmentally friendly fuel with low sulfur content, resulting in practically sulfur-free flue gas emissions. However, to detect even minor leaks, LPG is spiked with a smelly chemical such as mercaptan. It has lower and upper flammability limits (LFL and UFL) of 1.8% and 9.8% (v/v of gas in the air), an auto ignition temperature of 410 °C-580 °C, and a heating value of 50 MJ/kg. LPG is exceedingly dangerous due to its extremely low LFL and low boiling point (-20°C to -27°C). Experiments on the formation and spread of fireballs in the literature used explosives and propellants, gas-filled bubbles, and a container filled with a flammable liquid resulting in a boiling liquid expanding vapor explosion [4]. LPG (around 30% propane and 70% butane) has a volume 250 times higher than its liquid form when it is vaporized at room temperature and pressure. The amount of combustible and possibly explosive mixture produced by LPG vapor at a 5 percent concentration in air is therefore around 5000 liters, which is equal to 6945 liters of gas/air under stoichiometric circumstances [2]. LPG has a higher vapor density (1.93 kg/m^3 at 318 K) than atmospheric air. When emitted into the atmosphere, whether by accident or otherwise, it causes the formation of denser-than-air clouds with lower dispersion and dilution than passive atmospheric air [5]. If the safety relief valve fails, a continuous discharge from the vessel leakage or failure reduces the excess pressure in the container.

Flash vaporization and pool evaporation may occur during continuous liquid LPG release [6]. Most of the incidents involve fire and explosion during the handling, storage, and transport of LPG. LPG road tanker accidents are caused by the tanker's level of filling, road traffic, and population density. According to the literature, there are numerous possible leakage points in the road tanker, including the relief valve, flange, hose, pump seal, and pipe-work crack or rupture. The LPG container fails due to mechanical damage or overfilling of storage which can induce fractures in the vessel and weld failure. One of the most hazardous procedures while handling LPG is loading and unloading. LPG incidents typically occur in storage facilities, processing plants and during transportation [2].

Fig.1 shows the whole distribution system, from LPG manufacturing to consumer distribution. As can be seen, transportation is an important aspect of LPG handling. LPG is carried all over the world by many forms of transportation, although it is mostly transported via highways and trains. LPG is now carried via lengthy pipes, which are more convenient and safer. Due to a lack of LPG production capacity in Bangladesh, refineries companies imported LPG through large ships to fulfill supply and demand. Chain diagram of LPG production to distribution is shown in Fig. 2.

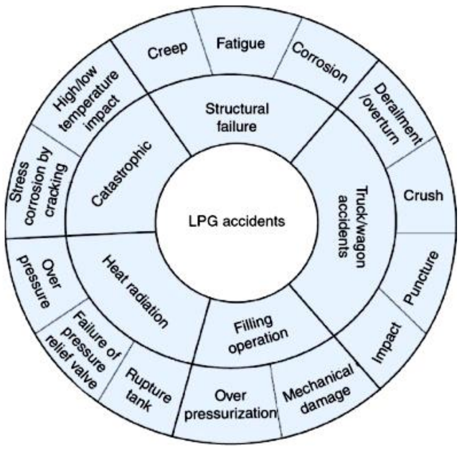


Fig. 1 Various possible incidents during handling of LPG [2]

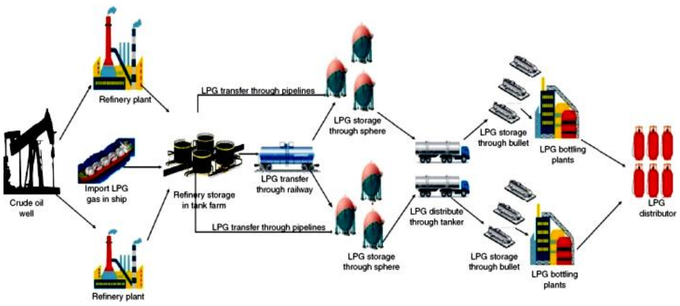


Fig. 2 Chain diagram of LPG production to distribution [2]

Table 1 shows the physical properties of LP gas. A blast wave can be formed depending on the velocity of the flame front, a phenomenon called as vapor cloud explosions. Wind speed, direction, discharge rate, vapor density, and mixing at the source are only a few of the meteorological parameters that have an impact on VCE. A gas explosion occurs when the combustion of a premixed gas cloud, fuel-air, or fuel/oxidizer creates a rapid increase in pressure. Gas explosions can occur inside the production process or pipes, buildings or marine modules, open process regions, or unconfined spaces [7].

Table 1 Physical properties of LPG[2]

Physical Properties	**LPG**
Chemical formula	$C_3H_6/C_3H_6\text{-}C_4H_{10}$
Boiling point (°C) at 101.3kPa	-22
Liquid density(kgm^{-3}) at 15°C	510
Flash point (°C)	-65
Upper explosive limit (vol. %)	9.1
Lower explosive limit (vol. %)	1.9
Auto ignition temperature (°C)	488-502
Calorific value (kcal/kg)	11840
Critical temperature (°C)	-97
Critical pressure (bar)	43
State	Colorless, odorless
Warning properties	Odor and dense appearance of gas cloud

As seen in the Figure 3, an explosion requires the discharge of gas. Then, the ignition must be present to ignite the expelled gas, which might result in a fire or an explosion. Most vapor cloud explosions on onshore and offshore petroleum processing plants would be classified as deflagrations [7]. When exposed to outside heating sources, LPG containers have pressure-relieving valves that allow LPG to escape to the atmosphere or a flare stack. A tank can experience a boiling liquid expanding vapor explosion (BLEVE) if a fire is allowed to burn for a long enough time and with enough intensity. The storage of several exceedingly big containers is a common problem for chemical and refineries. Frequently, tanks are built such that the product will vent before dangerous pressure levels are reached [8].

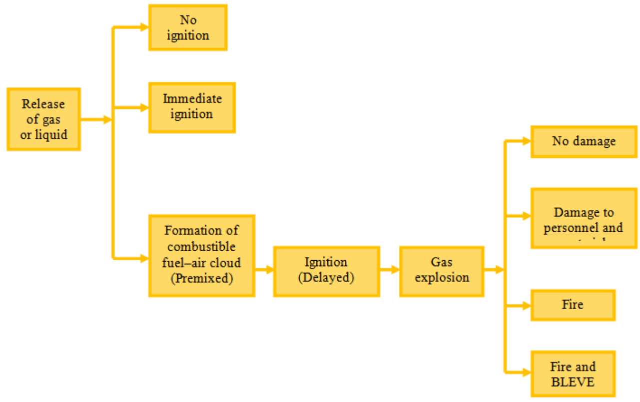


Fig. 3 Typical repercussions of flammable gas or evaporating liquid leaks into the atmosphere [7]

2. Methodology

The dispersion of chemical vapor and accidental discharges of hazardous compounds were simulated using the ALOHA dispersion model. ALOHA is open-source software developed by the United States Environmental protection agency and National Oceanic and Atmospheric Administration. It provides the user to select numerous accident situations and employs an appropriate source algorithm to insert material into the atmosphere in a short duration [9]. It was based on the Gaussian dispersion model of continuous, buoyant air pollution flumes. For more than 900 compounds, the model can replicate the dispersion model [10]. ALOHA can only assess the dangers of substances that go airborne. It includes models for calculating the rate of chemical escape and vaporization from confinement. ALOHA includes models for source intensity, Gaussian dispersion, and heavy gas dispersion. It can also solve the heat radiation and overpressure problems [4].

The study is concerned with the hazards caused by LPG emissions during cylinder bottling. The areal location of hazardous atmosphere (ALOHA Version-5.4.7) models were used in this analysis to assess the danger of fire and explosion from various LPG compounds under variable wind velocity and a fixed volume of LPG released into the surrounding environment.

2.1 Governing Equation

The discharge rate (kg/s) is calculated using the source model, and the airborne concentration (ppm or mg/m^3) is estimated using the dispersion model. Finally, the fire and explosion models are employed to calculate thermal heat flow. Fluid mechanics formulas may be used to compute the liquid discharge rate from a storage tank [11].

$$G_L = C_d A \rho_l [2(p - p_a)/\ \rho_l\ + 2gH]^{1/2} \qquad (1)$$

Where, G_L denotes the liquid mass emission rate (kg/s); C_d is the discharge coefficient (dimensionless); and A denotes the discharge holoe area (m^2). ρ_l =liquid density (kg/m^3); p=liquid storage pressure (N/m^2 absolute); p_a =downstream (ambient) pressure (N/m^2 absolute); g=gravity acceleration (9.81 m/s^2); H=liquid height above hole (m).

Using following Equation, calculate the airborne concentration of a chemical owing to dispersion from a continuous release source using the Gaussian Dispersion Model [11].

$$C=(G/2\sigma_y\sigma_z u)\exp[-1/2(y/\sigma_y)^2][\exp-(1/2)\{(z-H)/\sigma_z\}^2+\exp-(1/2)\{(z+H)/\sigma_z\}^2] \quad (2)$$

Where x,y,z are the distances from the source, and m is the magnitude of the distance. (x denotes downwind, y denotes crosswind, and z is vertical) G = vapour emission rate (kg/s); H = height of source above ground level + plume rise (m); σ_y,σ_z = dispersion coefficients (m), function of distance downwind; u = wind velocity (m/s).

3. Result and discussion

In Bangladesh, the majority of LPG bottling plants employ a combination of 30% propane and 70% butane. We studied the danger zones of propane (C_3H_8), butane (C_4H_{10}), and isobutene (C_4H_{10}). Chemical data of different LPG in ALOHA is shown in Table 2

Table 2 Chemical data of different LPG in ALOHA

LPG	AEGL-1 (60 min) (ppm)	AEGL-2 (60 min) (ppm)	AEGL-3 (60 min) (ppm)	LEL (ppm)	UEL (ppm)
Propane (C_3H_8)	5500	17000	33000	21000	95000
Butane (C_4H_{10})	5500	17000	53000	16000	84000
Isobutane (C_4H_{10})	5500	17000	53000	18000	84000

Assuming fixed amount of different LPG released into the surrounding environment in a certain period, as shown in Table 3. Assuming the amount of release each LPG was 0.25kg/s. For toxic area analysis the value of AEGL-1, AEGL-2 and AEGL-3 is 5500, 17000, 33000ppm. The LEL concentration of propane, butane and isobutene are 21000, 16000, 18000ppm. For analyzing flammable vapor cloud ALOHA used 60%LEL for red zone, 40%LEL for orange zone and 10%LEL for yellow zone analysis.

Table 3 Assuming amount of releasing LPG

LPG	Amount of release gas(Kg/s)	Release time (min)
Propane	0.25	60
Butane	0.25	60
Isobutane	0.25	60

Toxic area and flammable area of vapor cloud for propane (C_3H_8) with variable wind velocity are shown in Table 4 and Table 5 respectively. For releasing 0.25kg/s propane with variable wind velocity, the toxic area ranged from 11-30m. The red zone remains constant. The orange zone is ranged from 11 to 15m and yellow zone is ranged from 25-30m. Flammable area of propane with variable wind velocity is ranged from 15-54m. The red zone, orange zone and yellow zone are varied from 18-19m, 19-22m and 49-54m respectively.

Table 4 Toxic area of propane with variable wind velocity

LPG	Wind Velocity (ms^{-1})	Toxic area(m)		
		Red AEGL-3	Orange AEGL-2	Yellow AEGL-1
Propane	1.5	11	15	30
	2.5	11	12	28
	3.5	11	11	26
	4.5	11	11	26
	5.5	11	11	25

Table 5 Flammable area of propane with variable wind velocity

LPG	Wind Velocity (ms^{-1})	Flammable area (m)		
		Red AEGL-3	Orange AEGL-2	Yellow AEGL-1
Propane	1.5	19	22	54
	2.5	17	20	49
	3.5	16	19	48
	4.5	16	19	49
	5.5	15	19	49

Toxic area and flammable area of vapor cloud for butane (C_4H_{10}) with variable wind velocity are shown in Table 6 and Table 7 respectively. For releasing 0.25kg/s butane with variable wind velocity, the toxic area ranged from 10-33m. The red zone remains constant. The orange zone is ranged from 11-17m and yellow zone is ranged from 21-33m. Flammable area of butane with variable wind velocity is ranged from 14-64m. The red zone, orange zone and yellow zone are varied from 14-23m, 18-28m and 45-64m respectively.

Table 6 Toxic area of butane with variable wind velocity

LPG	Wind Velocity (ms^{-1})	Toxic area(m)		
		Red AEGL-3	Orange AEGL-2	Yellow AEGL-1
Butane	1.5	10	17	33
	2.5	10	11	23
	3.5	10	11	22
	4.5	10	11	21
	5.5	10	11	21

Table 7 Flammable area of butane with variable wind velocity

LPG	Wind Velocity (ms^{-1})	Flammable area(m)		
		Red AEGL-3	Orange AEGL-2	Yellow AEGL-1
Butane	1.5	23	28	64
	2.5	18	21	51
	3.5	16	20	49
	4.5	14	18	46
	5.5	14	18	45

Toxic area and flammable area of vapor cloud for isobutene (C_4H_{10}) with variable wind velocity are shown in Table 8 and Table 9 respectively. For releasing 0.25kg/s isobutene with variable wind velocity, the toxic area ranged from 10-33m. The red zone remains constant. The orange zone is ranged from 11-17m and yellow zone is ranged from 21-33m. Flammable area of isobutene with variable wind velocity is ranged from 12-60m. The red zone, orange zone and yellow zone are varied from 12-22m, 16-26m and 43-60m respectively. The flammability of the vapor cloud increases as the amount of LPG released increases. LPG vapor at concentrations ranging from 2% LEL to 10% LEL generates an explosive composite [12].

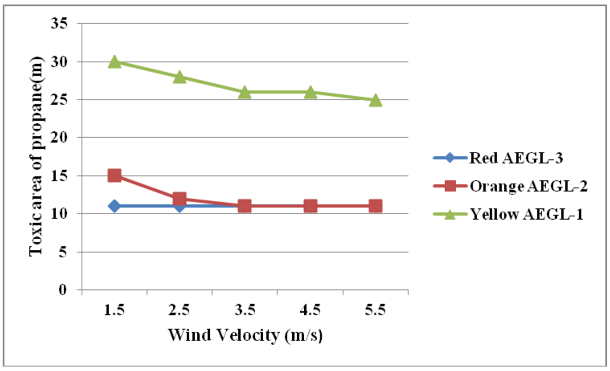
Table 8 Toxic area of isobutene with variable wind velocity

LPG	Wind Velocity (ms^{-1})	Toxic area(m)		
		Red AEGL-3	Orange AEGL-2	Yellow AEGL-1
Isobutane	1.5	10	17	33
	2.5	10	11	22
	3.5	10	11	22
	4.5	10	11	21
	5.5	10	11	21

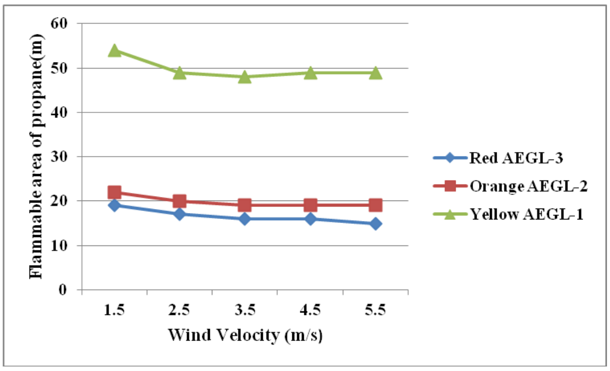
Table 9 Flammable area of isobutene with variable wind velocity

LPG	Wind Velocity (ms^{-1})	Flammable area(m)		
		Red AEGL-3	Orange AEGL-2	Yellow AEGL-1
Isobutane	1.5	22	26	60
	2.5	16	19	46
	3.5	13	18	44
	4.5	12	17	43
	5.5	12	16	43

Fig. 4 shows that toxic and flammable areas of the propane are decreasing with increasing wind velocity. But the red zone of the toxic area remains constant.



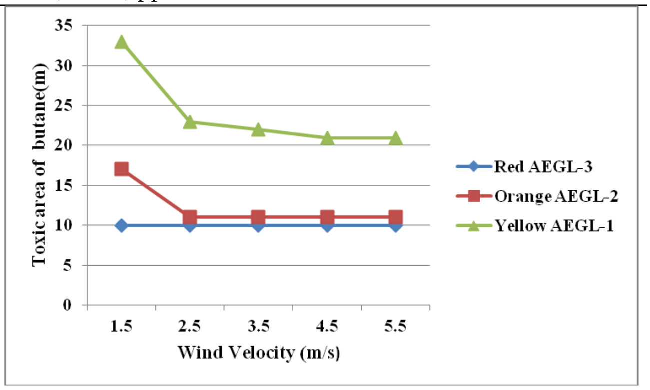
(a)



(b)

Fig. 4 (a) Toxic area (b) Flammable area of propane with variable wind velocity

Fig. 5 and Fig. 6 are showing the toxic and flammable areas of butane and isobutene respectively. Here also toxic and flammable areas are decreasing with increasing wind velocity. Red zone of the toxic area for all LPG (propane (C_3H_8), butane (C_4H_{10}), and isobutene (C_4H_{10})) remain constant. The orange zone (*AEGL-2*) of the all LP gas is little bit decrease with increasing wind velocity.



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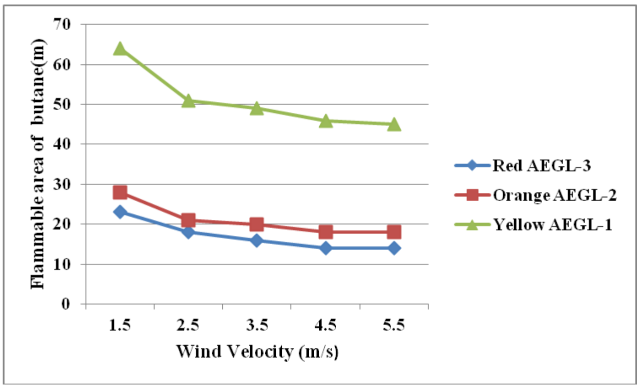
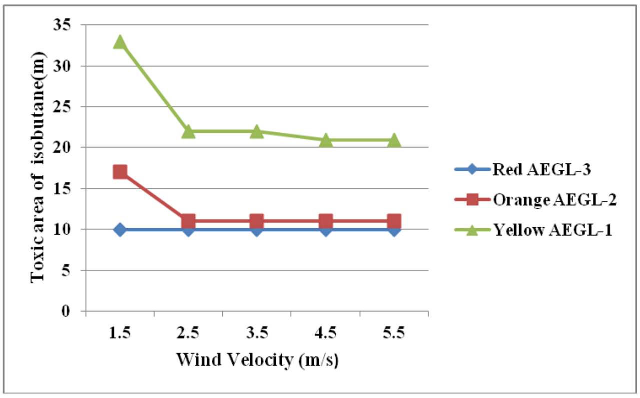
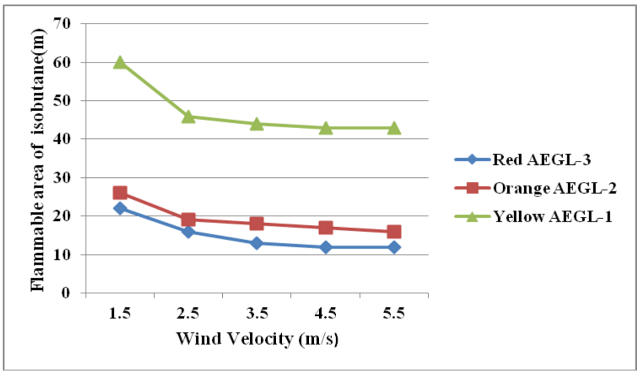


(b)

Fig. 5 (a) Toxic area (b) Flammable area of butane with variable wind velocity



(a)



(b)

Fig. 6 (a) Toxic area (b) Flammable area of isobutene with variable wind velocity

Fig. 7 shows that comparison of toxic and flammable areas from vapors cloud of different LP gas. Toxic and flammable area of butane is higher than the propane and butane. The red

(AGEL-3) zone of toxic and flammable area is propane > butane ≥ isobutene and butane > isobutene > propane. The orange (AGEL-2) zone of toxic and flammable area is butane > isobutene > propane. The yellow (AGEL-1) zone of toxic and flammable area is butane > isobutene > propane.

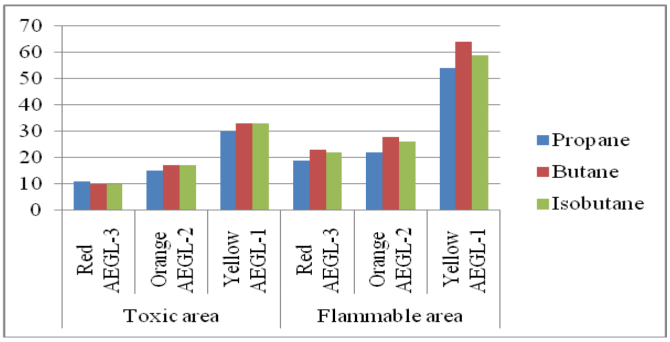


Fig. 7 Toxic and flammable area of release LPG

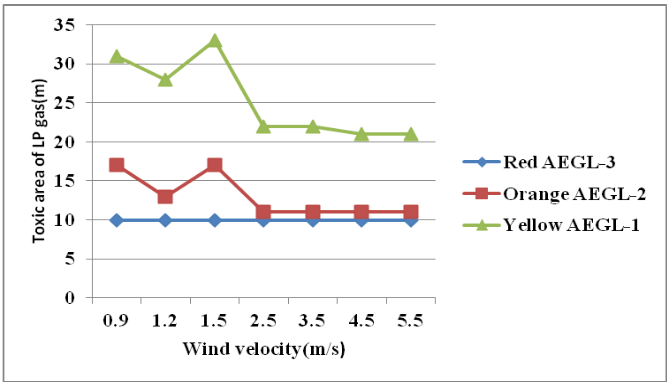


Fig. 8 Toxic area of LPG with wind velocity

In ALOHA (version-5.4.7) input the minimum wind velocity can take $0.85 ms^{-1}$. If we decreased wind velocity ups to $0.9 ms^{-1}$ the red zone remains constant as shown in Fig.8. Yellow and orange zones were decreased at $1.2\ ms^{-1}$, which is different from other cases.

4. Conclusion

In this study we have been analyzed threat zone of LPG bottling plant during bottling by assuming variable wind velocity with same amount LPG release using ALOHA software. Here we have been observed that the threat zone is increasing with decreasing wind velocity. But different case happened at wind velocity $1.2 ms^{-1}$.In case of toxicity, the explosion of LP gas varies in the order of butane > isobutene > propane. So, it is clear that butane more flammable than isobutene and propane. Instead of point/area modeling, a grid-based technique can be used to improve modeling and analysis of radiation and overpressure impact of releasing LP gas at various locations in the process area for future research. This study may be considered for future risk assessment in LPG plants with varied ambient wind speeds for minimizing the potential impact of LPG release.

5. References

[1] Mishra, K. B., Wehrstedt, K. D., Krebs, H., Lessons learned from recent fuel storage fires, *Fuel Process. Technol.*, vol. 107, pp. 166–172, 2013.

[2] Bariha, N., Srivastava, V. C., Mishra, I. M. , Theoretical and experimental studies on hazard analysis of LPG / LNG release : a review Center for Chemical Process Safety, 2016.

[3] Leslie, I. R. M., Birk, A. M., State of the art review of pressure liquefied gas container failure modes and associated projectile hazards, *J. Hazard. Mater.*, vol. 28, no. 3, pp. 329–365, 1991.

[4] Bariha, N., Mani, I., Chandra, V., Fire and explosion hazard analysis during surface transport of lique fi ed petroleum gas (LPG): A case study of LPG truck tanker accident in Kannur , Kerala , India, *J. Loss Prev. Process Ind.*, vol. 40, pp. 449–460, 2016.

[5] Pandya, N., Gabas, N., Marsden, E., Sensitivity analysis of Phast ' s atmospheric dispersion model for three toxic materials (nitric oxide , ammonia , chlorine), *J. Loss Prev. Process Ind.*, vol. 25, no. 1, pp. 20–32, 2012.

[6] Van Aerde S., Stewart, A., Estimating the impacts of LPG spills during transportation accidents, *J. Hazard. Mater.*, vol. 20, pp. 375–392, 1988.

[7] Bjerketvedt, D., Bakke, J. R., Van Wingerden, K., Gas explosion handbook, *J. Hazard. Mater.*, vol. 52, no. 1, pp. 1–151, 1997.

[8] https://en.wikipedia.org/wiki/Liquefied_petroleum_gas , "Liquefied petroleum gas - Wikipedia. 05/08/2022.

[9] Anandhan, M., Prabaharan, T., Muhaidheen, M., Ragavendran, S., Quantitative risk assessment in LPG storage area for different fire scenarios, *Int. J. Mech. Eng. Technol.*, vol. 10, no. 2, pp. 1425–1435, 2019.

[10] Tseng, J. M., Su, T. S., Kuo, C. Y., "Consequence evaluation of toxic chemical releases by ALOHA," *Procedia Eng.*, vol. 45, pp. 384–389, 2012.

[11] R. Bhattacharya and V. Ganesh Kumar, "Consequence analysis for simulation of hazardous chemicals release using ALOHA software," *Int. J. ChemTech Res.*, vol. 8, no. 4, pp. 2038–2046, 2015.

[12] Sölken, W. , Safety - What is %LEL / %UEL and PID and PPM? - Lower Explosive Limit, Upper Explosive Limit, PhotoIonization detector, Parts Per Million. 2022, [Online]. Available: https://www.wermac.org/safety/safety_what_is_lel_and_uel.html.

NOMENCLATURE

G : Vapour emission rate, kg/s
H : height of source above ground level + plume rise, m
σ_y,σ_z : dispersion coefficients
u : wind velocity, m/s^1
C_d : discharge coefficient
ρ_l : liquid density, kg/m^3
p : liquid storage pressure, N/m^2
p_a : downstream (ambient) pressure, N/m^2