Iranian Journal of Chemical Engineering, Vol. 19, No. 4, 38-51, (2022)

Iranian Journal of Chemical Engineering

Journal Homepage: www.ijche.com

pISSN: 1735-5397
eISSN: 2008-2355

Regular Article

Investigating Effective Parameters in the Hazardous Areas of the City Gas Station (CGS), Through Modeling by PHAST Software

V. Zaroushani [1]***, H. Mirzakhani*** [2]***, F. Khajehnasiri*** [3*]

[1] Social Determinants of Health Research Center, Research Institute for Prevention of Non-Communicable Disease, Department of Occupational Health Engineering, Faculty of Health, Qazvin University of Medical Sciences, Qazvin, Iran
[2] Student Research Committee, School of Public Health, Qazvin University of Medical Sciences, Qazvin, Iran
[3] Department of Community 5 Medicine, Faculty of Medicine, Tehran University of Medical Sciences, Tehran, Iran

ARTICLE INFO

Article history:
Received: 2022-11-09
Accepted: 2023-03-14
Available online: 2023-03-14

Keywords:
PHAST Software,
Consequence Modeling,
Weather Conditions,
Gas Station,
Compressed Natural Gas

ABSTRACT

Natural gas (NG) is one of the cleanest and safest sources of energy that is transmitted in a high pressure and must be reduced before entering the City Gas Station (CGS). Identifying the effective parameters in creating the hazardous areas of CGS is essential tothe crisis management. In this study, using PHAST version 7.11 (created by DNV Company), ther has been a consequence modelling conducted in three scenarios at three CGS stations in Qazvin Province, by using actual data including the weather conditions, gas pressure and temperature. The main results for the modeling in all three scenarios were a jet fire, flash fire, and explosion. Based on the modeling results, the highest flame lenght was obtained in the Avaj station which was 10 meters more than the same in others. The highest radiation levels were also in the Avaj station and in about 150 m downwind distance, which could be caused by the longer flame length in that station. The results showed that in the fire jet modeling, an increase in the air temperature could lead to an increase in the gas pressure and temperature, which in this study increased the flame length of 2 meters to 3 meters. However, the flame length and the hazardous area were bigger during the day and summer. The use of the PHAST modeling software can provide useful information including the high-risk operational area, hazard area, high-risk time period (day, night and season) for the management team to respond to emergency situations in industries. In addition, it is necessary to consider the combination of different operating parameters such as the gas pressure and gas temperature with different weather conditions.

DOI: 10.22034/ijche.2023.369154.1463 URL: https://www.ijche.com/article_168485.html

[*] Corresponding author: khajenasiri@tums.ac.ir (F. Khajehnasiri)

1. Introduction

It is known that the petroleum industry is an essential pillar of the economic development. Although it can dramatically improve the quality of people's lives and promote scientific and technological innovations, critical safety issues such as the exposure to toxic, corrosive, inflammable, or explosive materials can arise in production, transportation, and storage activities. The leakage of these materials often leads to casualties and causes financial losses [1].

Accidents in the process have been the main causes of the considerable economic and human damages in the industry in many countries over the years. These accidents may occur due to various factors including human error, natural disasters, defects in facilities, etc. So, figuring out the possible situations that could lead to these accidents and how they happen is a good way to find, prevent, and control hazards [2].

The specifications of damages can be determined using various modeling tools or software. In general, the prediction made by different developers are made by two main methods of experimental and theoretical studies. According to Pandya et al., dispersion models can be classified into three main categories, ranging from less to more complex that include Gaussian, integral-type, and Computational Fluid Dynamics (CFD) models. Gaussian is based on the diffusion equation and observations from experimental studies. Integral-type simplifies the conservation equations for mass, momentum, and energy [3]. The most popular dispersion integral-type models and widely used in safety engineering applications are Areal Locations of Hazardous Atmosphere (ALOHA), Dense Gas Dispersion (DEGADIS), HEGADAS, and Process Hazard Analysis Software Tool (PHAST). They can relatively easyily and fast provide dispersion estimations. Computational Fluid Dynamics (CFD) models have been used for years, allowing users to have three-dimensional analyses. Some standard CFD codes are CFX, FLACS, FDS, and FLUENT [3]. The ALOHA, PHAST, and CFD codes are the three most often used tools to study the consequences of gas dispersion in industries [4].

Over 300 enterprises globally use PHAST because of its dependability and incredible technical superiority. Det Norske Veritas (DNV) is the owner of PHAST, a complete hazard analysis tool that can be used at all design and operation phases in a variety of processes and chemical industries. It is used to pinpoint circumstances that could endanger human life, properties, or the environment. By redesigning the process or plant or by changing the current operational methods, such instances may be avoided. The remaining scenarios, such as thorough risk assessments, may be submitted for additional study where required, utilizing more advanced QRA tools like SAFETI. Numerous situations, such the BELEVE blast, abrupt emission, continuous emission, flash fire, pool fire, jet fire, ball fire, hazardous discharge, and others, can be modeled by this program [5].

Previously, the release and dispersion of natural gas (NG) have been studied by many researchers. They mainly focus on the effect of distance or identifying the safety zone. For example, in a study by Stephy et al. on the risk assessment of the liquefied natural gas to identify and rank failures that could result in the release of the liquefied NG to the environment, the authors stated that: "In either of the scenarios, if the worst case of the explosion occurred, then an area of around 17 km, which included crude storage consisting of

5 storage tanks, of which the capacity of each was 80,000-ton, which was 1.8 km, and the ammonia storage tank of 10,000-ton mass, would be affected" [6].

The layout of the process plant is a crucial consideration when building a chemical plant that can improve its performance and limit economic losses in the event of an accident in it [7]. In a study by Soltanzadeh et al. all modeling steps were performed using PHAST version 7.2. They reported that in summer, at the distances of 3788.94, 128.86 and 91.72 meters in the direction of the wind from the exploded tank, the emission would be 100, 500 and 1000 ppm of biogas respectively. Also, the pressure values due to the explosion in the catastrophic rupture scenario revealed that the distances of 57.19, 14.70, and 115.84 m from the biogas reservoir were in the range of 0.02, 0.13, and 0.2 bar increase respectively. Due to the treatment plant being located in a dense urban area, the biogas dispersion could expose many people to high risks [8]. Esfahani et al. have done another study in this area. Their study evaluates the risk of the gasoline tank of the National Iranian Oil Product Distribution Company (NIOPDC) in Sari region using the PHAST software. Due to the consequences of the explosion, the worst results were related to the weather conditions of 2/3 F for 4700, 2400, and 2300 m. Also, based on the data related to the eruptive and sudden fire, the intensity of radiation leading to immediate death of people or destruction of equipment was observed in weather conditions of 2.3 degrees Fahrenheit and 1.4 degrees Celsius at distances of 180 and 160 meters, respectively was observed. Under these two weather conditions, flammability intervals were 10520 and 450 m [9].

Alternatively, a review study by Dou et al. was conducted to identify the real problems in the emergency evacuation of chemically concentrated areas. This study informed that the poor efficiency of the emergency plan, inaccurate and time-consuming calculations for the potential affected zones, poorly designed evacuation routes, neglecting the evacuees' behaviors and lack of proper decision-making were the main practical errors [1].

As mentioned, most of studies concentrated on the effects of the accident and control measures. Modeling can predict and reduce accidents.. However, less studies attended to controlling fire, explosions, and the release of toxic substances before the accident to control the severity of the accident. Also, in this line, less research was done on the effect of the temperature and pressure of the material inside the tank or pipelines on the safe space.

One of the methods is the NG transmission which is transmission through high-pressure pipelines. This high-pressure gas (1000 psi) cannot not be used in residential or industrial areas. Regulators adjust the high-pressure of the gas to the level suitable for distribution (250 psi) as it moves along the pipeline [10].

Filter separators are the inseparable parts of the natural gas processing system. The filter/separator section removes solids and fluids from the gas. Investigations into past industrial accidents show that defects in filters could result in extreme financial losses and injuries [11].

Considering the research priorities on emergency response and crisis management, lack of similar studies and previous related accidents in Qazvin Province, this study was conducted with the ethical code of IR.QUMS.REC.1397.088 to investigate, with the PHAST software, the most influential parameter, including the weather conditions, leakage diameter, and physical conditions of materials including the temperature and pressure inside CGS stations, in determining hazardous areas.

2. Materials and methods

2.1. Description of the study

This study, as a master's thesis, was conducted with the ethical code of IR.QUMS.REC.1397.088 in six towns of Qazvin province and for all four seasons of the year. In this article it has been investigated the effect of three variables including the gas temperature, gas pressure and weather conditions on the output of the PHAST software. Based on this, three scenarios were identified that in each scenario, one parameter was constant and others were variable. For this reason, the seasons and city gas stations, when and where the conditions of the scenario are true, were selected. It is noticeable that the change of location and season was not investigated as a variable in this study. Finally, the three CGS stations of Buin Zahra, Avaj, and Takestan obtained the best matching criteria and were selected for modeling with the use of the PHAST software version 7.11. It is considerable that the required data were collected from the average of the same of the Qazvin Gas Company and Meteorological Department in the recent three years. Figure 1 shows a typical filter separator used in a city gate station.

It is noticeable that providing awareness of the effective distance and effective area of the explosion and the safe area around these three CGS stations was of utmost significance.

Figure 1. Typical filter separator used in a City Gate Station.

2.2. Determine the type and features of the scenario

Because the scenarios are hypothetical, the parameters that may cause failure in a process are nominally the initial event, expansion range, and outcome. Therefore, to determine the scenario related to the present study, the method of identifying experiences related to past accidents, which are available in the Hazard and Operability Study (HAZOP), similar studies in other national gas companies, reviews of accident reports, quasi-accidents in the different stations of Qazvin Province, and also experiences of experts, were used. After evaluating and identifying the various failures based on the risk matrix in MIL-STD-882-D, the highest risk at the CGS stations was identified as related to filter separator cartridges especially when replacing the filter cartridge. Figure 2 presents a typical used filter cartridge in CGS. Therefore, in the study it is considered a leak scenario with an orifice diameter equal to the filter door. The orifice diameter was 50 cm for all three stations.

Figure 2. Filter separator lid for the cartridge replacement.

As mentioned before in section 2.1. (study description) the effect of the three weather and operational variable parameters was investigated in three scenarios at three best matching CGS stations that were named the Buin Zahra, Avaj, and Takestan stations.

2.2.1. Scenario No. 1: Similar weather conditions

After determining the geographical location of the stations and obtaining the aerial maps of these three stations for using the PHAST software, the needed information on weather conditions was obtained from the Meteorological Department of Qazvin province. The average of the weather conditions data of three years was used. In this scenario, the weather conditions, including the day and night temperature, wind speed, and humidity in the two stations of Buin Zahra and Avaj (which were very close to each other in spring and summer and, in some cases, were equal), were considered as constant parameters. The operational parameters including the gas temperature and pressure, were considered as variable factors in this scenario. The Buin Zahra station had the highest Gas temperature in the four studied times including spring (day and night) and summer (day and night). But the gas pressure in all four weather conditions mentioned in the Avaj station was higher than the same in the Buin Zahra station. The detailed categorization is shown in Table 1.

Table 1
Release conditions in the Buin Zahra and Avaj stations for the scenario where the weather conditions are stable.

Station	Station capacity ($\frac{m^3}{h}$)	Orifice diameter (cm)	Gas temperature (°C)				Gas pressure (Psi)				Weather conditions							
											Temperature (°C)				Humidity (%)		Wind speed (m/s)	
			Spring		Summer		Spring		Summer		Spring		Summer		Spring	Summer	Spring	Summer
			Day	Night	Day	Night	Day	Night	Day	Night	Day	Night	Day	Night				
Buin Zahra	20000	50	16.74	16.9	20.88	21.9	663.7	639.4	675.6	657.2	20.2	6.6	29.9	13.4	39	31	3.3	3
Avaj	20000	50	8.87	8.6	12.13	18.32	701.55	694.44	697.16	675.92	20.2	6.6	29.9	13.4	41	33	2.9	3.1

2.2.2. Scenario No. 2: Similar gas pressure

Another set of information required for modeling is the operational parameter of the desired CGS station. The definition of the second scenario was defined based on the characteristics of the operation and weather. Considering the values of the pressure of natural gas at the inlet of the filter in the Takstan and Avaj stations was very close to each other in the winter season, the gas pressure was considered as a constant parameter. In this scenario, the gas temperature and atmospheric conditions were investigated as variable parameters. The gas temperature, wind speed and humidity in the Takestan station were higher than those in the Avaj station. The studied release conditions are reported in Table 2.

Table 2
Release conditions in the Takestan and Avaj stations for a stable gas pressure scenario.

Station	Station capacity ($\frac{m^3}{h}$)	Orifice diameter (cm)	Gas temperature (°C)		Gas pressure (Psi)		Weather conditions			
							Temperature (°C)		Humidity (%)	Wind Speed (m/s)
			Winter		Winter		Winter		Winter	Winter
			Day	Night	Day	Night	Day	Night		
Takestan	20000	50	16.5	16.6	592	580	11	-0.4	62.8	2.8
Avaj	20000	50	3.5	3.1	592	577	6.5	-3.2	63.2	3.4

2.2.3. Scenario No. 3: Similar gas temperature

For the third scenario, the temperature of NG at the filter inlet in the Takestan and Buin Zahra stations in winter, is considered as constant and the gas pressure and weather conditions as variable parameters.

It is worth noting that the NG parameter including the gas pressure in Buin Zahra was higher than the same in Takestan. Regarding the weather conditions, the temperatures of the two stations during the day and night were slightly different, but in Buin Zahra, the temperature was higher. The wind speed and humidity were marginally higher in Takestan. Table 3 presents the studied release conditions.

Table 3

The release conditions in the Takestan and Buin Zahra stations for a stable gas temperature scenario.

Station	Station capacity ($\frac{m^3}{h}$)	Orifice diameter (cm)	Gas temperature (°C)		Gas pressure (Psi)		Weather conditions			
							Temperature (°C)		Humidity (%)	Wind Speed (m/s)
			Winter		Winter		Winter		Winter	Winter
			Day	Night	Day	Night	Day	Night		
Takestan	20000	50	16.5	16.6	592	580	11	-0.4	62.8	2.8
Buin Zahra	20000	50	16.7	16.7	614	596	11.9	0.6	61	2.7

2.3. Components of natural gas

Table 4 shows the composition of NG, which is used for modeling. As it can be seen in this table, the composition was the same in all three stations.

Table 4

Chemical composition of natural gas in mole percent.

Component	Typical analysis
Methane (CH_4)	94.95
Ethane (C_2H_6)	3.47
Propane (C_3H_8)	0.94
Is propane (I- C_4)	0.41
Normal butane (N- C4)	0.23
Total	100

3. Results and discussion

The main results of the modeling in all three scenarios were the jet fire, flash fire, and explosion and the effective distance of the jet fire and the safe area of the flash fire are presented in Tables 5 and 6 respectively.

The comparative results of the flame length in the Avaj and Buin Zahra stations in spring and summer (Figures 3), comparison of radiation with distance for the jet fire in the Avaj and Buin Zahra stations in spring days (Figures 4), flame length in the Avaj and Takestan stations in winter (Figures 5), radiation vs distance for the jet fire in the Avaj and Takestan stations in winter days (Figures 6), flame length in the Buin Zahra and Takestan stations in winter (Figures 7) and radiation vs distance for the jet fire in the Buin

Zahra and Takestan stations in winter days (Figures 8) are shown.

3.1. Modeling results of the first scenario (similar weather conditions)

The flame length at the Avaj station was much longer than the same at the Buin Zahra station (Figure 3). According to the modeling results, the flame length in spring was 10 m during the day and 12 m at night. In summer the length was 6 m in days, and 2 m at nights. The flame length at the Avaj station was much longer than that at the Buin Zahra station in winter during the day and night. The length differences between three levels were 2 and 3 meters respectively (Figure 3).

The findings presented in Table 4 show that the radiation level in the Avj station is higher than in Buin Zahra, which can be caused by the longer flame length in this station.

Tables 5 and 6 show the effective distance resulted due to the jet fire, and the safe area border due to the flash fire respectively. Based on these, the Avaj station had a more functional space and safer zone boundary than Buin Zahra, under all climatic conditions.

Table 5

Effective distance (m) resulted due to the jet fire modeling in three damage levels 1, 2 and 3 (level 1: 4 $\frac{kw}{m^2}$ / level 2: 12.5 $\frac{kw}{m^2}$ / level 3: 37.5 $\frac{kw}{m^2}$.

Mod 1	Avaj Level 1	Avaj Level 2	Avaj Level 3	Buin Zahra Level 1	Buin Zahra Level 2	Buin Zahra Level 3
Spring/Day	612	429	321	593	413	310
Spring/Night	630	438	324	601	416	309
Summer/Day	600	418	314	586	409	308
Summer/Night	610	421	314	601	415	310

Mod 2	Avaj Level 1	Avaj Level 2	Avaj Level 3	Takestan Level 1	Takestan Level 2	Takestan Level 3
Winter/Day	579	403	300	562	390	293
Winter/Night	587	405	301	573	395	295

Mod 3	Buin Zahra Level 1	Buin Zahra Level 2	Buin Zahra Level 3	Takestan Level 1	Takestan Level 2	Takestan Level 3
Winter/Day	572	396	298	562	390	293
Winter/Night	580	399	298	573	395	295

Table 6

Flash fire modeling results in the filter separator and safe zone boundary.

Mod 1								Mod 2				Mod 3			
Avaj				Buin Zahra				Avaj		Takestan		Buin Zahra		Takestan	
Spring		Summer		Spring		Summer									
Day	Night	Day	Night	Day	Night	Day	Night	Winter/Day	Winter/Night	Winter/Day	Winter/Night	Winter/Day	Winter/Night	Winter/Day	Winter/Night
2000	1200	1800	1010	1000	950	1100	950	1000	950	750	890	800	850	750	890

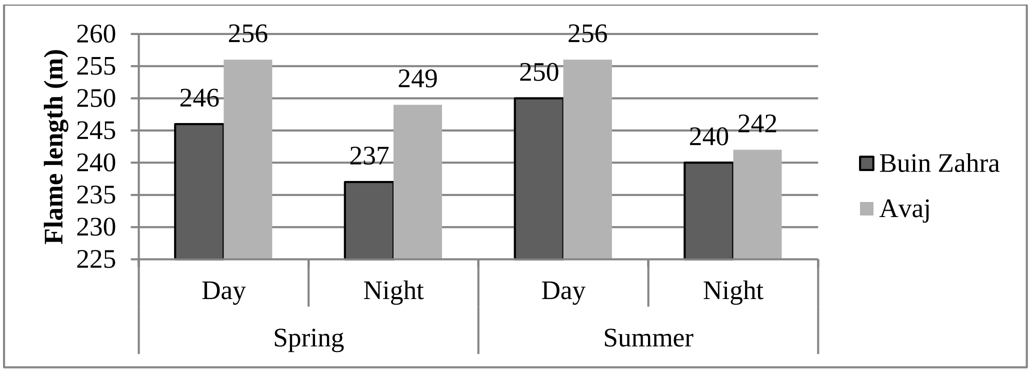

Figure 3. Comparison of the flame length in the Avaj and Buin Zahra stations in spring and summer. The effective distance of the jet fire, the edge of the safe zone, and the highest level of radiation were most affected by the gas pressure.

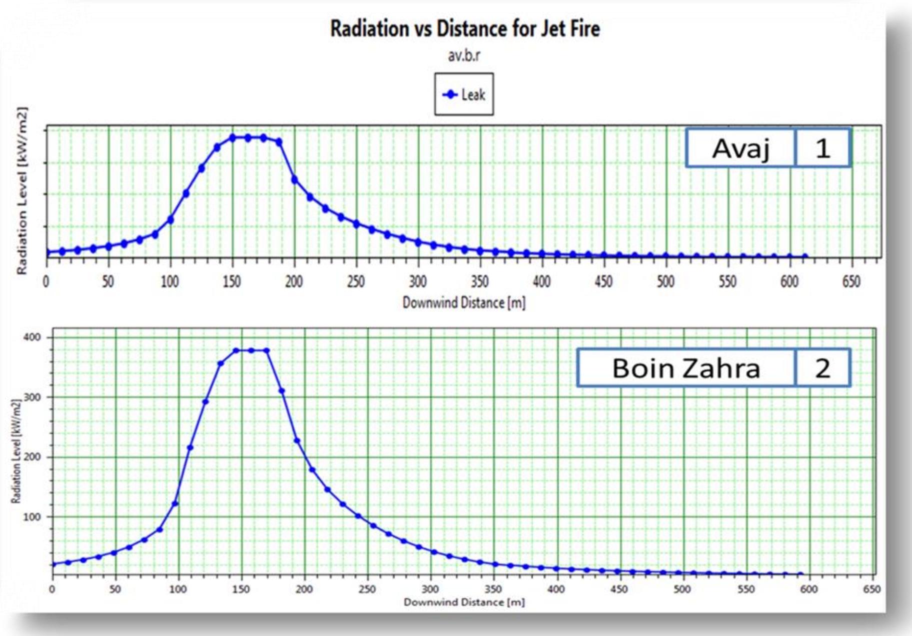

Figure 4. Comparison of radiation with distance for the jet fire in the Avaj and Buin Zahra stations in spring days.

As above mentioned, were the main modeling results in all three scenarios of the jet fire, flash fire, and explosion. In a flash fire, people in the explosive concentration area (between the lower and upper limits) most probably won't survive, and the people who are within half of the lower flammable limit of 1 m will suffer from breathing disorders [11].

As showed in Table 1, although the air temperature, wind speed, and air humidity in both the Buin Zahra and Avaj stations were almost the same, the gas temperature in Buin Zahra was higher than that in Avaj. However, in the Avaj station, the gas pressure was higher than that in the Buin Zahra station. The flame length at the Avaj station was much longer than the same in the Buin Zahra station (Figure 3).

Based on the results of this scenario, the effect of the process factors on the safe area caused by the flash fire and the maximum radiation level of the jet fire is much more significant than that of environmental factors. Mousavi et al. in a similar study, it was stated that the influence of environmental conditions compared to the gas pressure has less influence on the consequences of leakage. Process parameters can create more impact on the size of the flammable vapor cloud and the maximum radiation level of the jet fire on the ground than environmental parameters [12].

According to the results in Tables 5 and 6, in the Avaj station there was a more functional space and safer zone boundary than in Buin Zahra and Takestan, under all climatic conditions.

3.2. Modeling results of the second scenario (similar gas pressure)

As shown in Table 2, the air and gas temperatures in the Takestan station during the day were about 4.5 and 13 degrees Celsius higher than those in Avaj (gas pressure equal to 592 psi). This is despite the fact that, contrary to expectations, the length of the flame in Takestan was obtained 2 meters during the day and 3 meters at night less than those in the Avaj station.

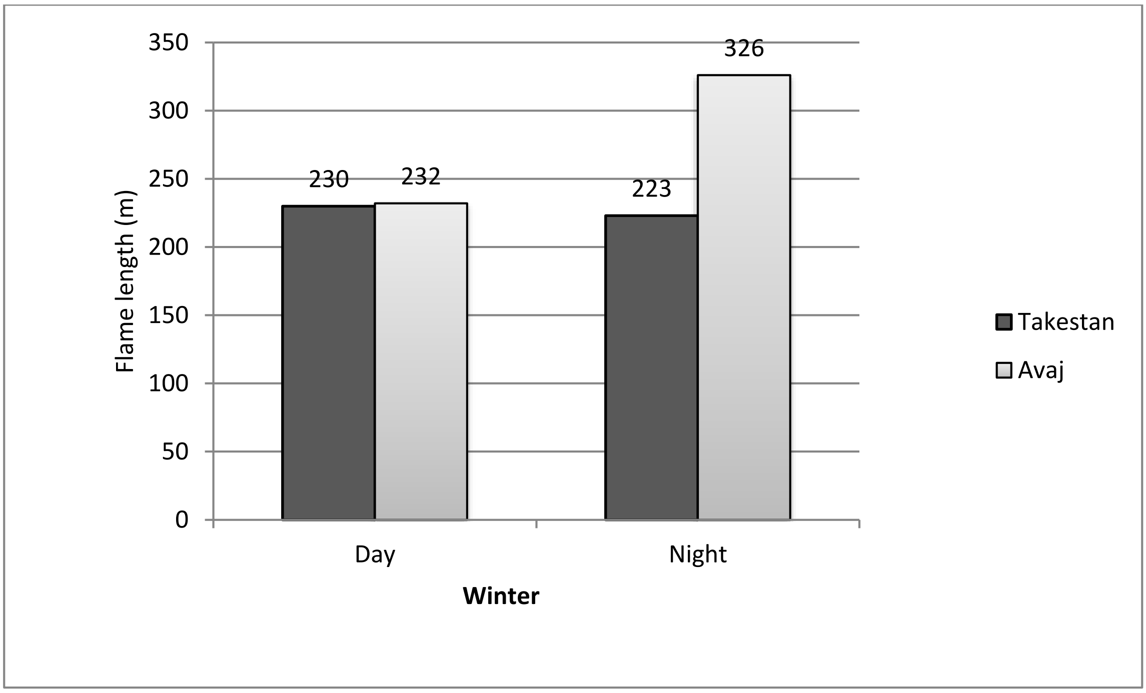

Figure 5. Comparison of the values of the flame length in the Avaj and Takestan stations in winter.

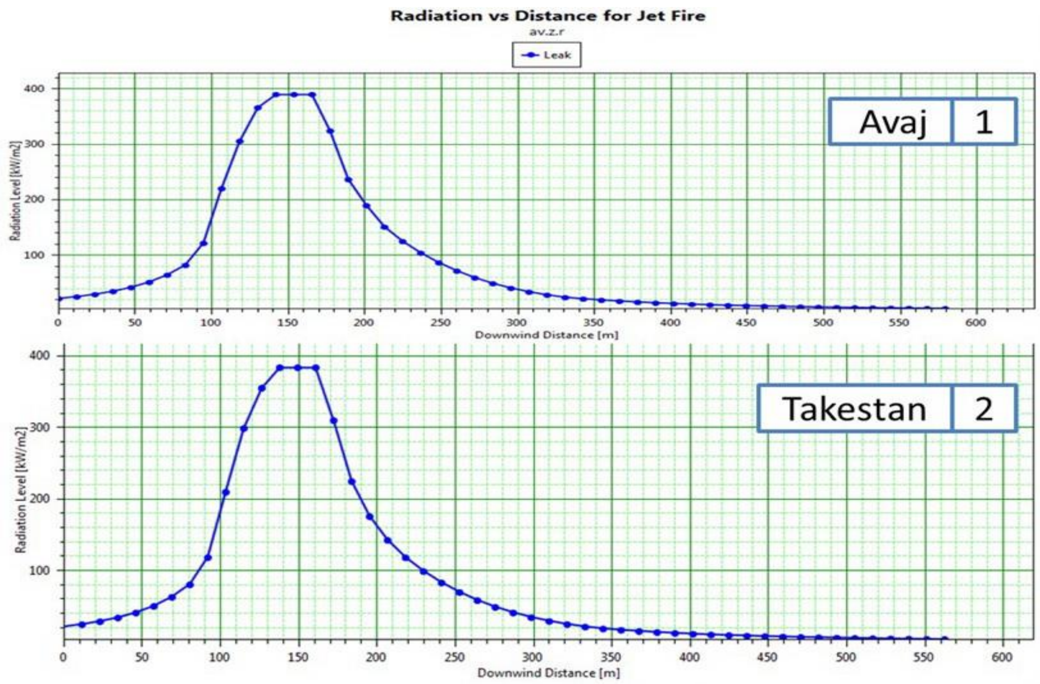

Figure 6. Comparison of radiation with distance for the jet fire in the Avaj and Takestan stations in winter days.

In the second scenario, at night, the gas pressure and gas temperature in Takestan were higher than the same in the Avaj station (Table 2), which caused an increase of 2 to 3 meters in the flame length that could be due to the higher air temperature at this station (Table 2).

Based on the results of the second scenario and the data from Tables 5 and 6, it was found that there is a significant difference between the effective distance and flame length under different weather conditions. This difference exists both during the day and at night. However, in some studies, the effect of the weather conditions on modeling results during the year is divided into two categories: hot seasons and cold seasons, whereas in some others only one weather condition is used. In this line, Rosa et al. only used one weather condition with hypothetical stability class D (class D characterizes a condition of neutral stability, which means that the wind turbulence may cause the dispersion of the toxic gas over a greater distance of the release source) for modeling with the PHAST software [13]. Cheraghi et al. used two titles for explaining weather conditions: "weather conditions 1" (spring and summer) and "weather conditions 2" (autumn and winter) for modeling with the PHAST software [14].

Anjana et al. mentioned the impact of weather conditions on determining the hazard areas. Even in their study, there is a direct reference to the effect of changing the direction of the wind and determining the hazard areas in proportion to the changes in the direction of the wind; however, they used only 4 weather conditions (two seasons, summer and winter) for modeling and did not take the change in the wind speed, which may obviously change throughout the year and have a direct impact on the hazard areas, into account [15].

3.3. Modeling results of the third scenario (similar gas temperature)

In the third scenario, the gas temperatures in the two stations of Takestan and Buin Zahra were equal, and the weather conditions were almost the same. In this scenario, the gas pressure as a variable parameter was higher in the Buin Zahra station than in Takestan station (Tables 1 and 2). As the modeling result showed in Figures 7, in the Buin Zahra station the flame length during the day and night in winter was longer than in Takestan (4 m difference between the two stations during the day and 3 m at night).

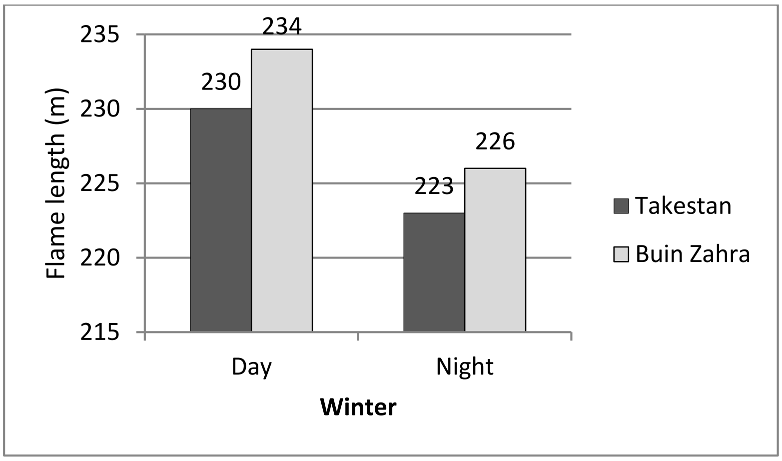

Figure 7. Comparison of the values of the flame length in the Buin Zahra and Takestan stations in winter.

Also, in this scenario, the Buin Zahra station had a higher radiation level (Figures 8), effective distance and safe zone boundary than Takestan (Table 5 and 6).

Khorram et al. used the weather conditions for modeling in 4 time periods: morning, noon, evening, and night. They observed that between the hours of 06:00 to 10:00 am and 19:00 pm to 06:00 am, chlorine gas traveled respectively longer and shorter distances to ERPG2-3 concentration, compared to other time intervals studied.They also noted the impact of weather conditions during the day [16].

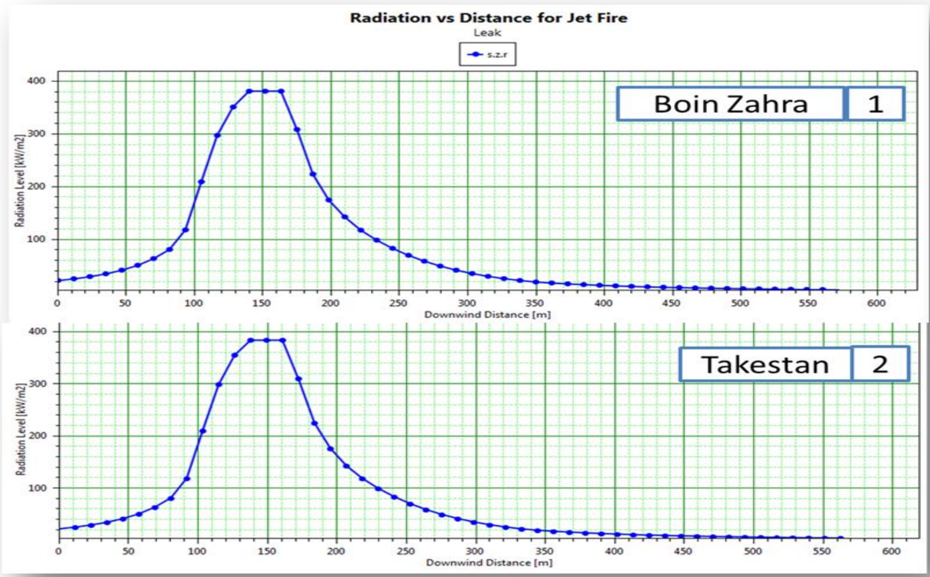

Figure 8. Comparison of radiation with distance for the jet fire in the Buin Zahra and Takestan stations in winter days.

The results of the third scenario show that the gas pressure has the greatest impact in determining the hazardous areas. Under constat gas pressure conditions, other parameters can affect the results. In this study, although the air temperature and gas temperature in the Takestan station were higher than those in the Avaj station, more hazardous areas were around Avaj than the Takestan station.

The results of this study are in accordance with what announced by Yang et al. It was concluded that when the wind speed is higher, the leakage pore rises, and when the environmental conditions are more stable, the leakage and diffusion of hazardous areas are more significant [17]. Increasing the wind speed has a direct effect on the length of the flame. Higher wind speeds at the Avaj station can cause this difference in the flame length and so on.

4. Conclusions

The use of the PHAST modeling software can provide useful information including the high-risk operational area, hazard area, high-risk time period (day, night and season) for the management team to respond to emergency situations in industries. In order to bring the accident scenario closer to reality, it is necessary to consider the combination of different operating parameters such as the gas pressure and gas temperature with different weather conditions. Using only one general climate condition for modeling with the PHAST software can cause significant errors in the results. Among investigated parameters, it was clearly observed that the gas pressure had the most effect in determining the safety zone boundary.

Considering that in this study, the residential and utility areas in the evaluated stations were outside the danger zone. Therefore, no decision was made regarding changing the location of the filter separator.

Acknowledgement

The authors thank the officials of the Qazvin Meteorological Administration and the Gas Company for providing the initial data used in this research.

References

[1] Dou, Z., Mebarki, A., Cheng, Y., Zheng, X., Jiang, J., Wang, Y., Li, Y. and Li, J., “Review on the emergency evacuation in chemicals-concentrated areas”, *J. Loss Prev. Process Ind.*, **60**, 35 (2019).

[2] Helsel, P., “2 dead, 2 injured in Texas gas pipeline explosion”, NBC News, (2021). (https://www.nbcnews.com/news/us-news/two-dead-others-hurt-texas-gas-explosion-n1272569).

[3] Pandya, N. G. N. and Marsden, E., “Sensitivity analysis of Phast’s atmospheric dispersion model for three toxic materials (nitric oxide, ammonia, chlorine)”, *J. Loss Prev. Process Ind.*, **1** (25), 20 (2012).

[4] Wang, B. and Qian, F., “Three dimensional gas dispersion modeling using cellular automata and artificial neural network in urban environment”, *Process Saf. Environ. Protect.*, **120**, 286 (2018).

[5] Naemnezhad, A., Isari, A. A., Khayer, E. and Esfandiari Birak Olya, M., “Consequence assessment of separator explosion for an oil production platform in South of Iran with PHAST Software”, *Model. Earth Syst. Environ.*, **3**, 1 (2017).

[6] James, S. and Renjith, V., “Risk assessment and vulnerability analysis of liquefied natural gas (LNG) regasification

terminal", *Process Integr. Optim. Sustain.*, **5**, 99 (2021).

[7] Anbari, E. and Parvini, M., "Process plant layout optimization considering domino effects and safety devices in a large-scale chemical plant", *Comput. Chem. Eng.*, **167**, 108006 (2022).

[8] Soltanzadeh, A., Mahdinia, M., Golmohammadpour, H., Pourbabaki, R., Mohammad-Ghasemi, M. and Sadeghi-Yarandi, M., "Evaluating the potential severity of biogas toxic release, fire and explosion: Consequence modeling of biogas dispersion in a large urban treatment plant", *Int. J. Occup. Saf. Ergon.*, **29** (1), 335 (2023).

[9] Esfandian, H., Goodarzian Urimi, M. and Shokoohi Rad, A., "Risk assessment of gasoline storage unit of national iranian oil product distribution company using phast software", *IJE Transactions A: Basics*, **34** (4), 763 (2021).

[10] Ghaebi, H., Farhang, B., Rostamzadeh, H. and Parikhani, T., "Energy, exergy, economic and environmental (4E) analysis of using city gate station (CGS) heater waste for power and hydrogen production: A comparative study", *Int. J. Hydrogen Energy*, **43** (3), 1855 (2018).

[11] Yousefzadegan, M. S., Masoudi, M., Ashtiani, Y. K., Kambarani, M. and Pishbin, S. I., "Consequence analysis for probable accidents of filter separators installed in gas pressure reduction stations", Proceedings of *2nd International Conference on Environmental Science and Development IPCBEE*, (2011).

[12] Mousavi, J. and Parvini, M., "Analyzing effective factors on leakage-induced hydrogen fires", *J. Loss Prev. Process Ind.*, **40**, 29 (2016).

[13] Rosa, A. C., de Souza, I. T., Terra, A., Hammad, A. W., Di Gregório, L. T., Vazquez, E. and Haddad, A., "Quantitative risk analysis applied to refrigeration's industry using computational modeling", *Results Eng.*, **9**, 100202 (2021).

[14] Cheraghi, H., Soltanzadeh, A. and Ghiyasi, S., "Consequence modeling of the ethylene oxide storage tanks explosion using the PHAST software (A case study in a petrochemical industry)", *Iran. J. Health Environ.*, **11** (2), 261 (2018).

[15] Anjana, N., Amarnath, A. and Nair, M. H., "Toxic hazards of ammonia release and population vulnerability assessment using geographical information system", *J. Environ. Manage.*, **210**, 201 (2018).

[16] Khorram, R., "Modeling the qutcome of chlorine emission based on emergency response planning values over 24 hours using the PHAST software (Case study: Bushehr nuclear power plant)", *Journal Mil. Med.*, **22** (5), 492 (2020).

[17] Yang, R., Gai, K., Yang, F., Zhang, G. and Sun, N., "Simulation of pressure tank leakage based on PHAST", IOP Conference Series: Materials Science and Engineering, IOP Publishing, (2019).