PERINTIS eJournal

PERINTIS eJournal, **2019**, Vol. 9, No. 1, pp. 15-29

CONSEQUENCE SIMULATION OF JET FIRE DUE TO LEAKAGE OF PIPELINES IN A NATURAL GAS POWER PLANT IN MALAYSIA

Najeeb Abdul Khalid [1], Mohd Zahirasri Mohd Tohir [1*], and Mohamad Syazarudin Md Said

[1]Safety Engineering Interest Group, Department of Chemical and Environmental Engineering, Faculty of Engineering, Universiti Putra Malaysia. 43400 Serdang, Selangor, Malaysia.

[*]Corresponding Author: zahirasri@upm.edu.my

ABSTRACT

There are several non-renewable sources for the generation of electricity and one of them is by the gas-fired power plant. Gas-fired power plant is utilizing natural gas which is mainly composed of methane in its process for the production of electricity. The usage of natural gas poses safety concerns should unwanted events occurred. Therefore, the objective of this work is to evaluate possible consequences of jet fire due to leakage of pipes inside the plant using ALOHA simulation software and followed by Quantitative Risk Calculation approach. There are several parameters studied in this work such as the size of leakage aperture, pipeline pressure, pipeline temperature and wind speed. It was found from the study that the bigger the leakage size and the higher the pipeline pressure resulted to greater consequence. Meanwhile, the higher the temperature of the pipeline has resulted a lesser consequence. It was also found that variation of the wind speed does not affect the degree of consequences in terms of severity. Moreover, the consequence from the worst case scenario was studied where it was found that heat radiation intensity from the possible jet fires at a distance of 50m, 100m, 200m, 300m and 400m are 12.1 kW/m^2, 3.04 kW/m^2, 0.754 kW/m^2, 0.342 and 0.196 kW/m^2 respectively. As a conclusion, the study has shown that the consequence of jet fire will only pose a deadly threat to the workers inside the plant compound. This study serves as a structured work for consequence assessment for other types of premises in the future.

Keywords: ALOHA, natural gas, vapour cloud explosion, jet fire.

1.0 INTRODUCTION

Over recent years, the expansion of megacities and metropolis are at its peak due to the increasing population of the Earth. This phenomena is not achievable without electrical power that had aggressively propelled scientific innovations since its findings in the 17th century. Nowadays, electricity is rendered through many sources and techniques. For example, electricity can be generated by two sources such as through renewable energy and non-renewable energy. Likely, the most preferred power generation is by the non-renewable energies conceived by its efficiency and dependability.

PERINTIS eJournal, **2019**, Vol. 9, No. 1, pp. 15-29

Natural gas is a product refined from the raw natural gas drilled and obtained from underneath the Earth's crust. Initially, the gas is obtained from the gas wells which ordinarily consisting of methane, both liquefied and gaseous hydrocarbons, water and acid gases [1,2]. The needs of dry natural gas is crucial for the energy sector which the gas-fired power plants are utilizing the natural gas for powering the electricity-producing turbines thus powering the entire towns and cities.

In Malacca, there is such a fully operated gas-fired power plant constructed nearby to a living public quarters and it is located at Teluk Gong. Exactly at the coordinate of 2^{o} 20" North and 102^{o} 03" East the Panglima Power Plant is a gas-fired power plant which utilizing natural gas for its operation. Likely, the plant is located about 150 meters to the nearest residential area and about 270 meters only to the public library. Likewise, the operation of the plant is imposing a susceptible risk and danger to the public safety. Such tragedies had happened in the past where thousands of people were affected by the explosion of plants and factories [3].

In response, there is a crucial need in modelling possible accidents due to leakage of the flammable gas from the plant and use it as future safety guidelines [4]. This has led to the objective of to evaluate possible consequences of jet fire due to leakage of pipes inside the plant using ALOHA simulation software and followed by Quantitative Risk Calculation approach. The study can be elaborated by determining the variables that affecting to the scale of the accident. In addition, the study towards the implication of jet fire should be highlighted as it is a significant accident to the hydrocarbon operating plants [5]. Besides simulation modelling, there is also a required analysis towards the consequences of the accident such the impact of the accident towards the living [6, 7, 8]. Individual risk or personal risk is a factor where there is a suppression of analysis towards the degree of an acceptable value of risk that can be endured by a regular human. As the accident propagates, the individual risk is determine all around the radius which gives a comprehensive idea towards public safety approach respectively [9]. Thus, a supplement of Quantitative Risk Calculation (QRA) is added for supporting the study. Eventually, this piece of work will provide a structured method for consequence assessment for decision makers.

2.0 METHODOLOGY

2.1 Pre-Simulation

At the beginning of this research, a comprehensive site visit and thorough surveying was conducted at the power plant specifically at the TG1 complex which lies on the coordinate of 2^{0} 20" North and 102^{0} 03" East. The complex is located on the shore of the state of Malacca and it is equipped with full fledge power plant facilities. The main pipeline conveying natural gas from the regulator station to the main processing plant was investigated. Thus, the operating condition of the pipeline such as pressure, temperature and dimension was obtained for the modelling and analyses purposes.

2.2 Weather and Atmospheric Condition

The information for weather and atmospheric condition is one important factor which determines the direction of the dispersion of emitted gases [10]. The local weather and its atmospheric condition of the investigated site are obtained directly from the Malaysian Meteorological Department which is under the Ministry of Science, Technology and Innovation (MOSTI). The data obtained is for ALOHA modelling purposes.

2.3 ALOHA Simulation

The simulation and analysis of the accident consequences was conducted by using Aerial Location of Hazardous Atmospheres (ALOHA®) version 5.4.7. In this study, ALOHA was used to model and predict the consequences of natural gas leakage due to the aperture of the pipeline [11]. Plus, ALOHA had granted the user a privilege to model accident according to various variables such as atmospheric and operating conditions.

2.3.1 Controlled Accident

The assessment of the leakage apertures was denoted on the study done Shao & Duan [9] and which in this study the diameter of the aperture was d_1 = 25mm, d_2 = 50mm d_3 = 100mm and d_4 = full bore (203.2mm). The four sizes of the aperture selected were double the size of the former size i.e. $d_2 = 2 \times d_1$ and so forth. The selection was based on the work by Koornneef et al. [12] which were expecting an increasing severity with several orders of magnitude. Controlled accident by means is that the source of the pipeline was shut off once the leakage is detected. Thus, the consequences of the remaining natural gas inside the pipeline escaping through the leakage aperture was able to be studied. Therefore, a significant difference of consequences will be notified and side to side comparison of modelling will be done via ALOHA simulation. Table 1 shows the conditions of the controlled accidents applied for the TG1 complex.

Table 1: The set conditions of the controlled accidents applied for the TG1 complex

Parameters	Value			
Leakage Size	25mm	50mm	100mm	203.2mm
Wind Speed	14 m/s	14 m/s	14 m/s	14 m/s
Wind Direction	SW to NW	SW to NW	SW to NW	SW to NW
Atmospheric Pressure	1 atm	1 atm	1 atm	1 atm
Pipeline Pressure	26 bar	26 bar	26 bar	26 bar
Surrounding Temperature	28°C	28°C	28°C	28°C
Pipeline Temperature	22°C	22°C	22°C	22°C

2.3.2 Uncontrolled Accident

This part enhanced on the study upon simulation of accident according to several variables such as pipeline pressure, pipeline temperature and wind speed [13]. The condition of the pipeline was maintain connected to the source as if no immediate response occurred due to the leakage. Therefore, the natural gas from the regulator station was let free running through the leakage aperture respetively. The pipeline pressure variable was studied on 26 Bar, 40 Bar and 80 Bar. On the other hand, for the pipeline temperature, the studied temperature is at 22°C, 40°C and 80°C. Lastly, for the wind speed variable, the speed of the wind studied was set at 14 m/s, 30 m/s and 60 m/s respectively. Table 2, Table 3 and Table 4 shows the conditions for the simulation according to the pipeline pressure, temperature and wind speed variables respectively.

Table 2: The conditions for the simulation according to the pipeline pressure variables.

Parameters	Value		
Wind Speed	14 m/s	14 m/s	14 m/s
Humidity	75%	75%	75%
Pipeline Temperature	22°C	22°C	22°C
Surrounding Temperature	28°C	28°C	28°C
Cloud Formation	Partly cloudy	Partly cloudy	Partly cloudy
Wind Direction	SW to NW	SW to NW	SW to NW
Atmospheric Pressure	1 atm	1 atm	1 atm
Pipeline Pressure	26 bar	40 bar	60 bar
Hole Leakage	Full bore	Full bore	Full bore

Table 3: The conditions for the simulation according to the pipeline temperature variables.

Parameters	Value		
Wind Speed	14 m/s	14 m/s	14 m/s
Humidity	75%	75%	75%
Pipeline Temperature	22°C	40°C	80°C
Surrounding Temperature	28°C	28°C	28°C
Cloud Formation	Partly cloudy	Partly cloudy	Partly cloudy
Wind Direction	SW to NW	SW to NW	SW to NW
Atmospheric Pressure	1 atm	1 atm	1 atm
Pipeline Pressure	26 bar	26 bar	26 bar
Hole Leakage	Full bore	Full bore	Full bore

Table 4: The conditions for the simulation according to the wind speed variables.

Parameters	Value		
Wind Speed	14 m/s	30 m/s	60 m/s
Humidity	75%	75%	75%
Pipeline Temperature	22°C	22°C	22°C
Surrounding Temperature	28°C	28°C	28°C
Cloud Formation	Partly cloudy	Partly cloudy	Partly cloudy
Wind Direction	SW to NW	SW to NW	SW to NW
Atmospheric Pressure	1 atm	1 atm	1 atm
Pipeline Pressure	26 bar	26 bar	26 bar
Hole Leakage	Full bore	Full bore	Full bore

2.4 Quantitative Risk Calculation

In this section, the consequences of jet fire such as heat radiation flux and heat radiation intensity are determined by a series of mathematical order. The purpose of applying Quantitative Risk Calculation (QRC) in this study is to compare side by side with the results obtained through the ALOHA simulation program. Therefore, it is much clearer to examine the effect of jet fire by either the ALOHA program or the strings of mathematical equations. The applied equations are based from the study done by Huang & Li [7] as they are in linear form respectively.

Applying the **Eq. (1)**, the heat radiation flux is determined by inserting the simulated data into the equation. The heat of combustion acts as a constant as it is referred to the Material Safety Data Sheet (MSDS) of methane gas respectively.

$$q = \frac{nQH}{n"} \tag{1}$$

where q = Heat radiation flux of point sources, W; q"=Heat radiation intensity of a point source, W/m^2 ;x_R= Radiation fraction, taken 0.2; = Efficiency factor, taken 0.35; n"= Hypothetical point radiation source number, taken 5; Q= Leaking velocity, kg/s; H= Heat of combustion for methane; and L= Distance of the target from the point source, m.

From the heat radiation flux, q it is possible to determine the heat radiation intensity by inserting the value of the distance between the central axis of the leakage point to the target location respectively. By utilizing **Eq. (2)**, the heat radiation intensity, q" at L, meters can be determined as follows:

$$q" = \frac{q.x_R}{4\pi L^2} \tag{2}$$

PERINTIS eJournal

PERINTIS eJournal, **2019**, Vol. 9, No. 1, pp. 15-29

3.0 RESULTS AND DISCUSSIONS

Table 5 summarizes the results of all of the controlled and uncontrolled simulation runs where the worst consequences were indicated in bold font. For the controlled simulation run, the worst consequence was when the pipeline was full bore in which it results the highest flame length. For the uncontrolled simulation by varying the pipeline pressure, it shows that the higher the pressure the bigger the consequences, this is consistent with the findings of Koornneef et al. [12]. Meanwhile, the higher the temperature of the pipeline has resulted a lesser consequence. It was also found that variation of the wind speed does not affect the degree of consequences in terms of severity which also is consistent with the findings of Koornneef et al. [12].

Table 5: The screened parameters are giving multiple readings.

Parameters	Hole Size			
Details	25mm	50mm	100mm	**Full Bore**
Total Amount Released, kg	130	130	130	**130**
Released Rate, kg/min	80.5	128	130.2	**130.2**
Max Flame Length, m	2	4	8	**17**
Parameters	Pipeline Pressure			
Details	26 Bar	40 Bar	**60 Bar**	
Total Amount Released, kg	154077	237093	**355574**	
Released Rate, kg/min	2600	4000	**5990**	
Max Flame Length, m	20	21	**22**	
Parameters	Pipeline Temperature			
Details	**22**	40	80	
Total Amount Released, kg	**154077**	149586	140868	
Released Rate, kg/min	**2600**	2520	2370	

PERINTIS eJournal, **2019**, Vol. 9, No. 1, pp. 15-29

Table 5 ***(Cont.)*****:** The screened parameters are giving multiple readings.

Parameters	Hole Size		
Max Flame Length, m	**20**	19	18
Parameters	Wind Speed		
Details	14 m/s	30 m/s	60 m/s
Total Amount Released, kg	154077	154077	154077
Released Rate, kg/min	2600	2600	2600
Max Flame Length, m	20	20	20

The studies on the consequence of natural gas leakage in the power plant at Telok Gong have been done successively. Thus, the catastrophic potential of jet fire had been identified by a series of significant variables.

In this current study, the set of scenarios are thoroughly identified and simulated by ALOHA simulaton software. The pre-simulation procedure does require an initial step in data collecting process such as the physical measurement of the plant and the information regarding the atmospheric condition. Those data were cautiously segregated and sort into several simulation scenarios. Thus, the simulated scenarios were carefully examined and compared respectively

Consequently, the objectives were successively investigated by commencing a complete simulation procedure through the ALOHA software. Several parameters such as pipeline pressure, pipeline temperature, wind speed and the leakage aperture were set as the investigated variables. The results show that the leakage aperture and pipeline pressure variables contributed to the positive effects to the leakage accident. On the other hand, the pipeline temperature variables did caused negative effects to the accident. Lastly, the wind speed variables are unlikely to cause a major difference between results respectively.

3.1 Worst-Case Scenario

From the generated simulations, it is found that the factor of pressure gives out the most devastative impact compared to the pipeline temperature and surrounding wind speed factors when there is a leakage happened to the gas pipeline. Table 6 shows the identified parameters that lead to the worst-case scenario.

Table 6: Identified parameters contributing to the worst-case scenario.

Parameters	Value
Wind Speed	14 m/s
Humidity	75%
Pipeline Temperature	22°C
Surrounding Temperature	28°C
Cloud Formation	Partly cloudy
Wind Direction	SW to NW
Atmospheric Pressure	1 atm
Pipeline Pressure	60 bar
Hole Leakage	Full bore

Referring to Figure 1, it shows the source strength of the leakage incident by the release rate of the natural gas against time. As predicted, the release rate of the natural gas went steady across the respective timeline and then suffers a sudden drop at the end. At the very beginning, the release rate was started at 5990 kg/min and suddenly plunges within the period of 60 minutes and this is affirmatively due to the massive opening of the leakage aperture together with the highly pressurised pipeline content.

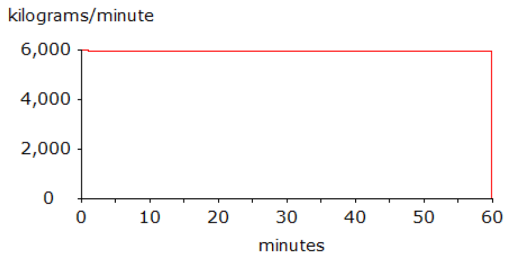

Figure 1. Release rate of natural gas during the worst-case scenario.

Denoting to the Figure 2, it is the simulated model of flammable area as if the formation of vapour cloud of the natural gas occurred and went drifted by the moving wind. At 50000 ppm (100% LEL) of the fraction methane concentration measured in the air, it reaches the distance of 112 meters while at 30000 ppm (60% LEL) it ranges at 146 meters respectively. On the other hand, at 5000 ppm (10% LEL) the vapour reaches the distance of 363 meters. In addition, referring to the Figure 3, the simulated model is jotted into the map and the disastrous incident can be clearly notified from the aerial view of the TG1 complex.

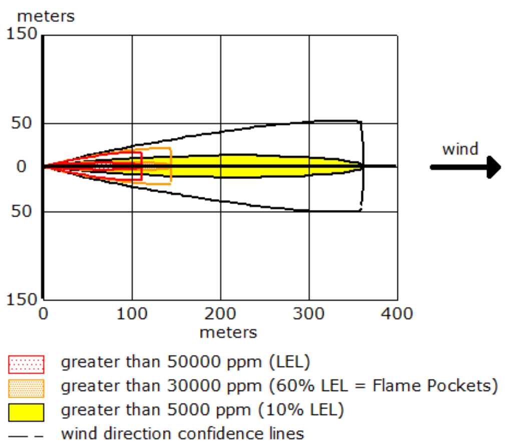

Figure 2. The modelled flammable area due to the vapour cloud.

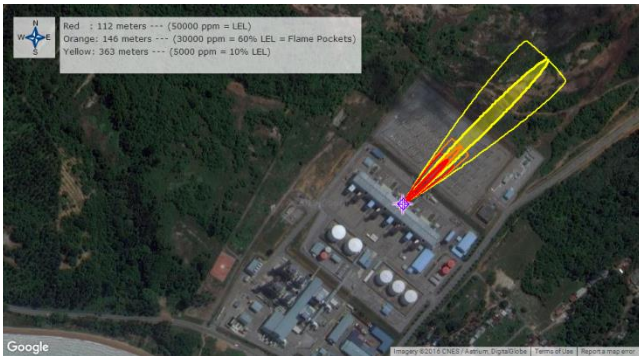

Figure 3. The flammable area model simulated onto the TG1 complex.

The blast wave that comes from the overpressure due to the Vapour Cloud Explosion (VCE) is categorised into 3 significant levels specifically for this study. The pressures highlighted in this section are at 6894 Pa, 24131 Pa and 55158 Pa respectively. Based on ALOHA setting, the 3 level of pressure was predetermined into the program as it indicates major and significant effect of the blast wave. At 6894 Pa, the force of the blast wave is causing a glass to shatter whereas at 24131 Pa the pressure is likely to cause a serious injury such as broken bones and minor injury to the internal organ. Furthermore, at 55158 Pa the blast wave is potentially to cause a major destruction to buildings and loss of lives.

Denoting to the Figure 4, it is the model of blast wave as if the formation of vapour cloud of the natural gas occurred and went ignited by nearby extraneous ignition or sparks. The wave pattern due to the overpressure of the VCE reaches 127 meters downwind and the pressure is measured at 6894 Pa which is only capable of shattering glasses respectively. For depiction of the incident, Figure 5 completely shows the simulated wave pattern onto the TG1 complex. From the aerial view, the blast wave from the overpressure is causing a serious devastative impact and forthwith compromised to the safety of occupants together with the structure's integrity within the parameter respectively.

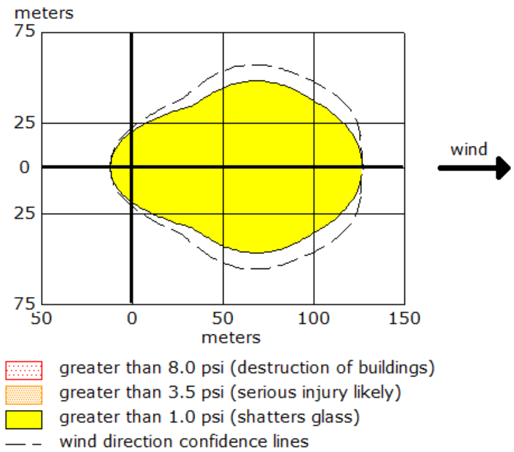

Figure 4. The modelled blast wave due to overpressure of VCE.

PERINTIS eJournal, **2019**, Vol. 9, No. 1, pp. 15-29

Figure 5. The VCE model simulated onto the TG1 complex.

For every gas leakage incident, the most terrifying event that should be prevented at all time is the formation of jet fire. In this scenario, at 60 Bar of pipeline pressure did forced a volume of natural gas measure up to 355574 kg and instantly catches external fire due to obscure ignition or sparks. The fire is then continuously burning and propelled outwards from the central axis of which the gas is forced out due to the remaining pressure inside the pipeline. The intensity of the release is best to referred to Figure 6 as it renders the burning rate of the jet fire within 60 minutes respectively. The fire is strongly spurred at the very first minute and diminished upon the 60th minute due to the decreasing volume of the fuel inside the pipeline. On the other hand, denoting Figure 7 it shows the heat profile of the fire routing from the leakage aperture. The fire is measured up to 22 meters while the heat radiation of the fire goes beyond that and it ranges approximately to 130 meters according to the direction of downwind. By citing the Figure 8, it presents the simulated model of the jet fire onto the TG1 complex. Atrociously, the heat radiation at 10kW/m^2 which imposed fatal threat within 60 seconds is ranged at 61 meters. Whereas, the heat radiation of 5kW/m^2 which is capable of inflicting 2nd degree burns to the skin within 60 seconds is in the range of 85 meters while the heat radiation of 2kW/m^2 which is capable of causing mild pain to the skin within 60 seconds is in the range of 130 meters from the central axis of leaking point respectively.

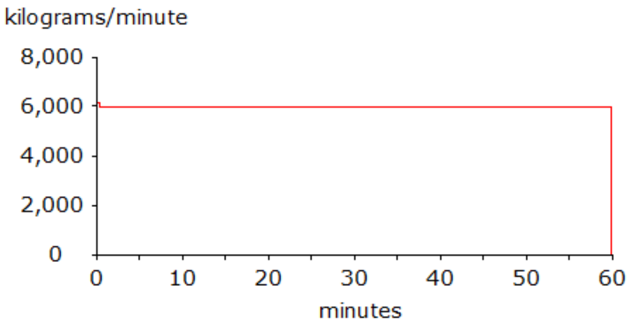

Figure 6. The burning rate of jet fire at 60 Bar of pipeline pressure.

PERINTIS eJournal

PERINTIS eJournal, **2019**, Vol. 9, No. 1, pp. 15-29

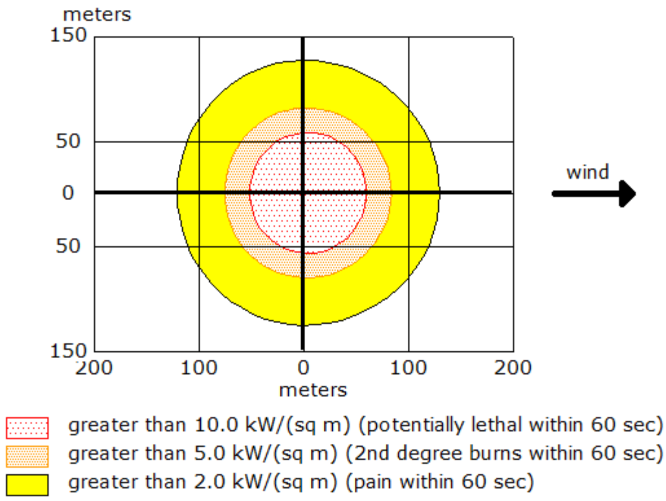

Figure 7. The modelled heat pattern due to the formation of jet fire.

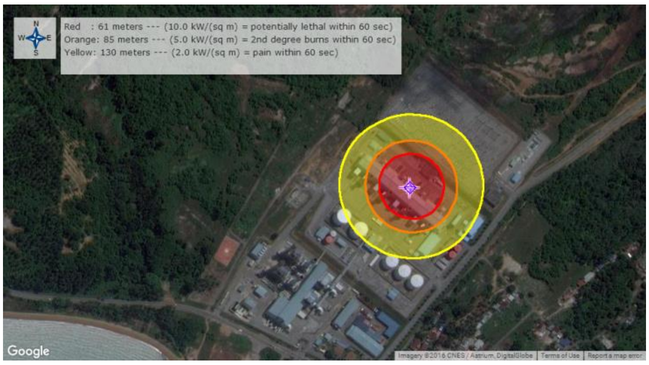

Figure 8. The jet fire model simulated onto the TG1 complex.

3.2 Quantitative Risk Calculation

Denoting Table 7, it shows the tabulated form of heat radiation intensity obtained from the simulation program against the value obtained from the previous mathematical calculation. Unlikely, there are huge differences between the different sources regarding the heat radiation intensity which originating from various distances respectively. As an example, the heat radiation intensity at 50 meters from the ALOHA program is at 12.1 kW/m^2 whereas it is only 2.2 kW/m^2 from the manual calculation. There are about 84.5% differences from the value. This is probably due to the comprehensive and surplus regression function added into the ALOHA program which is accurate in determining the consequence of jet fire which is regrettably missing from the manual calculation process respectively.

Table 7: Heat radiation intensities from different sources are tabulated.

	Heat Radiation Intensity at Specified Distance, kW/m^2				
Source	*400m*	*300m*	*200m*	*100m*	*50m*
ALOHA	0.196	0.342	0.754	3.04	12.1
QRC	0.03477	0.06181	0.13908	0.55631	2.22524

3.3 Further discussions

From the generated models, it is found out there are several parameters affecting the condition of the accident. Parameters such as sizes of leakage aperture and gas pipeline pressures are significantly affecting the orientation of the release condition and accident consequences. This is also known as positive response by the parameter. On the other hand, the factor of pipeline temperature is giving such a negative response whereby the higher the temperature of the pipeline, the lower natural gas release conditions. In addition, the factor of wind speed is unlikely to cause any significant response either to the release condition or accident consequences. The parameters of the worst-case scenario were set at full bore leakage aperture (203.2mm), 60 Bar pipeline pressure, 22^{o}C pipeline temperature and 14 m/s of surrounding wind speed respectively. On the other hand, from the QRC study, it shows that even in a worst-case scenario the settlement around the plant is considered safe while the workers and buildings inside the plant may suffers death and damage threat due to the formation of jet fire respectively.

4.0 CONCLUSIONS

In this study, it is concluded that the effect of gas leakage accident which leads to the formation of jet fire does not impose such threat to the public living outside the plant even so at the worst-case scenario. On the other hand, the worst case scenario accident does impose a deadly threat to the workers and buildings inside the plant. For future studies, it is recommended to simulate the scenario by using PHAST software owned by DNV-GL and the results should be compared side to side. Plus, a comprehensive probability study should be done as a surplus to this respective study.

Acknowledgements

The authors would like to pay appreciation to those who supported for this work. This work is supported by the Safety Engineering Interest Group, Department of Chemical and Environmental Engineering, Faculty of Engineering of Universiti Putra Malaysia.

References

[1] Liu, K., Zhang, B. J., & Chen, Q. L. 2015. A New Adsorption Process to Intensify Liquefied Petroleum Gas Recovery from Raw Natural Gas. *Energy Procedia*, *75*, 853-859.

[2] Mengal, A., Uqaili, M. A., Harijan, K., & Memon, A. G. 2014. Competitiveness of Wind Power with the Conventional Thermal Power Plants Using Oil and Natural Gas as Fuel in Pakistan. *Energy Procedia*, *52*, 59-76.

[3] Dou, Z., Mebarki, A., Cheng, Y., Zheng, X., Jiang, J., Wang, Y. & Li, J. 2019. Review on the emergency evacuation in chemicals-concentrated areas. Journal of Loss Prevention in the Process Industries.

[4] Baalisampang, T., Abbassi, R., Garaniya, V., Khan, F., & Dadashzadeh, M. 2019. Modelling an integrated impact of fire, explosion and combustion products during transitional events caused by an accidental release of LNG. Process Safety and Environmental Protection.

[5] Girgin, S., & Krausmann, E. 2016. Historical analysis of U.S. onshore hazardous liquid pipeline accidents triggered by natural hazards. *Journal of Loss Prevention in the Process Industries*, *40*, 578-590.

[6] Li, J., & Huang, Z. 2012. Fire and Explosion Risk Analysis and Evaluation for LNG Ships. *Procedia Engineering*, *45*, 70-76.

[7] Huang, Z., & Li, J. 2012. Assessment of Fire Risk of Gas Pipeline Leakage in Cities and Towns. *Procedia Engineering*, *45*, 77-82.

[8] Zhang, Q., Zhou, G., Hu, Y., Wang, S., Sun, B., Yin, W., & Guo, F. 2019. Risk evaluation and analysis of a gas tank explosion based on a vapor cloud explosion model: A case study. Engineering Failure Analysis, 101, 22-35.

[9] Shao, H., & Duan, G. 2012. Risk Quantitative Calculation and ALOHA Simulation on the Leakage Accident of Natural Gas Power Plant. *Procedia Engineering*, *45*, 352-359.

[10] Apiratikul, R. 2015. Approximation Formula for the Prediction of Downwind Distance that Found the Maximum Ground Level Concentration of air Pollution Based on the Gaussian Model. *Procedia - Social and Behavioral Sciences*, *197*, 1257-1262.

[11] Shu-jiao, T., Siu-ming, L., Pei-hong, Z., & Bao-zhi, C. 2013. Jet Fire Consequence Evaluation on the Natural Gas Transported by Pipelines. *Procedia Engineering*, *52*, 349-354.

[12] Koornneef, J., Spruijt, M., Molag, M., Ramírez, A., Turkenburg, W., & Faaij, A. 2010. Quantitative risk assessment of CO2 transport by pipelines—a review of uncertainties and their impacts. Journal of hazardous materials, 177(1-3), 12-27.

[13] Bjerketvedt, D., Egeberg, K., Ke, W., Gaathaug, A., Vaagsaether, K., & Nilsen, S. H. 2011. Boiling liquid expanding vapour explosion in CO_2 small scale experiments. *Energy Procedia*, *4*, 2285-2292.