www.arpnjournals.com

MODELLING OF POOL FIRE AND INJURY PREDICTION CONSIDERING DIFFERENT WIND SPEEDS AND DIRECTIONS IN OFFSHORE PLATFORM

Usama Muhammad Niazi[1], Mohammad Shakir Nasif[1], Masdi bin Muhammad[1] and Muhammad Imran[2]
[1]Mechanical Engineering Department Universiti Teknologi Petronas, Bandar Seri Iskandar, Tronoh, Perak, Malaysia
[2]Civil Engineering Department Universiti Teknologi Petronas, Bandar Seri Iskandar, Tronoh, Perak, Malaysia
E-Mail: ukniaxi@gmail.com

ABSTRACT

The offshore facilities are growing in number, size and complexity and so are the fire risks. Liquefied natural gas (LNG) is one of the most common hydrocarbon fuel produced in an offshore oil and gas platforms. LNG can cause different types of fires such as jet fire, pool fire, flash fire and fire ball. Among the various offshore accidents, pool fire is the most repeated phenomenon. It has the potential to cause significant injury to personnel, discontinuity of operations and damage to structure and equipment. Wind speed significantly affect the incident heat due to fuel radiation in case of pool fires in upwind and downwind direction. It is, therefore, requisite to quantify the hazards posed by pool fires in upwind and downwind direction at different wind speeds. The study is focused on modeling of pool fire using Computational Fluids Dynamics (CFD) with varying wind speed. For CFD modeling, Fire Dynamic Simulator (FDS) and Pyrosim are used. Effect of wind speed on smoke movement in downwind direction is investigated. The incident heat flux due to pool fire heat radiation is determined in upwind and downwind direction. Furthermore, radiative heat flux is utilized to calculate the impact on human for 1st degree of burn, 2nd degree of burn and death in upwind and downwind direction. The results exhibited that incident heat flux and probability of injury varies significantly in downwind direction by increasing wind speed and minor variation have been found in upwind direction.

Keywords: CFD, FDS, pool fire, pyrosim, probit model.

INTRODUCTION

The global demand of hydrocarbon production has increased rapidly overall the last few years. According to British Petroleum statistical review of world energy (2013), the demand of energy consumption has significantly increased. Leading source of energy is oil with 33 %, coal with 30 % and natural gas with 24 %[1]. Among the three major energy sources, natural gas is environmentally attractive fuel as it emits no sulphur, very less nitrogen oxide, no solid waste and less carbon dioxide as compared to oil and coal [2]. Due to major advantages of natural gas over coal, the increasing demand of natural gas has driven offshore platforms to more deeper, remote and harsh environments and as a result, fire risk associated with it is becoming challenging.

The function of majority of offshore platform is to extract from seabed, process and store the hydrocarbons. These hydrocarbons are highly flammable. Hydrocarbon release results into fire and explosion that could result into total collapse of offshore platform, loss of life and environmental pollution [3-5]. According to Pule *et al.* [2], fire is the most frequent accident occurring on an offshore platform. Recently, Vianna and Huser *et al*. [6] also described that total risk due to fire on an offshore facility is high. Fire incidents analysis showed that among different types of hydrocarbon fire (jet fire, flash fire, pool fire, fire ball), pool fire is the most frequent one [7] . The probability of pool fire occurrence on offshore platform are high due to presence of hydrocarbons on board [8]. Offshore accidents such as Deepwater Horizon and Piper Alpha have shown that consequences of fire on human injury are catastrophic [9]. Many methodologies are

developed to calculate the risk of fire considering human impact [10-12]. The effect of wind speed has significant effect on plume structure, flame structure and incident heat flux [13]. When the wind blows the flame of pool fire, it will cause variation of incident heat flux in upwind and downwind direction and as a result, probability of injury/death varies significantly. For accurately calculating the risk considering human impact, a number of softwares have been developed including empirical, semi-empirical, numerical and phenomenological models for inspecting the characteristics of accidents [11]. Among these models, numerical models based on CFD give more accurate results. It enables more realistic and detail simulation. According to recent report by International Association of Oil and Gas Producers [14], fire risk can be calculated using two approaches: simple mathematical formulas and Computational Fluid Dynamics methods. Therefore, the current study utilized CFD method to investigate the effect of wind speeds and directions on probability of human injury.

The present study modelled pool fire with varying wind speeds in upwind and downwind directions. Pool fire was modelled using Computational Fluid Dynamics software Fire Dynamics Simulator (FDS). The impact modelling considering human injury/death was done using probit model.

METHODOLOGY

The methodology applied in the current study consists of accident scenario selection, modelling approach for pool fire considering different wind speeds, directions and human impact (1st degree burns, 2nd degree

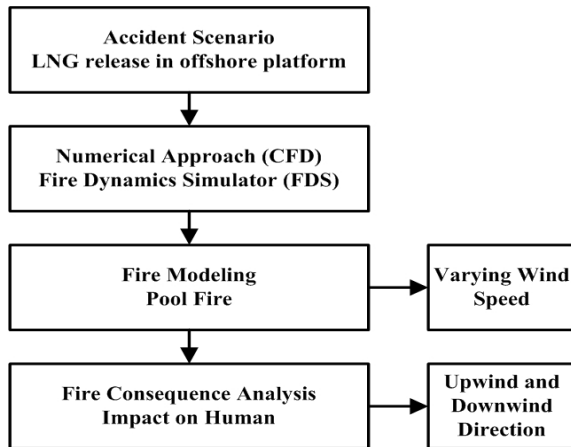burns, death) using probit model. The steps are shown in Figure-1.

Figure-1. Research methodology.

Accident scenario

An offshore facility consists of number of equipment for storing, processing and transporting hydrocarbons. The possibility of leakage could result from separators, compressors, pipes, storage tanks, flash drums etc. As hydrocarbons are highly flammable, the resulting leakage could catch immediate fire due to presence of ignition sources. In this scenario, LNG leakage took place due to a crack in the pipe.

Liquefied natural gas

Natural gas is hydrocarbon gas mixture consists primarily of methane and small percentage of ethane, butane and propane. The natural gas in raw state is extracted and refined in gaseous state. It is normally stored in liquid state (LNG) as it occupy 1/600th the volume as compared to the gaseous state that help in transporting. This research was intended to analyze consequence of LNG spill.

Fire type

Spillage or leakage of flammable material can cause a fire due to presence of number of ignition sources (open flames, sparks etc.). Depending upon the types of leakage scenarios in an offshore platforms, fires are mainly categorized into four types, jet fire, pool fires, flash fires and fire balls. A pool fire occur due to release of liquid fuel that forms a pool on the surface, vaporizes and due to presence of ignition sources, results into a pool of fire [11]. This research analyzed the impact on human considering thermal radiations from a pool fire.

Fire dynamics simulator

CFD modelling of different types of fires is complex because it includes aspects of multi-phase flow, radiative transport, conductive and convective heat transfer and bluff body aerodynamics. Fire Dynamics Simulator (FDS) is CFD software of thermally driven flow

developed by the National Institute of Standards and Technology (NIST). FDS was especially developed to deal with fire related problems. FDS solves numerically a form of the Navier-Stokes equations appropriate for low speed with an emphasis on smoke and heat transport from fires [15]. FDS uses Large-Eddy Simulation (LES) to solve the conservation equations and upgrade the solutions on a 3-D grid [16]. LES modeling does not utilize averaged parameters so a transient solution can be quickly obtained. FDS 6.3.2 version was used. Incident heat flux obtained at different wind speeds were analyzed later for (injury/death) of personnel.

Fire consequence analysis

The results obtained from FDS can be expressed in different representations. In this study, incident heat flux obtained from CFD simulation was used to evaluate its impact in downwind and upwind direction under different wind speeds. The effect of thermal radiation on personnel are 1st degree burns, 2nd degree burns and death. Probit functions are used to define these impacts. For determining the number of burns and deaths, incident heat dose "D" due to thermal radiation is employed [17] given by the Equation. (1),

$$D = t_{eff} \times q^{4/3} \tag{1}$$

Where q (W/m²) is the heat flux calculated, t_{eff} (s) is person's exposure time to this heat flux.
The exposure time is calculated from Equation. (2),

$$t_{eff} = t_r + \frac{x_0 - r}{u} \tag{2}$$

Where t_r (s) is person's reaction time which is considered as 5 seconds [17], x_0 (m) represents the distance between the flame's surface and the position where the intensity of heat flux is lower than 1 KW/m², r (m) is the distance of the person from the surface of flame and u (m/s) is the human escape velocity considered as 4 m/s [17]. For calculation of probability P of injury for 1st degree burns, 2nd degree burns and death due to thermal radiation dose "D" is given by the Equation. (3),

$$P = f_k \frac{1}{2} \left[1 + erf \left(\frac{p_r - 5}{\sqrt{2}} \right) \right] \tag{3}$$

Where probit function P_r is given by the empirical Equation. (4),

$$P_r = c1 + c2 \ln D \tag{4}$$

RESULTS AND DISCUSSIONS

LNG release and pool formation

The modelled scenario, considered 55 kg/s of LNG released at an offshore platform due to crack in a

pipe. The release duration is 100 s with an ambient temperature of 25 °C. The direction of wind is taken to be 337° (SSE). The wind speed varied from 1 m/s to 5 m/s. A pool of LNG is formed with an equivalent diameter of 12 m and immediately gets ignited. Pool fire is defined by specifying mass loss rate per unit area, which for LNG is 0.078 kg/m.s^2. Geometry of offshore platform is made using pyrosim. The simulation volume is 80 m × 70 m × 50 m with a grid dimension of 0.57 m in all directions. The total number of cells for mesh are 1680000. For calculating the incident heat flux in upwind and downwind direction at different wind speeds ranging from 1 m/s to 5 m/s, incident heat flux sensors are placed along x-axis at a distance of every 3 m from the pool fire in upwind and downwind direction. Wind direction is taken in z-axis. Wind is blown at a height of 5 m from the surface of platform.

From the output file of FDS, average heat release rate is around 461 MW. The flame height of pool fire is found to be 22 m. Figure-2 shows the FDS model of offshore platform.
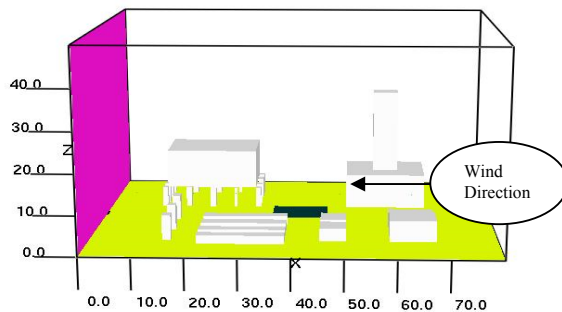

Figure-2. Modelled offshore platform geometry.

Effect of wind speeds on smoke movement in downwind direction

Figure-3 and Figure-4 exhibit the effect of wind speed variation at 2 m/s and 5 m/s in downwind direction respectively. The wind speed strongly affected the direction of flame and smoke. The figures clearly shows that the flame and smoke layer is close to the ground surface at 5 m/s as compared with 2 m/s that will severely affect the personnel working in that specific area.
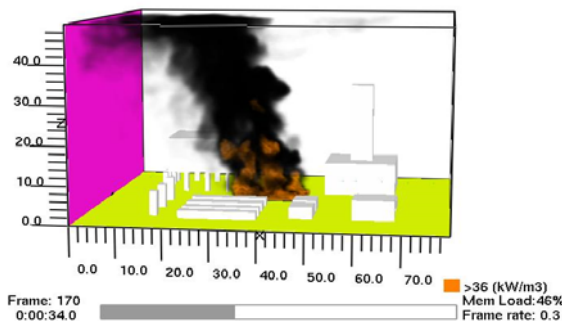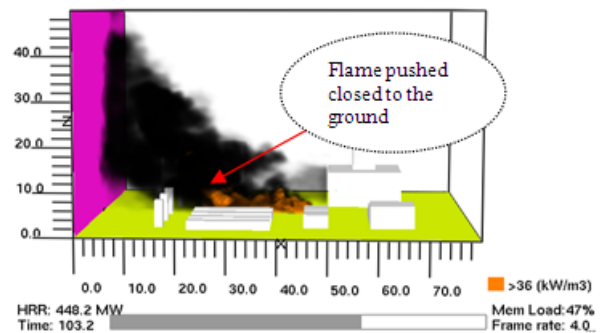

Figure-3. Pool fire wind speed (2 m/s).

Figure-4. Pool fire wind speed (5 m/s).

Variation of incident heat flux in downwind and upwind directions

Figure-5 shows the variation of incident heat flux in downwind direction with varying wind speed at different distances from the pool fire. The FDS model predicts that within 15 m from the fire, human are exposed to higher value of heat flux with a maximum of 180 KW/m^2. As seen, the highest incident heat flux was recorded at 5 m/s and the lowest was recorded at 1 m/s wind speed. This is attributed to the fact that when the wind speed increased, it pushed the flame further in the down wind direction as compared to other wind speeds. The incident heat flux gradually decreases up to 30 m.
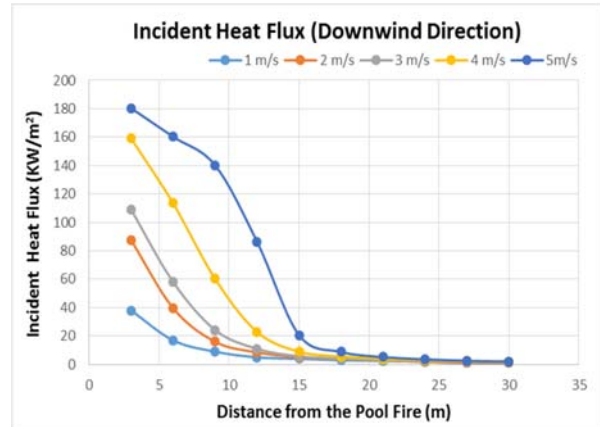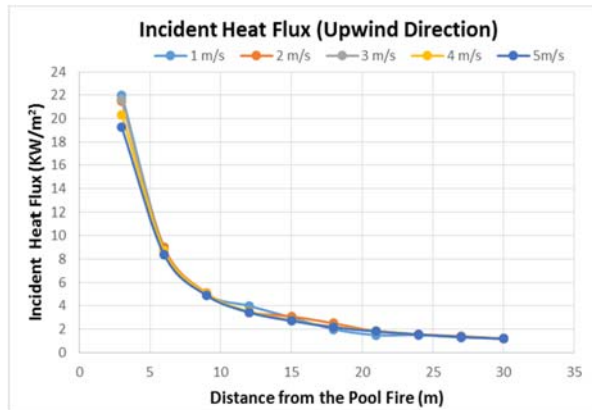

Figure-5. Effect of wind speed on incident heat flux in downwind direction.

Figure-6 shows minor variations of incident heat flux in upwind direction with varying wind speeds at different distances from the pool fire. FDS model predicts that the within 6 m from the fire, human are exposed to higher value of heat flux. The maximum value of radiative heat flux is 21 KW/m^2 at 3 m distance with a wind speed of 5 m/s. The heat load gradually decreases up to 21 m. The graphs illustrates that effect of heat load in upwind direction is not significant. Figures 5 and 6 showed that higher incident heat flux values were recorded at downwind direction as compared with upwind incident heat flux values.

Figure-6. Effect of wind speed on incident heat flux in upwind direction.

(a)

Probability of injury in upwind and downwind directions with varying wind speeds

Figure-7 (a, b, c, d, e) shows the probability of 1st degree burns, 2nd degree burns and death at different distances with varying speeds from 1 m/s to 5 m/s in upwind and downwind direction. At a distance of 3 m from the pool fire in downwind direction with wind speed of 1 m/s, the probability of 1st degree burns is 100 %, the probability of 2nd degree burns is 95 % and probability of death is 81 %. At the same distance in upwind direction, the probability of 2nd degree burns is 15 % and probability of death is 7.7 %. Similarly, by increasing the wind speed, the probability of injury increases in downwind direction due to flame tilt but it remains almost same in the upwind direction. At distance of 9 m with wind speed of 5 m/s in downwind direction, the probability of 1st degree, 2nd degree burns and death is 100 percent while in upwind direction, the probability of injury (1st degree burns, 2nd degree burns and death) is zero as shown in Figure-9 (c). As pool fires are strongly effected by wind speed, the significant increase in probability of injury results in downwind direction. But, in upwind direction, probability of injury does not significantly increases and 100 % probability of 1st degree burns is confined to within 3 m. Safe distance in case of downwind direction is 21 m and in case of upwind direction is 9 m.
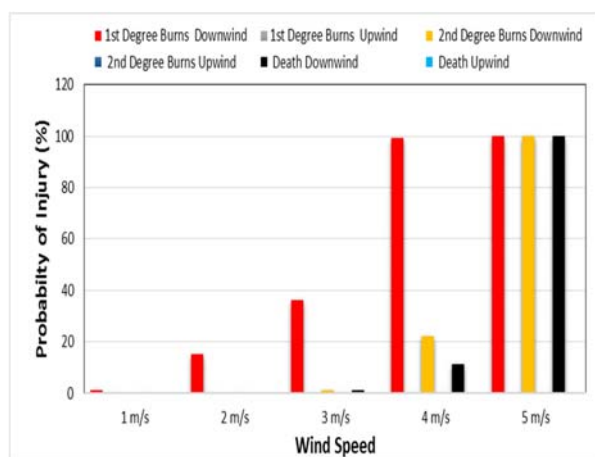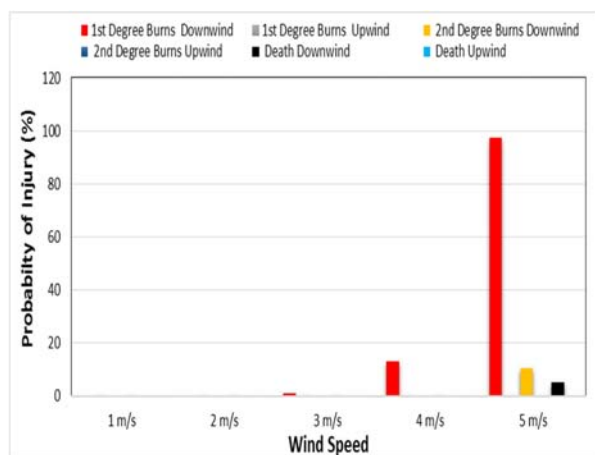

(b)

(c)

www.arpnjournals.com
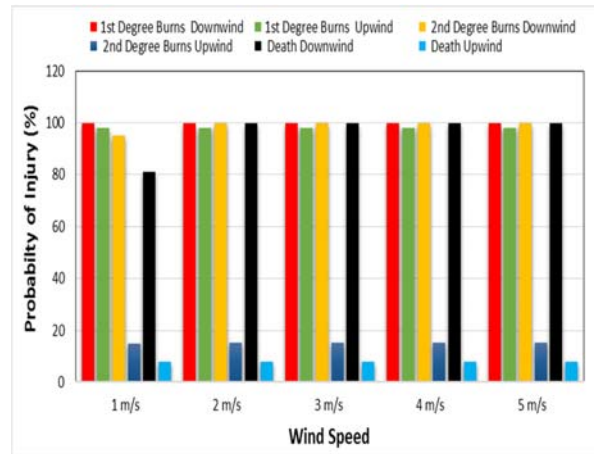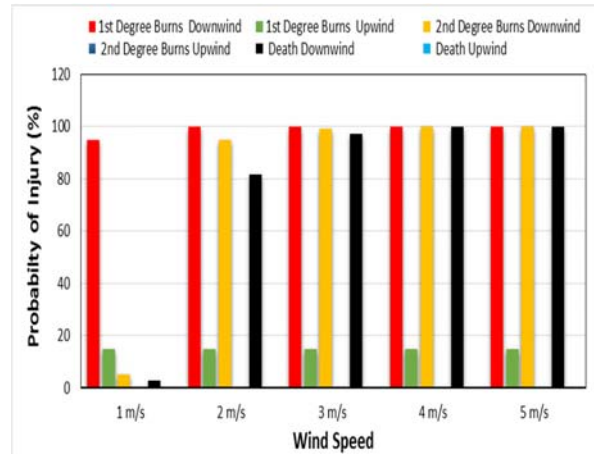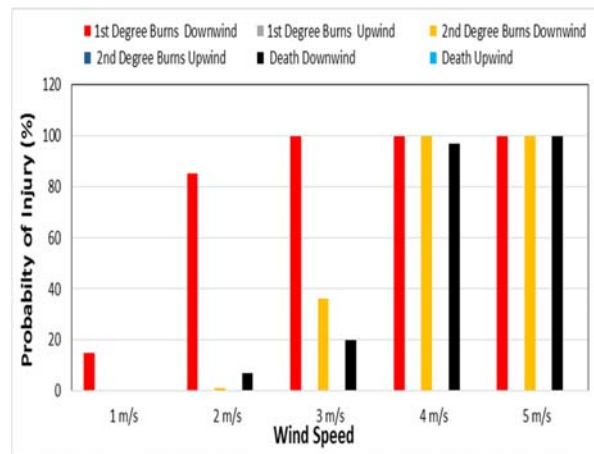
(d)

(e)

Figure-7. (a) Probability of injury at 3 m from pool fire with varying wind speeds. **(b)** Probability of injury at 6 m from pool fire with varying wind speeds. **(c)** Probability of injury at 9 m from pool fire with varying wind speeds. **(d)** Probability of injury at 12 m from pool fire with varying wind speeds. **(e)** Probability of injury at 15 m from pool fire with varying wind speeds.

CONCLUSIONS

Pool fire was investigated under different wind speeds in upwind and downwind directions using CFD based fire models. Effect of smoke evaluated under different wind speeds in downwind direction showed that at wind speed of 5 m/s, the smoke movement will be close to ground that will elevate fatality rates and incapacitation due to inhalation of smoke and prevention of evacuation. Probability of 1st degree burns, 2nd degree burns and death evaluated under downwind and upwind direction with varying wind speed showed that wind speed and downwind direction has major effect on the probability of injury (1st degree burns, 2nd degree burns and death). Probability of death (100 %) in downwind direction is 12 m while probability of death (100 %) in upwind direction is 3 m. Similarly, safe distance in downwind direction is 30 m and in upwind is 21 m. Probability of injury in upwind and downwind directions at different wind speeds showed large variation. So, safety measures should be considered by taking consideration of wind speeds that will help in identifying which areas need more protection. It will also help in developing safe emergency preparedness and evacuation plans.

ACKNOWLEDGEMENT

REFERENCES

[1] Petroleum, B., BP Statistical Review of World Energy. June 2013. London: British Petroleum.

[2] Pula, R., Khan, F. I., Veitch, B., & Amyotte, P. R. 2005. Revised fire consequence models for offshore quantitative risk assessment. Journal of Loss Prevention in the Process Industries. 18(4): p. 443-454.

[3] Vervalin, C.H. 1985. Fire protection manual for hydrocarbon processing plants..

[4] Paterson, A.T. 1993. Offshore fire safety: Pennwell Corp.

[5] Paik, J.K. and A.K. Thayamballi 2007. Ship-shaped offshore installations: design, building, and operation: Cambridge University Press.

[6] Vianna, S., A. Huser, and D.N. Veritas 2010. Fire CFD modelling applied to offshore design. Det Norske Veritas.

[7] Planas-Cuchi, E., H. Montiel, and J. Casal 1997. A survey of the origin, type and consequences of fire accidents in process plants and in the transportation of hazardous materials. Process Safety and Environmental Protection. 75(1): p. 3-8.

[8] Imran, M., M.S. Liew, and M.S. Nasif 2015. Experimental Studies on Fire for Offshore Structures and its Limitations: A Review. Chemical Engineering Transactions,. 45: p. Pages 1951-1956.

[9] Paik, J. K., Czujko, J., Kim, B. J., Seo, J. K., Ryu, H. S., Ha, Y. C., Musial, B. 2011. Quantitative assessment of hydrocarbon explosion and fire risks in offshore installations. Marine Structures. 24(2): p. 73-96.

[10] Dadashzadeh, M., Khan, F., Hawboldt, K., & Amyotte, P. 2013. An integrated approach for fire and

explosion consequence modelling. Fire Safety Journal. 61: p. 324-337.

[11] Pula, R., Khan, F., Veitch, B., & Amyotte, P. 2006. A grid based approach for fire and explosion consequence analysis. Process Safety and Environmental Protection. 84(2): p. 79-91.

[12] Rajendram, A., F. Khan, and V. Garaniya 2015. Modelling of fire risks in an offshore facility. Fire Safety Journal,. 71: p. 79-85.

[13] Ryder, N. L., Sutula, J. A., Schemel, C. F., Hamer, A. J., & Van Brunt, V. 2004. Consequence modeling using the fire dynamics simulator. Journal of hazardous materials. 115(1): p. 149-154.

[14] International Association of Oil and Gas Producers. Report No. 434–7:40, 2010. Consequence Modelling.

[15] McGrattan, K., S. Hostikka, and J.E. Floyd 2010. Fire dynamics simulator (version 5), user's guide. NIST special publication,. 1019(5): p. 1-186.

[16] Koo, J., Kim, H., So, W., Kim, K., & Yoon, E. 2009. Safety assessment of LNG terminal focused on the consequence analysis of LNG spills. in Proceedings of the 1st annual gas processing symposium.

[17] Assael, M.J. and K.E. Kakosimos 2010. Fires, explosions, and toxic gas dispersions: effects calculation and risk analysis: CRC Press.