

Study on Fire Hazard Simulation of A Port Oil Tank

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ABSTRACT

Port oil tanks are often listed as the most severe source of chemical fire. To avoid secondary hazards caused by the high radiant heat of fire on residents living near the port area, the hazard range should be quantified. The simulation of hazard ranges caused by thermal radiation from oil tank fire is simulated by ALOHA version 5.4.7., and we found that thermal radiation will rise to the maximum value with increasing wind speed. The most dangerous hazard range of the red zone will expand while the hazard ranges of the orange zone and yellow zone will be reduced. For pool fire, suppose a tank 2-70% full of toluene. The hazard range of thermal radiation will expand when the wind speed is greater than 5m/s but it will not change with the amount of toluene in the tank. Besides, given Boiling Liquid Expanding Vapor Explosion (BLEVE) and the wind speed greater than 12m/s, the hazard range of thermal radiation clearly expands. In addition, multiple linear regression equation of the pool fire shows that wind speed has the most important influences on the red zone.

Keywords: hazard range, oil tank fire, thermal radiation, wind speed

港埠儲油槽火災危害模擬之研究

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摘 要

油槽常被列為化學品火災嚴重性最高等級，為避免油槽火災產生的高輻射熱量造成附近居民的二次危害，提出量化危害範圍具有其重要性。本研究以 ALOHA 軟體作為分析主要工具，我們發現隨著風速增加，熱輻射將上升到最大值，最嚴重的紅色區域危險範圍擴大。分析顯示，當甲苯庫存佔 2-70% 時，池火產生熱輻射的危害範圍不會隨庫存比例而變化，但在風速大於 5m/s 時會明顯擴大。當發生 BLEVE 且風速大於 12m/s 時，熱輻射的危險範圍明顯擴大。

關鍵詞：危害範圍，油槽火災，熱輻射，風速

I. INTRODUCTION

Taipei Port is one of the important international commercial ports in northern Taiwan. Three oil tank companies rent the oil wharf in the port area, and 45 different oil tanks in total are installed. However, it is reported that some oil tank explosion occurs in foreign countries and many people are killed or injured. For example, 41 people have been killed and 80 others injured in the explosion of the oil tank in Amuay, Venezuela on August 25, 2012. Therefore, we should be more careful of the thermal radiation hazard range of the oil tank fire. The oil tank is used to store a variety of dangerous and inflammable oil products; it is characterized by a quick burning rate, high thermal radiation, thin fluidity, chain burn reaction, production of fireballs and BLEVE (Boiling Liquid Expanding Vapor Explosion), explosive hazards, etc., in case of fire [1]. The wind will drive the fire out of control and fire extinguishing will become rather difficult, which also reveals the importance of fire protection of the oil tank [2]. To avoid secondary hazards on residents near the port caused by the high radiant heat of fire [3,4,5], it is important to quantify the hazard range.

Oil tank fire is a low-risk but high-severity accident. Among relevant heat conduction, convection and radiation, the impact of radiation heat transfer is the greatest on the tank [6]. In addition, the spacing between the oil tanks in the port area has maintained a certain fire safety distance according to the regulations, and all of them are equipped with sound fire safety facilities, dikes and oil leak detection systems [7]. In case of a fire, self-defense fire grouping and the port area joint defense mechanism will be instantly activated to minimize the scope of the disaster. Up to now, no case of oil tank fire has occurred in Taipei Port. Therefore, in this study, a toluene tank located in the center of all tanks was selected to simulate the spreading of the scope of poisonous gas and radiation heat hazard when a fire breaks out.

The study took the toluene tank of Taipei Port as the example; its content is a highly flammable liquid heavier than air and can float on the water surface, with the flash point of 4.4 °C and exuding the characteristic odor of

aromatics [8]. When the tank leaks, the vapor will disperse along the ground and gather at low-lying areas; it may cause a backfire when exposed to fire sources [9]. As it is lighter than water, the leaked oil will expand burn along the water flow direction, easily causing the chain burn of oil tanks in the neighborhood due to their exposure to high radiation heat. We adopted ALOHA (Areal Locations of Hazardous Atmospheres) version 5.4.7 software as the main tool for analysis to simulate the spreading thermal radiation hazard produced by an oil tank fire [10,11,12]. We investigated the maximum hazard range of a tank fire in terms of different wind speeds, air temperatures, wind direction and humidity.

In addition, with wind speed and hazard range, we establish the pool fire multiple linear regression model and analyze effects red/orange/ yellow zones. The model is the followings:

$$R_{wind} = \beta_1 + \beta_2 R_{red} + \beta_3 R_{orange} + \beta_4 R_{yellow} + \varepsilon_1 \quad (1)$$

Where R_{wind} is wind speed, R_{red} , R_{orange} , and R_{yellow} are red zone, orange zone and yellow zone, respectively, of thermal radiation, β_1 , β_2 , β_3 and β_4 are coefficient of regression, ε_1 is error.

II. METHODS OF ANALYSIS

Chemical fire severity is a product of the flash point and inventory level [13]; thermal radiation is directly proportional to the fourth power of temperature [14]. Therefore, when the oil flash point is lower and the inventory level of an oil tank is greater, the fire severity will be higher and the burn time longer. In addition, the higher the heat source temperature, the stronger the radiation:

$$Fire\ Severity = Flash\ Point \times Inventory\ Level \quad (2)$$

$$E = \varepsilon \sigma T^4 \quad (3)$$

Where E is rate of radiant heat transfer (kW), T is surface absolute temperature, ε are the emissivity, and σ is Stephan–Boltzmann constant ($\sigma = 5.67 \times 10^{-8} \text{ kWm}^{-2} \text{ K}^{-4}$).

ALOHA is a kind of free software developed by the U.S. Environmental Protection Agency (EPA) and the National Oceanic and

Atmospheric Administration (NOAA), and it is widely used in situational simulation, such as toxic gas diffusion, fire or explosions. The meteorological data such as air temperature, such as on humidity in this study were obtained from Bali Survey Station information in Central Weather Bureau Observation Data Inquire System. The wind direction and wind speed were according to the measurements of Harbor & Marine Technology Center [15]. The wind direction and wind speed distribution in Taipei Port were similar from October to March, when the northeast monsoon was strong and stable. The wind was weaker with broader distribution of wind directions from April to September (Figure 1, 2). Therefore, according to the seasonal wind directions throughout the entire year, the simulations are categorized into windless situation, mean annual wind direction situation, mean summer wind (from April to September) direction situation and mean winter wind (from October to March) direction situation. The simulation parameters and operation results are shown in Table 1.

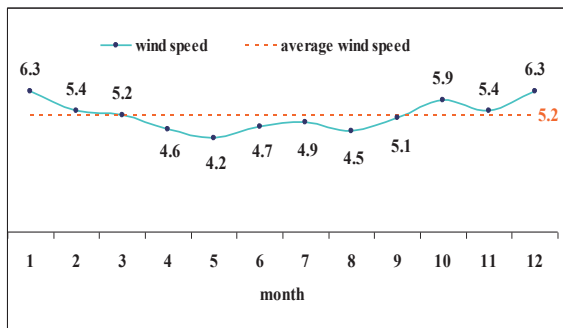


Fig 1. Monthly wind speed of Taipei Port over the years (compiled by this study)

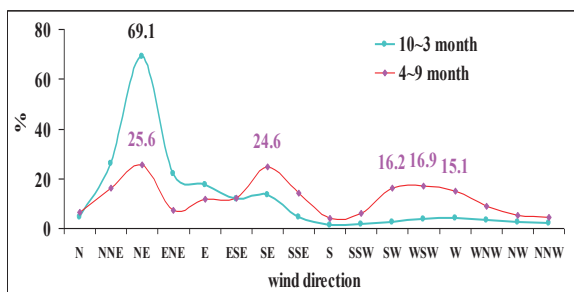


Fig 2. Monthly wind direction of Taipei Port over the years (compiled by this study)

Table 1. The simulation parameters and operation results.

Common parameters				
Location : 25°15'74.62" N 、 121°39'75.22" E				
Tank Diameter = 14 m, Length = 16.5 m				
Tank is 80% full by volume				
Opening diameter is 8 inches				
Opening is 0 m from tank bottom (worst- case)				
Weather parameters				
Situation simulation	windless	annual wind	summer wind	winter wind
Wind speed	1 m/s	5.2 m/s	4.7 m/s	5.8 m/s
Wind direction	0°	90°	225°	45°
Stability class	F	D	E	D
Air Temperature	23.24 °C	23.24 °C	27.20 °C	19.27 °C
Humidity	75 %	75 %	75 %	76 %
The hazard range of thermal radiation from pool fire				
Red zone (10 kW/m²)	82 m	82 m	82 m	83 m
Orange zone (5 kW/m²)	116 m	116 m	117 m	117 m
Yellow zone (2 kW/m²)	181 m	181 m	181 m	182 m
The hazard range of thermal radiation from BLEVE				
Red zone (10 kW/m²)	470 m	470 m	464 m	475 m
Orange zone (5 kW/m²)	648 m	648 m	641 m	655 m
Yellow zone (2 kW/m²)	991 m	991 m	979 m	1000 m
The hazard range from inflammable vapor cloud				
Red zone (11000ppm)	206 m	-	-	-
Orange zone (6600ppm)	243 m	-	-	-
Yellow zone (1100ppm)	481 m	272 m	233 m	-

III. RESULTS AND DISCUSSION

3.1 Fire hazard range simulation of oil fire tank

As shown in Table 1, the annual wind situation simulation is taken as an example. The hazard range of the red zone is 82 m when the thermal radiation of pool fire reaches 10 kW/m^2 , while the hazard range of the orange zone is 116 m when the thermal radiation of the pool fire reaches 5 kW/m^2 , while the hazard range of the yellow zone is 181 m when the thermal radiation of the pool fire reaches 2 kW/m^2 (Figure 3). When the thermal radiation of the fireball produced by BLEVE reaches 10 kW/m^2 , the hazard range of the red zone is 470 m, exceeding the port area. While the hazard range of the orange zone is 648 m when the thermal radiation of the BLEVE reaches 5 kW/m^2 , while the hazard range of the yellow zone is 991 m when the thermal radiation of the BLEVE reaches 2 kW/m^2 (Figure 4). When the oil storage tank experiences only a leak without a fire, the inflammable area of vapor cloud is as follows: the toluene concentration within the 206 m range of the red zone reaches Lower Explosive Limit (LEL), which is equal to 11,000ppm, within the 243 m range of the orange zone reaches 60% LEL (6,600ppm), within the 481 m range of the yellow zone reaches 10% LEL (1,100ppm), as shown in Figure 5.

The different wind speeds (1m/s, 4.7m/s, 5.2m/s, 5.8m/s) set in the situation of this section have no evident influence on the hazard range of thermal radiation produced by the pool fire and BLEVE. In addition, the windless situation (1m/s) and the mean annual one (5.2m/s) from Table 1 shows that the hazard range simulation results of thermal radiation of both pool fire and BLEVE are totally the same. They both get the same results if simulated under lower wind speed (2~3 m/s). Therefore, we think ALOHA is limited under the situation with very low wind speed ($\leq 3 \text{ m/s}$) [16], and the windless simulation results of thermal radiation hazard range from fire is not reliable.

The inflammable vapor cloud can easily reach the lower explosive limit under the windless situation, but the spreading distance is greater and the air dilution stronger in case of

Red zone is 82 m (10 kW/m^2 , potentially lethal),
Orange zone is 116 m (5 kW/m^2 , 2nd degree burn),
Yellow zone is 181 m (2 kW/m^2 , pain).



The influence ranges are the factories in the port area.

Fig 3. The hazard range of thermal radiation from pool fire in annual wind situation

Red zone is 470 m (10 kW/m^2 , potentially lethal),
Orange zone is 648 m (5 kW/m^2 , 2nd degree burn),
Yellow zone is 991 m. (2 kW/m^2 , pain).



The influence ranges of the Red zone and Orange zone include the factories and peripheral roads in the port area, while the Yellow zone influences the residents in the neighborhood of Bali District, and the alert areas include Expressway 64, Section 2 of Zhongshan Road and Wenchang Road, including Taipei Port Branch Office, Bali District Office, Shihsanhang Museum of Archaeology, etc.

Fig 4. The hazard range of thermal radiation from BLEVE in annual wind situation

Red zone is 206 m (11000ppm, LEL),
Orange zone is 243 m (6600ppm, 60% LEL),
Yellow zone is 481 m (1100ppm, 10% LEL).



The influence ranges include the factories and peripheral roads in the port area.

Fig 5. The hazard range from inflammable vapor cloud in annual wind situation

greater wind speed, which can dilute the vapor cloud concentration of inflammable gas and decrease the explosion probability. As shown in Table 1, the mean winter wind direction situation simulation is completely free from the accumulation of inflammable vapor cloud.

3.2 Analysis of wind speed and hazard range

3.2.1 Leaking tank, toluene is burning and forms a pool fire

For the mean annual wind direction situation, this section still uses the 80% inventory level to simulate the continuously increasing wind speed and analyze the hazard control range of the thermal radiation.

As shown in Figures 6, when the thermal radiation in the red zone of the pool fire reaches 10 kW/m^2 , the hazard range is 82 m in case of the wind speed equal to or smaller than 6 m/s and 91 m in case of 7 m/s, hitting the maximum value 98 m in case of 11-12 m/s.

We adopted the analysis (Table 2) of EViews version 10.0 software, which is developed by Quantitative Micro Software (QMS). EViews is a tool to predict simulation and is widely used in computational economics, and it gives the following equation, multiple linear regression model [17,18,19].

$$R_{\text{wind}} = 86.5045 + (2.2419 \times R_{\text{red}}) - (2.9799 \times R_{\text{orange}}) + (0.4565 \times R_{\text{yellow}}) \quad (4)$$

(1) In general, the higher the R-squared and Adjusted R-squared, the better the model fits this study data. ($R^2=0.9713$, Adjusted $R^2=0.9675$)

(2) After t-Statistic (Coefficient / Std. Error) of R_{red} and R_{orange} is transformed into p-value (<0.05), it shows that the two variables are significant in statistics.

(3) Of three hazard range (R_{red} , R_{orange} , R_{yellow}), R_{red} is the highest coefficient, which implies wind speed has the most important influence on the red zone.

(4) F-statistic shows overall model is significant. ($P < 0.05$).

3.2.2 BLEVE, tank explodes and toluene burns in a fireball

As shown in Figures 7, when the thermal radiation of the fireball produced by BLEVE reaches 10 kW/m^2 , the hazard range of the red zone is 470 m in case of the wind speed equal to or smaller than 12 m/s and 493 m in case of 13 m/s, hitting the maximum value 511 m in case of 17 m/s.

This section simulates mean summer wind direction situation and mean winter wind direction situation again and still finds that the hazard range of thermal radiation produced by the pool fire clearly expands when the wind speed is greater than 6 m/s. When there is BLEVE and the wind speed is greater than 12m/s, the hazard range of thermal radiation clearly expands.

Table 2. Regression results of pool fire

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	86.5045	12.8132	6.7511	0.0000
R red	2.2419	0.6416	3.4941	0.0020
R orange	-2.9799	0.9342	-3.1897	0.0041
R yellow	0.4565	0.3704	1.2325	0.2302
R-squared	0.9713	Durbin-Watson stat		1.1657
Adjusted R-squared	0.9675	Prob (F-statistic)		0.0000
F-statistic	259.7053			

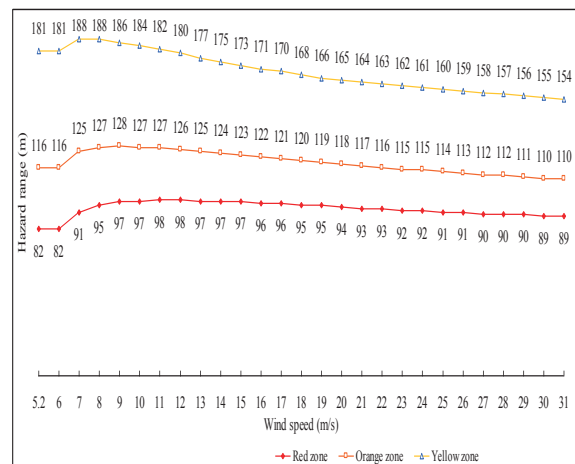


Fig 6. The hazard range of thermal radiation from pool fire.

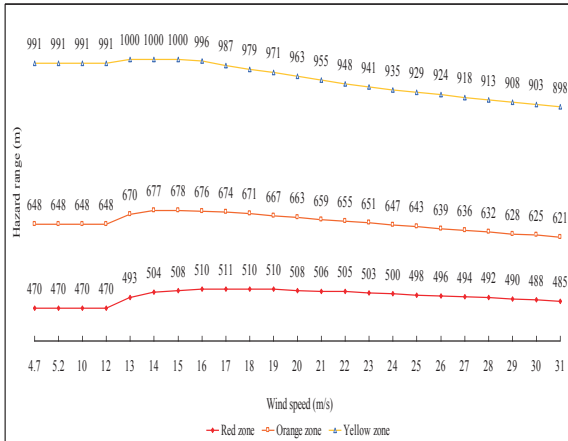


Fig 7. The hazard range of thermal radiation from BLEVE.

3.3 Investigation on thermal radiation and oil tank diameter

As shown in Figure 8, thermal radiation of the flame changes with the oil tank diameter, and the hazard degree of thermal radiation produced by oil tank fires has absolutely dominant aggression. When we simulated wind speeds 5.2m/s and 30m/s, we found the burning rate reached a constant value (5,880 kilograms/min) if the diameter of an oil tank is larger (≥ 23 m). Also, the higher the wind speed is, the shorter the flame length is. For example, suppose the diameter of the oil tank is 23m. The flame lengths are 48m and 35m if the wind speeds are 5.2m/s and 30m/s, respectively.

In contrast, the thermal radiation temperature produced by fire will also indirectly influence the heating degree of adjacent oil tank wall downwind. As shown in Figure 9, as the wind speed increases, the hazard range of the red zone (10 kW/m^2) expands, but the hazard ranges of the orange zone (5 kW/m^2) and yellow zone (2 kW/m^2) are comparatively lower. It shows the bigger the hazard range in the red zone under strong wind.

3.4 Analysis of inventory level and hazard range

According to the mean annual wind direction situation, this section simulates the hazard ranges of pool fire and BLEVE when different proportions of the inventory level of an oil tanks accounts.

3.4.1. Leaking tank, toluene is burning and forms a pool fire

(1) When 99-100% of the inventory level of an oil tank accounts, the simulation found that the hazard range of thermal radiation produced by pool fire clearly expands in case of wind speed greater than 7m/s. When 75-98% of the inventory level of an oil tank accounts, the simulation found that the hazard range of thermal radiation produced by pool fire clearly expands in case of wind speed greater than 6m/s. When less than 74% of the inventory level of an oil tank accounts, the hazard range of thermal radiation produced by the pool fire clearly expands in case of wind speed greater than 5m/s. In conclusion, the greater the toluene inventory level and the wind speed, the bigger the hazard range of thermal radiation in the red zone.

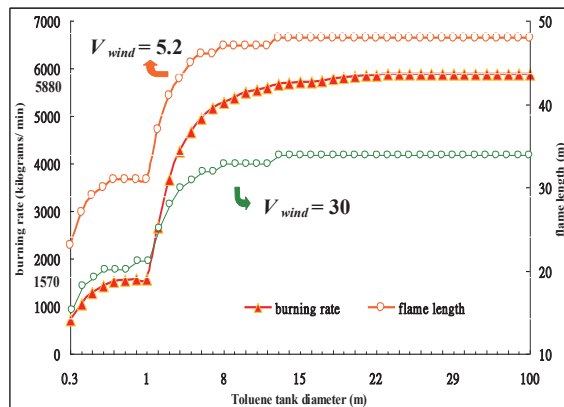


Fig 8. Relationships of tank diameter, burning rate and flame length.

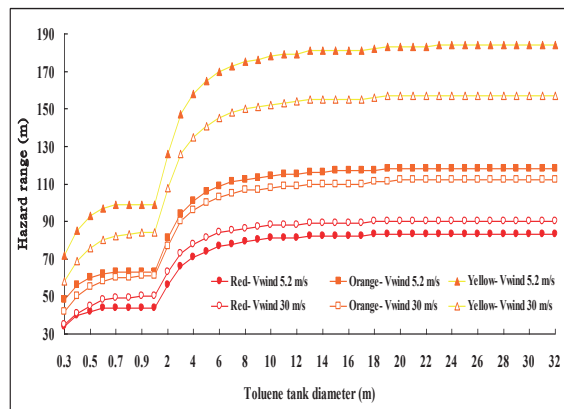


Fig 9. Relationships of tank diameter, thermal radiation hazard range and wind speed.

Table 3. Hazard range of thermal radiation in red zone under different proportions of inventory level and different wind speeds.

	2~70%	71~74%	75~98%	99~100%
≤ 5 m/s	43 m	48~66 m	69~106 m	107~108 m
6 m/s	50 m	55~68 m	69~106 m	107~108 m
7 m/s	53 m	58~76 m	79~107 m	107~108 m
8 m/s	54 m	60~78 m	82~118 m	119~120 m

(2) Besides, when 2-70% of the inventory level of an oil tanks accounts, the hazard range of thermal radiation is the same under the same wind speed condition. For example, when the inventory levels are 10% and 70% and the wind speed is 6m/s, the hazard ranges of thermal radiation are as follows: 50 m in the red zone, 69 m in the orange zone and 104 m in the yellow zone. (Table 3)

3.4.2. BLEVE, tank explodes and toluene burns in a fireball

When 6-100% of the inventory level of an oil tank accounts, the simulation found that the hazard range of thermal radiation produced by BLEVE clearly expanded in case of wind speed greater than 12m/s, while the obtained hazard control range won't change.

IV. CONCLUSIONS

This study is limited to the spreading simulation of oil tank fires and inflammable vapor cloud. The simulations of four mean wind direction situations in Taipei Port show that while the change in the hazard range of thermal radiation was not great, thermal radiation of the flame changed with the oil tank diameter. The burning rate approaches a constant value when the diameter is bigger; the higher the wind speed is, the shorter the flame length is. Moreover, when the inventory levels range between 2% and 70%, the hazard range of thermal radiation produced by pool fires won't change, but will clearly expand in case the wind speed is greater than 5m/s. The hazard range of thermal radiation produced by BLEVE won't change under different proportions of inventory levels, but will expand evidently in case of wind speed greater than 12m/s. The greater the inventory level and the leak, the bigger the hazard range in the red

zone under strong wind! The pool fire regression equation also shows that wind speed has the most important influences on the red zone. In addition, the initial BLEVE's hazard range is much higher than pool fire's, and BLEVE needs higher wind speed than the pool fire does to reduce hazard ranges.

For the 80%, inventory level of the toluene tank, ALOHA software was applied to simulate the hazard range of pool fire or BLEVE and establish the disaster relief database. The resulting effective reference program can be used to implement the preliminary on-site "area control" range for the relief workers. The results of this study can serve as a reference for Taipei port branch office and fire brigades disaster response handling in the future.

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