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Research on Safety and Security Distance of Flammable Liquid Storage Tank

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Abstract

Flammable liquid storage tanks usually plant a potential dangerous zone. The damage gets worse and worse. In order to avoid the tank fire, the tanks extended to the nearby storage tanks—facilities and buildings. In consideration of safety conditions, flammable liquid storage tanks for the safety and security distance is necessary. Through the FDS (Fire Dynamics Simulator) computer simulation of fire, flammable liquid storage tanks for spot the fires numerical simulation to detect a fire to happen. In order to establish an optimized model, the flammable liquid storage tanks save the temperature distribution by obtaining flammable safety distance of the liquid storage tank, by talking about the current laws and regulations, by looking forward to meeting the economic and security considerations.

Keywords: flammable liquid storage tank;safety and security distance;disaster prevention;Fire Dynamics Simulator (FDS)

1. Introduction

Rapid industrial development, the tanks in the plant has become more tend to large-scale, in addition to processes outside the configuration; it should be considered the safety factor when setting up a factory for maintenance and for future expansion, etc.. It is easily result in exposure to potential hazards, for damage to property when flammable liquid storage tank on fire or explosion occurs, the safety distance for the storage area is one of the important factors that will minimize the damage.

In recent years, many series tank explosion disasters occur. For example, the tank explosion disaster of Nan-Po Chemical Company in January 2010 in Chang-hua. The fire of the first chemical tank caused the explosion of other three chemical tanks and factory. Another example, No. 316 oil tank of mid-PetroChina Lanzhou Petrochemical Company exploded and caused oil pipes to break. Some part of the material of Non-burn tanks were leaking and threatening twenty-five liquid hydrocarbon storage tanks

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In October 2009, a huge explosion occurred in Puerto Rico. The fire of Gulf oil Caribbean Petroleum Corp. spread to two days, causing the nearby houses and passing vehicles, broken glass, two people were injured and a thousand people were evacuated. There are twenty-one tanks were burned down among of their forty tanks, stored of gasoline, diesel, aviation fuel and fuel oil (the company's refinery was closed in 2000).

In April 2006, Cosmo Company occurred explosion accident and triggered a fire in Japan's Chiba refinery. This explosion didn't cause casualties, and didn't lead to leakage of petroleum products and toxic chemical gases [1].

In Taiwan some storage tanks fire or explosion make more disasters, that were caused not enough safety distance between storage site and the other adjacent areas. Therefore, it is expectable that organization of safe distance to prevent a series of severe disaster.

2. Literature Review

In order to avoid tank fire or explosion incidents spreading to neighboring areas and evacuate people, it is essential to keep a safe distance between storage tank and other nearby areas.

2.1. Taiwan's regulations

According Taiwan's "Public Hazardous Substances & Flammable Pressurized Gases Establishment Standards & Safety Control Regulations", the storage area is classified into five types of storage sites for flammable liquid storage tank sites. The regulations are specified Indoor storage place, Outdoor storage place, Indoor storage tank, Outdoor storage tank, Underground storage tank and so on. Regarding open reservation space of outdoor tank sites and safe distance are clearly defined in the following regulations below Table 1~3: [2]

Table 1. Outdoor areas of the tank side wall and the tank outside the factory premises safe distance from nearby

Place	Safe distance
Historical relics, Libraries, museums, galleries, exhibit halls, libraries of historical relics, memorial halls, and similar establishments.	Not less than50m
Movie screening venues (theaters, cinemas), music halls, ballrooms, night clubs, clubs, beauty parlors (tourist parlors and audio-video parlors, etc), massage parlors, video viewing halls (MTV, etc), audio-visual sing-along halls (KTV, etc), bars, pubs, and liquor stores (clubs) with a capacity to accommodate 300 persons or more than the Equipment Standards. Bowling alleys, billiard halls, assembly halls, fitness and recreation centers (including facilities offering Shiatsu massage services, sauna rooms, and other weight-loss and body toning facilities), indoor pitch and putt golf course, game-playing ground, electronic game centers, and information recreation grounds with a capacity to accommodate 300 persons or more than the Equipment Standards. Tourist hotels, hostels, inns, and rest houses (limited to lodging houses only) with a capacity to accommodate 300 persons or more than the Equipment Standards Commercial establishments, markets, department stores, supermarkets, retail markets, and exhibit halls are with a capacity to accommodate 300 persons or more than the Equipment Standards Restaurants, food and beverage stores, coffee shops, and tea houses with a capacity to accommodate 300 persons or more than the Equipment Standards. Sauna houses and public bathhouses with a capacity to accommodate 300 persons or more than the Equipment Standards.	Not less than 30m
Bus stations, airport buildings, harbor waiting rooms with a capacity to accommodate 300 persons or more than the Equipment Standards. Future commodities agencies, stock exchange centers, and financial institutions with a capacity to accommodate 300 persons or more of the Equipment Standards. Temples, ancestral halls, churches, columbaria, and other similar establishments with a capacity to accommodate 300 persons or more of the Equipment Standards. Offices, shooting ranges, clinics, community rehabilitation centers, psychological guidance institutions for children and youth or home counseling institutions, employment service institutions for the handicapped, recreation centers for the elderly, service institutions for the elderly and welfare service institutions for the handicapped other than those set forth in Item (6) of the preceding Subparagraph with a capacity to accommodate 300 persons or more than the Equipment Standards. Collective residential buildings, boarding houses and halfway houses with a capacity to accommodate 300 persons or more than the Equipment Standards. Gymnasiums and activity centers with a capacity to accommodate 300 persons or more than the Equipment Standards. Indoor skating rinks and indoor swimming pools with a capacity to accommodate 300 persons or more than the Equipment Standards. Movie studios and TV signal relay on facilities with a capacity to accommodate 300 persons or more than the Equipment Standards. Warehouses and furniture display and sales centers with a capacity to accommodate 300 persons or more than the Equipment Standards.	Not less than 30m
Hospitals, sanitarium, long-term care institutions, nursing care institutions, respite care institutions, service institutions for the elderly (limited to daycare, temporary care, short-term protection and shelter facilities), infant nursery centers, early intervention institutions, settlement and education institutions (limited to institutions sheltering infants under 2 years of age), nursing homes, postpartum nursing care centers, welfare service institutions for the handicapped (limited to board and lodging, daycare, temporary, and short-term care facilities), vocational training institutions for the handicapped (limited to board and lodging establishments and facilities employing special equipment), and special schools for the blind, the deaf, and the mentally handicapped with a capacity to accommodate 20 persons or more of the Equipment Standards.	Not less than 30m
Schools classrooms, after-school nursery centers, supplementary learning centers, training facilities, study halls, and settlement and education institutions, and vocational training institutions for the handicapped other than those set forth in Item (6) of the preceding Subparagraph with a	Not less than 30m

capacity to accommodate 20 persons or more than the Equipment Standards.	
Kindergartens and nursery schools with a capacity to accommodate 20 persons or more than the Equipment Standards.	
Place used for the manufacturing, storage or process of public hazardous materials and flammable pressurized gases.	Not less than 20m
Place other than those specified in the preceding subparagraphs.	Not less than 10m
Elevated power line of 35,000V or higher.	Not less than 5m
Elevated power line between 7,000V and 35,000V.	Not less than 3m

Table 2.The open space to be reserved surrounding the storage tank shall meet the following requirements

The storage Materials	open space to be reserved surrounding the storage tank shall meet
When the storage contains the Six Materials with a flash point not higher than 21℃	1m+, in volume less than 2 k(; 2m+, greater than 2 k(and less than 4 k(; 3m+, greater than 4 k(but less than 10 k(; 5m+, greater than 10 k(but less than 40 k(; and 10m+, greater than 40 k(.
When the storage contains the Six Materials with a flash point higher than 21℃ and below 70℃	1m+, in volume less than 10 k(; 2m+, greater than 10 k(and less than 20 k(; 3m+, greater than 20 k(but less than 50 k(; 5m+, greater than 50 k(but less than 200 k(; and 10m+, greater than 200 k(.
When the storage contains the Six Materials with a flash point higher than 70℃	1m+, in volume less than 20 k(; 2m+, greater than 20 k(and less than 40 k(; 3m+, greater than 40 k(but less than 100 k(; and 5m+, greater than 100 k(.

Table 3. Tank Spacing（Shell-to-Shell）

The storage Materials	Safe distance
The storage containing the Six Materials with a flash point not higher than 60℃	The storage containing the Six Materials with a flash point not higher than 60℃: i. In case of a floating top tank in diameter less than 45m, the spacing shall be one-sixth (1/6) of the sum of the diameter of two abutted tanks, and not less than 90 cm; and not less than 45m, a quarter (1/4)
	In case of a fixed top tank in diameter less than 45m, the spacing shall be one-sixth (1/6) of the sum of the diameter of two abutted tanks, and not less than 90 cm; and not less than 45m, one-third (1/3)
The storage containing the Six Materials with a flash point higher than 60℃	In case of a floating top tank in diameter less than 45m, the spacing shall be one-sixth (1/6) of the sum of the diameter of two abutted tanks, and not less than 90 cm; and not less than 45m, a quarter (1/4)
	In case of a fixed top tank in diameter less than 45m, the spacing shall be one-sixth (1/6) of the sum of the diameter of two abutted tanks, and not less than 90 cm; and not less than 45m, a quarter (1/4)

2.2. NFPA

National Fire Protection Association(NFPA) NFPA 30 Flammable and Combustible Liquids Code 2000 edition, in which tanks and storage tanks for the safety of the distance between the have expressly determined, as shown in Table 4[3].

Table 4. Minimum Tank Spacing（Shell-to-Shell）NFPA 30

	Floating Roof Tanks	Fixed or Horizontal Tanks	
		Class I or II Liquids	Class IIIA Liquids
All tanks not over 150 ft in diameter	1/6 sum of adjacent tank diameters but not less than 3ft	1/6 sum of adjacent tank diameters but not less than 3ft	1/6 sum of adjacent tank diameters but not less than 3ft
Tanks lager than 150 ft in diameter			
If remote impounding is provided in accordance with 2.3.2.3.1	1/6 sum of adjacent tank diameters	1/4 sum of adjacent tank diameters	1/6 sum of adjacent tank diameters
If diking is provided in accordance with 2.3.2.3.2	1/4 sum of adjacent tank diameters	1/3 sum of adjacent tank diameters	1/4 sum of adjacent tank diameters

2.3. height of blocking wall

After the tank fire disaster, the other tanks without burning tend to spread burn situation due to impact of radiant heat under the dangerous temperature limits. According material safety data sheets(MSDS) of CPC Corporation (Taiwan), the ignition temperature of 92 unleaded gasoline is 280 ℃ ~ 456 ℃, low-sulfur fuel oil is 407 ℃ and super diesel and high diesel fuel is about 177 ℃. The impact of radiant heat is base on the size and continuing time of fire incident. The larger area of flame or the longer fire incident occurs, the farther distance of radiant heat will reach.

In order to ensure the places of manufacture, storage and disposal for public dangerous goods to block the fire effectively and prevent spread to the neighboring places[4]. In the November 2006 National Fire Agency of Ministry of the interior provides the following formula of spread curve to calculate the height of blocking wall[5].

$$Y = PX^2 + a$$

Where

Y： Retaining wall height from the ground

P： Spread curve coefficients (Table 5)

X： Manufacturing sites and other places with the distance between adjacent

a： Manufacturing sites such as the height of origin

Table5. Spread curve coefficients

Categories	P value
The wooden building is adjacent to those sites. Buildings adjacent to the site of construction or noncombustible materials for the construction of fire, and the face of manufacturing sites such as, the openings without fire doors.	0.04
Premises adjacent to the construction of buildings for non-combustible materials, and manufacturing sites such as, the face of the openings with fire doors. The buildings for fire protection nearby construction sites, manufacturing sites such as, the face of the openings, with more than 30 minutes fire rating of fire doors.	0.15
The buildings for fire protection nearby construction sites, manufacturing sites such as, the face of the openings, with more than 1 hour fire rating of fire doors.	∞

3. FDS and Smokeview[6]

FDS (Fire Dynamics Simulator) computer simulation of fire, by the National Institute of Standards and Technology(NIST) have developed the computational fluid dynamics fire thermal software. The software system designed primarily for fire simulation.

FDS mainly large eddy simulation (LES) CFD-based fire simulation software, the software is the core of Navier - Stokes equations, numerical method for solving the governing conservation equations of each. Used to resolve the heat-driven low-speed flow field, focusing on smoke and heat transport phenomena, to be divided into a number of the analog range of the cube of the grid, can be more accurate estimate when the fire smoke fire flow, temperature, thermal radiation and the speed of fire of the physical data, making it suitable for complex shape of the building space or large building fire simulation. Smokeview FDS is a combination of graphical post-processing software, which will be calculated from the FDS results to graphics, the effect of 2D or 3D animation rendering, the software operation flow shown in Figure 1

Radiant heat in the FDS in the formula is based on the finite volume method (Finite Volume Method, FVM) approach obtained, the use of nearly one hundred point of discontinuity, when computing station with around 20% CPU time, the thermal radiation is an appropriate computation

3.1. FDS Governing equationl

Conservation of Mass

$$\frac{\partial \rho}{\partial \rho} + \nabla \bullet \rho u = \dot{m}_b'''$$

Conservation of Species

$$\frac{\partial}{\partial t}(\rho Y_\alpha) + \nabla \bullet \rho Y_\alpha u = \nabla \bullet \rho D_\alpha \nabla Y_\alpha + \dot{m}_b''' + \dot{m}_{b,a}'''$$

Conservation of Momentum

$$\frac{\partial}{\partial t}(\rho u) + \nabla \bullet \rho uu + \nabla p = \rho g + f_b + \nabla \bullet \tau_{ij}$$

Conservation of Energy

$$\frac{\partial}{\partial t}(\rho h_s) + \nabla \bullet \rho h_s u = \frac{Dp}{Dt} + \dot{q}''' - \dot{q}_b''' - \nabla \bullet \dot{q}'' + \varepsilon$$

Where

ρ : Fluid density
u : Fluid velocity
h : Fluid enthalpy
$\dot{m}_b'''$: Unit volume of chemical production rate of species l
g : Gravity vector
f : External force vector
（Except to the amount of gravity）
τ : Viscous stress tensor
q_r : Radiation heat flux vector
k : Thermal conductivity of the fluid level
T: Current temperature level
P : Fluid pressure
t : Time

3.2. *FDS Fire flow simulation software to do gymnastics*

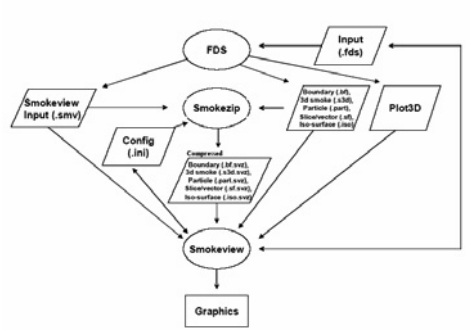

Figure 1. FDS Fire flow simulation software to do gymnastics[7]

4. Results

Second, in the absence of any storage tank under the protection of fire safety equipment, fire, tank fire, the occurrence of burn-round lift top wind speed affected by the fire, suffered from the height of 14 meters of radiant heat, in Figure 10 that the fire tank tank 31.22 seconds in the fire wall, the temperature reached the highest 622.4 ℃, 12 meters away from the tank fire at the highest temperature at 52.36 seconds the temperature 378.95 ℃, 24 meters away from the tank fire at the highest temperature in 4.53 seconds temperature 162.12 ℃.

At a height of 7 feet at the impact of radiant heat suffered in Figure 11 that the fire wall of storage slots in the fire 31.06 seconds, the temperature reached the highest 103.58 ℃, 12 meters away from the tank fire at the highest temperature at 22.50 seconds the temperature is 74.39 ℃ , 24 meters away from the tank fire at the highest temperature at 26.85 seconds temperature of 27.78 ℃.

0-foot suffered in a high degree of thermal effects of radiation, in Figure 12 that the fire wall of storage slots in the fire 5.87 seconds, the maximum temperature reached 74.1 ℃, 12 meters away from the tank fire at the highest temperature in 5.87 seconds temperature is 57.32 ℃ from the tank fire at the two highest temperature of 14 meters in 35.11 seconds at the temperature of 23.5 ℃.

When the adjacent sprinkler tank equipped with cooling equipment, and tank fire in the fire at the same time start the cooling sprinkler equipment, 14 meters high degree of impact suffered by radiant heat, in Figure 14 that the fire in the fire wall of storage slots 32.42 seconds, the temperature reached the highest 168.46 ℃, 12 meters away from the tank fire at the highest temperature at 48.61 seconds the temperature 122.23 ℃, 24 meters away from the tank fire at the highest temperature at 28.81 seconds temperature of 34.6 ℃.

7 meters in height, in Figure 15 that the fire wall of storage slots in the fire 34.22 seconds, the temperature reached the highest 47.82 ℃, 12 meters away from the tank fire at the highest temperature at 27.02 seconds temperature of 60.72 ℃, away from the fire Tank maximum temperature of 24 meters in 28.81 seconds temperature of 36.9 ℃.

0 meters in height, in Figure 16 that the fire wall of storage slots in the fire 36.01 seconds, the temperature reached the highest 39.99 ℃, 12 meters away from the tank fire at the highest temperature at 25.21 seconds temperature of 44.50 ℃, away from the fire Tank maximum temperature of 24 meters in 19.82 seconds temperature of 27.85 ℃.

Two adjacent flammable liquid storage tank, fire safety equipment without any protection, the occurrence of burn-round lift top wind speed affected by the flame, about 4 seconds of contact with the ignition is not adjacent tanks, the fire in about seven buoyant after ten seconds under hot fire, the fire flow gradually reduced by the external wind speed (Figure 6 to Figure 8).

Adjacent storage tank affected by radiant heat, in Figure 9 at a height of 14 meters, 4.53 seconds after the fire when the temperature reaches the maximum 162.12 ℃, about the fire in about 60 seconds the temperature dropped to ambient temperature.

Tank tank fire wall temperature reached the highest 622.4 ℃, 12 meters away from the tank fire at the maximum temperature 367.27 ℃, 24 meters away from the tank fire at the maximum temperature 162.12 ℃, the second tank

the longer the distance between the thermal effects of radiation have decreased significantly. Figure 10 to 12 that did not fire the lower tank height from the ground by the radiant heat of the lower. Effective safety distance in the adjacent storage tank by the maximum temperature 162.12 ℃, less than the ignition temperature of gasoline 280 ℃.

When the tanks did not start the fire sprinkler cooling of the fire wall of storage slots maximum temperature dropped to 168.46 ℃, the temperature dropped significantly, about the fire in about 70 seconds the temperature decreased and the temperature reduced.

As the storage tank adjacent to the top by radiant heat at the greatest impact, it was set up fire safety equipment should be strengthened protection. Safe distance from the effective storage tanks caught fire in the distance from 0 m to 24 m, can be double that distance away from the safe, the temperature has dropped by nearly half. If you start cooling in real-time fire sprinkler, the adjacent affected even smaller storage tank. Therefore, in the setting of flammable liquid storage tank, should maintain an appropriate safe distance, the spread of fire to prevent the possibility of tank. And ensure effective cooling sprinkler protection is not necessary, since the fuel tank.

5. Conclusions and Recommendations

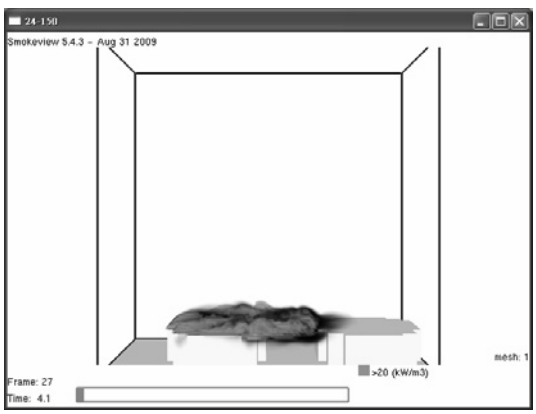

Figure 2.About 4 seconds after the fire burning case

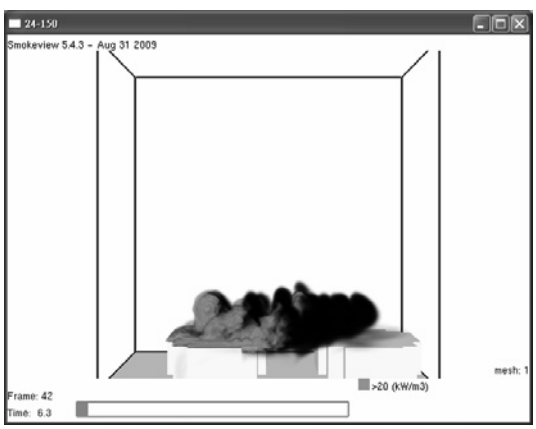

Figure 3. Fire burning in about 6 seconds of the case

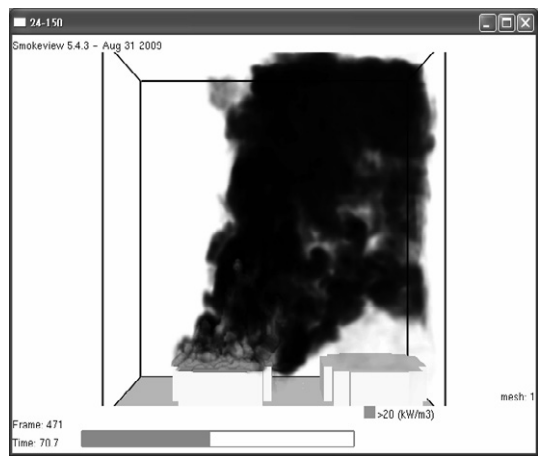

Figure 4. About 70 seconds after the fire burning case

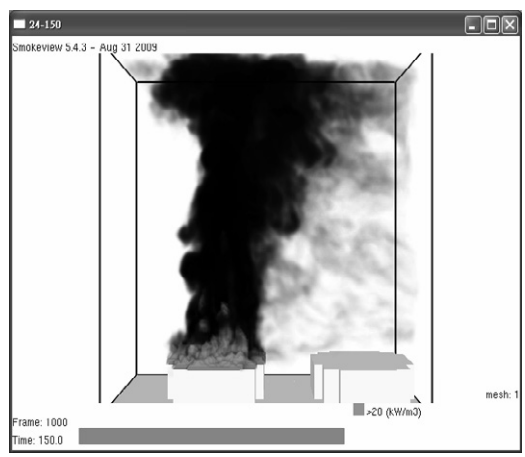

Figure 5.About 150 seconds after the fire of burning case

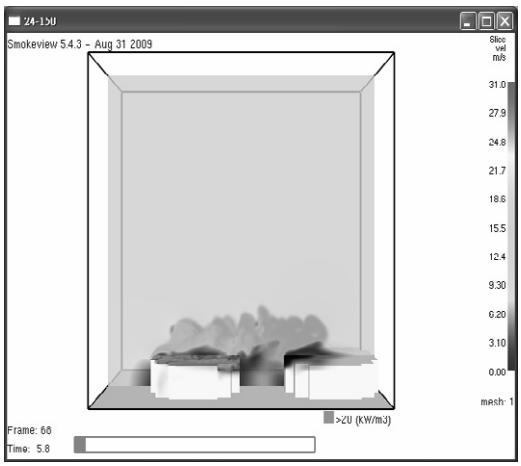

Figure 6.About 6 seconds after the fire effects of wind speed on fire

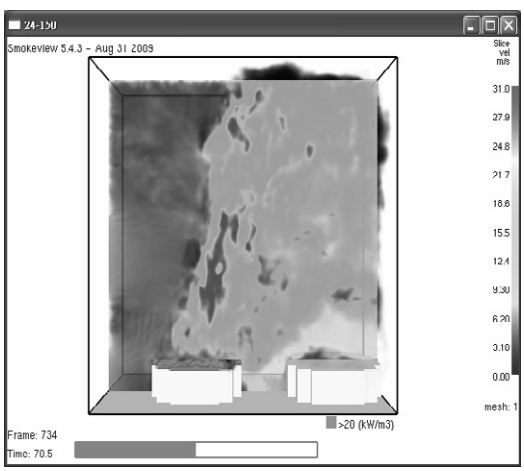

Figure 7.Wind speed of about 70 seconds after the fire effects on fire

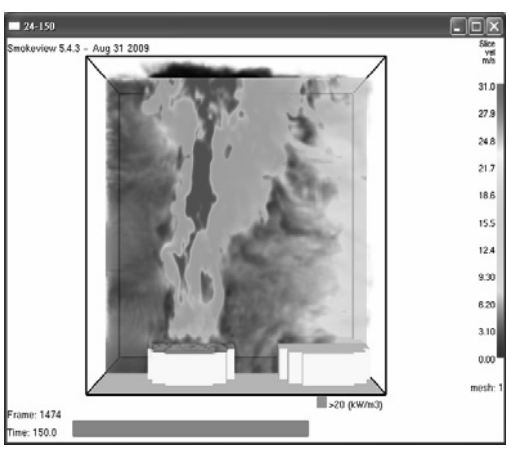

Figure 8.150 seconds after the fire effect of wind speed on fire

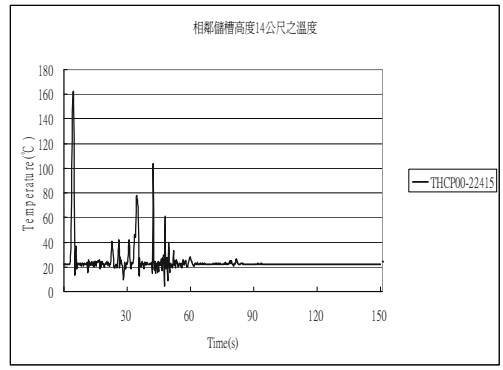

Figure 9. Tank adjacent to the temperature at the height of 14 m

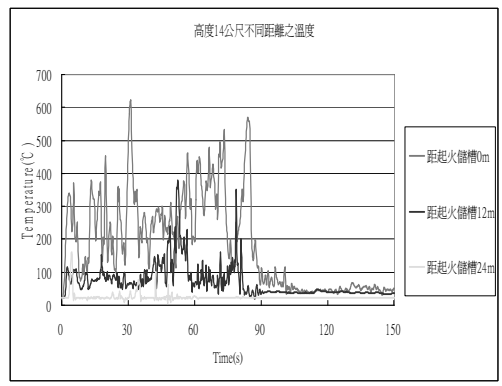

Figure10.Height of 14 m temperatures at different distances

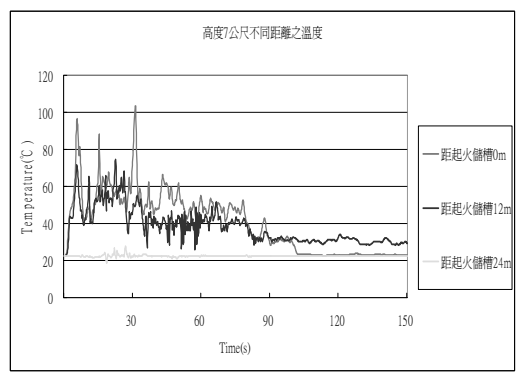

Figure11.Height of 7 meters from the temperature difference

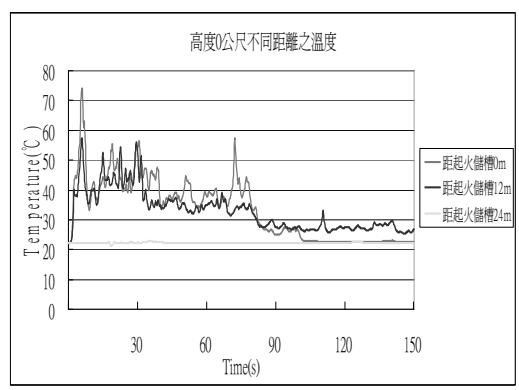

Figure12.0 m height temperature at different distances

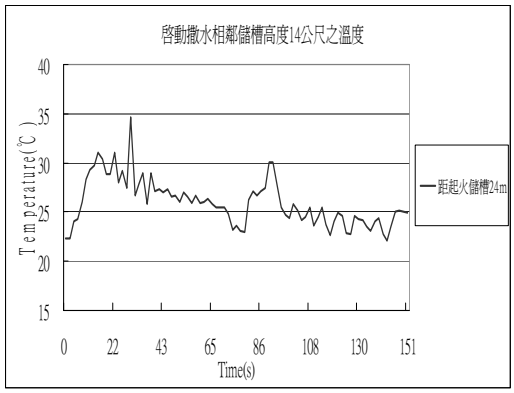

Figure13.Start sprinkler tank adjacent to the temperature at the height of 14 m

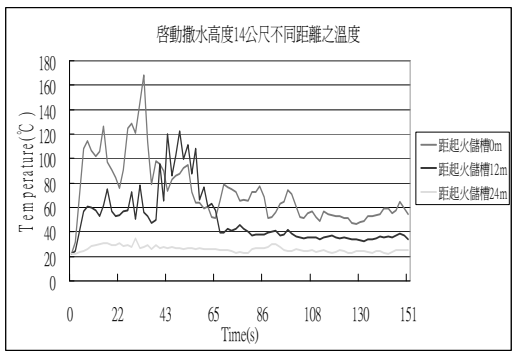

Figure14.Sprinkler height of 14 meters starting from the temperature difference

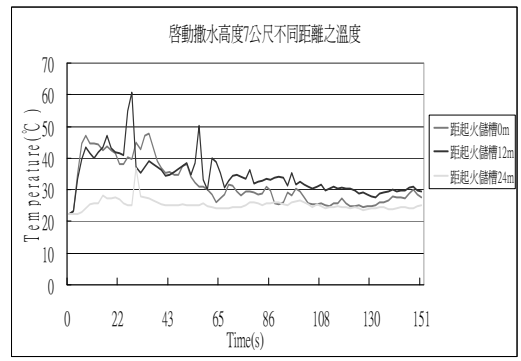

Figure15.Start sprinkler height of seven meters from the temperature difference

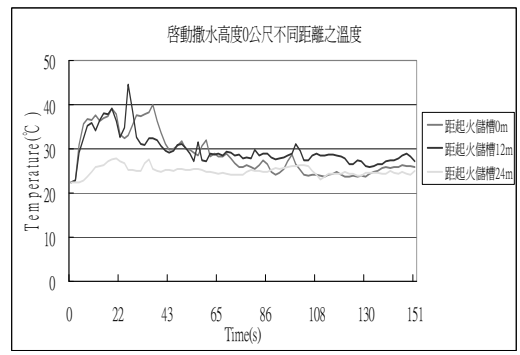

Figure16.Start sprinkler height of 0 m from the temperature difference

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