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Accident consequence simulation analysis of pool fire in fire dike

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Abstract

Pool fires are the most common of all process industry accidents. Pool fires often trigger explosions which may result in more fires, causing huge losses of life and property. Since both the risk and the frequency of occurrence of pool fires are high, it is necessary to model the risks associated with pool fires so as to correctly predict the behavior of such fires. In this paper, the petrochemical tank area of a chemical enterprise in Tianjin is selected as a study case, for the basic features of reserve materials and the specific circumstances of the storage tank area, hazard analysis and damage area of its pool fire in fire dike according to the model calculation and CFD simulation are discussed. The results showed that the strong thermal radiation of pool fire could destroy adjacent tanks, equipments, and public pipe, and even cause serious casualties within the scope of 28.46 meters. When the fire separation distance between tanks, tank and pipeline, tank and other buildings is more than 69.71 meters, the production equipment could not be damaged, and the production personnel inside could not be injured.

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Keywords: pool fire; mathematical model; CFD simulation; combustion; heat radiation flux

1. Introduction

Fire is the most common type of accident encountered in chemical process industries (CPI) which deal with production, transportation and/or storage of flammable substances, in the survey of accidents, taken mainly from major hazards incident data from home and abroad, conclude that the majority (approximately 42%) of all accidents in CPI involve pool fires[1]. Similar primacy of pool fire is revealed in a number of other reports. The different

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types of fire that may occur at a CPI - jet fire, flash fire, fireball, and pool fire - great importance is attached to pool fire as it is the most frequent, constituting more than 60% of all the fire incidents. Pool fire often triggers explosions as also newer pool fires result from explosions. Pool fires can be very large and persistent, difficult to douse[2].

A pool fire can occur when a flammable liquid is accidentally released on ground or water, and ignites. A buoyancy-driven, turbulent non-premixed flame is formed above the pool. The resulting fire is distinguished from other types of fires by a very low initial momentum and the propensity to be strongly influenced by buoyancy effects. Based on the medium on which the pool is formed, presence or absence of confinement, and the type of location, pool fires have been classified as in Fig. 1[3]. Many of the past accident reports state that dike fire of pool fire is the common disaster forms in petrochemical industry and result in more intense radiation, and higher flame, which can cause serious impact on the surrounding personnel and equipment and can also lead the boiling liquid to a vapor explosion or vapor cloud explosion .For example the pool fire that occurred at a petroleum repertory in Dalian, China, 2010 caused by pipeline damage since wrong operation, which led to massive oil spill, and destroyed most of the fixtures, caused great property losses directly and serious environmental pollution. Therefore, the research about hazard analysis and damage area of the pool fire in fire bund is of great significance for its prevention.

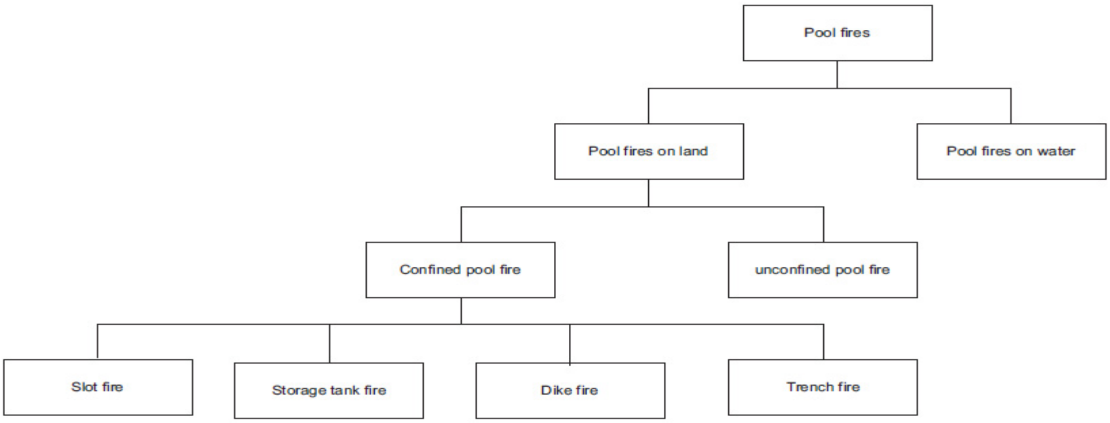


Fig. 1. Classification of pool fires.

Since the 1960s, domestic and foreign scholars carried out a wide range of relevant researches. Hamins[4] studied the flame structure of an oil pool, based on the summary of previous experimental data and research results; Planas-Cuchi[5] performed an experiment on a 4 m^2 pool fire of ethane and a 12 m^2 pool fire of kerosene oil; Koseki et al.[6] performed an experimental study on the combustion characteristics of a large-scale tank (80 m in diameter) and obtained some basic data. However, due to the restriction of multiple factors, doing large-scale experiments directly are very difficult and expensive. So many empirical and semi-empirical calculation models to describe the fire combustion process, the heating characteristics or the related factors' influence of different types of pool fire were established. And CFD modeling on dynamic simulation of fire has gained increasing concerns to investigate the characteristics of pool fires. In recent years, FDS (Fire Dynamics Simulator) shows its advantage in simulating pool fires as one of the most widely used CFD codes, which uses Lagrangian particles to represent burning gases and hot smoke to describe the flow behavior[7].

In this paper, the petrochemical tank area of a chemical enterprise in Tianjin is selected as a study case, for the basic features of reserve materials and the specific circumstances of the storage tank area, hazard analysis and damage area of its pool fire in fire dike according to the model calculation and CFD simulation are discussed.

2. Combustion calculation model of the pool fire in fire dike

The study of pool fire in fire dike mainly includes the geometry formation of liquid pool, the shape, height and temperature of flame, the heat radiation of and harm degree of flame. In accordance with the geometry changes of the liquid pool over time, the liquid pool's geometry of pool fire in the fire embankment can be divided into two types of a constant geometry of the pool and geometry change of the pool over time. Among the combustion parameters which determine the overall structure of a pool fire, the most important is flame height and radiation intensity.

2.1. Burning rate

The burning rate is a fundamental parameter for describing the pool fire; it is affected by the heat radiation, the flame location and shape, the thermal conductivity of the fuel container, and other factors[8]. In an ordinary way, the pool fire development process can be divided into three stages. The first stage is combustion with the burning rate accelerated in the course of flame temperature rising. After a while, the heat obtained by the fuel from the flame becomes comparable with the heat transmitted from the fuel to the ambient medium, and the burning rate reaches a stable value (Fig. 2). This is the second stage (steady combustion). At the third stage, the burning rate falls owing to inadequate supply of the fuel.

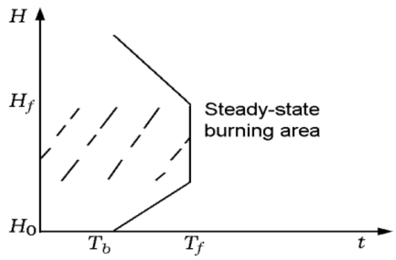


Fig. 2. Pool fire development process.

The burning rates of common combustible liquids can be found in the literatures. For some liquids, the burning rates can also be calculated by the model developed by Hertzberg et al.[9]. The calculation model is divided into two cases based on the level of the liquid boiling point. The burning rate of a combustible liquid with the boiling point below the ambient temperature is calculated by the formula

$$m' = 0.001 H_c / H_e \tag{1}$$

The burning rate of a combustible liquid with the boiling point above the ambient temperature is calculated by the formula

$$m' = \frac{0.001 H_c}{c_p (T_b - T_0) + H_e} \tag{2}$$

where m' is the burning rate, kg/(m^2·s); H_c is the combustion heat, kJ/kg; H_e is the evaporation heat, kJ/kg; c_p is the specific heat at constant pressure, kJ/(mol·K); T_b is the boiling point, K; and T_0 is the ambient temperature, K.

2.2. Flame height

Flame height as another important characteristic parameter, is directly related to the heat transfer process of pool fire and the influence of flame around environment. Many researchers have studied flame height of pool fires in static environment and deduced some formulas based on a series of experimental data.

The BrLtz empirical formula of flame height[10]

$$H / D = 1.73 + 0.33 D^{-1.43} \tag{3}$$

where *H* is flame height, m; D is diameter of pool fire, m.

The Thomas empirical formula of flame height[11]

$$H = 84R\left(\frac{m'}{\rho_a\sqrt{2gR}}\right)^{0.61} \tag{4}$$

where ρ_a is the air density, value of 1.29 kg/m^3; R is radius of pool fire, m; g is acceleration due to gravity, value of 9.81 m/s^2.

If consider the influence of wind speed, the flame height (H) and angle (α) can be expressed by the following equations that are deduced by Thomas[12].

$$\frac{H}{D} = 55\left(\frac{m''}{\rho_a\sqrt{gD}}\right)^{0.67} u^{*-0.21} \tag{5}$$

$$\cos\alpha = 0.7\left[\frac{u_w}{(gm''D/\rho_a)}\right]^{-0.49} \tag{6}$$

$$u^* = \frac{u_w}{(gm''D/\rho_v)^{1/3}} \tag{7}$$

where u_w is the local wind velocity, m/s; u^* is the dimensionless wind velocity; ρ_v is the fuel vapor density, kg/m^3.

The Heskestad empirical formula of flame height[13]

$$\frac{H}{D} = 0.235\frac{Q^{2/5}}{D} - 1.02 \tag{8}$$

where Q is the heat release rate, kW.

2.3. Radiation intensity

The flame transfers the heat mainly to the objects around the liquid pool by radiation. The radiation flux depends on the flame temperature and thickness, the concentration of the radiative particles in the flame, and the geometric relationship between the flame and the radiated object. For the calculation of the radiation intensity in the pool fire, the three common mathematical models are the point source model[14], the Shokri and Beyler model[15], and Mudan model[16](Table 1).

The point source model assumes that the pool flame is concentrated in the center of the real flame axis, and the heat is released from the center of the real flame, as shown in Fig. 3. The radiation heat flux absorbed by the object located at the distance L from the center of the point source is the heat received per unit time and unit area of the spherical surface of radius L whose center is the point source (P) (Fig. 4). The point source model uses the Heskestad equation (see Table 1) to estimate the pool fire height. The Heskestad equation is built on a large number of experimental results including the pool fire and the buoyancy jet fire[17].

The Shokri and Beyler model assumes that the pool fire is a blackbody radiation source of a cylindrical shape having a uniform radiation capacity; the diameter of this source is equal to the liquid pool scale, and its height is the length of the pool fire [18]. The Shokri and Beyler model analyzes the heat radiation flux mainly through the effective thermal radiation flux on the flame surface and the visual coefficient between the pool fire and the radiation-absorbing object. The flame height is calculated by the Heskestad equation.

The Mudan model views the pool fire as a vertical (in the absence of wind) or inclined (in the presence of wind) cylindrical radiation source. The Mudan model, in addition to the consideration of the effective heat radiation flux of the pool fire surface, the location of the radiation-absorbing object, and the pool fire center, also takes the impact of the atmospheric transmission coefficient into account (see Table 1). The flame height is calculated by the Thomas empirical formula[19].

The heat radiation flux on the surface of flame is usually associated with the fuel properties, the burning extent, the geometry, size of the flame and the flame surface location, and the flame shape and temperature. We should select different mathematical model to calculate the heat radiation flux on the surface of flame depending on the pool diameter. Generally, we assume that the energy uniformly radiates from the top and side face of the cylindrical flame to the surroundings, and the surface thermal radiation flux on the surface of the flame should be calculated according to the Mudan model. The mass heat release rate is calculated by the following formula

$$Q = \frac{\left(\pi R^2 + 2\pi RH\right)\left(\mathrm{d}m/\mathrm{d}t\right)\eta H_c}{72\left(\mathrm{d}m/\mathrm{d}t\right)^{0.61} + 1} \tag{9}$$

where η is the efficiency factor, value of 0.13-0.35; H_c is the combustion heat, kJ/mol.

The surface thermal radiation of target location (I) which is X meters distances from the center of the pool fire is

$$I = \frac{Q\eta}{4\pi X^2} \tag{10}$$

where X is distance between target location and the centre of pool fire.

The consequences caused by thermal radiation where the target location is X meters from the flame center is in accordance with the thermal radiation intensity and the damage/failure criterion to determine the impact of different intensity of thermal radiation on human health and the devastating consequences of the buildings. The common criteria of the thermal radiation hazard can be associated with the damage/failure criterion, as shown in Table 2.

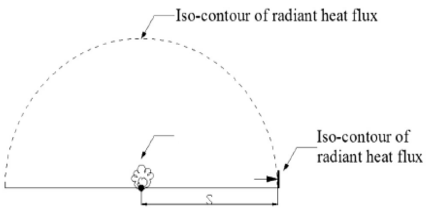


Fig. 3. Point source model.

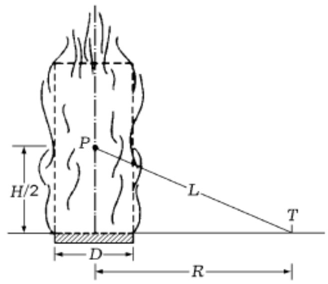


Fig. 4. Radiation in the point source model.

Table 1. Three common mathematical models of the pool fire thermal radiation flux.

Main parameter	Point source model	Shokri and Beyler model	Mudan model
Thermal radiation flux	$q = \frac{E\cos\theta}{4\pi L}$	$q = EF_{12}$	$q = EF_{12}\tau$
Heat release rate	$E = (0.21 - 0.0034D)Q$	$E = 58.10^{-0.00823D}$	$E = \frac{0.25\pi D^2 \eta m' \Delta H_c}{0.25\pi D^2 + \pi DH}$
Flame height	$H = 0.235q^{0.4} - 1.02D$ (Heskestad equation)	$H = 0.235q^{0.4} - 1.02D$ (Heskestad equation)	$H = 12D\left[\frac{m'}{\rho_0 (gD)^{0.5}}\right]^{0.61}$ (Thomas empirical formula with no wind)
Length or visual coefficient	$L = \sqrt{R_2 + (H/2 - H_t)^2}$	$F_{12} = \sqrt{F_{12H}^2 + F_{12V}^2}$	$F_{12} = \sqrt{F_{12H}^2 + F_{12V}^2}$

Table 2. Damage/failure criteria for different thermal radiation intensities.

Thermal radiation intensity, kW/m^2	Degree of damage of buildings or equipment	Personnel injury
37.5	Operating equipment and buildings all damaged	1% dead with 10 s, all dead within 1 min
25	Minimum radiation intensity for ignition of timber and deformation of steel equipment under normal conditions	Seriously injured within 10 s, all dead within 1 min
12.5	Minimum radiation intensity for plastic melting under normal conditions	Minor injured within 10 s, 1% dead within 1 min
4.0	Glass broken after long-time radiation	Pain after radiation more than 20 s, but no injuries
1.6	No harm	No harm

3. Numerical simulation of radiation intensity

Numerical simulations were performed by Fire Dynamics Simulator (FDS). It was developed by National Institute of Standards and Technology, USA. It solves numerically the Navier-Stokes equations appropriate for low-speed, thermally driven flow on smoke and heat transport from fires. FDS has been aimed at solving practical fire problems in fire protection engineer, while at the same time providing a tool to study fundamental fire dynamics and combustion. There is a distinguishing feature, the k-ε turbulence modeling, applied in FDS. It can describe fires in complex geometries, and the incorporation of a wide variety of physical phenomena. And turbulence determines the extent of interaction of various parameters of a pool fire, including combustion, wind velocity, and entrainment of the ambient air[20].

3.1. Theoretical background

The FDS model includes the following equations[21,22].

Continuity equation

$$\frac{\partial \rho}{\partial t} + \nabla \rho \mu = 0 \tag{11}$$

Momentum conservation equation

$$\rho\left(\frac{\partial \mu}{\partial t} + \frac{1}{2}\nabla|\mu|^2 - \mu\omega\right) + \nabla p - \rho g = f + \nabla\sigma \tag{12}$$

Energy conservation equation

$$\frac{\partial}{\partial t}(\rho h) + \nabla(\rho h \mu) = \frac{\partial p}{\partial t} + \mu\nabla p - \nabla q_r + \nabla(k\nabla T) + \sum \nabla(h_i \rho D_i \nabla Y_i) \tag{13}$$

Component conservation equation

$$\frac{\partial}{\partial t}(\rho Y_i) + \nabla(\rho Y_i \mu) = \nabla(\rho D_i \nabla Y_i) + m_i \tag{14}$$

State equation

$$p_0 = \rho TR \sum \frac{Y_i}{M_i} \tag{15}$$

There are two forms of pool fire in fire dike, one is the storage tank wall or various of valves and pipelines are damaged and cause flammable liquid leak to fire dike to form a pool fire in fire, the other is the fire explosion accident near the tank lead to the liquid spill and form flowing fire in fire dike. The flammable liquid leakage has decisive effect on the size of the fire. The leakage form is not only about the material, but it is also associated with the area of the leaking. Generally, the small hole leakage model is adopted to define the spillage of flammable liquid when the medium leakage accident is happened (the spill is continuous and the pipe diameter is 10 mm), which includes the following equation

$$Q_0 = C_d A \rho [2(P - P_0)/\rho + 2gh]^{0.5} \tag{16}$$

where Q_0 is the liquid leakage, kg/s; C_d is leakage coefficient, value of 0.65 (the crack shape is round, see Table 3); A is leakage area, m^2; ρ is density of the liquid, kg/m^3; P is medium pressure within the container, Pa; P_0 is environment stress，1.01×10^5 Pa; h is the liquid level height above the leaking, m.

Table 3. The liquid leakage coefficient.

Reynolds number(Re)	Crack shape		
	Circle(Polygon)	Triangle	Rectangle
>100	0.65	0.60	0.55
≤100	0.50	0.45	0.40

If the ground around the leakage source is flat, the leakage liquid could not spread indefinitely, but tend to a maximum value. The maximum area of liquid pool is defined by the minimum thickness of different liquid pools choose according to the different surface conditions, which are obtained from

$$S = \frac{V}{H_{\min}} = \frac{m}{H_{\min}\rho} \tag{17}$$

where S is the maximum area of liquid pool, m^2; V is the volume of leakage liquid, m^3; $H_{\min}$ is the minimum thickness of liquid pool, m. The values of the minimum liquid layer thickness of different ground are shown in Table 4.

Table 4. The minimum liquid layer thickness of different ground.

Ground	the minimum liquid layer thickness/m
Lawn	0.020
Rough earth	0.025
Bare ground	0.010
Concrete earth	0.005
Flat water	0.0018

3.2. Simulation scenarios

The 1A storage tank area is arranged on the north side of the chemical factory with a total storage capacity of 9.9×10^4 m^3, including 38 tanks (1500 - 6000m^3) on the ground. According to volume of tanks, 1A storage tank area is divided into three groups of storage tanks which are east-west arrangement in turn. Among them, the butyl acrylate tank (T0109) is the closest to public pipeline in the west side of factory with the volume of 1500 m^3, the diameter of 12.5 meters, and the height of 14 meters. The storage condition is often pressure at room temperature. The general layout plan of tank area is shown in Fig. 5.

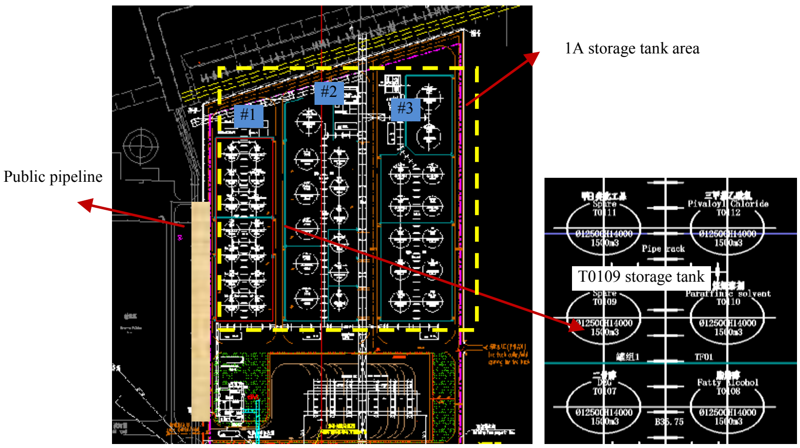


Fig. 5. Radiation in the point source model.

The fire protection embankment in the tank area is reinforced concrete structure. The dike in the tank area is about 2.4 meters thick and 1 meter high, with the effective volume of 68000 m^3, and the fire resistance is 4 hours. The distance between tanks is 0.6 D, and the distance between tank and the interior wall of fire dike is not less than the half of tank height.

Supposing that the tank spills and pool fire happens in fire dike in the process of material handling. The spill port is located in the joint part of tank wall and pipeline, with the height of 0.5 m, within the medium pressure of 3×10^5

Pa, and the leakage time is 5 minutes. The thermal radiation effect on the adjacent tank of pool fire in fire dike is simulated and analyzed through FDS in this work. The physical and chemical properties of butyl acrylate are shown in Table 5, and the basic situation and storage condition of evaluation unit are shown in Table 6-7.

Table 5. The physical and chemical properties of butyl acrylate.

Relative molecular weight	128.17
Ignition point (℃)	275
Relative density (air=1)	4.42
Relative density (water=1)	0.894
Critical temperature (℃)	324.7
Boiling point (℃)	147
Saturated vapor pressure (KPa)	1.33 (35.5℃)
Latent heat of vaporization (KJ/g)	0.35
Heat of combustion (KJ/mol)	5783

Table 6. The basic situation of evaluation unit.

Unit	Tank group	Capacity/m^3	Size of fire dike/m^2	Radius of equivalent circle/m
Butyl acrylate tank (T0109)	1A storage tank area	1500	65×47	31.2

Table 7. The storage condition of evaluation unit.

Storage material	Tank type	Size of storage tank	Temperature/℃	Pressure/MPa
Butyl acrylate	dome roof tank	Φ 12.5m H14m	normal temperature	normal pressure

3.3. Computational geometry and grid

The space for simulation according to the pool fire scale was built and meshed in FDS. The mesh size must be no larger than 0.1D* to guarantee the reliable operation of FDS. *D** represents the characteristic length scale for a fire plume and is written as

$$D^* = \left(\frac{\dot{Q}}{\rho_\infty T_\infty c_p g^{1/2}} \right)^{2/5} \tag{18}$$

In this work, the simulation space was set to 35×35×30 m^3, uniform grid cells with a size of 0.1×0. 1×0.1 m^3. The simulation time was set to 60 s. The simulation model of pool fire in fire dike is illustrated in Fig. 6.

3.4. Boundary conditions and initial conditions

The top surface was set to OPEN and the side faces and the bottom was set to INERT. And there was a controllable vertical plane set at the center of each fire to record the output of the heat radiation intensity. In the process of FDS simulation, the effect of the wind was ignored and the fire was set up on the surface of the combustible liquid spill area. There are two different methods to set the fire sources. One is to set a fixed fire source, and the other is to set a fire source based on the chemical reaction heat release rate. As the chemical reaction mechanism of crude is very complex, the method of a fixed fire source was applied in our study and the value of heat release rate of fire source was 1500 kJ/m^2. In order to simplify the simulation and calculation, it was assumed that the simulated space boundary blackness was equal to unity, the temperature was 300 K, and the ground was adiabatic.

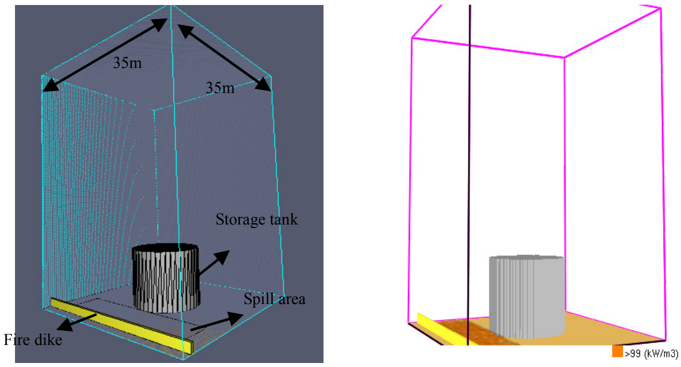


Fig. 6. Geometric model of tank in FDS.

4. Results and discussion

4.1. The thermal radiation damage based on injury model

It is easy to get radiation intensity of specify location and its injury radius by the calculation models of pool fire in fire dike. According to the damage / injure criteria, the corresponding distances *X* to the center of pool fire for the key radiation intensity are shown in Table 8. From the table it can be seen that once the butyl acrylate tank leaks and causes a pool fire in fire dike, the equipments and buildings could be damaged completely within the scope of 40.25 m from designated target position to the center of pool fire, and all people dead within one minute. When the distance from designated target position to center of pool fire is less than 49.29 m, the steel-structure equipments and buildings in this range could be deformed, and all people dead within one minute. When the distance from designated target position to center of pool fire is less than 69.71 m, the building was not affected basically and workers suffered minor injuries in ten seconds.

According to the actual fire prevention design of tank area, the storage tank with adjacent tanks minimum distance between the butyl acrylate tank and adjacent tanks is 8.5 m, the minimum distance between the butyl acrylate tank and fire dike is 7 m, and the distance between the butyl acrylate tank and public pipe is 20 m. The strong thermal radiation of pool fire could destroy adjacent tanks, equipments, and public pipe, and even cause serious casualties.

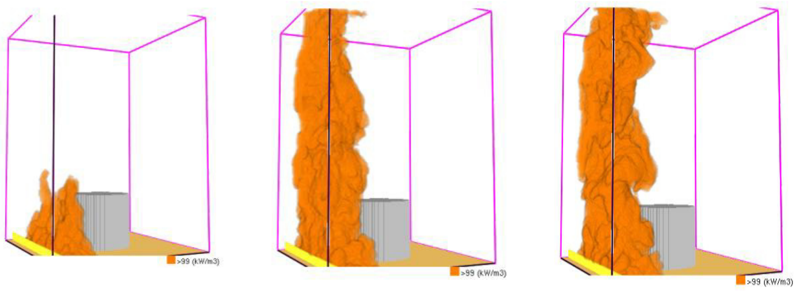
Table 8. Statistics of accident consequences.

Dangerous source	Leakage mode	Disaster mode	combustion rate/kg/(m^2·s)	Flame height/m	Heat radiation intensity/kW
Butyl acrylate	Whole container breakage	Pool fire in fire dike	0.044	52.12	762968.80
	Damage radius/m	Damage degrees to equipments		Personnel injury	
	40.25	operating equipments all damaged		1% dead within 10 seconds, all dead within1 minute	
	49.29	the minimum radiation intensity to ignite the timber, and deform the steel structure equipment under the normal circumstance		seriously injured in 10 seconds, all dead within 1minute	
	69.71	the minimum radiation intensity to melt the plastic under the normal circumstance		suffered minor injuries in 10 seconds, 1% dead within 1 minute	

4.2. The thermal radiation damage based on FDS simulation

4.2.1. Flame shape

The flame shape of pool fire changes in different time is shown in Fig. 7. It can be seen from the figure the fire expands gradually with the burning of butyl acrylate liquid and release a lot of smoke with high temperature, the flame spreads vertically along the tank wall with the appearance of cylindrical. After the pool fire happens 20 seconds, the flame spreads to the top of simulation space and the height is about 30 meters. Since then, the thickness of flame changes occasionally due to the interaction between the flame and fresh air of external environment, but the shape is cylindrical on the whole. The shape and height of flame do not change and keep in a stable condition. At the same time, with the development of combustion, in the absence of timely and effective control, the pool fire develops rapidly and produces strong thermal radiation on the surrounding equipments and buildings.

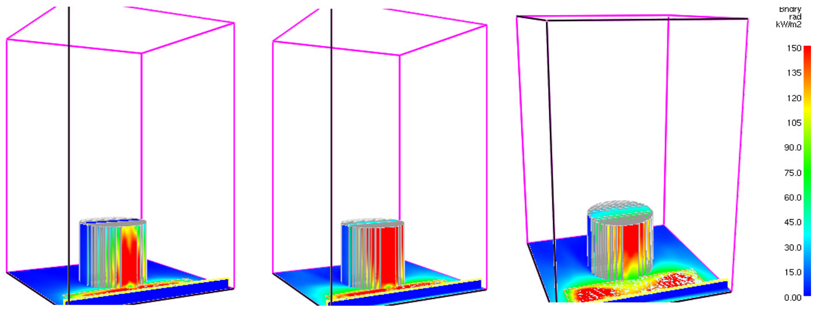


(a) T= 5s (b) T= 10s (c) T=20s

Fig. 7. The flame shape in different time.

4.2.2. Thermal radiation intensity

Fig. 8 shows changes of flame radiation intensity in different time. As shown in figure, it is found that the radiation intensity changes over the burning time. In the early stages of the fire, the flame radiation intensity was small and only a fraction space at the top of tank. With the development of combustion, flame radiation intensity was significantly bigger than before and influence range was increased. After the pool fire happens 20 seconds, the radiation area on one side of the tank wall is up to 80% and the maximum radiation intensity in flame center was 150 KW/m^2. The apparent radiation intensity was first decreased and then remained at 75 KW/m^2 with combustion stability and atmospheric turbulence effect.



(a) T= 5s (b) T= 10s (c) T=20s

Fig. 8. The distribution of flame radiation intensity at different moments.

Under the condition of simulation, thermal radiation intensity remains at 75 kW/m^2 and the injury radius is 28.46 meters which could damage adjacent 5 tanks (T0107, T0108, T0110, T0111, T0112) and the public pipeline on the west side of factory and even causes secondary fire explosion (see Fig. 9).

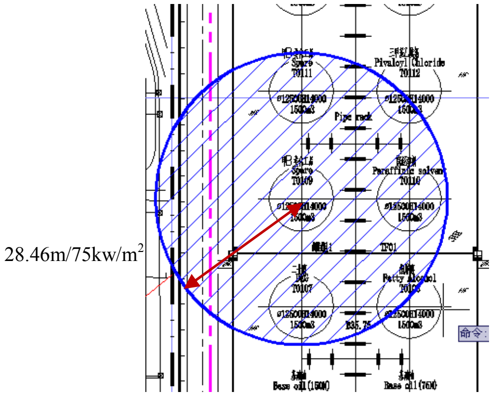
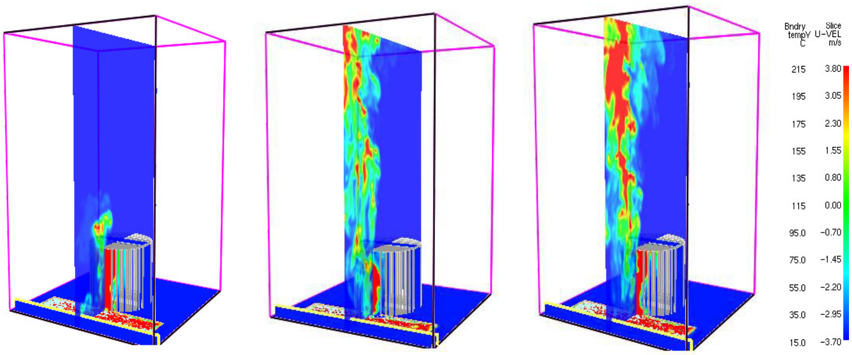


Fig. 9. Injury radius of the butyl acrylate tank in pool fire.

4.2.3. Smoke velocity vector distribution

Fig. 10 shows the distribution of smoke production rate in flame center at different moments during the combustion of pool fire. In the process of the simulation, select a center vertical section of storage tank as the observation plane to detect the change of flue gas velocity. Smoke production rate changes little when the pool fire happened early. Smoke velocity vector distribution mainly concentrates around the pillar of pool fire, the smoke production rate near the tank wall is higher, the smoke velocity close to the flame center is lower and it on the edge of flame is higher due to the development of combustion. Along with the rise of flame height, within the scope of 20~30 meters in height, the smoke velocity increases again, the maximum smoke velocity is 3.8 m/s and the maximum temperature of hot smoke is 215 ℃.

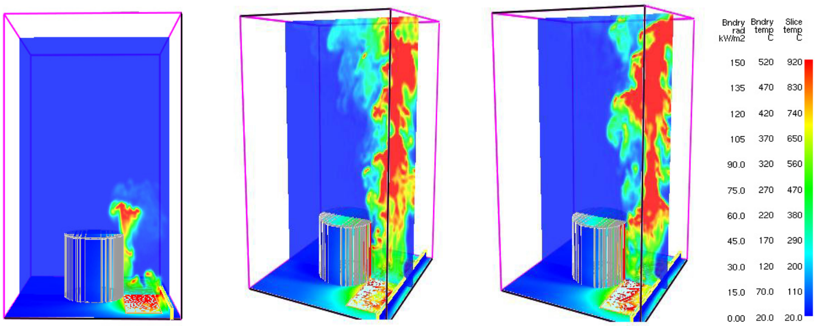


(a) *T*= 5s (b) *T*= 10s (c) *T*= 20s

Fig. 10. The distribution of smoke production rate in flame center at different moments.

4.2.4. The surface temperature of adjacent tank

Fig. 11 shows the surface temperature distribution of adjacent tank at different moments. As shown in figure, it is found that the flame center temperature is 830-920 ℃, and the maximum surface temperature of storage tank wall is about 520 ℃. The butyl acrylate tank in the event of pool fire can produce higher flame temperature, and cause larger security threats to environmental and other tanks.



(a) *T*= 5s (b) *T*= 10s (c) *T*= 20s

Fig. 11. The surface temperature distribution of adjacent tank at different moments.

5. Conclusions

In this paper, the accident consequence simulation of pool fire in fire dike is discussed, including the burning rate, flame shape, heat radiation intensity and injury radius calculation model. The simulation results show that the butyl acrylate tank leaks and causes a pool fire in fire dike, thermal radiation intensity of pool fire increases along with the development of combustion. The maximum radiation intensity in flame center is 150 kW/m^2. The apparent radiation intensity is first decreased and then remains at 75 kW/m^2 with combustion stability and atmospheric turbulence effect. The flame height is about 30 meters, the maximum smoke velocity is 3.8 m/s and the maximum temperature of hot smoke is 215 ℃. The flame center temperature is 830 ℃-920 ℃, and the maximum surface temperature of storage tank wall is about 520 ℃.

According to the damage / injure criteria, when thermal radiation intensity is 37.5 kW/m^2, the equipments and buildings could be damaged completely within the scope of 40.25 meters from designated target position to the center of pool fire, and all people dead within one minute. Under the condition of simulation, thermal radiation intensity remains at 75 kW/m^2 and the injury radius is 28.46 meters which could damage adjacent 5 tanks (T0107, T0108, T0110, T0111, T0112) and the public pipeline on the west side of factory and even causes secondary fire explosion. The accident consequence is very serious. The simulation results are of important reference value for the study of pool fire development law and environmental impact assessment and safety design in storage tank area.

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