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ABOVE GROUND PETROLEUM PRODUCT STORAGE TANK FIRES: A NUMERICAL ANALYSIS OF THERMAL RADIATION FOR DEVELOPING FIRE PREVENTION STRATEGY

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Tank fire; Thermal radiation; Water cooling system; Pipeline station; Numerical simulation

ABSTRACT

Above ground petroleum product storage tanks are tanks or other containers that are above ground, partially buried, bunkered, or in a subterranean vault. These are built to store petroleum product for pipeline system, oilfield and refinery.

Tank fires are one of the most terrible accidents in oil pipeline transportation stations. Tank fires pose a significant hazard to people, buildings, process piping, the environment and other facilities as a result of thermal radiation exposure. It is necessary and meaningful to study the distribution of the thermal radiation of a tank fire for emergency response, prevention and reducing loss.

To analyze potential tank fire incidents at a pipeline station, a three-dimensional station model was built using a computational fluid dynamics (Abbreviated as CFD, is a branch of fluid mechanics that uses numerical methods and algorithms to solve and analyze problems that involve fluid flows) software package to evaluate the thermal radiation distribution under different conditions. Numerical simulations were carried out for a total of six simulation scenarios to analyze 3 types of potential fires for 2 different liquid products (gasoline and diesel). The three kinds of fires that were modeled included: 1) disk pool fire on top of the tank; 2) ring pool fire on the top of a tank; and 3) pool fire in a dike. The simulation evaluates the effect of the thermal radiation on facilities and people.

The simulation results show that the water cooling system is effective at decreasing the magnitude of thermal radiation exposure and as a result is effective at protecting nearby tanks and facilities. Without water protection, the disk fire or ring fire can destroy or damage nearby structures significantly. The results of the simulation also show that the dike pool fire can have a catastrophic consequence to nearby facilities. Further the analysis showed that environmental wind does not change the thermal radiation distribution significantly. The results of the simulation point out countermeasure activities to enhance fire prevention at oil pipeline transportation stations in a scientific way.

INTRODUCTION

Above ground petroleum product storage tanks are tanks or other containers that are above ground, partially buried, bunkered, or in a subterranean vault. These are built to store petroleum product for pipeline system, oilfield and refinery.

Tank fires are one of the most terrible accidents in oil pipeline transportation station. The hazard of the tank fire to people, building, process piping, and other facilities, is mainly from thermal radiation. It is necessary and meaningful to study the distribution of thermal radiation of tank fire for emergency response, preventing and reducing loss.

Recent tank fire incidents within China petroleum companies have caused significant loss. In response, PetroChina Pipeline company (PPC) developed a research program to evaluate liquid pipeline station safety[1]. One branch study aims to assess the safety of tank fire although the tanks in PPC are designed and built according to the mandatory codes. It includes assessing the safety distance, the consequence of tank fire and the effectiveness of water cooling system.

In the past years, many experimental and theoretical research on the thermal radiation from tank fires are carried out and many inexpensive and effective methods are developed in a rational way. Computational fluid dynamics, abbreviated as CFD, is a branch of fluid mechanics that uses numerical methods and algorithms to solve and analyze problems that involve fluid flows. In this research program, CFD technology was selected as a study tool instead of the costly and impractical real-scale experimental method.

In this research, Fire Dynamics Simulator (FDS), a professional CFD fire simulator, is applied to simulate the tank fire in pipeline transportation station. FDS is a large-eddy simulation (LES) code for low-speed flows, with an emphasis on smoke and heat transport from fires[2]. It is developed by National Institute of Standards and Technology (NIST) of U.S.A. It is widely used to simulate the industrial and civil fires and is confirmed to provide a credible result. In the research, a real oil pipeline station is introduced as a case to be simulated and be studied.

CASE AND SIMULATION SCENARIOS DESCRIPTION

Case and Simulation Inputs

The station used in the research has a tank area of 270m by 230m. It also has 5 main facilities including station control building, fire pumps room, power station room, valves room and pumps room as Figure 1. The tank area has 8 production tanks. Tank 1, 2, 3 and 4 is 24m high and 40m in diameter. Tank 5, 6, 7 and 8 is 20m high and 28m in diameter. The distance between tanks, d1, d2, d3 and d4, is 24m, 19m, 24m and 23m, respectively. Simulation inputs of parameters such as thermal conductivity, density and specific heat of facilities and tanks are listed according to the materials property as shown in Table 1[3,4].

The intensity of thermal radiation depends on the scale and intensity of the fire. As a parameter describing intensity of fire, heat release rate (***HRR***), in unit of kW/m^2, is defined as [Eq. 1]. χ is fuel burning efficiency; m_f is mass burning rate, estimating combustion velocity in fire; ΔH is heat of combustion. In this simulation, the parameters are assigned the values as shown in Table 2[4,5,6].

$$\boldsymbol{HRR} = \chi \cdot m_f \cdot \Delta H \qquad \text{[Eq. 1]}$$

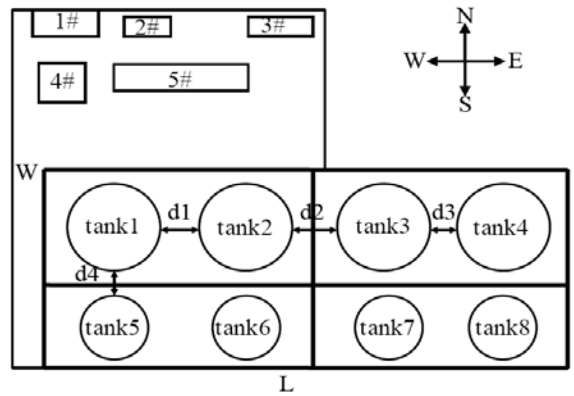

Figure 1. Layout of the oil pipeline station

Table 1. Facilities and material parameters for simulation

No.	Facilities	Materials	Thermal conductivity (*W/mK*)	Density (kg/m^3)	Specific heat (kJ/kgK)
1	station control building	concrete	1.2	2200	0.88
2	fire pumps room	concrete	1.2	2200	0.88
3	power station room	concrete	1.2	2200	0.88
4	valves room	steel	45.8	7850	0.46
5	pumps room	concrete	1.2	2200	0.88
6	Tanks(1~8)	steel	45.8	7850	0.46

Table 2. Values assigned to HRR parameters

	Gasoline	Diesel
χ	0.85	0.68
m_f ($kg \cdot m^{-2} \cdot s^{-1}$)	0.083	0.062
ΔH ($kJ \cdot kg^{-1}$)	46500	42500

Simulation Scenarios

The 3D station model in FDS software is established as Figure 2. 6 scenarios are set with different fire sources, fire types and the water cooling system status, see Table 3.

Scenario 1 consists of a disk pool fire on the top of domed roof Tank 3, diesel as the product type, with the water cooling systems of fire tank (Tank 3) and nearby tanks (Tank 2, Tank 4 and Tank 7) off. Scenario 2 is same as scenario 1 but the water cooling systems are effective. Scenarios 1 and 2 are both typical to domed roof tank fires. Scenario 3 consists of a ring pool fire on the top of floating roof Tank 2, gasoline as the product type, with the water cooling systems of fire tank (Tank 2) and nearby tanks (Tank 1, tank 3 and Tank 6) off. Scenario 4 is same as scenario 3 but the water cooling systems is effective. Scenarios 3 and 4 are both typical fire scenarios with the oil leaks from the seals in floating roof type tanks. Scenario 5 is a big pool fire in the dike of Tank 1 and Tank 2 and is a representative condition of leaking from Tank 1 and/or Tank 2.

Scenario 6 is same as scenario 5 but the environmental wind speed from the west is 2.6 m/s.

The purpose of scenarios 1, 2, 3 and 4 is to study the thermal radiation (heat flux) distribution of a disk fire or a ring fire on the top of tank and the protection function of the water cooling system. The purpose of scenarios 5 and 6 is to study the thermal radiation (heat flux) distribution of a dike pool fire and the influence of wind speed to the fire consequence.

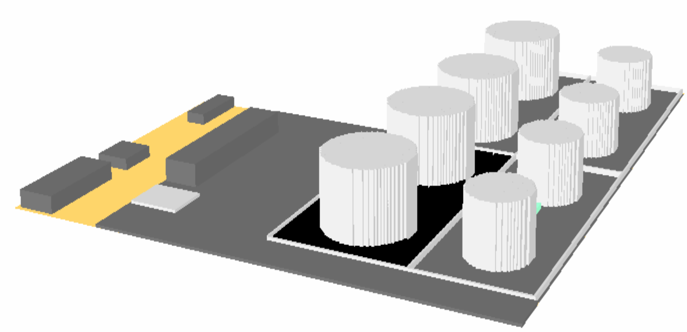

Figure 2. 3D station model built in FDS software

Damage Criteria of Thermal Radiation

To evaluate the thermal hazard of tank fires to facilities and people, the damage criteria of thermal radiation used in the study as shown in Table 4[7]. The time period that the thermal radiation continues for is another important factor which determines whether the effected equipment will be destroyed or not. In the study, it is assumed that there is enough fuel in the tank for burning to destroy effected equipment, deform effected facilities or damage people.

Table 3. Six simulation fires scenarios

S.	Fire source	Fire type	Fire area (m^2)	Product	Wind speed (m/s)	Water cooling system /flow rate ($L \cdot min^{-1} \cdot m^{-2}$)
1	top of tank 3	disk pool fire	1257	diesel	0	off
2						on / 2.0
3	top of tank 2	ring pool fire	175	gasoline	0	off
4						on / 2.0
5	dike of tank 1 and 2	dike pool fire	6618	gasoline	0	off
6					2.6	

Table 4. Equipment status to different heat flux[7]

Heat flux （kW/m^2）	Equipment status
35.0	Facilities will be destroyed; exposed to radiation for 30 minutes, steel structure will be broken or collapsed. People will be killed.
25.0	Exposed to radiation for 30 minutes, steel structure will be deformed obviously.
12.5	Facilities will be damaged. Wood is ignited by flame. Plastic will be melted.

SIMULATION RESULTS

The spatial distribution of the thermal radiation fire scenarios is obtained from the numerical simulation. To assess the influence of fire on the nearby tanks and facilities, the maximum heat flux is collected and shown as Table 5.

Table 5. Simulation results of 6 scenarios

S.	Maximum heat flux at the nearby tank wall (kW/m^2)	Maximum heat flux at the facilities wall (kW/m^2)
1	Tank 2:25 Tank 4:15 Tank 7:20	Not considered as the facilities are much more distant than the nearby tanks and the heat flux is much less.
2	Tank 2:5 Tank 4:3 Tank 7: 3	
3	Tank 1:10 Tank 3:12 Tank 6:10	
4	Tank 1:3 Tank 3:5 Tank 6:3	
5	Tank 3:>35 Tank 5:>35 Tank 6:>35 Tank 7:25	1#:10 2#:6 3#:6 4#:13 5#:13
6	Tank 3:>35 Tank 5:>35 Tank 6:>35 Tank 7:25	1#:10 2#:6 3#:6 4#:13 5#:13

The 3D flame model of disk pool fire in scenario 1 is shown as Figure 3 and the heat flux distribution of scenario 1 is shown as Figure 4. The 3D model of water cooling system in scenario 2 is shown as Figure 5 and the heat flux distribution of scenario 2 is shown as Figure 6. In scenario 1, the maximum heat flux at the nearby tank wall is 25 kW/m^2(Tank 2), that means the nearby tank structure can be deformed in 30 minutes. It is a high risk scenario. In scenario 2, with the water cooling system protection, the maximum heat flux at the nearby tank wall is 5 kW/m^2(Tank 2), that means the nearby tank will not be damaged. It is in less danger. These results indicate that water cooling systems can decrease the radiation heat flux greatly and protect the nearby tanks effectively.

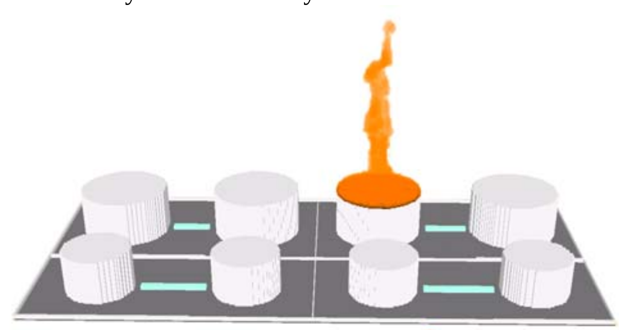

Figure 3. 3D flame model of disk pool fire in scenario 1

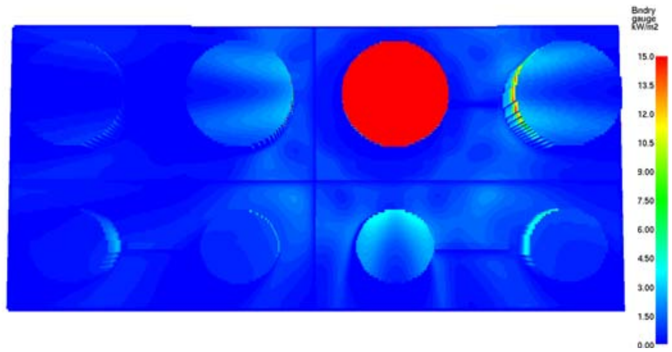

Figure 4.Thermal radiation distribution of scenario 1 (top view)

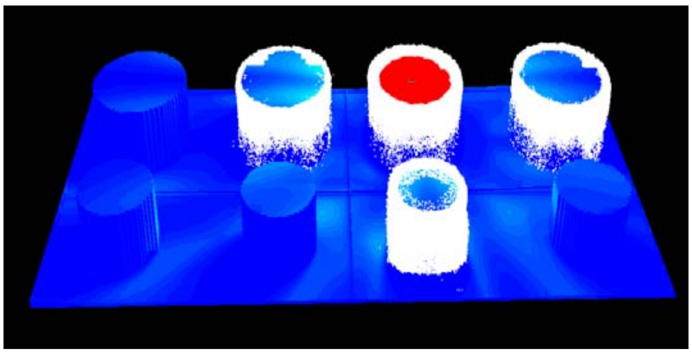

Figure 5. 3D model of Water cooling system in scenario 2

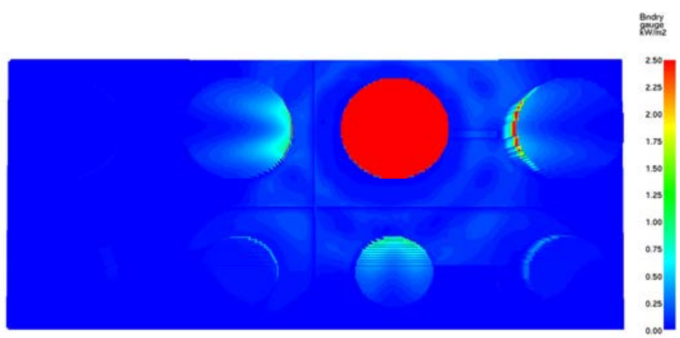

Figure 6.Thermal radiation distribution of scenario 2 (top view)

The heat flux distribution of scenario 3 and 4 is shown as Figure 7 and Figure 8. In scenario 3, the maximum heat flux at the nearby tank wall is 12 kW/m^2(Tank 3), that means facilities attachments will be damaged. It is dangerous to the tank and attachments. In scenario 4, with the water cooling system protection, the maximum heat flux at he nearby tank wall is 5 kW/m^2(Tank 3) and is in less danger. These results indicate the effectiveness of the water cooling system as shown above. They also show the ring pool fire is less dangerous than the disk pool fire since it has much less fire area.

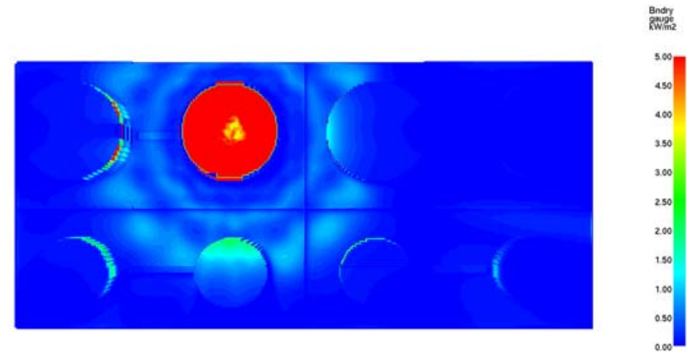

Figure 7.Thermal radiation distribution of scenario 3 (top view)

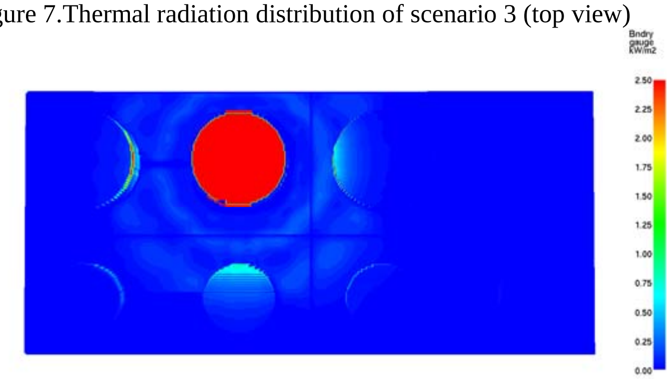

Figure 8.Thermal radiation distribution of scenario 4 (top view)

The heat flux distribution of scenario 5 is shown as Figure 9 and the vertical velocity distribution in scenario 6 is shown as Figure 10. In scenario 5, the maximum heat flux at the walls of Tank 3, Tank 5 and Tank 6 is more than 35.0 kW/m^2, that means the nearby tank structure will be broken or collapsed in 30 minutes. It can lead to a catastrophic consequence. The maximum heat flux at the wall of Tank 7 is 25 kW/m^2, that means Tank 7 structure can be deformed obviously in 30 minutes. It is in significant danger. Facilities such as valve room and pump room face a heat flux of more than 12.5 kW/m^2, that can cause serious damage and the secondary fire. In scenario 6, the vertical velocity of the fire flame driven by fire is about 60m/s, much more than the wind speed of 2.6m/s, because the buoyancy of the fire is more powerful than the wind. So the fire flame has very little offset and does not influence the heat flux distribution significantly.

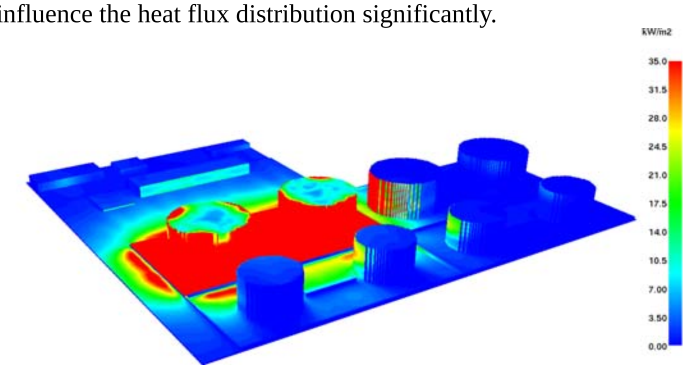

Figure 9. Thermal radiation distribution of scenario 5

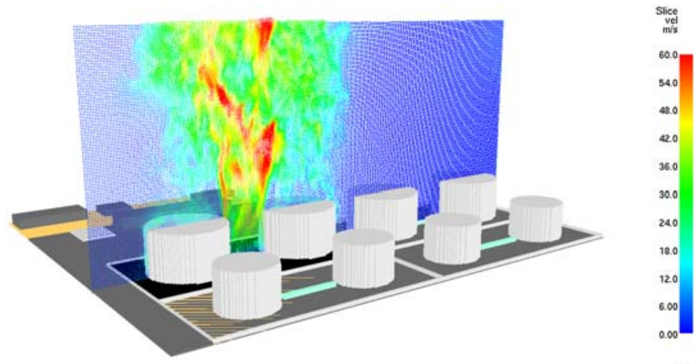

Figure 10.Vertical velocity distribution of fire flame in scenario 6

CONCLUSIONS

In this study, a numerical simulation method is used to analyze the thermal radiation effects of fires in above ground petroleum product storage tanks in transmission pipeline stations. Six fire scenarios including disk fire, ring fire on the top of a tank and dike pool fire were simulated and analyzed. The following are conclusions of the analysis:

(a) Ring fires are less dangerous than disk fires due to smaller fire area and produced heat. However, both types of fires can destroy or damage the nearby tanks without the water cooling system protection.

(b) Water cooling systems play a significant role to decrease thermal radiation and thereby protecting nearby tanks when tank fires occur. Subsequently it is very important to maintain water cooling systems as they are a critical component of fire prevention in oil pipeline stations. Disk fire or ring fire on the top of a tank require active and preventative mitigation measures to reduce and eliminate the fire. In this case, fixed and mobile firefighting resources should be activated and concentrated to the fire tank to prevent spread of the fire, mitigate or extinguish the burning. Meanwhile, water cooling systems and fire hydrants should be used to cool down the fire tank, nearby tanks and facilities to prevent those assets being damaged.

(c) Dike pool fire is catastrophic; it can involve the nearby facilities and tanks resulting in very serious consequences. When dike pool fires occur, conservative and defensive measures should be taken to control the fire and contain loss. In this case, to mitigate or eliminate the fire is normally very difficult, sometimes quite dangerous to the firefighters. So the practical strategy is to shut down the process, cut down the fuel supply, concentrate the firefighting resources to prevent spread of the fire. In the same time, cool down and isolate the nearby facilities from the fire.

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REFERENCES

[1] Feng Wenxing, Shui Biyuan, etc., “Application of Quantitative Risk Assessment at Stations of Oil Product Pipelines,” Oil and Gas Storage and Transportation(in Chinese), Volume 28, NO. 10, 2009.

[2] “Fire Dynamics Simulator (Version 5) Technical Reference Guide,” 2010, National Institute of Standards and Technology, Maryland, U.S.A.

[3] “Fundamental of Heat Transfer,” 1999, University of Science and Technology of China, Hefei, China.

[4] M. Muñoz, J. Arnaldos, J. Casal, E. Planas, “Analysis of the Geometric and Radiative Characteristics of Hydrocarbon Pool Fires,” Combustion and Flame, Volume 139, NO. 3, 2004.

[5] Yi Liang, Huo Ran, Zhang Jingyan, etc., “Characteristics of Heat Release Rate of Diesel Oil Pool Fire,” Journal of Combustion Science and Technology(In Chinese), Volume 12, NO. 2, 2006.

[6] Zhuang Lei, Chen Guoqing, Sun Zhiyou, etc., “On the Damage Study of the Thermal Radiation of the Large Oil-Tank Fire Accidents,” Journal of Safety and Environment y(In Chinese), Volume 8, NO. 4, 2008.

[7] “Guidelines for Quantitative Risk Assessments”, 2005, Committee for the Prevention of Disasters, Netherlands.