Radiative Heat Flux of a Burning Crude Oil Tank to the Adjacent Tank under the Conditions of Varied Wind Flows

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Abstract. Simulation about the large-scale crude oil tank fire is conducted. By utilizing the FDS to simulate the $10^5$m³ crude oil tank fire and gaining the feature of the flame under four different wind conditions, the incident radiation distribution of the flame on the adjacent tank is acquired. The cylindrical flame radiation model is used to simplify the flame and the radiation simulation is conducted with COMSOL software. It suggests that the wind condition influence the incident radiation distribution as well as the radiation intensity. In the same wind condition, the position and the incidence angle hold different effect on radiation distribution. Finally, according to the characteristics of incident radiation, some suggestions are proposed for firefighting.

1. Introduction
The large-scale crude oil tank has been widely used in the export and import oil storage with development of China's economy. The application of large-scale oil tank predigests the management of oil storage zone and make the construction of related facility economy. However, the risk for the oil tank fire is in negligible. When a crude oil is on fire, it is difficult to extinguish it. The heat flux from the fire will also influence the adjacent tanks, which may result in a series of disasters [1]. For example, the radiation will weaken the steel wall of nearby tank and ignite the oil of other tanks, causing a more serious accident. There are several large-scale oil tank fires happened in 2006, 2007 and 2012 [2, 3]. The oil tank fire happened in Zhangzhou in 2012 last three days and causing 3000 citizen evacuated form residential area, which ignited two adjacent tanks, leading to a huge amount of economic loss and negative impulse. So, one of the important objectives for the fire fighter in the case of crude oil fire is to cool down the adjacent tanks.

The wind environmental wind condition in crude oil tank zone near the ocean will often be different. And the environmental wind condition is one of factors influence the combustion and the radiation distribution. So, it is necessary to understand the effects of wind flow on the burning tank and the heat flux in firefighting.

2. Modeling
The simulation is conducted by FDS software and COMSOL software to obtain the characters of flame and the radiation distribution on the adjacent oil tank. The main condition is shown in Fig. 1. There are two $1\times10^5$m³ crude oil tank. The height of tank steel wall is 21.96m. The level of the storage of crude oil reach the height of 19.89m. The thickness of floating roof is 780mm. The inner diameter is 80m and the outer diameter is 80.5m. And the spacing between two tanks’ wall is 32m.
The parameter about the oil combustion characteristics is shown in the Table 1. The maximum burning rate is an important parameter in the oil tank fire simulation. As previous research shown, the burning rate will increase with the diameter increasing and then reach the max line burning rate 4mm/min [4-7].

![Fig. 1 Schematic of the burning tank with crude oil and the adjacent one](image1)

| Character                        | Value  |
|----------------------------------|--------|
| Density (kg/m³)                  | 817.5  |
| Specific heat capacity (kJ/(kg·K)) | 2.4    |
| Heat conductivity (W/(m·K))      | 0.15   |
| Combustion reaction heat (kJ/kg) | 47500  |
| Maximum burning rate (kg/(m²·s)) | 0.054  |

The simulation of oil tank combustion is conducted in FDS under different wind speed boundary condition 0m/s, 6m/s, 10m/s, 20m/s. And the result of simulation about the flame geometry under various wind speed is shown in Fig. 2. Table 2 illustrate the features of flame under different wind speeds. The cylindrical flame radiation model is utilized to simplify the fire plume oscillatory behavior and to simulate the radiation distribution on the adjacent tank wall on stable stage of oil tank fire [8-11]. Abstracting the complex flame into the cylindrical flame, flame under different wind condition will be characterized by various overall height and slope. The flame is separated into two parts, the bottom flame and the upper flame. The bottom flame diameter is assumed to be same as oil tanks and the upper flame diameter shrinks due to plume swirl in different wind condition.

![Fig. 2 Flame Geometry of the Burning Tank under Varied Wind Flows](image2)
Table 2 Flame Geometry of the Burning Tank under Varied Wind Flows

| Wind speed (m/s) | Overall height of flame (m) | Inclination of flame (°) | Height of bottom flame (m) | Diameter of upper flame (m) |
|-----------------|-----------------------------|--------------------------|---------------------------|---------------------------|
| 0               | 122.05                      | 0                        | 6                         | 20                        |
| 6               | 84.37                       | 20                       | 6                         | 20                        |
| 10              | 33.15                       | 62                       | 6                         | 30                        |
| 20              | 40.30                       | 68                       | 6                         | 40                        |

3. Results and Discussions

The geometry model is established in the COMSOL software and the results are presented in follow. The overall radiation distributions with four wind speeds are slight different. The incident radiation is mainly concentrated at the root of the flame which sustain the combustion. But it varies on the adjacent oil tank when wind speed increases. Fig. 4 ~ Fig. 7 show a more detailed incident radiation distribution in different wind condition on the adjacent. The radiation on the roof holds the features that the high incident radiation intensity is concentrate on the small area near the fire tank. The radiation on the floating roof mainly attenuate with distance from the fire tank. The high incident radiation also concentrates on the center of upper edge of the tank wall. But the radiation is not only attenuate along the direction of height but also along the arc away from fire tank.

![Heat Flux Distribution for the Burning Tank and Adjacent One with different Wind Flow](image)

Fig. 3 Heat Flux Distribution for the Burning Tank and Adjacent One with different Wind Flow of (a) v=0 m/s; (b) v=6 m/s; (c) v=10 m/s; (d) v=20 m/s

Comparing the adjacent oil tank radiation distribution between the floating roof and the side wall, it is shown that the incident radiation on the side wall towards the fire is generally larger than the radiation on the roof. However the relationship on the amount of radiation between roof and side wall changes with the increase of wind speed. In a low wind speed condition, the radiation on the wall is bigger than the top roof. But the incline of the flame change this kind of radiation distribution traits and the radiation on the roof is larger than it on the wall. When comparing the radiation distribution on the roof under different wind flows, it is clear that the radiation in same position is approximately linear to the wind speed. When the fire slope to the adjacent, the distribution changes, which the radiation attenuates along the distance from fire and also starts to attenuate along the distance away...
from the symmetry axis. This trend is due to that the slope of fire makes the flame more close to the adjacent to the floating roof of the tank. And when the flame is vertical, distance from the fire to the roof takes less influence on the radiation along the direction vertical to the symmetry axis. In fact the angle of radiation incidence affect the radiation distribution more than the distance. But when the flame is too close to the roof, the distance change in the radiation attenuation takes more important roles. The radiation distribution on the side wall holds the same feature as it on the roof. But the incident radiation at same position change with wind speed with smaller slope. And the trend of attenuation along the radius is obvious at a low wind speed and it don not enhance significantly when wind speed raises.

Fig. 4 Heat Flux Distribution for the Side Wall and the Floating Roof of the Adjacent Tank with Wind Flow of 0 m/s
Fig. 5 Heat Flux Distribution for the Side Wall and the Floating Roof of the Adjacent Tank with Wind Flow of 6 m/s

Fig. 6 Heat Flux Distribution for the Side Wall and the Floating Top of the Adjacent Tank with Wind Flow of 10 m/s
Fig. 7 Heat Flux Distribution for the Side Wall and the Floating Top of the Adjacent Tank with Wind Flow of 20 m/s

Fig. 8 shows the relationship between radiation distribution on the side wall and the vertical height when the wind speed is 0 m/s. And the x mean the distance from the symmetry axis to the vertical line on the tank wall. The incident radiation intensity is almost linearly related to the height and the slope of the line is larger with the position near the symmetry line. When considering the radiation on the wall of x more than 30 m, the radiation from the flame is almost same as the thermal radiation from the sun at noon. Fig. 9 shows that the incident radiation changes horizontally along the tank wall. Within the interval of horizontal distance y from 0 to 15, the curve characterizes parabola, the attenuation gradually steep with the distance increase. But when the horizontal distance is longer than 15, the change of slope is so slight that the numerical relationship between radiation and y distance can be considered linear. The lower figure in Fig. 9 demonstrates the radiation changes with the cosine of incidence angle. However the cosine of incidence angle make a different influence on the distribution of radiation. Comparing the upper figure and the lower figure in Fig. 9, it is confirmed that the cosine of incident angle takes more important role in the central part (near y=0 m) of the tank wall but the y distance exactly holds a stronger influence on the part away from the symmetry axis. However, these two factors all alter the distribution of incident radiation.
4. Conclusion Remarks

The simulation is conducted under four different wind speed conditions. And the feature of distribution of incident radiation to adjacent tank from the fire crude oil tank is acquired. The results show that the wind speed not only influence the intensity of radiation but change the distribution pattern on the position. It also indicates that the radiation on the partial zone of the adjacent can reach a relatively dangerous level which may weaken the steel strength of tank wall and ignite the crude oil. More attention should be paid to the upper center parts of the tank wall and the parts form $x=30m$ to $x=40m$ could be put less efforts when the wind speed is slow. But when the wind speed is high, the radiation on the top roof should be paid attention and the radiation on the overall tank wall is on
dangerous level. So the fire fighter are supposed to put more human and equipment to prevent the failure of the tank wall and cool down the temperature of floating roof.

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