Study on Pool Fire Characteristics of Port Crude Oil Storage Tank Based on Pyrosim

Fengyun Chen [a], Chao Han [b,*]

Security and Emergency Technology Research Center, China Waterborne Transport Research Institute, Beijing, China

[a]chenfy@wti.ac.cn, [b*]hanchao@wti.ac.cn

Abstract. In order to study the influence of wind speed on the flame development process, pool fire flame shape and thermal radiation distribution after the occurrence of the full-surface pool fire accident of the port crude oil storage tank, the pyrosim software was used to establish the fire accident model of 50000m^3 crude oil storage tank under different wind speeds. The numerical simulation shows that after a full-surface pool fire accident occurs in one of the tanks, the thermal radiation received by the adjacent tanks when the wind speed is large is above the critical thermal radiation value, which is very easy to spread into a multi-tank pool fire. With the increase of wind speed, the height and length of the pool fire flame gradually decrease, and the flame inclination angle increases. With the increase of wind speed, the strong radiation area gradually spreads to the downwind direction, and the tank in the downwind direction may have an indirect pool fire spread accident.

Keywords: crude oil; storage tank; pool fire; numerical simulation.

1 Introduction

With the rapid development of China 's economy, China 's waterway dangerous goods traffic continues to grow steadily. At present, China has built more than 8,000 dangerous goods storage tanks in ports, with a total capacity of more than 100 million cubic meters and an annual turnover of more than 500 million tons. The types of storage and transportation mainly include crude oil, refined oil, natural gas and liquid chemical products[1].There are many storage and transportation facilities for port storage tanks, large amount of loading and unloading operations, and relatively concentrated storage areas. There are great potential safety risks and accident hidden dangers. Fire and explosion accidents in oil tank at home and abroad have occurred repeatedly, causing serious social public safety hazards and loss of life and property[2].

In the typical fire mode, the full-surface pool fire has the largest hazard range [3]. The most serious impact after the fire accident of the storage tank is thermal radiation. The fire storage tank releases a large amount of thermal radiation, which causes the adjacent storage tank to burn or even explode. At the same time, the large amount of radiation

© The Author(s) 2025

K. Yuen et al. (eds.), *Proceedings of the 2025 International Conference on Engineering Management and Safety Engineering (EMSE 2025)*, Advances in Engineering Research 267,
https://doi.org/10.2991/978-94-6463-780-9_18

heat generated by the combustion of the oil also poses a serious life threat to the on-site inspection personnel and firefighters.

At home and abroad, the research on large oil tank fire is mainly carried out from three aspects: experiment, theoretical analysis and numerical simulation. With the continuous maturity of large oil tank fire experiment and numerical simulation technology, the use of numerical simulation software to analyze large oil tank fires is becoming more and more extensive. Pourkeramat[4] studied the effect of pool fire dimension and its stand-off distance on the structural behavior of thin-walled tanks. Ahmed[5] studied the fire-influenced domino accident propagation pattern, The results show that the incident heat flux due to tilted flame doubles in magnitude with a four-order increase in the escalation probability for the most affected tank, intensifying its vulnerability.

In the numerical simulation of large crude oil storage tank fires, the frequent fire scenarios are generally concerned. There are few studies on the most serious full-surface fire scenarios, and the simulation of the consequences of large crude oil storage tank fires under different environmental winds is not systematic. Based on this, this paper uses numerical simulation to analyze the flame shape, thermal radiation distribution and its damage to personnel of the full-surface liquid pool fire with wind speed of 0-10m / s in the 50000m^3 storage tank commonly used in the crude oil reservoir area based on pyrosim, which provides a reference for the safety risk analysis and emergency treatment of crude oil storage tank fire accidents.

2 Materials and Methods

2.1 Simulation Model

In this paper, pyrosim software is used for numerical simulation. The accuracy of the three-dimensional fire simulation results of the software has been verified by various experiments, and is widely used in fire simulation in large spaces such as factories, underground passages and buildings [6].

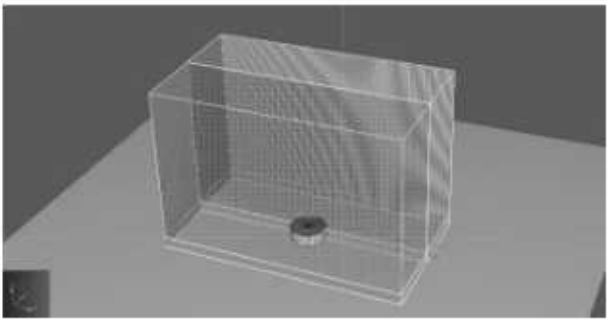


Fig. 1. Numerical simulation model, grid and detector arrangement

In this paper, an internal floating roof storage tank with a capacity of 50000m^3 storage tank and an internal diameter × height of φ60.0m×20.0m is constructed, and the corresponding numerical simulation model is established. The size of the calculation area is

set to 210m×120m×300m, and the uniform cubic grid is used. The grid is 1.5m×1.5m×1.5m, with a total of about 9 million grids. At the same time, the radiation heat flux detector is arranged in the upwind and downwind of the storage tank. On the planes of tank height (20.0m), From the edge of the tank to 3 times the diameter, the thermal radiation flux detector is arranged at an interval of 0.1 times the diameter of the tank, as shown in Fig. 1.

2.2 Material Parameter

In the simulation process, the material of the storage tank is set to steel plate, the ground material is concrete, the four sides and top surfaces of the numerical simulation surrounding area are set to OPEN boundary, and the oil tank and ground are set to INERT boundary, which can avoid the accumulation of heat in the grid area and affect the simulation results. The values of thermal physical and chemical properties parameters[7] are shown in Table 1.

Table 1. Parameter table of thermal physical and chemical properties of materials

parameters	material	
	Steel	*Concrete*
Thermal conductivity (W/m·K)	49.8	1.0
specific heat (kJ/kg·K)	0.47	0.8
Thermal diffusivity (%)	1.77×10^{-5}	5.7×10^{-7}
Material thickness (m)	0.1	1.0
Density (kg / m^3)	7900	2400
Emissivity (%)	0.45	0.95

2.3 Simulation Parameters

The setting of simulation parameters includes simulation time and environmental conditions. In this paper, the annual average temperature of the storage tank area is 15.2℃, the annual average atmospheric pressure is 101.6kPa, the annual average relative humidity is 80%, and the simulation time is 60 s.

As the port will stop operation when it encounters wind above six levels, In this paper, 0-10m/s is selected as the simulated wind speed, with an interval of 1m/s to accurately explore the influence law of wind speed.

2.4 Fire Source Setting

In pyrosim, setting the fire source is a very important part. The current simulation calculation usually calculates a fixed heat release rate per unit area by combining the thermal physical and chemical properties of the fuel with the combustion rate calculation model.

The combustion rate of crude oil is 0.0732kg/(m^2s) calculated by Babrauskas formula. Combined with the thermal physical and chemical properties of crude oil in Table 2, the

median value of combustion efficiency is 0.765, and the heat release rate per unit area of crude oil is calculated to be 2373 kW/m^2.

Table 2. Parameter table of thermal physical and chemical properties of crude oil

parameter	material
combustion heat (kJ/kg)	42700
maximal combustion rate (Kg/m$^{2)}$	0.027-0.119
Density (kg/m^3)	783
Thermal conductivity (W/m·K)	0.14
specific heat (kJ/kg·K)	2.4
combustion efficiency (%)	0.68-0.85

2.5 Limitations of Models and Parameters

Due to the limitations of Pyrosim in the geometric model setting, the cylindrical tank cannot be directly constructed. In this paper, the cylindrical tank is approximately replaced by a combination of multiple triangular prisms. At the same time, due to the complex characteristics of crude oil, the parameters set by numerical simulation cannot be completely consistent with the actual properties, and the calculation results will produce certain errors. However, the parameter setting has been as practical as possible, and the error is within the controllable range.

3 Results & Discussion

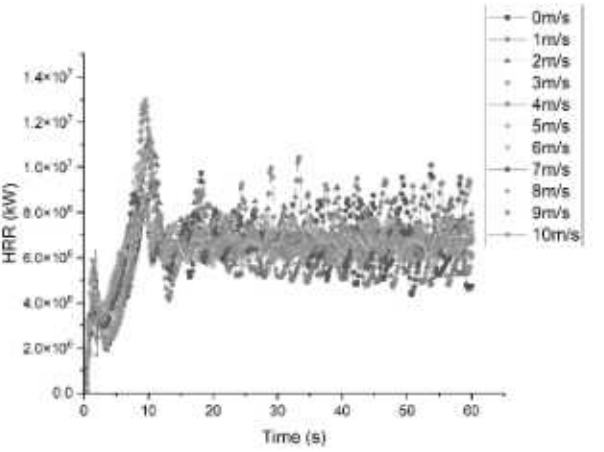
3.1 Analysis of Flame Heat Release Rate (HRR)

From Fig. 2(a), it can be seen that in an open environment, the time required for crude oil to burn from ignition to the most intense combustion is very short, reaching a peak around 10 s. This peak represents the maximum development stage of the flame, and the peak of the heat release rate here jumps obviously. From Fig. 2(b), it can be seen that as the wind speed increases, the wind provides more sufficient oxygen for combustion and promotes the combustion reaction. Therefore, the peak of HRR increases and reaches the maximum at the wind speed of 3 m / s. After that, the tank is in an unstable state at the initial stage of combustion due to the wind, and its effect overwhelms the wind to promote the combustion effect, so the peak of HRR decreases. When the wind speed is 10m / s, the HRR value is about 16.2 % lower than the HRR peak under the static wind condition, and 34.9 % lower than the wind speed of 3m/s. After this stage, the heat release rate gradually decreases and the fluctuation range is reduced.

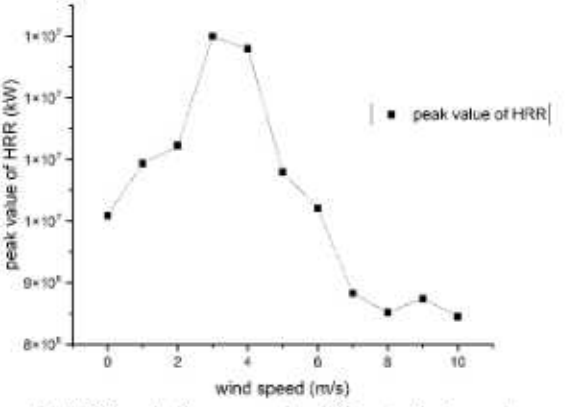
3.2 Analysis of Fire Plume Morphology

Crude oil is composed of a variety of hydrocarbons with high carbon content, and a large amount of black smoke is produced during combustion. The flame above the black smoke and fuel is called a fire plume, which is divided into a clean combustion zone

and a flue gas coverage zone. Fig. 3 shows the shape of the fire plume when the tank burns stably after a full surface fire. It can be seen that the clean combustion zone is located at the bottom of the visible flame layer, the height is low, and the thermal radiation energy is extremely high. the flue gas coverage area is located above the clean combustion area, where there are a large number of smoke particles.



(a) HRR trend diagram under different wind speeds



(b) HRR peak diagram under different wind speed

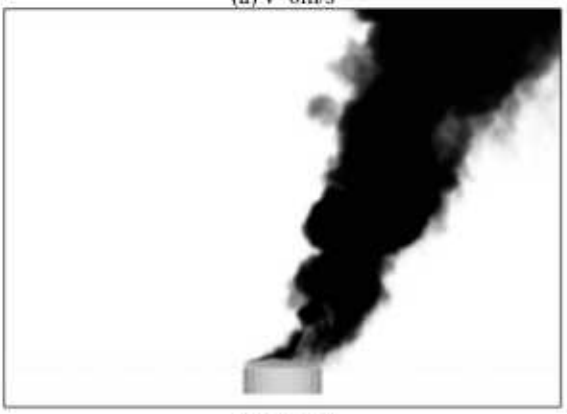
Fig. 2. Numerical simulation model, grid and detector arrangement

By simulating and observing the dynamic flame plume morphology, it can also be seen that in the early stage of oil combustion, the flame moves up and down under the action of buoyancy, which is due to the negative pressure area formed at the bottom of the flame and the liquid level of the oil. A large amount of air is inhaled in this area to form a churning air mass, resulting in flame pulsation, smoke column or mushroom-like entrainment. With the increase of time, the concentration of flue gas produced by combustion is getting larger and larger, and the flame is weakened. However, as the oil combustion becomes more and more sufficient, coupled with the dilution effect of

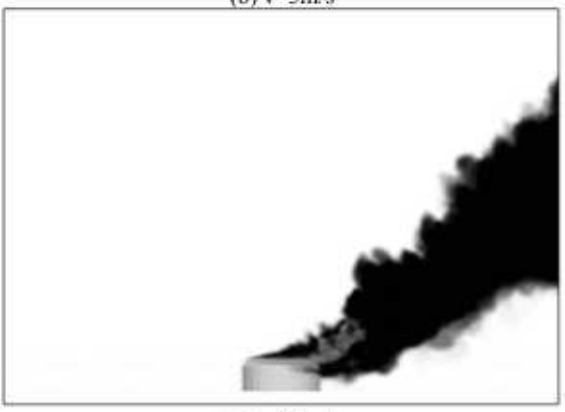
wind, the concentration of flue gas decreases, and the flame becomes more and more obvious.



(a) v=0m/s



(b) v=5m/s



(c) v=10m/s

Fig. 3. The shape of fire plume at different wind speeds

3.3 The Influence of Wind Speed on the Shape of Pool Fire

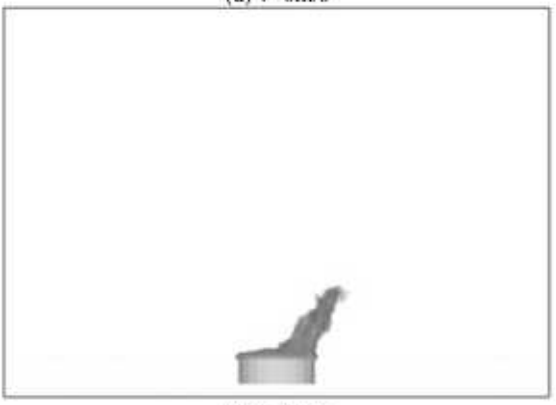
Fig. 4 (a) is the flame shape diagram of steady pool fire under no wind condition. It can be seen that the flame is roughly conical. Fig. 4(b) is the flame shape diagram when the wind speed is 5m/s. It can be seen that the whole flame is inclined at a certain angle towards the downwind direction. At this time, the highest point of the entire flame is no longer located in the vertical direction of the tank center.

Fig.4 (c) shows the geometric characteristics of the flame at different wind speeds. The geometric characteristics of the flame can be roughly determined by the temperature distribution map of the flow field. The flame height can be obtained by subtracting the height of the liquid level from the highest point of the flame. The height of the flame at 1~ 10m/s wind speed is shown in fig.4 (c), which is between the upper and lower limits of the empirical formula.

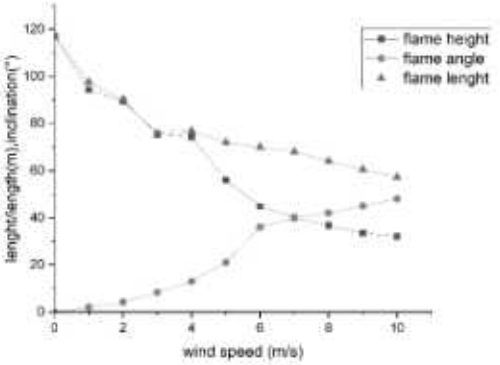
The linear distance between the highest point of the flame and the center of the liquid surface is the length of the flame. It can be seen from Fig.4 (c) that the change trend of the flame length is basically the same as the flame height, and gradually decreases as the wind speed increases.



(a) v=0m/s



(b) v=5m/s



(c) Flame parameters at different wind speeds

Fig. 4. Pool fire shape and flame parameters

As the wind speed increases, the flame inclination angle increases. When it reaches 10m / s, the flame inclination angle even reaches 48°, At this inclination angle, the tank in the downwind direction may have an indirect pool fire spread accident, which will eventually lead to major accident consequences.

3.4 The Influence of Wind Speed on Thermal Radiation Intensity

The thermal radiation intensity is generally defined by the thermal radiation value generated by the flame of the accident tank. According to the regulations of the American Chemical Engineers Association, this paper defines the thermal radiation value greater than 13.5 kW/m^2 as the strong radiation area[8].

Fig. 5 shows the distribution of thermal radiation under different wind speeds. It can be seen that the area with large heat flux density under fire conditions is mainly concentrated above the storage tank, and there is also some thermal radiation around the storage tank, but the attenuation phenomenon is very obvious. The wind speed has a great influence on the distribution of thermal radiation near the tank. With the increase of ambient wind speed, the strong radiation area gradually spreads to the downwind direction, and the storage tank in the downwind direction may have an indirect pool fire spread accident.

Fig. 6 shows the strong radiation distribution area at the liquid level of the storage tank under different wind speeds. The diameter of the storage tank in this paper is 60.0m. According to China's specifications, the minimum distance between the center of the accident tank and the adjacent storage tank is 54.0m (red area in Fig. 6). When the wind speed is 10m/s, the farthest distance between the strong radiation area in the downwind direction and the center of the accident tank is 83.0m. After the full surface pool fire accident, the adjacent storage tank is directly exposed to the strong radiation area caused by the tank.

The thermal radiation values at the downwind direction of the accident tank and the liquid level height (z=20.0m) of the tank are extracted. As shown in Fig. 7, the thermal radiation value generated by the pool fire will first decrease sharply and then decrease

slowly in the direction away from the accident tank. The wind speed has a great influence on the thermal radiation distribution near the tank. When the distance from the tank is close, the thermal radiation value reaches the maximum when the wind speed is 10m/s. When the distance from the tank is far, the thermal radiation value reaches the maximum when the wind speed is 6m/s.



(a)v=0m/s

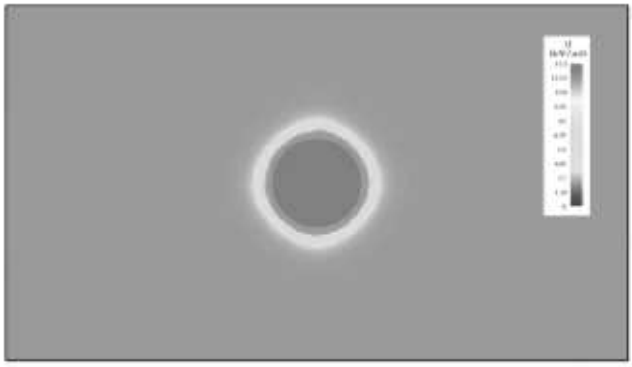


(b) v=5m/s

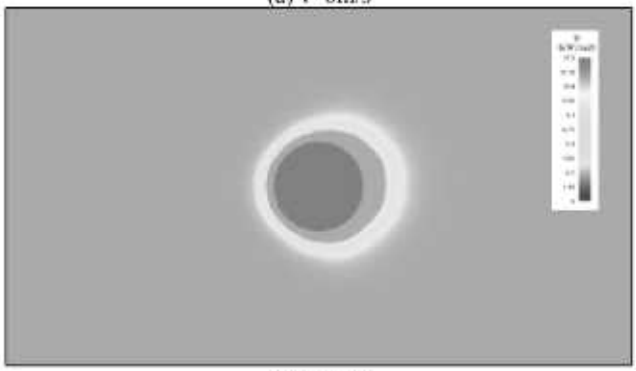


(c) v=10

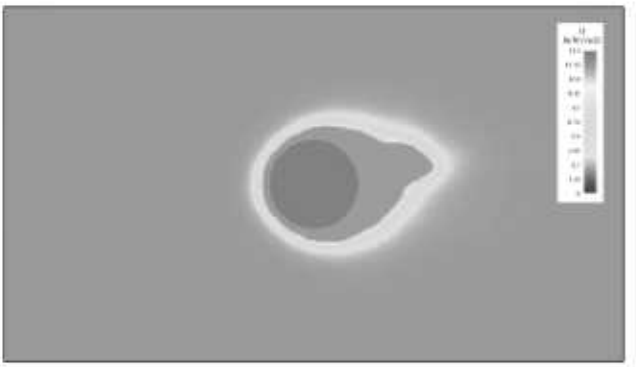
Fig. 5. Pool fire shape and flame parameters



(a) v=0m/s



(b) v=5m/s



(c) v=10

Fig. 6. Pool fire shape and flame parameters

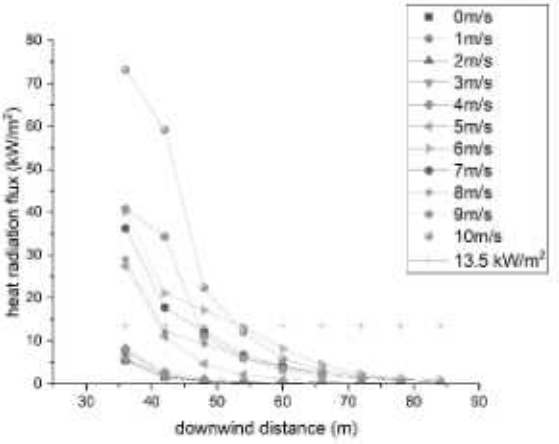


Fig. 7. Under different wind speeds, the thermal radiation distribution in the downwind direction at the liquid level height (z = 20.0m) of the accident tank.

3.5 Emergency Strategies

According to the numerical simulation results, the strong radiation area gradually spreads downward with the increase of wind speed, and the storage tank in the downwind direction may have an indirect pool fire spread accident. Once the crude oil storage tank in the port occurs, the fire fighting and rescue must strictly follow the basic principle of ' control first and then extinguish, plugging and drainage at the same time '. The primary task is to quickly cut off all the material conveying and connecting pipelines of the burning storage tank, and open the emergency shut-off valve of the adjacent storage tank. While controlling the fire, it is also necessary to implement cooling protection for the surrounding storage tanks to reduce the secondary disasters caused by the domino effect.

4 Conclusions

1) According to the tank spacing defined by China's specifications, after a full surface pool fire accident occurs in one of the tanks, the thermal radiation received by the adjacent tanks when the wind speed is large is above the critical thermal radiation value, which is very easy to spread into a multi-tank pool fire.

2) In the case of wind, the height and length of the pool fire flame gradually decrease with the increase of wind speed. As the wind speed increases, the flame inclination angle increases, and when it reaches 10m/s, the flame inclination angle reaches 48°.

3) In the process of full surface pool fire accident, the strong radiation area is mainly concentrated in the space above the oil pool of the accident tank, and gradually spreads downward with the increase of ambient wind speed. The wind speed has a great influence on the thermal radiation distribution near the tank, and the tank in the downwind direction may have an indirect pool fire spread accident.

References

1. Huang M L, Chen F Y, Ma M L. (2023) Construction of fire and explosion accident scene of dangerous cargo leakage in port. Science and technology of ports, (04):22-26.
2. LIU Z H. (2017) Analysis on the disposal and rescue measures to fluid fires in fire dikes of crude oil tanks. China Public Security(Academy Edition), (2): 54-58.
3. E D M. (2022) Study on thermal radiation characteristics of crude oil tank pool fire. Chemical safety and environment, 35 (16) : 14-17 + 20
4. Pourkeramat Alireza, Daneshmehr Alireza, Jalili Sina, Aminfar Kiyarash. (2022) Numerical Assessment of Thermostructural Instability of Cylindrical Tanks Subjected to Pool Fire. ASCE-ASME Journal of Risk and Uncertainty in Engineering Systems, Part A: Civil Engineering ,8(4).
5. Asher M A ,Mohammad N S ,Ainul M A , et al. (2022) CFD Simulation Approach to Predict Fire-Influenced Domino Accident Propagation Pattern. 517-528.
6. Raya Haqqi Ismail, Omar H. Kharufa. (2023) The Effect of Plan Corner Shapes on the Spread Speed of Fire in High-Rise Buildings. International Journal of Safety and Security Engineering, 13(4).
7. ZHANG M, SONG W H, WANG J, et al. (2014) Accident consequence simulation analysis of pool fire in fire dike. Procedia Engineering, 84(1): 565-577.
8. Huang K, Li Q, Xu J, et al. (2019) Study on the influence of wind speed on the thermal radiation distribution of tank pool fire in refined oil depot. Thermal Science and Technology, 18 (05) : 386-391.

Open Access This chapter is licensed under the terms of the Creative Commons Attribution-NonCommercial 4.0 International License (http://creativecommons.org/licenses/by-nc/4.0/), which permits any noncommercial use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license and indicate if changes were made.

The images or other third party material in this chapter are included in the chapter's Creative Commons license, unless indicated otherwise in a credit line to the material. If material is not included in the chapter's Creative Commons license and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder.

