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Study on Longitudinal Filling of Fire Smoke in Long Confined Space

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Abstract

The long confined space is a kind of special building corridor, such as highway corridors, subway channels and various corridors in ships that greatly facilitate people's daily life with the development of sea transportation. Once a fire occurs, because of the space-constrained of the long confined space, the high temperatures will not only damage the entire corridors' structure, but cause more serious consequences due to the semi-closed nature of the corridors. And people will not be easily evacuated. Fire smoke is the general term for the gas produced after a fire , accompanying with the floated smoke particles. It is a mixture of combustion and pyrolysis products. It is estimated that asphyxiation due to the inhalation of toxic and harmful smoke. Therefore, it is significant to study the spread process of fire smoke in long confined space. This thesis studied the sedimentation process of one-dimensional spread of fire smoke in long confined space in combination with theoretical analysis and numerical simulation, using FDS to conduct a numerical simulation study on a 30m long and 3m high building corridor. Firstly, ensuring the influencing factors of one-dimensional smoke spread process by dimension analysis, mainly considering the influence of the smoke sedimentation on the size of the fire source, the distance from the fire source and the time, then establishing the model by PyroSim to set the corresponding temperature and smoke height, studying the spread process of the smoke by changing the parameters such as the size of the fire source and the aspect ratio. Through the analysis of simulation data, when the smoke had not filled in the upper layer interface, no matter which parameter is changed in the one-dimensional spread of the smoke , the spread always fluctuated in the longitudinal of corridor first, and then it began to stable in the sedimentation phase, and finally gradually increased to ceiling height.

Keywords

Corridor; Fire smoke; Numerical simulation.

1. Introduction

A confined corridor is a kind of long passageway whose longitudinal length is much larger than the length and width of its cross section[1]. Along with the continuous development of urbanization in China, more and more narrow passages are in our life, such as highway or railway corridors, subway passageways and corridor corridors of ships or buildings. However, the evacuation route is single. Once a fire occurs, the hot smoke is difficult to discharge, and a large amount of heat will accumulate in the corridor, and the internal temperature will rise rapidly. Due to space limitation, evacuation and rescue are very difficult. It is very easy to cause severe consequences. In real life, accidents caused by traffic accidents, vehicle self-ignition and so on are common. There are many examples of

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casualties and property losses. For example, in October 24, 2001, two large trucks in the Swiss St Gotthard highway corridor caused a traffic accident, which caused 20 people to die and 128 people to disappear. In 2003, the arson fire occurred in Daegu subway in South Korea, resulting in a serious influence. 198 people were killed, 146 were injured and 289 were missing finally. In February 3, 2016, a car accident in the Guang Le high-speed corridor in Guangzhou causing many vehicles on fire, resulting in heavy traffic congestion at the high-speed road. Fortunately, only 1 people were slightly injured eventually. In May 9, 2017, an accident occurred in the Tao Jia corridor in Weihai, Shandong, resulted in a fire on the vehicle. 12 people died and 1 people were seriously injured finally. Therefore, the study of fire smoke in long confined passages has a very important scientific significance [2].

The smoke from fires can not only cause asphyxiation due to poisoning, but also cause high temperature to damage the building structure, which bring about severe economic losses. It's estimated that more than 85% of death in fires are caused by fire smoke [3]. On the one hand, the space is relatively closed, the evacuation conditions are poor and the route is longer in long confined passages. Once the fire breaks out, it becomes the main route for people to escape which also makes it more difficult for evacuation; on the other hand, the relatively small natural ventilation area at both ends of the confined space also leads to a weak ventilation capacity, which causes the high heat, toxic and harmful fire smoke cannot be discharged timely, and the temperature inside the corridor rises rapidly, which will further damage the structure. In the condition of fire, it is easy to develop into a larger accident. Because the fire smoke is mainly driven by buoyancy, it will spread quickly and will soon fill the whole passageway. The influence of fire smoke will also reduce the visibility of personnel, distract people and increase the possibility of two times of injury [4]. The study of fire in long confined space is very important.

At present, there are three kinds of research methods for fire problems in long confined space, namely, large and full-scale experiments, small size experiments and numerical simulation experiments carried out by computers. Large scale and full experiments were initiated by the Germany in 1992. EUREKA499 projects were jointly conducted to scientifically understand the development and impact of corridor fires in 2001 and 2003 in many countries, including Britain, France, Norway, Italy, Finland, Switzerland, Sweden, Australia and Spain Norway [5], Shimiuztesst and Runehmaaretsts, researchers in Japan and Norway, carried out the full-scale experiments of corridor fire. The main purpose of these two experiments was to study the work rate of fire source and the temperature growth of corridor fire detection, firefighting system and large truck during the fire in the corridor; Hu Longhua carried out a series of full-scale experiments in Yangzong corridor in 2005 [6]. Dafeng pass Yuanjiang 1# corridor, to study the rule of smoke spread under different fire power conditions, established a prediction model for longitudinal attenuation of smoke layer temperature, and verified the maximum temperature of smoke in the prediction model of Kurioka. Lee et al established a 13.7m long for small size test in 1979[7]. The small size test rig with a cross-sectional area of 0.27m 2 is designed to study the longitudinal critical wind speed of the corridor fire suppression. In 2003, Kurioka et al. [8] studied the near fire source area of the corridor fire under different longitudinal ventilation rates through the small size model, and got the theoretical model for predicting the maximum temperature at the top of the corridor fire source; in 2011, Yi Liang et al [9]. Through comparative study and analysis, the slope correction coefficient K s is introduced to improve the Kurioka model, thus the modified prediction model for the maximum smoke temperature of the corridor vault is established. The CFD software is used to simulate in the numerical simulation. Despite of more convenience compared to the two former methods, the disadvantages is that the computing time is longer. As early as 1995, the Woodburn simulated the influence of the longitudinal ventilation speed and the heat release rate of the fire source on the reflux diffusion range in the United Kingdom [10]. The S.S.Levy and J.R.Sandzimier et al in the USA utilized the CFD software to carry out the three-dimensional transient simulation in 2000, and studied the relationship between the exhaust volume and the smoke control effect in the condition of a Ted Williams corridor fire[11]. In 2005, Gu Zhenghong and other colleagues used the FDS software to carry out the numerical

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simulation experiment on the subway station hall fire[12]. The relationship between the critical wind speed and the data of the fire power and the vertical height of the smoke barrier was combined.

Based on the theory of fire dynamics and numerical simulation, the settlement rule of fire smoke in one-dimension spread phase of long confined passageway is studied by FDS software. The three main parameters of fire smoke power, fire source distance and time are changed, the corresponding model is established by PyroSim. The characteristics of settlement of smoke in one-dimensional longitudinal spread stage is studied. A one-dimensional smoke spread model for long confined space was initially established.

2. Study on the Rule of Settlement in the Process of One-Dimensional Spread of Fire Smoke in Long confined space

2.1 FDS modeling

The section headings are in boldface capital and lowercase letters. Second level headings are typed as part of the succeeding paragraph (like the subsection heading of this paragraph). All manuscripts must be in English, also the table and figure texts, otherwise we cannot publish your paper. Please keep a second copy of your manuscript in your office. When receiving the paper, we assume that the corresponding authors grant us the copyright to use the paper for the book or journal in question. When receiving the paper, we assume that the corresponding authors grant us the copyright to use the paper for the book or journal in question. When receiving the paper, we assume that the corresponding authors grant us the copyright to use.

This article will use PyroSim to build a 3D physical model as a building corridor. In order to reach the real situation of fire, the whole corridor length, width and height is set to 30m ×2m × 3m. Simulated fire source is located in the middle of the corridor, and the fire source area is 0.1M × 0.1M, the material of side wall and ceiling of the corridor are made by concrete, and the boundary conditions of the longitudinal section of the corridor are set out as Table 1. The grid settings are shown as Table 2. The ambient temperature before fire is 20 ℃, and the simulation time is 200 s.

Table.1 Setting of longitudinal section in two ends

Exhaust01 section geometry	
Normal Direction:	Automatic (Recommended)
Plane X=	0.0m
Bounds:	
Min Y:0.0 m	Min Z:0.0 m
Max Y:3.0 m	Max Z:3.0 m
Surface:	OPEN
Exhaust02 section geometry	
Normal Direction:	Automatic (Recommended)
Plane X=	30.0m
Bounds:	
Min Y:0.0 m	Min Z:0.0 m
Max Y:3.0 m	Max Z:3.0 m
Surface:	OPEN

ISSN: 2414-1895 DOI: 10.6919/ICJE.202006_6(6).0038

Table.2 Mesh settings

Description	Mesh		
Order/Priority	1		
Synchronize Meshes-Slower,but less prone to numerical instability.			
Mesh alignment test :		Passed	
Mesh boundary (m):	Min X:0.0	Min Y:0.0	Min Z:0
	Max X:30.0	Max Y:2.0	Max Z:3.0
Division method:		Uniform	
X cells:	450	Cell Size Ration:	1.00
Y cells:	30	Cell Size Ration:	1.00
Z cells:	45	Cell Size Ration:	1.00
Cell Size (m):		0.0667*0.0667*0.0667	
Number of cells for mesh:		607500	

Since this article focuses on the one-dimensional spread process of smoke, the location of the hydraulic jump of the corridor is about 2.5m at the height of the fire source. Therefore, we set the smoke height measurement line at the left side 3.5m from the location of the fire source. We set the smoke height measurement line vertically from the ceiling position, and set up a probe tree every 23 (a total of 23).

2.2 Influence of fire power on height of smoke

For further study the influence of fire power on smoke sedimentation, the different situations of smoke sedimentation under 5 kinds of fire power are considered. The power of fire source is set at 100-300kW, and the interval is 50kW, that is 100kW, 150kW, 200kW, 250kW and 300kW, respectively.

According to observing the three-dimensional image interface generated by FDS , as shown in Figure 1, we can found that when the fire power reached 100kW, the time required for the gas forwards to reach the ends from another ends is 22.6 s.

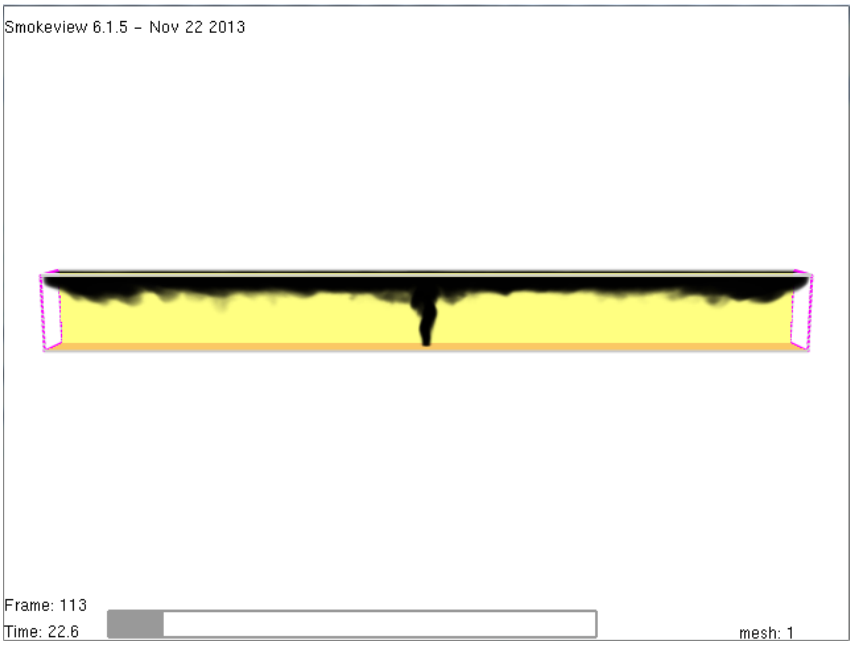

Fig.1 HRR=100kw

Table 3 Records of the different time when the smoke forwards reach one end of the two ends under different fire power sources.

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Table.3 Time of smoke front of different fire power reaching the boundary

HRR(kW)	Time(s)
100	22.6
150	19.8
200	18.2
250	16.8
300	15.8

According to the time variation of the opening of the smoke front at the two ends in Table 3, we can find that the velocity of the smoke spreading along the longitudinal direction of the corridor will also increase gradually with the increase of the power of the fire source,.

Figure 2 is a three-dimensional image of smoke spread at different power sources of 100kW.

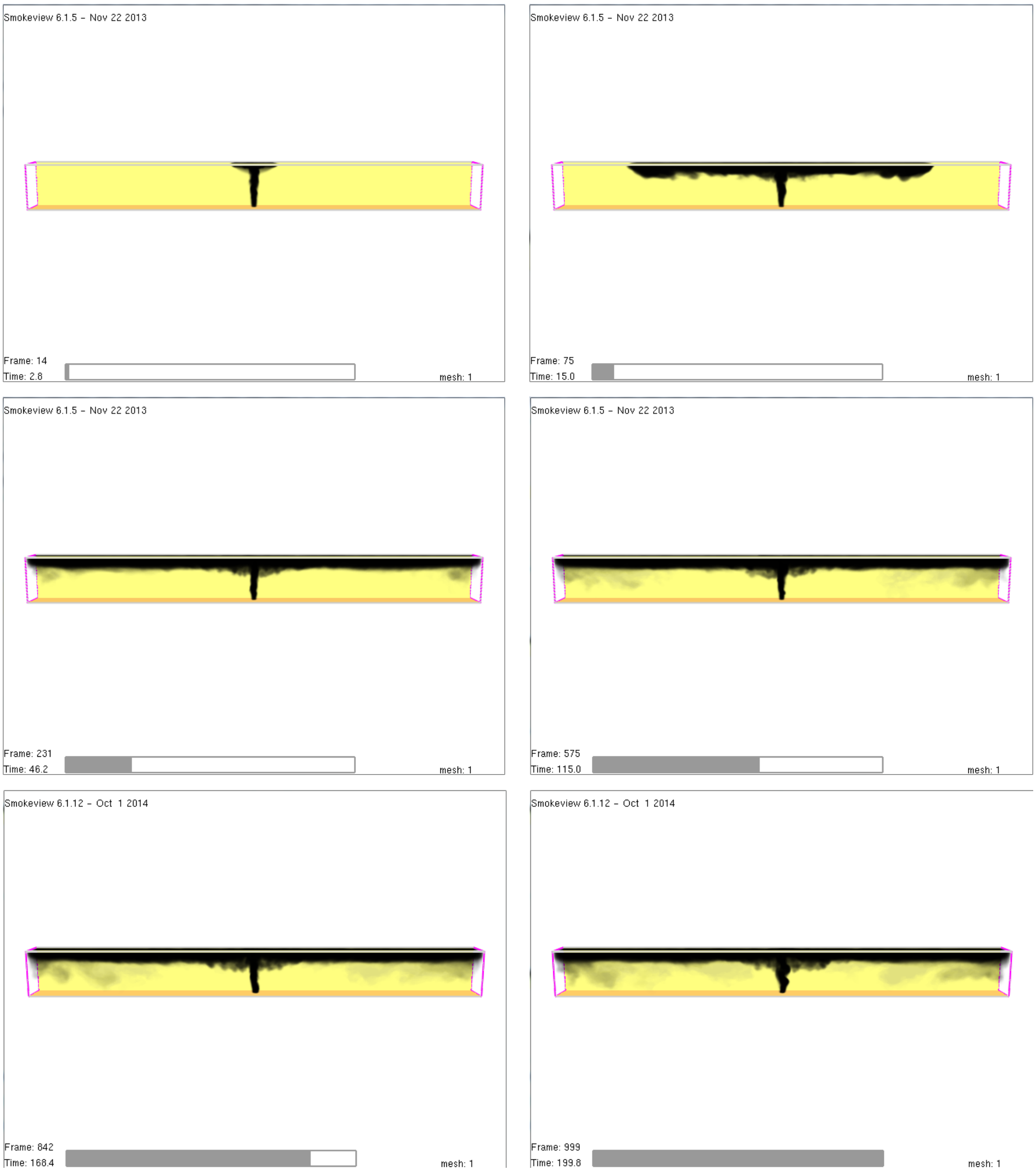

Fig.2 Image of smoke spreading at different moments（HRR=100kw）

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Through the above picture, we can observe the image of smoke movement in the whole simulation phase. When the smoke is spreading along the corridor, t a good interface between the smoke layer and the air layer was observed. Before the front gas reaches the boundary of both ends, the smoke layer kept relatively stable irrespective of the longitudinal ventilation of the corridor. The stability of the smoke layer is reduced. Different degrees of sedimentation in the smoke showed clearly from the image.

2.3 Study on the smoke behavior from different locations of the fire source.

2.3.1 Study on the relationship between h of smoke height and R of fire source

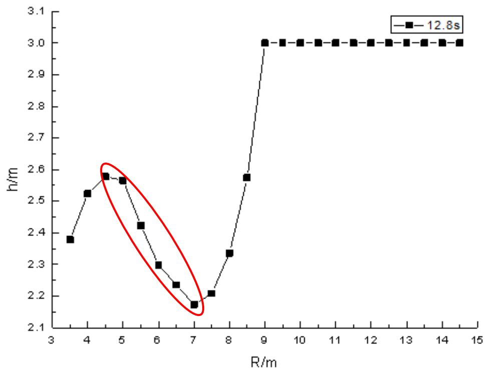
From the above, we can find that the longitudinal spread of smoke in the one-dimensional spread process must first undergo a wave process, and then start a steady downward process. The height of the passageway ceiling is increased again eventually. Figure 3 is a fitting curve of the smoke height varying with the distance from the fire source at the source power of 100kW and height width ratio of 1.5 and 12.8s. The fitting curve of Figure 4 is obtained from the red circle portion of Figure 3.

The fitting equation is as follows:

$$y = a * x^b \tag{1}$$

Among them, a=3.410, b= -0.179;

Therefore, the smoke height H and the distance from the fire source R meet the power function relationship in the settlement stage of one-dimensional longitudinal spread of smoke.



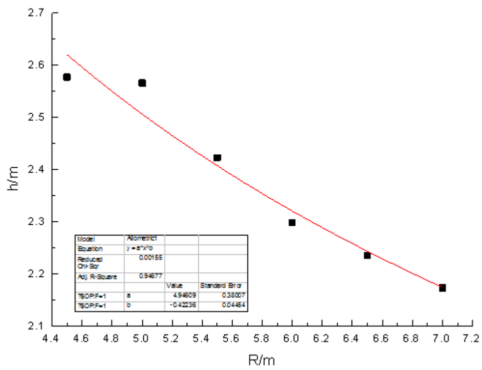
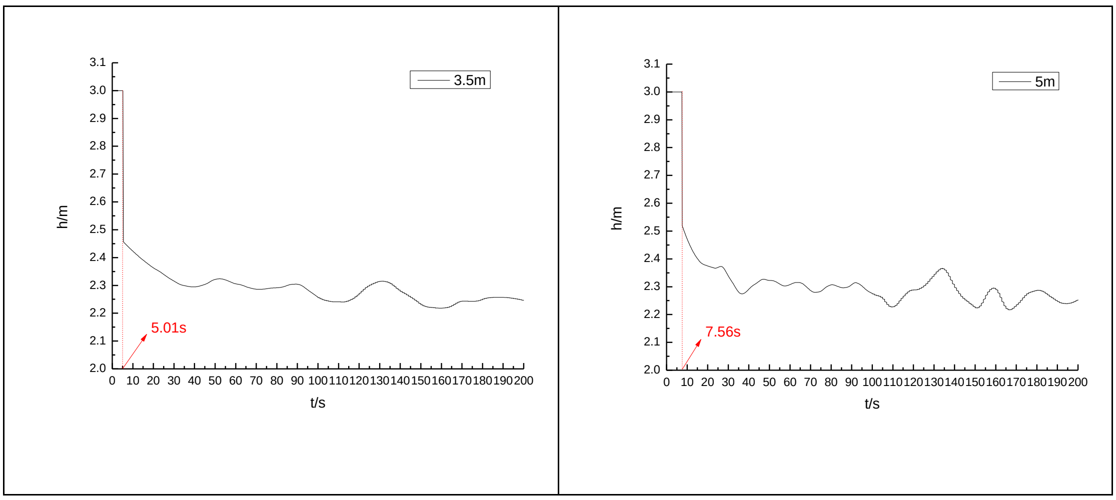


Fig.3 Longitudinal spread fitting curve Fig.4 Settlement section fitting curve

2.3.2 Study on the behavior of smoke varying from time to time in different locations.

The case, fire power 100kW and height width ratio 1.5, five points (3.5m, 5m, 7m, 10m, 14m) with different distance from fire sources, are selected. Figure 5 is the data of the of smoke height varying with time.



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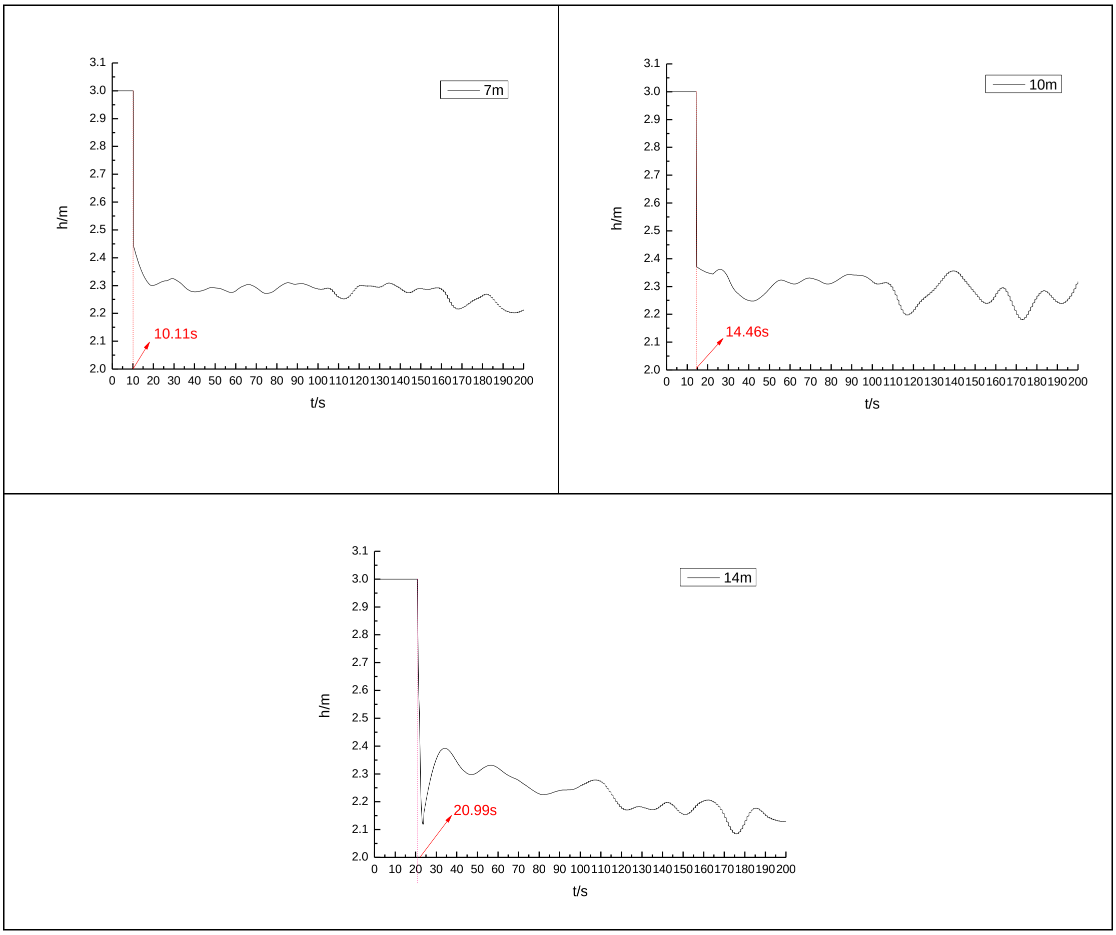

Fig.5 Diagram of the relationship between smoke height and time

As shown in the diagram, the height of smoke always decreases gradually, and then the smoke layer produces a certain fluctuation (which is larger than the distance from the fire source at 1.4m). The fluctuation may be due to the interference of the external air flow from the close boundary of the exit boundary. The fluctuation of smoke air height becomes smaller with the passage of time, and gradually becomes stable finally. The starting point of the smoke sedimentation time enable to reflect from the diagram. Because the smoke height fluctuate less after the smoke filling in the upper interface, the variation rule of the smoke height is selected before the front smoke reaches the boundary of both ends.

Figure 6 showed the height variation of the 22s, the fire source power100kW, the height width ratio 1.5, the distance from the fire source 5M and 10m.

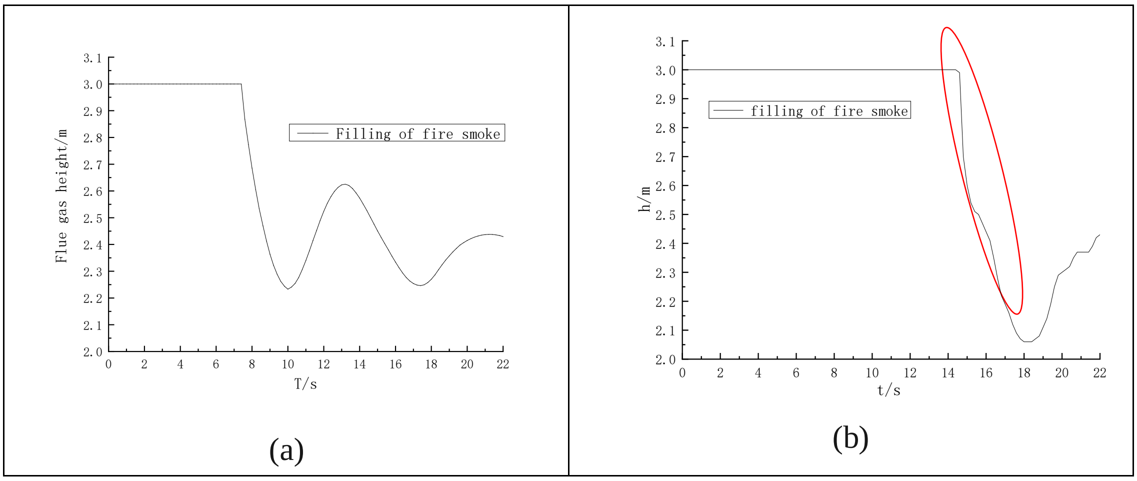

Figure 6 Change of smoke height with time at 5M and 10m and

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As shown in（Figure 5b）, the smoke height at the same position before the upper layer of smoke appeared two relatively large fluctuations. while only one fluctuation occurred in the height of the smoke (Figure 5b). Considering the poor ventilation and ventilation conditions of the long confined space, the flashover of the combustible gases formed by the combustion could cause a flashover phenomenon (flashover is a critical phenomenon in the indoor fire system). It is a rapid transformation between the initial development stage and the full bloom stage of the fire development. The compression wave generated by flashover could cause the fluctuations of smoke height approaching the distance of the fire source, which barely influenced on the near location of the boundary opening. Therefore, the sedimentation phenomena caused by the two different longitudinal positions are different.

Taking the red circle sedimentation part (b) to fit the curve, the height of smoke h and time t also meet the power function relationship.

3. Conclusion

Considering the property of the smoke spread in long confined fires, we studied the one-dimensional longitudinal spread of fire smoke by varying the parameters of the fire source power, the distance from the fire source and their three parameters. By processing, fitting and analyzing the FDS simulation data, the smoke followed certain rules in the one-dimensional longitudinal spread process.

[1] Before the front smoke reaches the boundary, the longitudinal spread of the smoke after the water jump point fluctuated at first, then entering a steady sedimentation stage, and finally enhanced to the height of the corridor ceiling.

[2] In the case of changing the power of the fire and controlling other parameters, the height of the smoke reduced with the increase of the fire source power and becomes a linear functional relationship. When the front smoke reached the boundary of both ends, the greater the power of the fire source, the velocity of the longitudinal movement of the smoke were found.

[3] Through the study of stable sedimentation stage and fitting analysis of data, the distance between smoke height h and fire source R satisfied the power function relation.

[4] The smoke presented the same position at the same time as the source of fire over time. It first decreased and then kept fluctuating. This article studied the sedimentation rule of the front smoke reaching the boundary time. By fitting the data, the fluctuation near the location of the fire tend to be affected by the fluctuation disturbance, resulting in two large amplitude fluctuations.

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