Analysis on fire smoke characteristics of ship closed cabin

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Abstract: As one of the effective means of ship fire fighting, the research on the smoke characteristics of closed compartment fire has important engineering application value. In this paper, the smoke height model, flameout time model, compartment temperature model and CO concentration model of closed compartment fire are established from two aspects: the development of closed compartment fire and the analysis of smoke characteristics. An example is used to verify this theoretical model. The results show that this theoretical model can better analyze the generation characteristics and flow characteristics of fire smoke in closed compartments, and can provide a reference for damage control in the scenario of crew sealing and fire extinguishing.

1. Introduction

The ship structure is complex and the fire load distribution is relatively concentrated. Once a fire occurs, it is very easy to spread, which is easy to cause heavy casualties and seriously affect the vitality of the ship. In order to reduce the loss of ship vitality caused by fire and improve the effectiveness of ship fire prevention, it is necessary to strengthen the research on the occurrence, development and Prevention Law of ship fire. As an important content in the field of ship fire safety, smoke is an important factor causing casualties and fire growth. Its generation and flow characteristics are of great significance to ship fire fighting and personnel escape. This paper makes a theoretical analysis of a small cabin of a ship, focusing on the fire smoke filling model, cabin fire extinguishing model, temperature characteristics and toxicity of cabin fire smoke, which has important application value for ship fire control.

2. Development process of closed compartment fire

As shown in Figure 1, at the initial stage of ship cabin sealing and fire extinguishing, the upper layer of the cabin is a hot smoke layer and the lower layer is a cold air layer, and there is a transition layer between them; With the development of fire, the whole cabin of the ship is rapidly filled with smoke. The cabin can be divided into dense smoke layer and thin smoke layer. The internal temperature of the dense smoke layer is uniform, and the internal temperature of the sparse smoke layer presents an obvious gradient. At this time, the traditional two region model has some limitations in analyzing the characteristics of fire smoke; In the stable stage of the fire in the closed compartment of the ship, the fire smoke will occur cyclic entrainment: on the one hand, the thickness of the dense smoke layer increases, on the other hand, the temperature of the thin smoke layer increases until the fire smoke reaches dynamic equilibrium; With the occurrence and development of fire, the fire in ship's closed cabin changes from fuel control to ventilation control. Finally, due to the lack of oxygen, the purpose of fire suffocation and extinction is achieved. In order to facilitate the establishment of mathematical model of ship cabin fire, the following assumptions are put forward in this paper:

Hypothesis 1: the heat release rate of fire source is constant, and the growth process of heat release rate of fire source is ignored.

Hypothesis 2: fire smoke spreads from the ceiling to the bottom of the cabin, ignoring the plume rise of smoke and the ceiling jet process.

Hypothesis 3: the increase of air mass m caused by combustion in the process of compartment fire is negligible compared with the initial gas mass in the compartment, that is $\rho_0 = \rho_{-}$。

Hypothesis 4: the volume concentration of O2 at the time of flameout of the closed compartment is 12%.

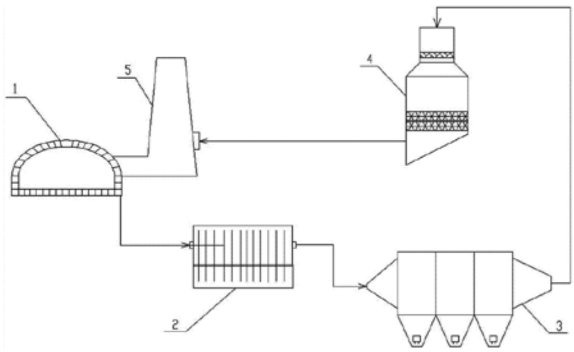

Figure 1 Fire smoke filling process of ship closed cabin

3. Smoke characteristics of compartment fire

3.1 Fire smoke temperature distribution

Because the fire smoke of the closed compartment quickly fills the whole compartment, and the bottom of the compartment is covered with thermal insulation cotton, this paper takes the compartment gas as the research object when studying the temperature distribution of the fire smoke of the closed compartment, Ignoring the change of temperature inside the cabin (the change of flue gas along the vertical height is relatively small due to the interaction between gases inside the cabin) and the heat transfer at the bottom of the cabin, the energy conservation equation of cabin flue gas is established by single region simulation:

$$C_p P_0 AH = Q - H^g_{ev.w} A_w (T - T0)$$

3.2 CO concentration of fire smoke

Fire smoke contains a variety of toxic substances, including Co, CO2, HCl, HF and HCN. The results show that when the CO concentration exceeds 100ppm,The human body will produce dizziness, fatigue and other discomfort; When the concentration of CO exceeds 600ppm, it will cause suffocation death in a short time. Since about half of the deaths in the fire are caused by CO poisoning, it is necessary to analyze and predict the component concentration of fire smoke, especially Co. In this paper, ger theory is used to make use of fuel air ratio$\varphi$and the correlation between the generation rate of product components and yco is used to predict the generation of fire smoke products.φrepresents the ratio of fuel to air mass consumed by the fire source divided by their equivalent ratio.

The results show that in the stable combustion stage of fire, the generation and consumption rate of main components of flue gas are unchanged, which has nothing to do with the flame structure; The combustion process and fire flue gas composition are related to the temperature in the flue gas layer, but not to the properties of the wall and heat insulation. Therefore, before the stable combustion of fire, the relevant research of gottuk and Lattimer can be obtained:

$$\mathrm{Y_{co}}=\begin{cases}(0.19/180)arctan(x)+0.095 & Tn<800k\\(0.22/180)arctan(x)+0.110 & Tn>900K\end{cases}$$

$$x=\begin{cases}10(\phi-0.08) & Tn<800k\\10(\phi-1.25) & Tn>900K\end{cases}$$

In the stable combustion stage of fire, the co production of fire smoke is theoretically analyzed by taking the productivity of smoke component co when the smoke fills the compartment as the co productivity in the stable stage of closed compartment fire smoke.

4. Example analysis

Taking the small-scale model of a ship cabin as the research object and heptane as the ignition fuel, this paper theoretically analyzes the fire smoke characteristics of the closed space, and establishes various physical parameter models of fire smoke in a small-scale ship cabin based on MATLAB. The internal dimension of the small-scale closed cabin of the ship is 1m (L) × 1m(W) × 0.75m (H), and its bulkhead structure complies with A60 standard. Cabin gas density ρ 0=1.1763kg/m3, T0=300K, Cp= 1.007kJ(kggK).See Table 1 for physical property parameters of heptane. In the process of analyzing the physical parameters of smoke in small-size closed cabin of ship, this paper assumes that the mass loss rate of heptane remains constant, taking = 7.5 × 10-5kg / s, at this time, the heat release rate QG of heptane stable combustion is:

Q=x$m^g H_e$=0.7×7.5×10^{-5}×44.6×10^6*J/S* =2.3415*kJ/S(*x is the combustion efficiency, generally x = 0.7*)*

Table 1 Physical properties of heptane

Attribute name	describe
Molecular formula	C_7H_{16}
Molecular weight	100
Density	684kg/m^2
Melting point	-90.5℃
Flash point	-4℃
Boiling point	98.5℃
Vapor pressure	5.33kPa/22.3℃
Heat of combustion	44.6MJ/kg
Hazard characteristics	Flammable, heptane vapor and air can form explosive mixture

Based on the analysis of compartment fire smoke characteristics, combined with MATLAB 7 The software is programmed to analyze the change of CO concentration and air temperature with the time of fire and the height of the cabin, and the change of CO concentration with the time of fire extinguishing is obtained. The simulation results of this theoretical model are consistent with the experimental results of heptane fire in closed cabin under the same parameters, which has a certain reference value.

The air height of closed cabin decreases rapidly with the development of fire. In this paper, the time corresponding to the cabin air height of 0.01M is taken as the time when the smoke fills the cabin (because generally speaking, the height of the oil pan is 0.01M). Therefore, when t = 60s, the cabin smoke fills the whole cabin.Based on the analysis of fire extinguishing model of closed compartment, it can be obtained that the fire extinguishing time te of closed compartment meets 301s ≤ te ≤ 441s.Based on the analysis of compartment temperature characteristics, it can be concluded that the compartment temperature when the fire is extinguished is t = 359K. In the process of fire in the closed compartment, the temperature of the bottom air begins to rise when t = 60s; With the passage of time, the gas in the closed compartment is gradually mixed under the action of circulating entrainment, buoyancy and pressure of fire smoke, forming a typical double region model of dense smoke and thin smoke, and the fire in the closed compartment reaches the stage of stable combustion.At the time of cabin flameout, the average temperature of fire smoke in the cabin is 359K (84 ℃).With the passage of time, the co generation rate of smoke in closed compartment fire first decreases and then remains unchanged; The cabin CO concentration increases continuously with the passage of time. At the time of cabin flameout, the cabin CO concentration is between 2242ppm and 3289ppm (concentration when fully converted to co).

Based on the above analysis, closed compartment fire has the characteristics of rapid development, high fire site temperature and easy to produce high-temperature toxic gases. In the early stage of cabin fire development, the smoke characteristic parameters are relatively low, which is the best time for fire extinguishing and personnel escape. Therefore, it is necessary to strengthen the prevention and monitoring of ship fire, strive to find the fire source in a short time, put out the initial fire and minimize the damage of ship. If the initial fire fails to be extinguished, personnel shall be evacuated quickly and emergency measures of sealing the cabin and extinguishing the fire shall be taken to prevent the spread of the fire. In addition, the cabin door cannot be opened immediately after the cabin fire is extinguished. At this time, the high-temperature smoke in the cabin has complex components and strong toxicity. Once it comes into contact with the outside air, it is easy to rekindle the fire, resulting in the spread of the ship cabin fire.

5. Conclusion

This paper analyzes and demonstrates the smoke flow characteristics of ship closed cabin fire from the perspective of theory, which lays a theoretical foundation for ship fire fighting. As one of the emergency means of ship fire, cabin sealing fire extinguishing can effectively extinguish cabin fire. At the beginning of sealing and extinguishing the fire, the evacuation of personnel should be organized quickly to limit the spread of compartment fire; After the cabin fire is extinguished, the cabin door cannot be opened blindly to prevent the recurrence of cabin fire.However, the research of this paper is based on the fact that the mass loss rate of heptane remains unchanged, which is different from the actual closed space fire. It needs to be deeply studied and analyzed on the combustion characteristics of closed space fire.

References

[1] Yin Chengbin, Ma Weidong, Li Jie, et al Analysis on fire smoke characteristics of ship closed cabin [J] China new technology and new products, 2016 (2): 178-179.

[2] Wu Xu Considering the influence of parameter uncertainty on the life of personnel in ship closed cabin fire [J] Ship science and technology, 2013,35 (8): 1-5.

[3] Wang Xiao, Tang Xionghui, Yu Tao, et al Effectiveness evaluation of ship cabin ventilation system [J] Ship science and technology, 2018,40 (1): 139-142.