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Research on Fire Behavior of Ship Engine Room

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ABSTRACT

Due to the need for high performance and reduced commercial cost of ownership, and due to many outstanding advantages such as high strength and light weight, steel has been widely used in engineering practice. In the case of fire, in order to prevent and protect these structures, it is the key issue to study the fire behavior environment. The engine room is also the source of power for ships. It is a high-risk area with frequent fires. Therefore, this paper mainly uses FDS to conduct numerical simulation research through a scaled-down engine room with a size of 3m×3m×3.5m. The change of temperature, pressure and smoke movement in the closed cabin with time at a fire source height of 1.5m is studied. The research shows that the fire behavior inside the closed cabin conforms to the two-zone model, and the fire suppression method of the closed fire has its significant advantages, And looked for the best time to reopen the cabin and the location of subsequent repair structures.

Keywords: Fire behavior; Ship engine room; FDS

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1. Introduction

Economic globalization has made shipping and logistics increasingly used in various production and operation activities and resource allocation activities, making shipping one of the most mainstream ways in the world's logistics. The ship, as an independent building entity, is the main means of transport for shipping. While ships bring convenience to human transportation, the casualties and property safety caused by ship fires and the social impact are huge. Ship fires account for 11% of the total number of shipwreck accidents, ranking fourth, but the losses caused by fires First in all shipwrecks[1]. On January 13, 1994, an ocean-going rescue tugboat in China caused a fire in the engine compartment of the main engine on the way home, causing the ship to be scrapped, resulting in a direct economic loss of 24.5 million yuan. In 2002, the British "Pennsylvania" container carrier cost $ 43 million. The maiden voyage caused a cabin fire due to an accident, which caused the ship to be almost scrapped. On March 26, 2003, the "Changan 91" freighter accidentally caught fire during the transfer, causing 2 deaths and 2 injuries, and a direct economic loss of 188,000 yuan; On February 3, 2018, the engine room of the MOL container ship caught fire, and 5 seafarers were injured in the fire extinguishing process. On March 6, 2018, a fire broke out in the engine room of the Singaporean container ship "Maersk Honam", which killed 4 crew members. The above cases can be seen, because various machinery and equipment are running inside the ship's engine room and a large amount of fuel is stored. The operation of machinery and equipment will generate a large amount of heat radiation. When a fuel leak occurs in the engine room, it will be easily ignited by a high-temperature heat source, which will cause a fire and make the engine room the highest frequency of ship fires[2]. Statistics show that 75% of ship fires are caused by engine room fires[3].

The whole of the ship's engine room shell is constructed of an all-steel structure. Steel is widely used in prefabricated construction, marine, aerospace, civil infrastructure and automotive industries due to its high strength, light weight, good seismic performance and high reliability. Although steel has a lower thermal conductivity than other traditional metal materials and can prevent the spread of fire, the physical and mechanical properties of steel structures are extremely sensitive to high temperatures. Engine room fires are different from ordinary high-rise buildings and large-span structural fires, such as different fire causes, burning materials, environment, and fire fighting methods[4]. The reason why ship fires are difficult to extinguish is because, on the one hand, ship fires can only rely on self-rescue, and the possibility of receiving external assistance is very small, and the manpower and material resources on board are almost limited. In addition, if the fire occurs in extreme weather such as strong waves the weather and wind have contributed to the spread of the fire, making it even more difficult to fight the fire, and the engine room is the ship's power system. Once a fire occurs, it can easily cause ship paralysis and huge loss of personnel and property. Therefore, it is necessary to study the analysis of the fire behavior of the ship's engine room, among which the sealing of the fire is a unique fire fighting method on the ship[5].

Compared with ordinary high-rise buildings, the ship's engine room has its special features in terms of design use, cabin structure and ventilation conditions. First of all, the combustibles in the engine room are mainly liquid fuels, and the specific types of fires are mostly oil pool fires[6]. Liquid fuels in oil pool fires are prone to spread and flow. Compared with general fires, engine room fires spread more rapidly and fire loads are bigger. Second, it is difficult to dissipate heat and smoke. The ship's engine room is a similar closed space made of special steel plates. Ventilation openings and doors are mostly set on the top. The surrounding walls are closed walls. There are a lot of machinery and equipment in the space and the temperature is too high. In the event of a fire, the temperature rises sharply, and the smoke cannot be discharged in a timely manner, and the safety of the staff in the cabin will be threatened in a short time. In summary, due to the high frequency, destructiveness, and huge losses of ship engine room fires, the previous researches on engine room fires have little research value, and the study of the characteristics of fire characteristics can be used as a prevention and reference for ship fire prevention effect. At present, domestic and foreign discussions on ship cabin fires are mainly aimed at fully enclosed or confined spaces with an opening. The methods used are mainly numerical simulation and small-scale experiments. Regarding indoor fires with open tops, Merci.B etal.[7] studied the effects of different heat release rates, fire source areas, and vertical openings on the temperature field through experiments. Chen etal.[8] found that with the increase of the opening, the average heat release rate in the remaining area of the fuel was relatively stable. For closed compartment fires, Quintiere etal.[9] conducted an oil pool fire experiment in a simplified cabin and found that changing ventilation conditions affected the oxygen concentration at the time of flameout. Pearson[10] studied the effect of changes in the location of the fire source on the combustion of the cabin. Chow etal.[11] carried out numerical simulation and theoretical analysis of the pressure field and heat transfer process of the ship's closed compartment under fire conditions. Huetal.[12] found that the distribution of flue gas temperature at the time of flameout obeys the Boltzmann distribution. In summary, at the present stage, there have been more studies on indoor fires in general buildings, and confined spaces with horizontal or vertical openings. For confined compartment fires, existing studies have focused on fire behavior on the floor level. However, in the real situation, there are many equipment platforms in the ship's engine room, and it is likely that the fire source is higher than the water level, and the fire source will affect the fire behavior under certain conditions.

This paper uses the engine room scale model with special steel plates on all sides to perform similar fire behavior analysis. The existing results show that the model experiments designed using similarity analysis are feasible and effective in engine room fire simulation[13]. The fire behavior of a ship's engine room fire with a certain fire source height was studied using the Fire Dynamics Simulator (FDS), an open source fire simulation program developed by the National Institute of Standards and Technology (NIST).

2. Theoretical basis

The fire process in a closed engine room can be simplified as a convection problem caused by combustion in a closed rectangular space without openings. In a closed engine room with a defined geometric structure, the amount of oxygen is constant. The consumption of oxygen, the production of products, and the heat released from combustion constantly change the pressure and temperature in the cabin, the convection weakens, and the restrictions on the walls will affect the flame propagation Gas phase flow and temperature field distribution[14]. These changes will continuously affect the combustion behavior of the fire in the cabin, which is an unstable combustion process.

2.1 Heat transfer method

The heat transfer process of the gas inside the structure in the fire is summarized into three aspects:

Heat conduction: The temperature of each location in the fire area is different due to the different spatial locations of the fire source surface in the research area. The heat transfer is conducted along the high temperature area to the low temperature area until the temperature field is consistent. According to the Fourier law of heat conduction and the principle of heat balance, the differential heat conduction equation of the steel member section can be obtained as:

$$\rho c\frac{\partial T}{\partial t}-\frac{\partial}{\partial x}\left(\lambda_x\frac{\partial T}{\partial x}\right)-\frac{\partial}{\partial y}\left(\lambda_y\frac{\partial T}{\partial y}\right)-\frac{\partial}{\partial z}\left(\lambda_z\frac{\partial T}{\partial z}\right)-q_v=0 \qquad (2.1.1)$$

In the formula: T is the temperature of the point (x,y,z) at time t, t is the time, q_v is the heat generated by the internal heat source, λ_x、λ_y、λ_z Is the thermal conductivity in the x, y, and z directions, ρ is the medium density, c is the specific heat capacity of the object。

Thermal radiation: The phenomenon of energy release and absorption between the structure and high-temperature smoke. Stefan-Boltzmann's law describes the energy radiated by the black body to the outside world in a unit time (where the black body is an idealized object, assuming that it can absorb all electromagnetic radiation as a standard object for thermal radiation research, the absorption coefficient is 1. Fact Such objects do not exist. Natural objects are generally gray bodies, which can absorb part of the energy radiated to their surface). By modifying the formula of Stefan-Boltzmann's law, it is obtained that in an actual fire scene, the heat transferred by the high-temperature gas in the fire field to the steel structure in the form of thermal radiation can be expressed as:

$$q=\varepsilon\sigma A_a F_{ab}\left(T_a^4-T_b^4\right) \qquad (2.1.2)$$

In the formula: q is the Heat flux, ε is the blackness, $0<\varepsilon<1$, σ is Stefan-Boltzmann constant, usually taken $\sigma=5.67\times10^{-8}[W/(m^2\cdot K^4)]$, A_a is the area of a radiation surface, the unit is m^2, F_{ab} is the shape coefficient from a radiation surface to b radiation surface, T_a is the absolute temperature of the a radiation surface, the unit is K, T_b is the absolute temperature of the b radiation surface in K。

Thermal convection: The temperature difference between the high temperature gas and the surface of the structure causes thermal convection. The heat transferred in the process of thermal convection can be calculated by the Newton cooling formula:

$$q_c=\alpha_c\cdot\left(T_g-T_b\right) \qquad (2.1.3)$$

In the formula: q_c is the heat flux value per unit area through the surface of the object in unit time, the unit is W/m2, α_c is the convective heat transfer coefficient, the unit is $W/\left(m^2\cdot℃\right)$, T_g is the temperature of the fire scene air, the unit is ℃, T_b structural surface temperature in units of ℃。

2.2 Smoke movement

During the fire, the motion of the smoke greatly affects the distribution of the temperature field. The temperature field caused by the motion of the smoke at each moment is a transient temperature field. The simulation is mainly carried out through experiments and numerical calculations. Among them, the CFD developed by NIST Software-Efficient fire dynamics simulator FDS is widely used in fire simulation. The principle is to solve the NS equations of low-speed flow by numerical methods. The thermal properties of materials are used to solve the process of smoke spread and heat transfer in a fire. Divided into multiple three-dimensional rectangular element form, calculate the parameters (such as density, velocity, temperature, pressure, etc.) in each element, and use the finite volume method to calculate heat transfer, fluid flow and turbulence on the same grid. Results can also be visualized with the attached Smokeview.

3. Model analysis

3.1 Fire scene construction and measurement point arrangement

FDS uses a grid as the minimum calculation unit. The size of the grid is the most important mathematica parameter in the model. It specifies the spatial and temporal accuracy of the partial differential equations inside the model. In theory, the finer the mesh division, the more accurate the calculation results. FDS can calculate the temperature, density, and pressure in each grid in each discrete time step, but the fine grid greatly increases the calculation time and the requirements for computer performance. Equilibrium point, get reasonable calculation results in reasonable calculation time. The size of the scaled-down cabin is 3m × 3m × 3.5m, the grid resolution is 0.1m × 0.1m × 0.1m, and the total number of grids in the calculation area is 40960. The bulkhead is made of Q235-A steel, and the constitutive relations of thermal expansion coefficient, density, Young's modulus, specific heat capacity, and thermal conductivity at 20℃at normal temperature are taken from the European code Eurocode 3 [15]. Assume that the ignition source started from an inert bearing platform with a center height of 1.5m at the bottom, and the size is 0.2m × 0.2m, as shown in FIG. 6. The fire source power is set to 1800kw / m2, the fire growth type is t2 fire, and the burning time is set to 1200s.

In this paper, temperature monitoring points are set on the X = 1.5m plane inside the cabin. The monitoring point numbers are 2-i (0.7m from the wall, i is 1, 2, 3 ... 17) and 2-'i. Among them, 2-'i is axially symmetric with respect to 2-i about the center point, so as to monitor the change of temperature with height at the moment of flameout. X = 0.7m and X = 2.3m at the same distance from the bulkhead surface. The same thermocouple tree is set on the two planes with axial symmetry. Each tree is provided with a total of 17 temperature monitoring points, which are arranged from 0.2m away from the bilge. Arrange a monitoring point every 0.2m, as shown in Figure 2. The internal surface of the cabin roof is set at a horizontal Z = 3.38m plane at the projections on the X = 1.5m and Y = 1.5m planes. Horizontal temperature monitoring point- s are set up, and the monitoring points are numbered x and y respectively to monitor the ceiling maximum temperature and average temperature at the time of flameout. 14 temperature monitoring points are arranged horizontally and longitudinally, from 0.2m away from the side wall of the nacelle, and one monitoring point is arranged every 0.2m along the x and y directions, as shown in Figure 3, denoted as Xj, Yj (j take 1, 2, 3 ... 14).

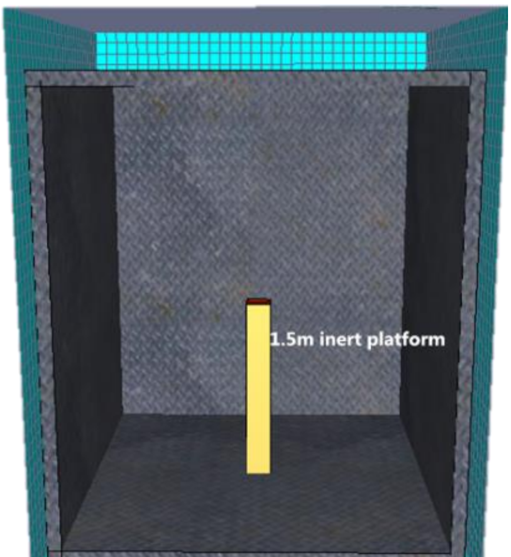

Fig.1 FDS simulates a closed cabin fire

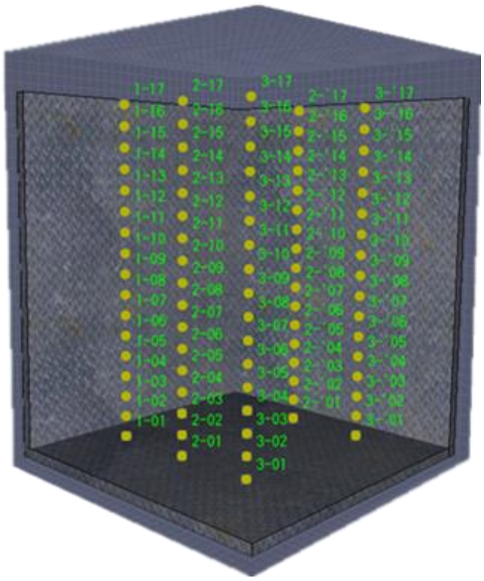

Fig.2 Vertical point distribution

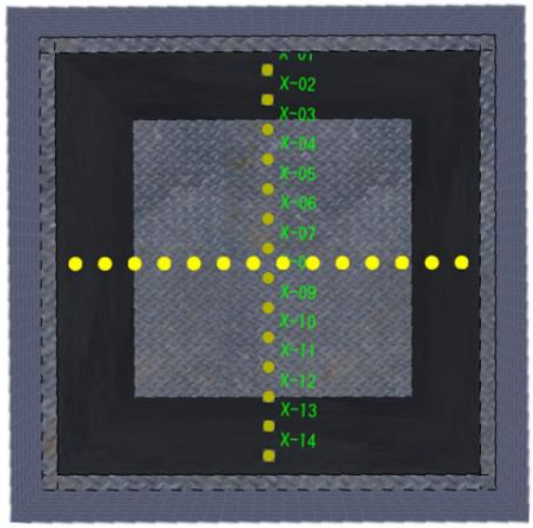

Fig.3 Cabin roof distribution point distribution

3.2 FDS temperature and pressure changes

It can be seen from Fig. 4 that the ignition source release rate reaches the maximum instantaneously. After 880 seconds, the oxygen concentration in the cabin decreases. For a certain structure, the amount of oxygen is constant. The decrease in the amount of oxygen affects the flame diffusion, and it also affects the continuous increase in temperature. Therefore, the fire source release rate drops sharply until it is extinguished within a certain period of time, and eventually the fire source release power gradually approaches zero [16].

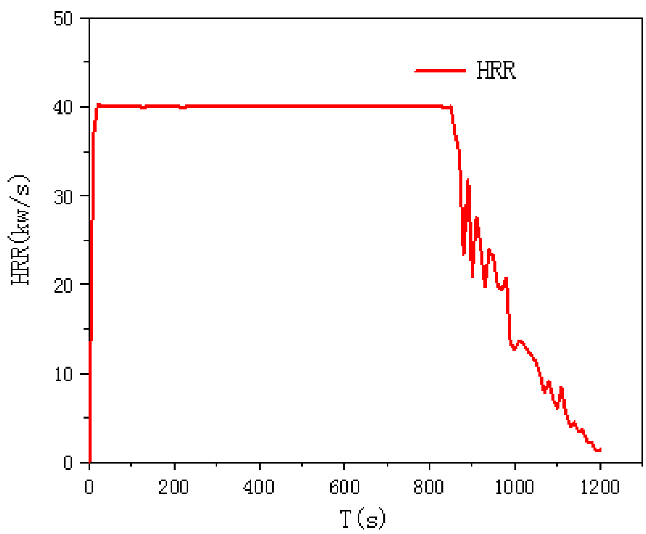

Fig.4 Fire source heat release rate

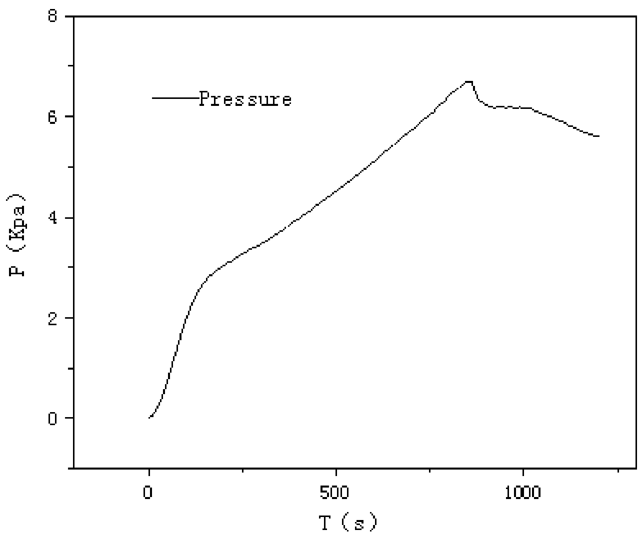

Fig.5 Pressure change during fire

From Figure 5, it is known that from 0 to 160s, the development of the fire is in the initial stage, the oxygen is sufficient, the pressure is linearly increasing, and the growth rate is rapid; 160s to 880s, the fire is developing at the stage of full development. The rising rate will slow down with the gradual weakening of combustion, and the pressure will reach a maximum around 880s, which is almost the same as the time when the power released by the fire source begins to decay.

3.3 Regularity of measuring point temperature change

In a closed environment, the heat released during the combustion process increases the pressure in the cabin, thereby weakening the convection, and the restriction of the wall surface will affect the gas-phase flow field and tem- perature field distribution during the flame propagation process. Simplify the fire process in closed cabins to convection problems caused by combustion in rectangular spaces. Because there is no external air supply in closed spaces, closed space fires maintain two-layer areas (high-temperature hot smoke in the upper layer and low-temperature cold air in the lower layer). Area) of smoke, as the fire develops, the pressure neutral side will gradually disappear. In a short time, the entire confined space was filled with fire smoke. Due to the entrainment of the fire source, the smoke sinking to the bottom re-engaged in the combustion, resulting in a cyclic entrainment phenomenon that only occurred in the enclosed space until the end of insufficient oxygen. Burn out. At this time, there are two areas in the cabin temperature distribution: the upper part of the high-temperature dense flue gas layer is directly affected by the plume of the source of the fire. See Figure 6.

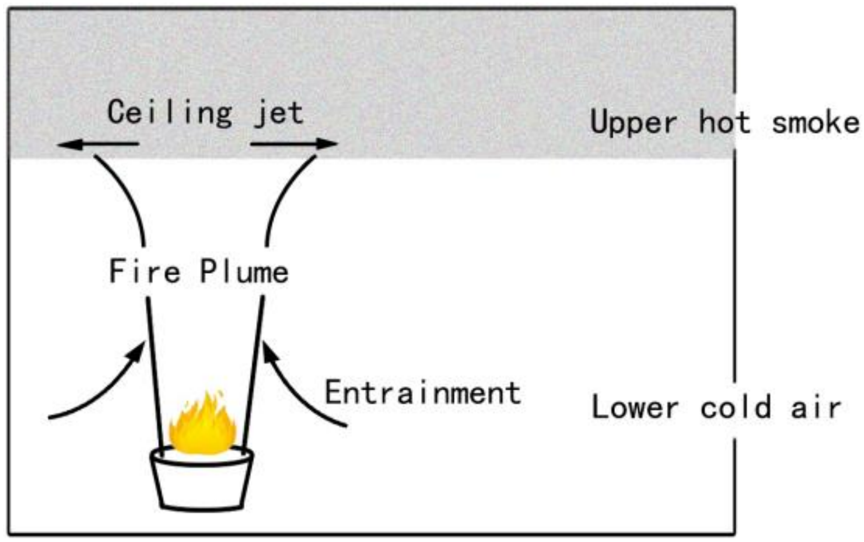

Fig.6 Two-region model

Figure 7 selects the iconic thermocouple measurement points in FDS, a, b, and c are the measurement points with the abscissa equal to 0.7m, 1.5m, and 2.3m in the plane with a height of 0.8m, and d and e are the abscissa equal to 0.7m and 2.3m in the plane are measured at a height of 2.8m, and d is the temperature measured at the center ceiling of the nacelle. It can be seen from the figure that the thermocouple point has a similar temperature curve. The curve can be roughly divided into three stages in the figure: ①②③: In the initial growth stage, the smoke trajectory in the cabin at this time is a process that diffuses from the upper part of the cabin to the lower part, causing the temperature of the lower space to rise. 2. In the continuous stage, the temperature of each flue gas layer is basically stable at the highest value. 3. In the flameout stage, after 880s, there is insufficient oxygen, the heat release power of the fire source decays, the combustion begins to become unstable, and the fire enters the near flameout stage. The measurement points (such as a, b, and c) at the same height in different planes are roughly similar in temperature, and affected by the plume of the fire source, the upper part of the simulated cabin is a high-temperature dense smoke layer, the temperature is slightly higher than the lower part, of which the roof center (f) Highest.

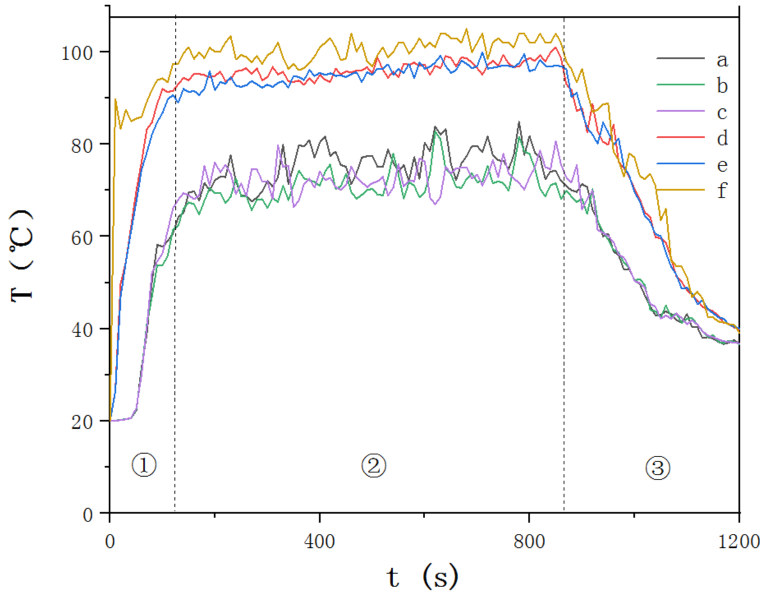

Fig.7 Thermocouple measuring point

3.4 Temperature distribution at the time of flameout

In actual cabin fires, the method of sealing the cabin is often used to suppress the fire and extinguish it. How to determine the time to reopen the cabin has become a difficult task. The flameout time is 880s. This time is the maximum point of the end of the heat release rate and the maximum point of the cabin pressure. Therefore, the temperature distribution at this time largely determines the reopening time [17].

After the fire was sealed, the fire spread quickly, and the hot smoke moved upwards, hitting the cabin ceiling, forming a ceiling jet, and then spreading to the surroundings while entraining air, and began to settle to the lower space. Due to the cyclic entrainment, the temperature is distributed with a certain gradient with height; an improved two-region model[12] that is consistent with the fire temperature distribution of enclosed cabins. As shown in Figure 8, due to the cyclic entrainment, the temperature below the area near the fire source surface (0.7m from the wall surface) is lower than the temperature below the area far from the fire source surface (0.3m from the wall surface); Under the influence of plume, the temperature above the area closer to the source surface is slightly higher than the area farther from the source surface.

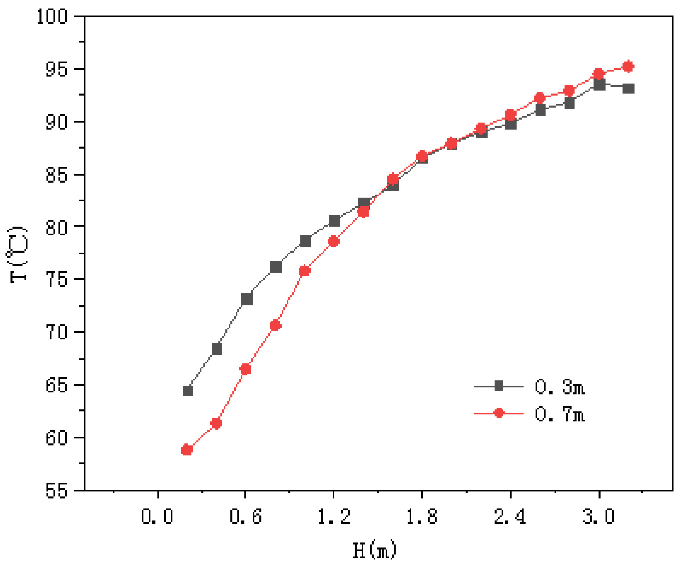

Fig.8 Temperature curve of different thermocouple trees with height at the time of flameout

3. Conclusion

The effects of fire suppression methods on fire extinguishment on the fire behavior were studied, and the following conclusions were obtained:

There are two areas in the temperature distribution of the closed engine room: the upper high temperature dense smoke layer and the lower low temperature lean smoke layer; due to cyclic entrainment, the temperature of the surrounding bulkhead wall surface is distributed with a certain gradient with height, and below the bulkhead The temperature gradient is larger than the temperature gradient above; the high temperature area is concentrated in the center area of the inner wall surface of the roof, above the surrounding bulkheads, and at the top bulkhead.

The flameout time of 880s is the peak point of the whole model. After this time, the temperature and pressure decrease sharply, and reach the lowest point at 1200s. You can consider reopening at the lowest point. The fire source with a certain height will make the ceiling directly above the highest temperature. Post-disaster repair at this location can be considered after reopening the cabin.

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