ITM Web of Conferences **47**, 03040 (2022) https://doi.org/10.1051/itmconf/20224703040
CCCAR2022

Study on the influence of rolling amplitude on fire heat of aviation kerosene pool

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Abstract. In order to study the effect of rolling amplitude on the heat release of aviation kerosene, an experimental oil pool was designed. The rolling frequency of the oil pool was used as a fixed amount. The rolling amplitudes were 0, 15°, 30° and 45°, respectively. The initial thickness of aviation kerosene was 0.646 mm, 1.291 mm and 1.940 mm, respectively. The results show that the heat release rate of aviation kerosene increases significantly with the increase of rolling amplitude, and the total heat release of aviation kerosene increases with the increase of swing amplitude. When the initial aviation kerosene was relatively thin, the upward trend was not obvious, with only slight changes; the thicker the oil pool is, the more obvious the upward trend is and the greater the total heat released is.

Keywords: Rolling amplitude, Initial thickness, Aviation kerosene, Pool fire, Heat.

1 Introduction

Fire engineering safety is an important part of national engineering safety. China's maritime and air transport industry is in rapid development. Although new energy is constantly innovating, the power source used in the field of ships and aviation is still dominated by oil. As a special liquid, oil will burn after encountering fire sources. Especially on rolling ships, burning creates a special fluid fire. In this regard, researchers have paid attention to the combustion characteristics of flowing fire of oil products at different slopes, and studied the combustion differences caused by the change of slope[1, 2]. Before that, continuous research was carried out on the size of oil tank [3-5], oxygen concentration[6, 7], and even various influencing factors were combined with experiments[8] to obtain the differences of combustion characteristics such as flame morphology, combustion rate, heat release rate and flue gas change of oil tank fire in different complex environments. In the previous studies, the oil pool is often fixed. Although the external environmental conditions are changed, the fluctuation caused by the change of external conditions of the ship itself in maritime transport is ignored, which cannot reflect the security risks caused by the change of the stability conditions of the oil pool itself.

The ship has six forms of rolling, pitching, yawing, swaying, surging and heaving during navigation[9] , as shown in Figure 1. When the oil spills in the ship, it flows on the deck. Once

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exposed to the fire source, it will form a flow fire[10]. Compared with the heat generated by the same amount of oil in the horizontal state, the heat generated by it may be changed. The spilled oil rolling with the same frequency as the ship rolling, and more serious casualties and losses will occur in the fire. Therefore, the heat change of aviation kerosene pool fire combustion in the rolling state is studied.

2 Experimental design

2.1 Oil pool rolling design

The most influential rocking mode on the ship is rolling, which takes the longitudinal axis as the standard line and has periodic left and right rocking. The experiment was set to be carried out in a square tank with the size of 8.8 cm × 8.8 cm × 4 cm, side length D of 8.8 cm and height H of 4 cm. In order to ensure the stability of pool rolling, stainless steel support frame is set under the tank. Aviation kerosene is often used as fuel in cabin power source in practical application [11]. Therefore, in order to be closer to reality, aviation kerosene is used as experimental oil. The rolling frequency is set to 0.25 Hz, and the rolling amplitude is set to 0°, 15°, 30° and 45°, respectively. The rolling mode is shown in Figure 2. Since previous research results showed that environmental wind speed had an impact on pool fire combustion, the experiment was carried out in indoor windless environment [12-14].

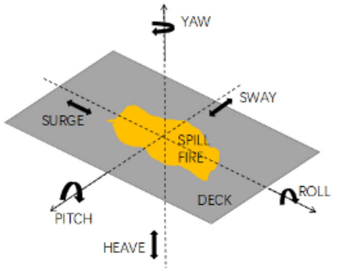


Fig. 1. Vessel motions in 6 degrees of freedom.

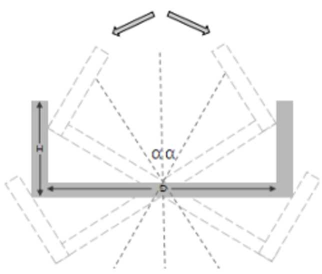


Fig. 2. Roll amplitude.

2.2 Platform and parameters

The flame spread calorimeter (FPA)manufactured by the United States FTT was used for data collection of heat release rate, and the experimental platform is shown in Figure 3. In order to reduce the error caused by the single change of oil volume and consider the influence of initial oil thickness on combustion characteristics, three different oil thickness combustion were set, which were 0.646 mm, 1.291 mm and 1.940 mm, respectively. The experimental condition design was shown in Table 1.

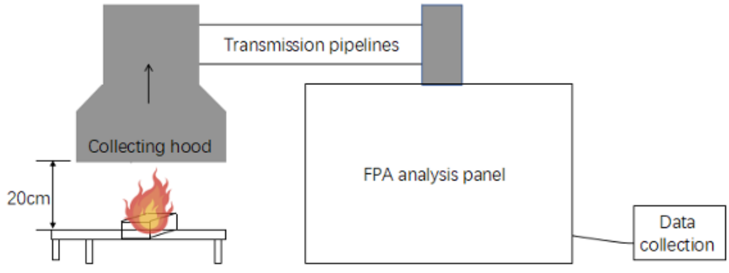


Fig. 3. Experimental platform design.

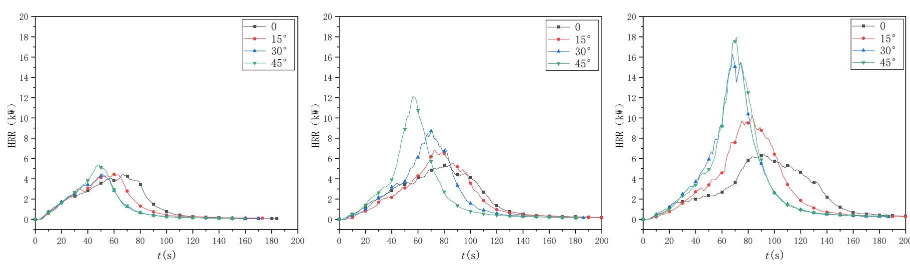
Table 1. Experimental parameters.

Case	α(°)	Initial Thickness (mm)
0-1	0	0.646
0-2	0	1.291
0-3	0	1.940
15-1	15	0.646
15-2	15	1.291
15-3	15	1.940
30-1	30	0.646
30-2	30	1.291
30-3	30	1.940
45-1	45	0.646
45-2	45	1.291
45-3	45	1.940

3 Results and discussion

3.1 Experimental result

The heat release rate can represent the combustion intensity of the fire and the heat released during the whole combustion process. The real-time data of the heat release rate of aviation kerosene combustion under different rolling states are collected, and the results are shown in Figure 4 indicating the changes of heat release rates of three different initial aviation kerosenes. The transverse axis represents the real-time change of time t (s), and the ordinate axis represents the heat release rate HRR(kW) at different times.



(a) 0.646mm (b)1.291mm (c) 1.940mm

Fig. 4. Change of Heat Release Rate at different initial thickness.

Under the premise of the same thickness of aviation kerosene, with the increase of rolling amplitude, the heat release rate of aviation kerosene increases rapidly, and the peak value can be reached is also higher. When the HRR value is higher, the flame exchanges more airflow in the air. The higher the convective heat is, the higher the feedback heat on the oil surface is, and the reverse heating effect on the aviation kerosene in the oil tank is achieved, which accelerates the evaporation of the oil and shortens the combustion time.

The combined analysis of the results of three different reservoir thicknesses shows that even in the same rolling state, the change intensity of heat release rate varies with the initial kerosene set. When the initial aviation kerosene thickness is 0.646 mm, the rolling state has a slight influence on the heat release rate; when the initial thickness is 1.291 mm, the increase of heat release rate by the change of rolling amplitude is more intense. Even when the rolling heat release rate has reached the peak at 45°, the heat release rate in the equilibrium state has just begun to increase. It can be shown that the thicker the initial thickness is, the greater the impact on the heat release rate is. Under the condition of 1.940 mm thickness, the difference between the heat release rate at 45° and 30° is small, because the total heat released by a certain amount is limited, so the heat release rate is not infinitely increased.

3.2 Experimental analysis

3.2.1 Peak heat release rate

The peak heat release rate and the time to reach the peak in the extraction experiment were analyzed specifically. As shown in Figure 5, the X-axis represents the variation of the swing amplitude α in degrees (°); the left Y-axis represents the peak of the measured heat release rate in kilowatts (kW) in the form of a bar graph; the right Y-axis represents the time taken to reach the peak heat release rate in seconds (s) in the form of a line graph.

Under equilibrium condition, the peak value of heat release rate increases slightly with the increase of initial kerosene thickness, and the increment of peak value caused by each increase of kerosene thickness is almost the same, which indicates that the experimental design is reasonable. When the rolling amplitude is increased, because the amount of oil in the thickness of 0.646 mm is too small, the heat released is limited, so even if the rolling amplitude increases, the influence on the peak value is still weak. With the increase of thickness, the peak value of heat release rate increases more obviously with the increase of rolling amplitude, especially when the initial thickness of 1.940 mm is doubled. While the peak value increases, the time to reach the peak value decreases with the increase of the swing amplitude, indicating that the flame combustion in the swing process is more intense and accelerates the combustion of aviation kerosene.

3.2.2 Total heat release rate

The total heat release rate Q during combustion can represent the total heat released, which can be integrated by the heat release rate per unit time:

$$Q = \int_{T_1}^{T_2} Q(t)dt$$

In the formula, T_1 denotes the beginning time of combustion, T_2 denotes the end time of combustion reaching stability, and Q(t)denotes the heat release rate per unit time. The total heat of combustion under each condition is compared, as shown in Figure 6.

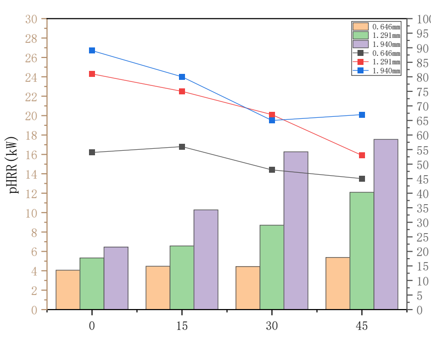


Fig. 5. Peak change of heat release rate.

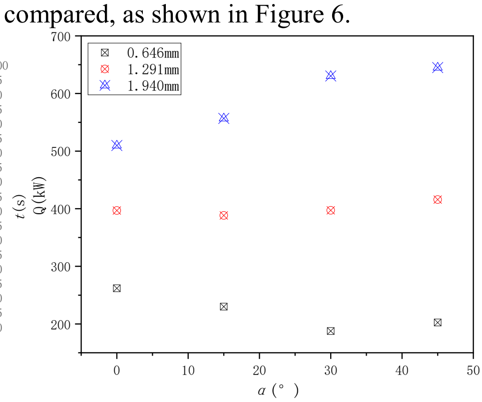


Fig. 6. Total heat of combustion process.

The thicker the aviation kerosene is, the greater the heat change is affected by the pool swing. When the minimum thickness of the oil layer is 0.646 mm, the rolling amplitude increases and the heat released by combustion decreases. Because of too little oil and the viscosity of aviation kerosene, the bottom of the oil pool cannot be covered in the rolling process, and the combustion is not complete, so the heat released is reduced. When the thickness of the oil layer is 1.291 mm, the rolling amplitude increases and the heat released by combustion is almost unchanged, because the aviation kerosene can cover the bottom of the oil pool during the swing process, but it does not form accumulation, which is similar to the combustion state in the horizontal state of the oil pool. When the oil layer thickness is the maximum of 1.940 mm, the swing amplitude increases, and the total heat released by combustion increases accordingly.

3.3 Discussion

The main reasons for the analysis are as follows. First of all, from the perspective of the state of the oil itself, when the oil pool is in a balanced state, the kerosene in the pool is covered at the bottom, which is the combustion of thin oil. As shown in Figure 7(a), when the rolling reaches the maximum amplitude of 45°, the kerosene accumulates most obviously on the wall of the tank.

(a)Thin-layer oil in equilibrium state (b)Oil accumulation during rolling

Fig. 7. Oil flow in oil pool.

As shown in Figure 7 (b), the original thin oil layer has a low combustion rate because of the obvious heat transfer process with the bottom. When the thickness increases, the combustion rate increases, and the heat release rate also increases. Secondly, when rolling, the flame continuously sucked air. The combustion intensified, resulting in the increase of flame height, and the flame showed a trend of upper fracture. Thirdly, when the oil volume is small, the rolling of the oil pool can only expand the oil surface area in a very small range, resulting in little change in the heat feedback of the oil tank, so the influence on the heat release rate of kerosene is relatively small. Fourthly, the increase of oil content enables the aviation kerosene in the oil pool to flow back and forth in a rolling state, covering the bottom of the entire oil tank and increasing the actual combustion area. Moreover, aviation kerosene accumulates at a low position, and internal stirring occurs to promote temperature rise. The diffusion rate of liquid vapor above the pool surface is accelerated, and the flame height is stretched. The upper combustion area increases, and the flame constantly hits the sidewall, which will produce stronger feedback heat to the fuel on the pool surface[15]. Strengthen combustion and evaporate more combustible gas to form a cycle, as shown in Figure 8. After the depletion of aviation kerosene, the flame quickly extinguished and the heat release rate rapidly decreased.

Fig. 8. Thermal cycle during rolling.

4 Conclusion

When the fuel pool is burning, increasing the rolling amplitude will change the combustion characteristics of aviation kerosene in the horizontal stable state: making the flame height of kerosene burning higher, burning more intense, burning faster, heat release rate rising, releasing more heat. At the same time, the thicker the oil is, the greater the heat growth rate can be caused. When the fire release heat is too large than the maximum value that the cabin can withstand, it will damage the integrity of its fire resistance and cause danger. Therefore, in order to ensure the safety of ships sailing in the sea, it is of great significance for ship fire protection design to study the change of combustion characteristics of tank fire in rocking state.

This work is supported by the Hebei Province Natural Science Foundation of China, Project No. E2017507012 and the Key scientific research projects of CPPU, Project No. ZDZX202005.

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