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# An Experimental Study on Fuel Combustion Under External Irradiance

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**Abstract:** In order to investigate the burning characteristics of a 0# diesel and 3# jet fuel, a small-scale experimental bench mainly composed of a cone calorimeter was arranged. The heat release and burning rates were investigated changing the external irradiance in order to clarify the triadic relationship among these quantities. The effective heat of combustion of 0# diesel and 3# jet fuel were 38.89 MJ/kg and 43.15 MJ/kg, respectively, with the corresponding combustion efficiencies being 96.78% and 99.60% (the effective peak heat of combustion being 1.665 times the mean value for both types of fuel). According to our experimental results, the heat release rate and burning rate of 0# diesel and 3# jet fuel both grow linearly with an increase in the external irradiance. Moreover, the heat release rate and burning rate of 3# jet fuel are greater than the equivalent values for the 0# diesel. The average smoke production rate of 0# diesel grows with an increase in the external irradiance, while for the 3# jet fuel it remains approximately the same. The specific extinction area of these two kinds of fuel shows a subtle decrease with the increase of external irradiance. The time to ignition of 3# jet fuel is smaller than 0# diesel for all the considered external irradiances, which indicates that 3# jet fuel is easier to ignite than the 0# diesel.

**Keywords:** External irradiance, heat release rate, burning rate, effective heat of combustion.

## 1 Introduction

Petroleum products are combustible and explosive. As a result, the oil fire accidents are very dangerous. When tank farm burns, the oil burns in the type of pool fire in the tank, and the flame and dense smoke which rise from the fire bring plenty of heat constantly to the surrounding tank farms in the form of heat radiation. In order to effectively control the spread of fire accidents, we must grasp the burning rules of oil under the condition of outside heat radiation.

Heat release rate (HRR), burning rate, specific extinction area, smoke production rate and time to ignition are important combustion characteristics in fire research and heat release rate is considered to be the most important parameter [Babrauskas and Peacock (1992)]. Therefore, many scholars at home and abroad have carried out many researches on the heat release rate. For instance, Spearpoint et al. [Spearpoint and Quintiere (2001); DiDomizio, Mulherin and Weckman (2016); Vermesi, DiDomizio, Richter et al. (2017); Alakoski, Jämsén, Agar et al. (2016)] studied the heat release rate of wood with the help of the cone

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calorimeter, and found that Non-charring polymers burn away completely leaving no or very few residue, which can be modeled using theory similar to flammable liquids. Galgano et al. [Galgano, Di Blasi and Milella (2010); Zhai, Gong, Zhou et al. (2017)] predicted the heat release rate of the sandwich panel and wood under external heat flux, and the changes of characteristic process time were also discussed. They both found that the strongest impact on the model predictions is exerted by the imposed external heat flux. Shi et al. [Shi (2013); Martinka, Martinka and Rantuch (2018)] studied the release law of toxic gases such as CO by combining the law of heat release rate during wood combustion process, and mainly discussed CO release rate at various conditions. Chen et al. [Chen and Wei(2014)] processed and analyzed the data of crude oil pool fire experiments in Tomakomai, Japan, compared the accuracy among Babrauskas formula, Thomas model and Heskestad model in different diameters, and accuracy between Shokri Beyler model and point source model in different thermal radiation intensities.

Some achievements have been reached through the above literatures, but the combustion characteristics of oils have not been studied under the condition of outside heat radiation and as a result, oils' combustion conditions under the condition of outside heat radiation when tank farms burn cannot be simulated. The method which studies building materials' outside heat radiation is applied to oils' combustion characteristics test to simulate and study the oils' combustion characteristics of one oil tank when surrounding oil tanks burn and radiate heat outward. For the convenience of study, this test is carried out on a small scale. The conclusion obtained on a small scale can be applied to the real scale according to the scale similarity of fire [Babrauskas and Wickstrom (1989)] to provide references for practical production safety. Two common fuels, 0# diesel and 3# propellant (jet fuel), are applied to this test.

## 2 Experimental setup and method

According to the requirements of this experiment, small-scale fuel combustion characteristics experimental bench which provides steady outside heat radiation quantificationally is set up on the basis of cone calorimeter. The main equipment of this experimental bench in this paper is a cone calorimeter which is mainly included heat flux unit, heat release rate test unit, mass burning rate test unit, smoke characteristics test unit. Relevant parameters during the experiments can be measured in real time during the process of oil burning by this bench.

The cone calorimeter is made by FTT (Fire Testing Technology) corporation of British and its photo is shown by Fig. 1.

### *2.1 Heat flux unit and method*

The heating wire contained in cone heater which is carried by small-scale fuel combustion characteristics experimental bench can transmit steady, sustaining heat radiation to lacquer tray and it can meet the requirement of simulating outside heat radiation in the paper. According to the actual condition of small-scale burning experiment, one radiation intensity experimental point is set up from 5 kW/m$^2$ to 50 kW/m$^2$ at the interval of 5 kW/m$^2$ and 10 experimental points are set up. In consideration of flame height, the radiation distance is set as 60 mm. High voltage detonating fuse head is set up below heater as ignition source.

### 2.2 Heat release rate test unit and method

The methods to measure heat release rate include oxygen consumption theory method, weightlessness velocity method, and heat insulation box method and so on. Currently the most common method is oxygen consumption theory method which means that for most materials, net heat released when1 kg oxygen burned can reach nearly constant $13.10\times10^3$ kJ [Thornton (1917)]. Paramagnetic oxygen analyzer is carried by the experiment bench which can accurately measure oxygen content of sample gas in real time to obtain heat release rate at the corresponding time.

### 2.3 Burning rate test unit and method

The methods of oil mass lose rate and liquid level drawdown rate are used to represent burning rate in the research of pool fire and mass lose rate is wildly used because of not suffering the influence of liquid bath diameter. Mass lose rate which refers to weight loss rate, mass burning rate is used as the combustion rate of oil in the paper. The mass of oil products is measured in real time by precision electronic balance carried by this experiment bench and obtain the value of combustion rate. A fuel pan with size of 10 cm×10 cm is designed when the oil products are weighed by the electronic balance. The photo of this fuel pan is shown in Fig. 2.

**Figure 1:** Photo of the cone calorimeter

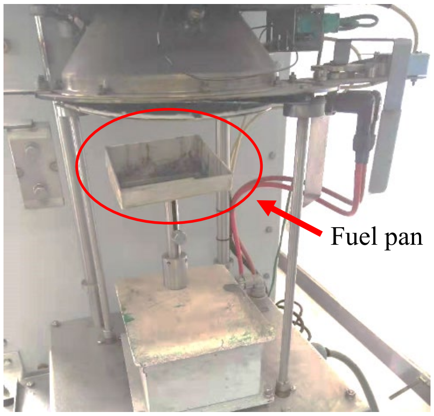

**Figure 2:** Photo of the fuel pan

### 2.4 Smoke characteristics test unit and method

Smoke characteristics mainly include specific extinction area, fuming rate, RSR, TSP and so on. He-Ne laser that is carried by this experiment bench can measure smoke density within gas flue in real time. The rules of specific extinction area and fuming rate are focused in this paper.

### *2.5 Two-phase water mist emergent fire extinguishing system*

To ensure the safety of this simulation experiment, two-phase flow water mist spray nozzle (shown in Fig. 3) for fire suppression is set up above the lacquer tray and linked to multicomponent two-phase flow water mist fire extinguishing system (shown in Fig. 4) which can put out oil fire in time in an emergency to avoid accident. Multicomponent two-phase flow water mist fire extinguishing system includes two-phase flow water mist spray head, liquid storage pot, high-pressure hose, pressure-regulating component and so on [Zhdanova, Volkov, Voytkov et al. (2018)].

**Figure 3:** Two phase flow water mist fire extinguishing nozzle

**Figure 4:** Multi-component two phase flow water mist fire extinguishing system

Diesel and jet fuel are two kinds of oil commonly used in modern production and life, so the 0# diesel and 3# jet fuel are selected as the test samples in this paper. The preparation of the test samples before the experiments are followed as following principles:

- In order to prevent excessive volatilization, deterioration and forming hazardous mixture with air as the result of the fuel samples' volatility, the fuel samples were put into the fuel pan and start the experiment immediately after other preparatory work were completed.
- Follow the specification, the thickness of fuel samples in the pan is not less than 6mm and the duration of the experiment is not less than 5 min, 60 g fuel samples are weighed each time for the facilitation of comparison.
- Since the initial temperature of fuel samples has a significant impact on combustion characteristics, after each experiment, the fuel pan was cleaned and cooled to room temperature fully before the next set of experiments.

## 3 Experimental result and discussion

In order to obtain obvious characteristic parameters of combustion stationary phase, the current researches of oil plants pool fire usually inlet fresh fuel to the bottom of the pool constantly when burning to maintain the steady state using fuel level control device. However, fresh fuel is usually not added when actually oil pool catches fire. Characteristics and rules of oil pool fire with none fresh fuel added is studied by this paper. In addition, this experimental environment is not airtight and there is relative enough air to be burn in the condition of compulsive exhaust air, so the burning of this experiment is non-confined space burning.

### *3.1 Heat release rate*

Mean HRR refers to the average value of heat release rate during the whole combustion process of oil; Peak HRR refers to emerging maximum of heat release rate during the whole combustion process. Mean HRR and Peak HRR of diesel and jet fuel under different irradiances ranging from 5 kW/m$^2$ to 50 kW/m$^2$ are shown in Tab. 1 and graphs are shown in Fig. 5 and Fig. 6.

**Table 1:** HRR of 0# diesel and 3# jet fuel under different irradiances

| External irradiances (kW/m$^2$) | Mean HRR (kW/m$^2$) | | Peak HRR (kW/m$^2$) | |
|---|---|---|---|---|
| | diesel | jet fuel | diesel | jet fuel |
| 5 | - | 530.9629 | - | 893.8986 |
| 10 | 338.8951 | 643.0161 | 494.5095 | 1134.859 |
| 15 | 384.5326 | 746.0362 | 607.9446 | 1412.891 |
| 20 | 472.4999 | 871.3524 | 807.9656 | 1674.771 |
| 25 | 571.0586 | 912.0315 | 1138.7 | 2062.963 |
| 30 | 630.8386 | 1140.562 | 1143.34 | 2308.617 |
| 35 | 693.1823 | 1262.794 | 1313.637 | 2559.236 |
| 40 | 733.1749 | 1317.815 | 1447.52 | 2592.706 |
| 45 | 833.0371 | 1434.342 | 1755.164 | 2644.376 |
| 50 | 921.7077 | 1562.801 | 2060.621 | 2990.657 |

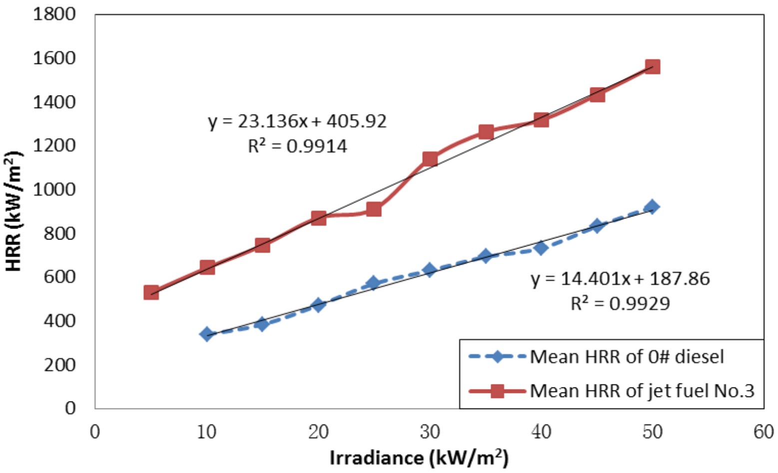

**Figure 5:** Mean HRR curve of 0# diesel and 3# jet fuel under different irradiances

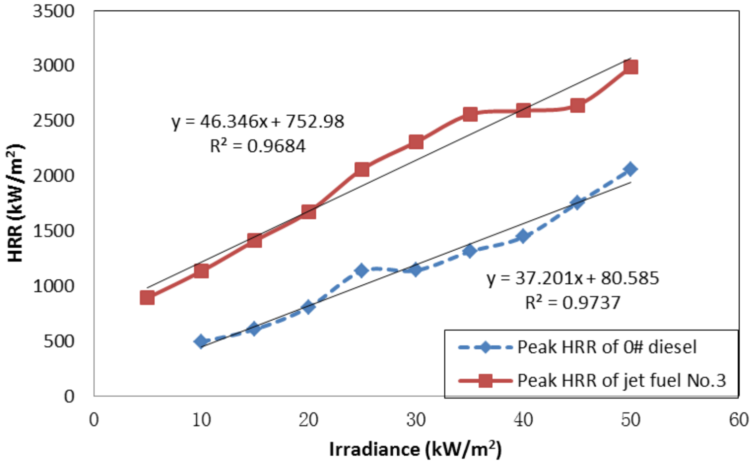

**Figure 6:** Peak HRR curve of 0# diesel and 3# jet fuel under different irradiances

From Fig. 6 above, it can be found out that with the increase of outside irradiances, Mean HRR and Peak HRR of both diesel and jet fuel will all increase, which means that the stronger the outside heat radiation, the more violent the oil burns. Oil obtains much more energy when outside irradiance is great and the temperature of oil rises, and as a result, oil gas volatilizes faster. It is known that burning is a series of complex chemical reactions and the higher the oil gas concentration above oil level and the higher the reaction temperature, the faster the reaction rate and the more violent the oil burning will be. It is a enlightenment for us that when one storage tank catches fire in the tank farm, the stronger the tank's fire behavior is, the more violent the burning of tanks which is ignited by it will be and it will cause vicious circle. So when putting out actual storage tank fire, we should discover as soon as possible and act quickly to control fire behavior at the initial stage.

From Fig. 5, it is observed that Mean HRR of jet fuel is higher than that of diesel in a whole under different irradiances and the rising trend of jet fuel's Mean HRR is greater. The two kind of oil's rising curves of Mean HRR are approximately fitted to two straight lines and the result of fitting straight line of jet fuel's Mean HRR (y, unit kW/m$^2$) with outside irradiances (x, unit kW/m$^2$) is:

$$y = 23.136x + 405.92 \tag{1}$$

The result of fitting straight line of diesel is:

$$y = 14.401x + 187.86 \tag{2}$$

It is found out that the straight line's slope of jet fuel is larger than that of diesel which is determined by their different physicochemical property. During the process of petroleum fractionation, jet fuel is fractionized earlier because the boiling point of jet fuel is lower than that of diesel and the elements of jet fuel are lighter than that of diesel generally, so jet fuel has better volatility. As for the occasions, aircraft engine asks for a better startability and complete combustibility of fuel and fuel needs to be volatilized enough to mix with air before burning, so fuel is required to have better volatility. In this experiment, the volatilization of jet fuel is more violent, the concentration of oil gas above oil level is higher, and the burning is more violent.

The rules of two oils' Peak HRR in Fig. 6 are similar to that of Fig. 5. Fitting the straight lines of two oils' Mean HRR with outside irradiances, the result of fitting straight line of jet fuel is:

$$y = 46.346x + 752.98 \tag{3}$$

The result of fitting straight line of diesel is:

$$y = 37.201x + 80.585 \tag{4}$$

Comparing Peak HRR with Mean HRR, the Peak HRRs at certain points (such as diesel under 50 kW/m$^2$) is twice over Mean HRR, so from the point of safety protection, Peak HRR that can be reached during the process of burning must be used to predict the harm of fire.

It is pointed out by Messerschmidt et al. [Messerschmidt, Van Hees Patrick and Wickström (1999)] that there is a linear relationship between the Mean HRR of material and outside irradiances and the expression between them is provided. The result of this experiment not only proves that the linear relation is also suitabe for oil but also shows that there is a similar linear relation between the Peak HRR and outside irradiances. One point to explain complementally, after 3 times repeated experiments, diesel does not catch fire after being exposed to the outside irradiance of 5 kW/m$^2$ for 10mins which means that it can be considered as not lighted.

### *3.2 Study on the rate of combustion characteristics*

Mass loss rate, namely mass burning rate, refers to the rate at which the fuel sample consumes after set on fire, and reveals the evaporation rate of pyrolysis of the sample. Same with HRR, MLR can be studied according to mean loss rate (Mean MLR) and peak weight loss rate (Peak MLR) of the combustion process. Both the mean and peak MLR curves of two fuels are shown in Fig. 7 and Fig. 8 respectively.

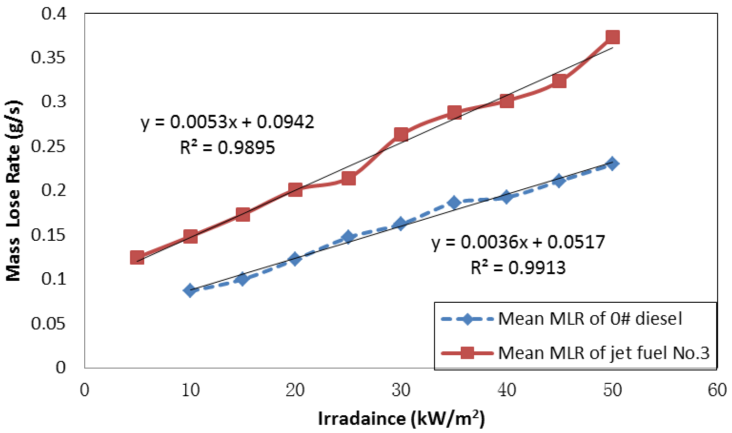

**Figure 7:** Mean MLR curve of 0# diesel and No. 3 jet fuel under different irradiances

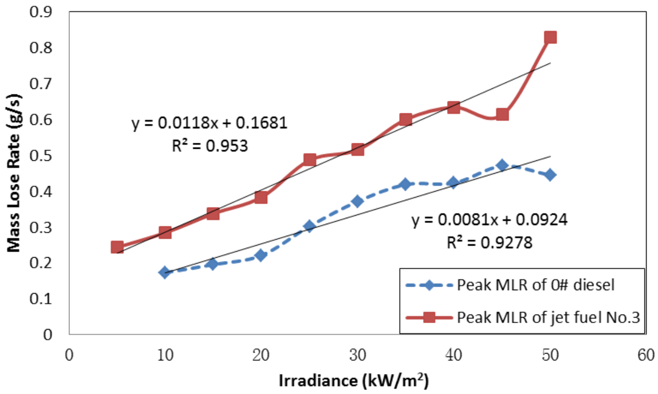

**Figure 8:** Peak MLR curve of 0# diesel and No. 3 jet fuel under different irradiances

What can be concluded from the two pictures by contrast is that the mean MLR curve is more like a straight line than the peak one. As shown in Fig. 7, the curve of diesel has a good linear characteristic, while the curve of jet fuel behaves differently. At the external radiation intensity of 5 kW/m$^2$, 10 kW/m$^2$, 15 kW/m$^2$ and 20 kW/m$^2$, the mean MLR of jet fuel present substantially linear rise although it encounters slightly offset when the radiation intensity comes to 25 kW/m$^2$ and 45 kW/m$^2$. The equations expressing the relations between Mean MLR of diesel and jet fuel and external radiation intensity can be got by linear fitting and are listed as follows.

Jet fuel:

$$y = 0.0053x + 0.0942 \tag{5}$$

diesel:

$$y = 0.0036x + 0.0517 \tag{6}$$

The relations summarized according to the same way as Mean MLR between Peak MLR (y, g/s)of the two fuels and the external radiation intensity (x, kW/m2)are as follows:

Jet fuel:

$$y = 0.0118x + 0.1681 \tag{7}$$

diesel:

$$y = 0.0081x + 0.0924 \tag{8}$$

Whether it is seen from the mean MLR fitting results or the peak one, they all reflect that the slope of the line of jet fuel is greater than that of diesel, which implies that mass loss rate of jet fuel will rise more sharply with the increase of external heat radiation intensity, which is the same with the law of heat release rate.

In Fig. 7 and Fig. 8, the peak MLR curve of jet fuel and diesel performs an overall upward trend but its linear feature is not good enough. The relatively large uncertainty of peak MLR parameter measured is one of the reasons. And a brief period of strong combustion because of the accumulation of oil and gas by accident and the inhalation of a large amount of oxygen, which leads to a high peak on the MLR curve, can also interprets that.

### *3.3 Study on effective heat of combustion*

Heat of combustion of fuel refers to the heat released when the fuel completely reacts with oxygen. Combustion efficiency is one of the important combustion characteristics drawing much concern. When burning in engine, the fuel is expected to achieve as complete combustion as possible. However in the fire control field, the higher the degree of post-combustion of the material is, the higher the risk of fire becomes, which should be controlled and avoided. EHC (effective heat of combustion) refers to the ratio of heat release rate to mass loss rate per unit area (Specific MLR) at time t, i.e., EHC=HRR/Specific MLR, (international standard unit, MJ/kg). The mean EHC and peak EHC of diesel and jet fuel at each radiation intensity are listed in Tab. 2.

Heat of combustion of a fuel should be substantially constant under the same condition, and the data in the Tab. 2 also shows that the enhancement of external thermal radiation does not have an effect on EHC. The average value of mean EHC of the two fuels under different external radiation intensity is calculated respectively according to the data in Tab. 2, shown in Tab. 3. The average diesel EHC is 38.88887 MJ/kg and jet fuel 43.15073 MJ/kg. By access to references [Standardization Administration of China. GB 19147-2013; Standardization Administration of China. GB 6537-2006], the heat of combustion of diesel and jet fuel burned completely is 40.18418 MJ/kg and 43.32357 MJ/kg respectively. If the experimental values are divided by the standard heat of combustion, the combustion efficiency of diesel and jet fuel under the experimental conditions of this study can be obtained and are 96.78% and 99.60% separately. Thus we can conclude that under the small-scale experimental condition, the combustion efficiencies of diesel and jet fuel both can be very high, among which the value of jet fuel is higher, nearly 100%.

It also can be seen form Tab. 3, that the average values of peak EHC of diesel and jet fuel at all kinds of external radiation intensities are 64.74086 MJ/kg and 71.84717 MJ/kg respectively, 1.664766 and 1.665028 times of each mean EHC under the same condition. The multiples are very close in spite of different types of oil, which guides us to conclude that the peak EHC oil combustion can release on a small scale is about 1.665 times the mean one.

**Table 2:** EHC of 0# diesel and No. 3 jet fuel under different irradiances

| External irradiance (kW/m$^2$) | Mean EHC (MJ/kg) | | Peak EHC (MJ/kg) | |
|---|---|---|---|---|
| | diesel | Jet fuel | diesel | Jet fuel |
| 5 | - | 42.45759 | - | 77.34954 |
| 10 | 39.05516 | 43.34129 | 64.14042 | 65.53042 |
| 15 | 38.29336 | 43.02993 | 60.94471 | 78.86016 |
| 20 | 38.4089 | 43.18853 | 77.44858 | 64.30004 |
| 25 | 38.68496 | 42.54539 | 61.69673 | 77.69171 |
| 30 | 38.85111 | 43.26969 | 64.80525 | 60.32313 |
| 35 | 39.18104 | 43.85277 | 61.74092 | 77.4816 |
| 40 | 38.04993 | 43.6857 | 62.78416 | 77.21848 |
| 45 | 39.43917 | 44.27411 | 57.65923 | 68.23854 |
| 50 | 40.03623 | 41.86229 | 71.44774 | 71.47808 |

**Table 3:** Average values of peak EHC of diesel and jet fuel at various external radiation intensities

| | Mean EHC (MJ/kg) | | Peak EHC (MJ/kg) | |
|---|---|---|---|---|
| | diesel | Jet fuel | diesel | Jet fuel |
| Average (MJ/kg) | 38.88887 | 43.15073 | 64.74086 | 71.84717 |
| Heat of combustion from references (MJ/kg) | 40.18418 | 43.32357 | - | - |
| Combustion efficiency (100%) | 0.967766 | 0.996011 | - | - |
| Multiples | - | - | 1.664766 | 1.665028 |

### *3.4 Study on smoke produce rate and specific extinction area*

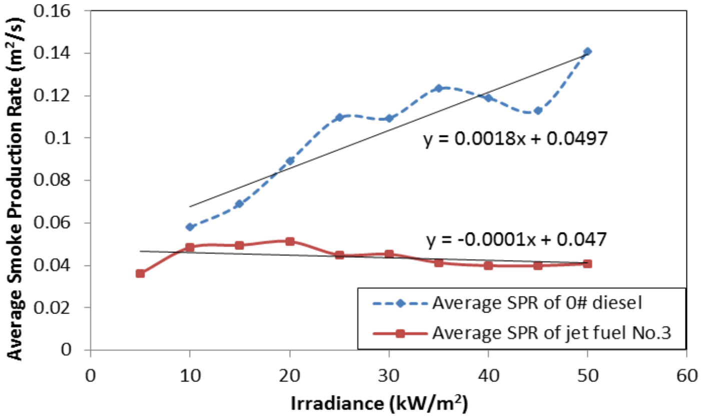

**Figure 9:** Average SPR curve of 0# diesel and No. 3 jet fuel under different irradiances

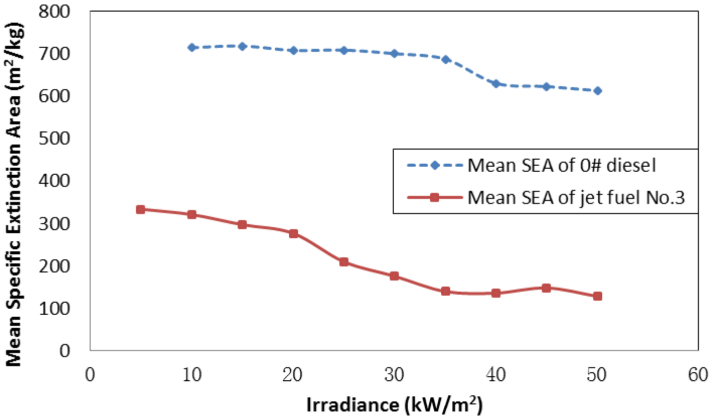

**Figure 10:** Mean SEA curve of 0# diesel and No. 3 jet fuel under different irradiances

Smoke feature is also one of the important characteristics of combustion. After the oil fires, unburned carbon particles in the smoke carry a lot of heat, and the thermal radiation they cause will pose a great threat to the personnel and facilities around. Specific extinction area characterizes smoke generation of the fuel, and can be calculated by the following formula:

SEA=SR·V·MLR-1, $m^2$/kg

Among which, SR (Smoke Ratio) is the smoke density index measured directly by a cone calorimeter, m-1; V is the volume flow rate of the smoke in the flue, L/s.

Smoke Produce Rate, SPR is the ratio of specific extinction area to weight loss rate, namely, SPR=SEA/MLR, $m^2$/s. SPR rate studies the smoke emission quantity per unit time and reveals fume-released "speed", while specific extinction area focuses on smoke emission quantity per unit mass of the fuel and reveals "how much" of the fume. That the difference between the two parameters.

Average SPR refers to the average fuming rate during the stage when burned oil changes from 10% to 90% (in terms of time); Mean SEA refers to the average value of specific extinction area during the whole process of oil combustion under a certain radiation. Fig. 9 and Fig. 10 depicts separately the arrangements of Average SPR Mean SEA of diesel and jet fuel under different radiation intensities.

From the two charts above, we can see that the curve of diesel is above that of jet fuel, which indicates that both smoke produce quantity and smoke produce rate of diesel are larger than those of jet fuel. Analyzing the curves in Fig. 9, we discover that the Average SPR of jet fuel mainly remains constant with the increase of external radiation intensity. The linear fitting formula of its Average SPR ($m^2$/s) with the radiation intensity (kW/$m^2$) is:

$$y = -0.0001x + 0.047 \tag{9}$$

The slope of the expression above is very close to zero, which implies that the Average SPR of jet fuel has nothing to do with external thermal radiation intensity. In contrast, the Average SPR of diesel is greatly affected by it and presents an overall upward trend with the increase of intensity, only declined slightly under the two intensities of 40 kW/$m^2$ and 45 kW/$m^2$. In the same way with jet fuel, its linear fitting formula is:

$$y = 0.0018x + 0.0497 \tag{10}$$

The main components of the smoke produced by oil combustion are carbon particles without sufficient burning. And the weaker the smoke production capacity is, the more sufficient the combustion is. Fig. 10 shows that the Mean SEA values of diesel and jet fuel decrease with the increase of external radiation intensity, indicating that the stronger the external radiation, the less smoke oil combustion will generate in a small scale. It is thought to be one of the oil properties that how much smoke is produced by combustion of oil per unit mass for this experiment. If the Mean SEA value is averaged in terms of quality, then smoke production quantities measured by area at the consumption of per kg of oil can be got. They are 677.2991 $m^2$ for diesel and 216.8481 $m^2$ for jet fuel.

### *3.5 Time to ignition*

Time to ignition (TTI) indicates the time period of a certain kind of material to go from heated on surface to continuous burning under external irradiance, which unit is "s". For solid materials, TTI is an important parameter in evaluating the fire-resistant property, and for oil, it reveals the inflammability of oil under certain external irradiances. Time to ignition characteristics of 0# diesel and 3# jet fuel under different irradiances are showed in Fig. 11.

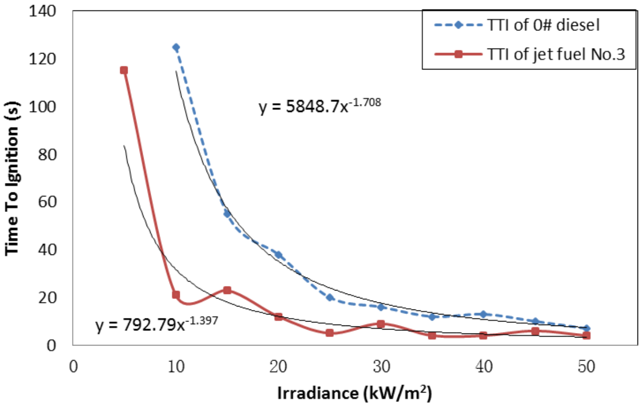

**Figure 11:** TTI curve of 0# diesel and 3# jet fuel under different irradiances

Known from the Fig. 11 above, 0# diesel and 3# jet fuel have similar TTI characteristics. Oil is hard to be ignited under low irradiances, for instance, it takes more than 2 minutes for 0# diesel to be on fire under the irradiance of 10 kW/m$^2$. Start from 15 kW/m$^2$ (10 kW/m$^2$ for jet fuel No. 3), TTI drops rapidly with the rise of irradiance, it becomes easy for both kinds of fuel to be ignited under higher irradiances, for instance, 0# diesel is ignited within 10s under the irradiance of 50 kW/m$^2$, and even faster for jet fuel No. 3, which is ignited in 4 s.

It is known that neither 0#diesel nor 3# jet fuel could be ignited directly in room temperature, but the experimental results indicate that they can be easily ignited when exposed in surrounding heat flux. The fitting formulas of TTI curves of two kinds of fuel are showed respectively below, in which y stands for TTI with the unit “s” and x stands for external irradiance with the unit “kW/m$^2$”:

0# diesel:

$$y = 5848.7x^{-1.708} \tag{11}$$

Jet fuel No. 3:

$$y = 792.79x^{-1.397} \tag{12}$$

According to the formulas above, time of fuel to go from exposure to heat flux to ignition in actual fire hazards can be estimated, which can be referred in determining the optimum extinguishing time limit.

## 4 Conclusions

In this paper, a small scale fuel combustion characteristic experimental bench with external irradiance simulation module was set up, heat release rate, burning rate, effective heat of combustion, smoke characteristics and time to ignition parameters of fuel pool fire under different external irradiances were researched, and the main conclusions can be summarized as follows:

(1) Heat release rate and burning rate of 0# diesel and 3# jet fuel both increase linearly with the increase of external irradiance, this trend of 3# jet fuel is more obvious, heat release rate and burning rate of 3# jet fuel are both greater than 0# diesel.

(2) Under the conditions of present experiments, effective heat of combustion of 0# diesel is 38.89 MJ/kg and 3# jet fuel is 43.15 MJ/kg, combustion efficiencies are 96.78% and 99.60% respectively, the peak effective heat of combustion of two kinds of fuel are both 1.665 times of mean.

(3) Average smoke production rate of 0# diesel increases with the increase of external irradiance, 3# jet fuel remains about the same. Specific extinction area of two kinds of fuel both show subtle decrease with the increase of external irradiance, smoke productions of 0# diesel and 3# jet fuel with the consumption of per kg are 677.30 $m^2$ and 216.85 $m^2$ respectively.

(4) Time to ignition of 3# jet fuel is shorter than 0# diesel in all external irradiances, which indicates that 3# jet fuel is easier to get on fire, fitting formulas of time to ignition of two kinds of fuel in respect to external irradiances are worked out.

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