ISSN: 2414-1895 DOI: 10.6919/ICJE.202011_6(11).0052

Research on Combustion of Single Pool Fire

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Abstract

The principle of In-situ combustion is quickened the oil combustion rate, which is one of the important means in the handling of the oil spill. Increasing the burning rate and burning it is one of the important measures to reduce its impact on the ecological environment. This article reviews the dynamics of oil pool fire combustion. this article combs the influence of the oil pool fire burning rate from both external and internal factors, and prospects for future research work.

Keywords

Oil pool fire, Burning rate, Lip height, Accelerated combustion.

1. Introduction

In recent years, people's increasing demand for oil has accelerated the development of the ocean oil industry, and at the same time increased the risk of ocean oil spills. When an ocean oil spill occurs, the basic problem of how to quickly clean up residual oil has caused Attention of academia. Studies have shown that the use of in-situ combustion method to deal with spilled oil is more efficient and can clean up 90% of the oil volume [1]. But even with this method, a large amount of crude oil is still untreated, causing environmental pollution.Because in the process of in-situ combustion, a large amount of flame energy is lost to the environment through buoyancy convection and radiation, and only a limited small part will be fed back to the fuel surface for fuel evaporation and combustion[2]. In order to further understand the mechanism of the in-situ combustion method of ocean oil spills, the study of oil pool fire was born.

Oil pool fire combustion generally refers to the buoyant diffusion flame formed by the burning of the fuel surface when the combustible liquid fuel is confined in a certain space. In the past 50 years, the fire characteristics of single oil pool fires have been the focus of the fire field. Key issues. The scholars analyzed the combustion phenomenon through experimental research, theoretical analysis and numerical simulation, combined with knowllip of combustion and fire dynamics, and obtained the combustion characteristics of the oil pool fire: combustion rate, flame height, flame temperature, etc. The burning rate is an extremely important characteristic of the combustion process. Therefore, researchers have begun to explore the factors that affect the burning rate of oil pool fires. Scholars' research mainly focuses on the size of the oil pool, fuel type, placement, external wind environment, lip height and other aspects. In addition to the above factors that affect the combustion rate, the absorption of the fuel itself, the fluidity of the gas, the ambient temperature, and the relative humidity will also have a certain impact on the combustion rate.

This article focuses on the combustion characteristics of a single oil pool fire, analyzes the influence of external and internal factors on the combustion of oil pool fires, summarizes the current research status of oil pool fire combustion behavior, and further understands the key points and difficulties of the problem. This will provide reference for the cleanup of ocean oil spills.

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2. Internal factors affecting the burning of single oil pool fire

2.1 The influence of oil pool size on combustion rate

VIBlinov and GNKhudiakov [3] were the first to study the combustion of a single oil pool fire with different diameters. They used four fuels of gasoline, diesel, kerosene and solar oil to carry out a large number of pool fire simulation experiments. The diameter of the oil pool was set from 0.004m to Between 3m. The study found that there is a non-linear relationship between the burning rate and the diameter of the oil sump. As the diameter of the oil sump increases, the burning rate first decreases and then increases (Fig.1). When the diameter of the oil sump is less than 1 cm, the burning rate is greater , The oil sump diameter and the burning rate are negatively correlated; when the oil sump diameter is about 10 cm, the burning rate is the smallest; after that, the oil sump diameter and the burning rate are positively correlated. In addition, the study pointed out that the flame height and burning rate showed similar laws with the diameter of the oil pool.

Hottel [4] proposed through research that the combustion rate change of oil pools of different diameters is divided into three regions: laminar flow state (D<3cm), transition state (3cm<D<1m), turbulent flow state (D>1m). When the diameter of the oil pool is less than 3cm, the flame is in a laminar flow state, and the burning rate decreases with the increase of the oil pool diameter; when the oil pool diameter is between 3cm and 1m, the flame is in a transitional state, and the burning rate is The pool diameter is positively correlated; when the oil pool diameter is greater than 1m, even if the oil pool diameter is increased, the combustion rate will no longer increase significantly. He pointed out that oil pool fire combustion is a process of heat transfer. Heat transfer mainly includes three methods: conduction, convection and radiation. Three methods exist in the entire combustion process.

Through research, J.L.deRis [5] proposed that as the diameter of the oil pool increases, the dominant way of heat transfer will change. The research results show that the heat transfer of the laminar oil pool fire with a diameter of less than 5cm is dominated by heat conduction; when the diameter is between 5cm and 50cm, the flame radiation is not important, so the flame transfer is controlled by convection heat transfer; for those with a diameter greater than 50cm The heat transfer of oil pool fire is dominated by radiation. We found that for pool fires with a smaller diameter, the contribution of conduction and convection to the overall heat transfer is considerable. In this case, heat conduction and heat transfer can be controlled by the choice of wall materials, and convective heat transfer can be controlled by the fuel level.

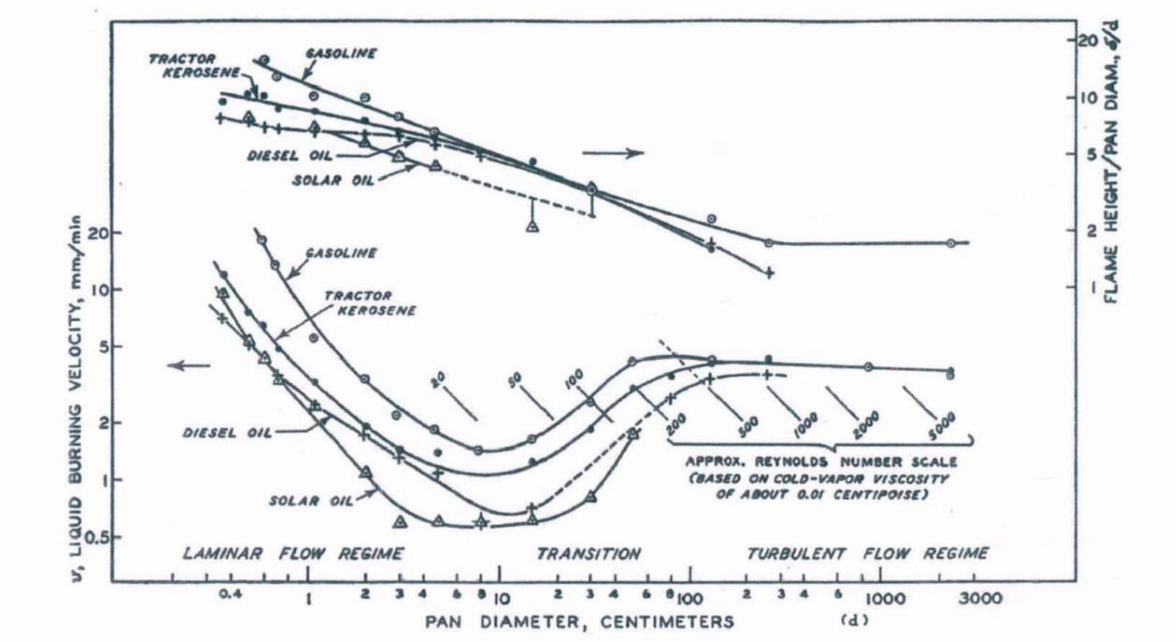

Fig.1 The burning rate and flame height of an oil pool fire vary with the diameter of the oil pool

ISSN: 2414-1895
DOI: 10.6919/ICJE.202011_6(11).0052

2.2 The influence of fuel type on combustion rate

Except that the size of the oil pool has a significant effect on the burning rate, the burning rate of an oil pool fire with the same diameter varies greatly with different fuel types, which is related to the combustion properties of the fuel itself. For example, the burning rate of flammable liquids such as alcohol is relatively large, while the burning rate of oil pool fires of crude oil is relatively low.

Jill M. Suo-Anttila [6] used common transportation fuel ethanol, toluene mixture, JP-8 and heptane to measure the radiation distance from the pool surface to 1 meter above the pool fire at a distance of 1.3 to 4.8 mm at 38 cm Thermal radiation spectrum. The emission and absorption characteristics of ethanol, toluene mixed fuel, JP-8 and heptane are studied. Water and carbon dioxide are the main emission sources of ethanol fires, and the products of the other three fuels are mainly soot. Due to the absorption of cold water, carbon dioxide, fuel vapor and soot, a large part of the heat radiation reaching the fuel surface is absorbed. The fraction of heat transferred by each fuel is different, the ratio of transferred heat drops the fastest in the first 1 mm, and then steadily decreases. Ethanol is the most absorbing, more than 90% of the heat is absorbed by the first 3 mm of fuel; heptane is the most transmissive, the first 3 mm of heat absorbed just over 65%; JP-8 absorbs more than 75% within 3 mm The toluene mixture absorbs about 85% of the heat.

3. External factors affecting the burning of a single oil pool fire

3.1 The influence of the inserted object on the burning rate

If you want to speed up the burning rate of the oil pool, you should reduce the heat loss of the flame to the surrounding environment and increase the heat feedback of the fuel. The study found that adding a good conductor to the oil sump can increase the burning rate of the oil sump.

In 2015, Rangwala [7] and others explored the effect of inserting heat-conductive objects (thin aluminum rods) into the liquid oil pool fire on the burning rate of the pool fire. They used three oil pool diameters: 10cm, 50cm, 1m, and studied the insertion The effect of the height and number of thin aluminum rods on the burning rate is that the fuel and heat-conducting materials used in the three oil pool diameters are different. This is because the fire temperature of the oil pools of different diameters is different. The larger the oil pool diameter, the higher the flame temperature. The experimental results show that the thin aluminum rod can increase the heat transfer from the flame to the fuel surface and increase the burning rate of the oil pool. The burning rate of an oil pool with a diameter of 10cm increased by about 3.3 times, the burning rate of an oil pool with a diameter of 50cm increased by about 2.8 times, and the burning rate of an oil pool with a diameter of 1m increased by nearly 6 times, indicating that the insert can increase the burning rate of the pool fire.

On the basis of Rangwala's research work, Sezer [8] et al. further analyzed the influence of a good thermal conductor on the combustion behavior of n-hexane pool fires by establishing a numerical model. They used cylindrical aluminum rods with different heights ranging from 9cm to 16cm, immersed them in a liquid pool, and studied the physical process of heat transfer from the flame to the aluminum rod and the aluminum rod to the liquid pool: one-dimensional transient transmission of the embedded object with heat conduction Thermal model (flame-aluminum rod) and two-dimensional transient heat transfer model (aluminum rod-liquid fuel), and then obtain the temperature field distribution of aluminum rod and fuel. The experimental measurement results of temperature field and mass burning rate are in good agreement with the prediction results of the numerical model. Due to the good thermal conductivity of the inserted object, the heat transfer from the flame area to the unburned fuel area is very fast, so the temperature near the fuel surface can reach the boiling point of the fuel, accelerate the evaporation of the fuel, and significantly increase the combustion rate. Through parameterized study of the influence of the length of the aluminum rod on the flame, it is found that the burning rate of the liquid oil pool flame has increased by 4 times due to the heat transfer effect of nucleate boiling and film boiling on the surface of the aluminum rod.

In 2018, Arsava[9] and others designed a burner to quickly deal with oil spills. The burner is made of copper, and a 0.25cm thick copper porous mesh is placed on the liquid surface (Figure 1.2). The effect

ISSN: 2414-1895 DOI: 10.6919/ICJE.202011_6(11).0052

of centimeter-thick crude oil film on the northern slope of Alaska on the burning rate of salt water. The experimental results show that the temperature of the copper mesh is higher than the boiling point of the oil, which may cause nucleate boiling. The mesh coil system can burn thin slick oil on the water surface, and the efficiency is 400% higher than the baseline. A simple integral model is proposed to predict the temperature distribution of grid, oil layer and water layer. The predicted temperature distribution is in good agreement with the experimental results.

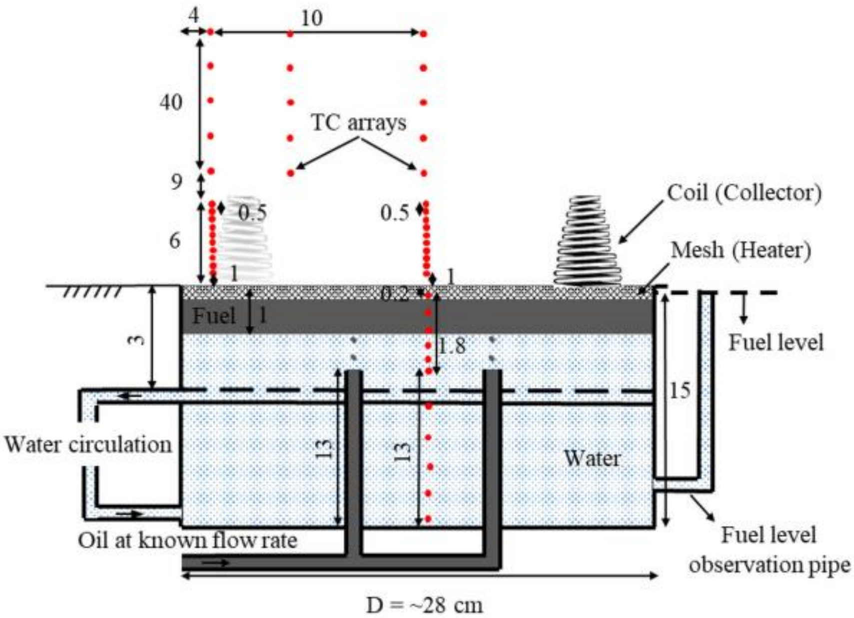

Fig.2 Schematic diagram of experimental device and control heat transfer mechanism

Wang Jingwu[10] and others used FDS software to study the combustion behavior of n-heptane oil pool fire when aluminum plates of different heights were inserted. After the plate was inserted, the combustion continued to expand, the flame height continued to rise, and finally reached a stable state. , The height does not change; the height of the flame in the stable state is higher than that of the uninserted plate, and as the height of the plate increases, the flame height shows a non-monotonous change trend of first increasing and then decreasing. This non-monotonic change is mainly the result of the game of two effects: one is that the aluminum plate feeds back the flame heat to the fuel through heat conduction; the other is the external radiation and convection heat dissipation after the aluminum plate absorbs the flame heat. When the height of the dimensionless aluminum plate is 2.5~3.0, the insert plate has the greatest effect on combustion enhancement.

3.2 The influence of external wind environment on the burning rate

The flow of air in the external environment, the wind speed, also has an impact on the combustion rate. Blinov [3] studied the burning behavior of oil pool fire at a certain wind speed. The results show that, within certain conditions, for light oils, the burning rate is proportional to the wind speed. The greater the wind speed, the greater the burning rate, but it will not increase indefinitely. When it reaches a maximum, it will stabilize; For heavy oils, wind speed has almost no effect on the burning rate.

F. Tang [11] tested the response of the burning rate of an acetone pool fire to the lateral air velocity. The correlation between the mass combustion rate of acetone pool fire and the fuel type and crosswind is proposed. A relatively small pool fire has a higher combustion rate enhancement rate than a relatively large pool fire. Pool fires generally increase linearly with the increase of lateral air velocity. Apte [12] et al. used aviation kerosene as fuel, and the diameter of the oil pool was 0.6m to 2m. They pointed out that the burning rate of the oil pool fire decreased with the increase of wind speed.

ISSN: 2414-1895
DOI: 10.6919/ICJE.202011_6(11).0052

Hu et al. [13] studied the effect of lateral airflow on flame radiation feedback in a medium-sized pool fire. Two fuels, ethanol and heptane, were used in a pool fire test with a lateral air velocity of 0-2.5 m/s in square water with a combustion size of 10-25 cm. The experimental results show that the radiant heat flux of the upstream fuel surface area varies with The monotonous decrease of the lateral air velocity increases more significantly. At the same time, it is proved that under the action of lateral airflow, for a medium-sized pool fire, conduction and convection feedback through the pool wall dominate, rather than flame radiation feedback. The researchers also found that at a certain lateral air velocity, the combustion rate decreases with the increase in the size of the liquid pool, which is the opposite of still air conditions. Under the action of lateral airflow, the burning rate of gasoline pool fire increases linearly with the increase of lateral airflow velocity [14]. In general, the effect of wind speed on oil pool fire is uncertain, and is greatly affected by the diameter of the oil pool and the type of fuel.

3.3 The influence of lip height on combustion rate

The lip height refers to the vertical distance between the top of the side wall of the oil pool and the fuel surface. In the experiments of V.I.Blinov and G.N.Khudiakov [3], it has been clearly pointed out that the lip height has a significant effect on the combustion behavior of the oil pool fire. In the early stage of research, the liquid level balance device was not used, and the lip height dynamically increased with fuel consumption, making it impossible to quantitatively study the influence of lip height. During this period, Magnus [15] studied the lip height in 1961. The burning behavior of the oil pool fire changes when it is rising, pointing out that the lip height affects the burning rate by changing the air entrainment. Artemenko and Blinov [16] analyzed the influence of lip height on the burning rate of small-scale oil pool fire in 1968, and believed that the lip height inhibited the burning of oil pool fire to a certain extent: the oil pool burning rate and the lip height are in inverse proportion.

Later, scholars applied the liquid level balance device to the experiment and entered the stage of quantitative research on lip height. In 1974, Nakakuki [17] explored the effect of lip height on combustion behavior. The diameter of the oil pool was 1cm-2cm. The study pointed out that the burning rate of oil pool fire of this size decreased with the increase of lip height. Babrauskas [18] analyzed the influence of the lip height on the heat feedback mechanism of the oil pool: (1) Increased the turbulence at the lip of the oil pool, thereby enhancing the convective heat transfer; (2) The temperature distribution of the inner wall of the oil pool changes with the lip height , Thereby changing the heat loss and heat transfer; (3) enhancing the external heat radiation.

Dlugogorski and Wilson [19] conducted a small oil pool fire experiment. The diameter of the oil pool was 4.52cm, 4.73cm and 6.71cm. They pointed out that the combustion rate decreased exponentially with the dimensionless lip (the ratio of lip height to oil pool diameter). . In 2015, Hu et al. [20] selected the lip height of 0.3cm-2 cm to study the effect of different lip heights (0.3-2 cm) on the flame necking dynamics and unstable motion in the ethanol pool fire (4cm-25cm) . Flame necking is one of the basic characteristics of diffusion cell fire. It is the flame caused by the close buoyancy (density difference) of the air flow, and it is also the main source of unstable flame oscillation. Three different flame unstable motions are determined: small size R-T instability, extended R-T instability and puffing instability. It is found that as the height of the lip increases, the main unstable motion transitions from extended R-T instability to puffing instability.

In 2017, Shi et al. [21] carried out experiments using methanol as fuel, the diameter of the oil pool was 2.5cm and 5cm, and different dimensionless lip heights were selected as the research objects. The results showed that the effect of convective heat transfer on the mass combustion rate It becomes more prominent, the dimensionless height increases, and the combustion rate presents a non-linear trend of decreasing first and then increasing. A numerical model is used to verify the experimental results, and the numerical simulation results are in good agreement with the experimental results. In 2018, Dang Xiaobei et al. [22] used experimental and numerical simulation methods to study the evolution of the burning rate and flame height of oil pools with different lip heights. The oil pool diameters were set to 5cm, 10cm, 15cm and 20cm, and the lip heights were respectively. Corresponds

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to 0.25, 0.5, 1, 1.5 and 2 times the diameter of the oil pool. The research conclusions show that the combustion rate of all sizes of oil pools has the same evolution law with the lip height, showing a trend of decreasing, then increasing and then decreasing. The reason is that the thermal feedback mechanism evolves with the lip height. With the increase of the lip height, the flame height of the oil pool with a diameter of 5 cm decreases first and then rises with the increase of the lip height, and the flame height trend of the other oil pools decreases with the increase of the lip height. According to the current research status of oil pool fire, predecessors have carried out many studies on oil pool fire (Table 1), verifying that the lip height has a non-negligible effect on the burning behavior of oil pool fire.

Table 1 Predecessors' research on the height of the lip of the oil pool (in time order)

Time	Oil pool diameter(cm)	Lip height	fuel	Measurement parameters	literature
1961	12,18,25.5,30,60,120	—	Ethanol,gasoline	Burning rate, axis temperature	Magnus[15]
1968	1.5,2.2,3.6,5,8,15	—	Aviation gasoline, isoamyl alcohol	Flameheight,Burning rate	Artemenko & Blinov[16]
1974	1,2	0-4cm	N-heptane, ethanol	flame geometry, Burning rate	Nakakuki[17]
1995	4.52,4.73,6.71	0.22-2.04cm	Ethanol	Dimensionless temperature,Burning rate	Dlugogorski & Wilson[19]
2015	4~25	0.3-2cm	Ethanol	Flame frequency	Hu et al[20]
2017	2.5,5	0.25D-2.4D	Methanol	Temperature,Burning rate	Shi et al[21]
2018	5,10,15,20	0.25D-2D	N-heptane	Flame height,Burning rate	Dang et al[22]

Note: "—" means that the liquid level balance device is not used

4. Conclusion

The continuous occurrence of ocean oil spills has made marine and coastline oil pollution one of the environmental problems that plague people around the world. Comparing the factors that affect the burning of oil pool fires, it can be found that external factors have a greater impact on the burning rate of a single pool fire. In the case of an oil spill at sea, how to create favorable external conditions to maximize the burning rate of the spilled oil and promote its application is still the focus of future work.

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