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Research Progress on Combustion Characteristics of Multi-pool Fire

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Abstract

In-situ combustion is a common method to deal with oil spills at sea. In order to speed up the burning rate of oil spills, it is necessary to understand the burning behavior of oil pool fires. In view of the related research work, this paper summarizes the combustion dynamics of pool fire analyzing the combustion characteristics and behavior of multi-pool fire, including the flame merge, fire whirlwind, burning rate, burning time four aspects.

Keywords

Multi-pool flame; Flame merging; Combustion rate.

1. INTRODUCTION

Multi-oil pool fire source refers to the simultaneous burning of two or more adjacent fire sources. It is a special and important burning phenomenon in forest fires and mass urban fires. Once it occurs, it is easy to develop into a very dangerous regional fire. Due to the interaction between fire sources, the mechanism of multi-fire source combustion is more complicated.Multi-fire source combustion is very different from single fire source combustion, including the following aspects:

(1) In terms of heat feedback. A single oil pool fire source burns, and the energy to maintain the fire source comes from the heat feedback of its own flame to the liquid surface; multi-fire source combustion, the liquid surface of each fire source not only receives the heat feedback from its own flame, but also receives adjacent fires. The radiant heat transfer of the source, the radiant heat flow received by the fire source is greater than the radiant heat flow required to maintain combustion, the fuel evaporation increases, and the external manifestation is that the combustion rate increases.

(2) Air entrainment. Each fire source requires enough air to sustain combustion. When a single fire source burns, the oxygen comes from the air entrained from the surrounding; when multiple fire sources burn, when the fire sources are far away from each other, the number of fire sources has little effect on air entrainment, but when the distance between the fire sources is close, There may be competition for air.

(3) In terms of flow, when a single fire source burns, air entrainment only flows from around the fire source to the fire plume; multi-fire source combustion not only entrains the air around the fire source, but also the gap between the fire sources. There is also an entrainment effect on air in the air. When there are multiple fire sources, the flow of air will become very complicated and turbulent.

(4) In addition, there are differences in the influence of atmospheric pressure between the two. The air supply of the fire source of a single oil pool is sufficient, the entrainment air is not restricted, and the atmospheric pressure around the fire source remains basically unchanged;

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when there are multiple fire sources During distributed combustion, the air flow is obstructed, the fire sources compete for air, and the atmospheric pressure around the fire source decreases. It can be seen that when multiple fire sources burn, the complex interaction between fire sources not only has a significant impact on the burning rate and flame shape, but also induces special fire phenomena, such as flame mergers and fire whirlwinds. Due to the huge hazard and destructiveness of mass fires, in recent years, scholars have conducted in-depth research on the physical mechanism of the combustion behavior of multiple fire sources, mainly focusing on the four aspects of flame merger, fire cyclone, burning rate, and burning time.

2. FLAME MERGE

Combustion of flames is a typical sudden fire phenomenon in multi-fire source combustion. The combustion flames are inclined and merged under certain conditions. The combined flames have an impact on air entrainment and heat feedback, resulting in flame height and burning rate. A significant increase. Putnam and Speich [1] were the first to study the phenomenon of multi-fire source combustion. They used natural gas as fuel to study the flame merging phenomenon of fire arrays. The gas jet fire is used to make the air flow velocity low enough to ensure that the flame is buoyant. The fire array composition method includes two fire points, three fire points to form a triangle, three fire points to form a straight line, and six to seven fire points. Form a regular hexagon. They deduced the dimensionless expression of flame height based on the combustion model of a single fire source.

$$\frac{L/L^{*}-1}{n^{2/5}-1}=f\left[D,n,S/({Q_0}^{2}/g)^{1/5}\right]$$

Where is the combined flame height, the flame height of a single fire source, the distance between the fire spots, the volume flow rate of the fuel, the number of fire spots, and the acceleration of gravity. However, in the analysis process, they assumed that the flame did not tilt significantly due to the interaction, resulting in a large deviation between the experimental data and the theoretical model. Subsequently, Thomas [2] analyzed the flame fusion problem when two rectangular fire sources were placed in parallel (Figure 2). The oil pools had diameters of 30cm×30cm and 30cm×60cm. Natural gas was also used as fuel to analyze the flame force. It is believed that the interaction between the upward buoyancy of the flame and the pressure perpendicular to the flame surface is the cause of the flame tilt. After simplified mathematical derivation, the critical basis for flame merging is obtained

$$:\frac{L}{D}=9(S^{3}/DW^{2})^{1/2}$$

The formula represents the height of the flame, the distance between the fire points, and the sum is the length and width of the rectangular oil pan. This formula is only suitable for small cases. The relationship does not include the number of fire sources, so they believe that the combined flame height has nothing to do with the number of fire sources. Experiments also found that when the flame height is 1.2 times the height of a single flame, flame merging occurs.

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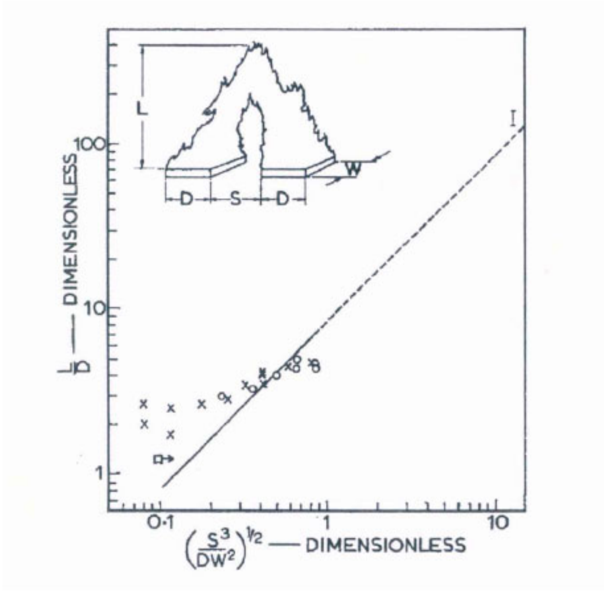

Figure 1. Two rectangular oil pool fire studies by Thomas

On this basis, Baldwin [3] did further research on the fire source of multiple oil pools. He introduced a series of assumptions: the amount of air flowing into the fire array is equal to the amount of air required for fuel, the flame length of any flame is equal, and the flame The height has nothing to do with the distance between the fire spots, etc., and the critical criterion for the occurrence of flame merging is deduced:

$$\mathrm{S}/(\mathrm{W}^2\mathrm{D})^{\frac{1}{3}} = 0.14(L/D)^{0.96}$$

The relationship also does not involve the number of fire sources. They believe that when the distance between the fire points/the height of the flame is less than 0.22, the interaction between the fire sources has a significant influence. The article also discussed the situation of urban fires, and concluded that when the building density of the city reaches more than 64%, urban fires may merge with flames.But as far as the actual situation is concerned, when multiple fire sources burn, the position of each fire source may not be evenly distributed, the flame length is different, and the amount of air flowing into the fire array is not equal to the amount of air required for fuel, so the author adopts the assumption Not very reasonable. Sugawa and Takahashi [4] used hexane as fuel to study the flame fusion judgment basis and flame height when two rectangular fire sources were placed in parallel and when 3-4 circular oil pools with a diameter of 12 cm were symmetrically distributed. The empirical formula for the flame height of a circular fire source and a rectangular fire source. As the distance between the fire sources increases, the flame height gradually decreases.

Weng [5] and others have made great contributions to the study of flame mergers, and the research methods are very worthy of our study. They used a combination of experimental research, theoretical analysis and numerical simulation to further study the flame height of the flame combination. The diameter of the oil pool is 15cm, and propane is used as the fuel. The author first compares the FDS numerical simulation results with the experimental data, and the results show that the FDS simulation of multi-fire source combined flame is accurate.

Based on the above research, it is worth noting that when using gas fuel to study multi-fire source combustion, scholars in most cases only consider the effect of air entrainment flow on flame merging, and do not consider the effect of fuel's own heat feedback. Therefore, The adaptation of the empirical model is very limited. Scholars generally believe that the fundamental combustion mechanism is the interaction of air entrainment and heat feedback.

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Because flame merging and flame height, fire source size, fire point distance, burning rate, and flame temperature are mutually influencing rather than independent of each other, there may be no contradiction between different flame fusion critical criteria [6]. In 2018, Jiao Yan et al. proposed another criterion for the combination of flames of multiple oil pool fire sources, that is, the type of fuel. They used n-heptane and ethanol for comparative experiments, and the results showed that the multi-oil pool fire source composed of dense smoke fuels such as n-heptane has a larger flame fusion critical S/D than the array composed of low-smoke fuels such as ethanol. The reason is the burning rate and flame height.

However, up to now, there is no good criterion for whether the flame reaches flame fusion. It is generally considered that the flame tip is in contact with each other as flame fusion. However, due to the instability of pool fire combustion, it is difficult to judge in the real experiment process. Different degrees of flame fusion will cause the fire source to show different changes in the combustion characteristics such as fire cyclone, burning rate, and burning time.

3. FIRE WHIRLWIND

Fire cyclone, also known as flame tornado, is another special fire phenomenon in the burning of multiple fire sources. Its essence is a swirling flow with combustion chemical reaction. When multiple fire sources burn, the plumes between the fire sources The flow influences each other, the flow field is complex and turbulent, and it is easy to form a vortex. When the strength of the vortex is large enough, a fire whirlwind may be formed. The strong tangential velocity, air entrainment velocity, and axial velocity of the fire cyclone are far greater than those of ordinary fire plumes, which make the flame height higher, the flame volume larger, and the burning rate faster, which greatly accelerates the spread and spread of the fire.

Byram and Martin [7] first produced a fire cyclone in the laboratory. The diameter of the oil pan used in the experiment was 12 cm, and the fuel was alcohol. The experiment found that the burning rate of alcohol in the fire whirlwind is three times that of the ordinary pool fire. They discussed the basic causes of the fire cyclone, and proposed that the generation of vortices, fluid pools and friction are the three basic conditions for the formation of the fire cyclone.Satoh and Yang [8] based on the four-wall-slit-flame fire cyclone physical model study, and believed that the generation of the fire cyclone may be due to the instability of the atmosphere. They used a variety of fuels to conduct research and found that the length of the fire cyclone was related to the heat of combustion. The length of the fire cyclone decreased as the fuel volatility decreased, but they did not carefully measure the flow and combustion characteristics of the fire cyclone.Lei Jiao and Liu Naian [9] used n-heptane as the experimental fuel and used the four-wall-slit model to study the relationship between the combustion rate, flame height and flame temperature of the medium-sized fire cyclone formed by n-heptane. , And gave a conclusion on the different combustion characteristics between the fire whirlwind and the ordinary pool fire. Experimental observations and data show that the free-burning fire cyclone is a highly stable combustion phenomenon, and during the combustion process, the fire cyclone has a long and stable combustion stage.

Li Zheng et al. [10] studied the fire source of multiple oil pools and found that three heptane oil pools with a diameter of 40cm and an interval of 1.2m had a fire cyclone phenomenon (as shown in Figure 2), and the flame height was about 2.2m. Summarizing the results of previous studies, it is found that most of them use walls or glass to make it easier to form a fire tornado. However, there is no clear conclusion about the relationship between the combination of flames formed by the free burning of a multi-oil pool and the fire tornado.

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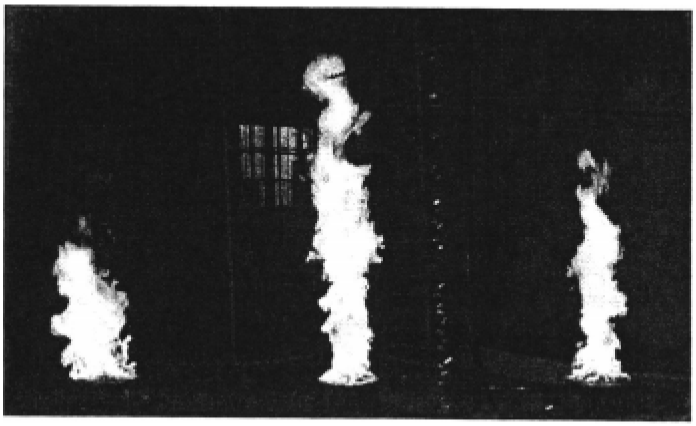

Figure 2. Fire whirlwind phenomenon caused by the burning of three fire sources

4. BURNING RATE

Liu Qiong and his colleagues [11-12] studied the combustion rate change law of n-heptane free diffusion with multiple fire sources, and the results showed that changes in the distance between fire sources and the number of fire sources have an effect on the combustion rate of multiple oil pool fire sources. The size of the impact is not consistent. They also analyzed the changes in the burning rate of different fire source arrays and found that the burning rate increases as the array increases, which is in line with the actual situation.

Li Zheng [10] and others carried out an experimental study on the combustion characteristics of heptane pool fires. The flame heights of single, two and three single fire sources burning in heptane pool fires with diameters of 0.1m, 0.2m and 0.4m were measured. The characteristics of flame volume, burning rate and flame temperature were studied. The study found that: (1) The characteristic parameters such as flame height, flame volume and burning rate increase with the decrease of the distance between the fire sources. (2) The interaction mechanism between the fire sources changes with the distance between the fire sources . When the dimensionless distance between fire sources S/D (S means fire source distance, D means oil pool size) is greater than 4, the heat feedback enhancement effect is dominant; when S/D is 2 to 4, the two action mechanisms compete with each other; S When /D is 0~2, the heat feedback is strengthened and once again dominates. (3) The author also established a heptane multi-fire source combustion rate calculation model, which can use flame temperature and flame volume to calculate the combustion rate of any fire source in multi-fire source combustion.

Vasanth et al. [13] used CFD to perform numerical simulations (as shown in Figure 3). Assuming that the air entrainment rate does not affect the burning rate, they studied the flame fusion of double circular heptane pool fires with diameters of 4.8cm, 6.8cm, and 8.3cm, respectively. Behavior, focusing on the effect of S/D on flame merging, where S is the distance between the fire points and D is the diameter of the oil pool. The results show that: (1) The flame temperature, flame height and burning rate all increase with the increase in the diameter of the participating oil pool. And increase. (2) Among the four S/D ratios of 0.25, 0.45, 0.66 and 1.08, when the S/D is 0.45, the flame height and burning rate are the largest. (3) Flame fusion occurs when S/D is less than 0.45.

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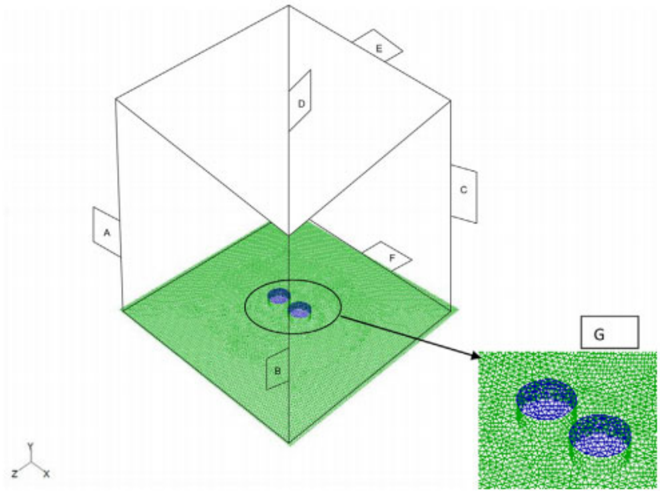

Figure 3. CFD simulation model of Vasanth et al

Afterwards, Huffman [14] and others conducted a more detailed multi-oil pool fire source experiment. They placed the fire source along the diagonal of the octagon . The fire sources were 9 and 13 respectively. The experimental fuel Using methanol, propanol, hexane and cyclohexane, the diameter of the oil pool is 5cm, 10cm, and 15cm respectively. The experimental results found that with the continuous increase of the fire point distance, the burning rate of the center oil pool and the edge oil pool both increased first and then decreased. The research revealed the variation of the burning rate and flame height of the fire source of the multi-oil pool with the diameter of the fire spot, the distance between the fire spots and the fuel type. The heat feedback of the fire source of the multi-oil pool and the air entrainment mechanism were discussed.

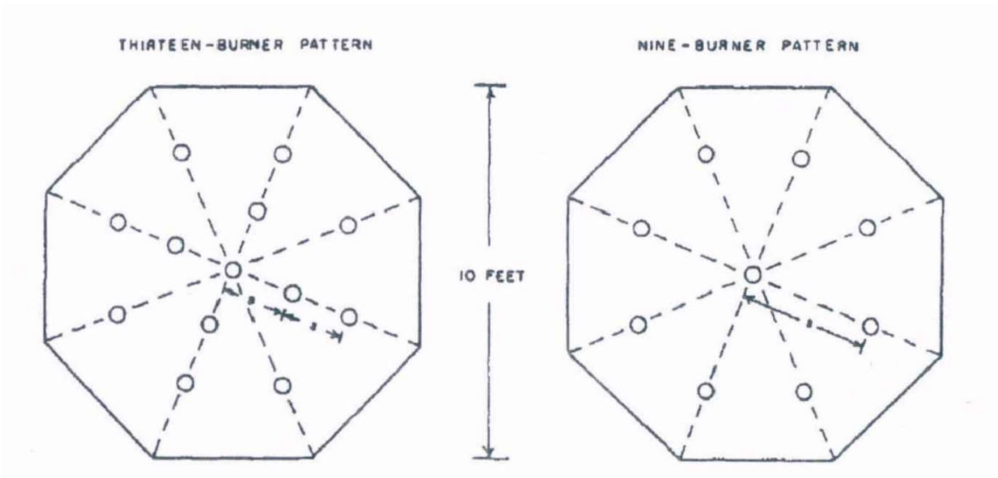

Figure 4. Huffman et al.'s regular octagonal multi-oil pool fire source model

5. BURNING TIME

Burning time refers to the total burning time from the start of the fire to the complete extinguishment of the fire source. It represents the burning rate of the fire source in the sense of time average, and it is more convenient to obtain the burning time data during the combustion process of multiple fire sources. whole. Satoh and his collaborators [15] have made outstanding contributions to the study of the burning time of multiple fire sources. They creatively introduced the burning time of multiple oil pool fire sources to describe the flame characteristics and defined the dimensionless comprehensive influence coefficient:

$$I(m) = 1 - \frac{ABOT(m)}{BOTR}$$

Where is the burning time of the numbered fire point in the static state, which is the burning time of a single fire point, and the interaction coefficient A(m,n) is defined to characterize the interaction between the fire point and the fire point n, assuming the fire The size of the interaction between the sources is inversely proportional to the distance between the fire points, and then the sum of A(m,n) is equal to I(m,n). In order to study the influence of shear wind on the burning time, they defined dimensionless shear Flow influence coefficient:

$$IS(m) = \frac{BOTS(m) - BOT(m)}{BOTR}$$

Among them, it represents the burning time of the fire source when there is a shearing wind. A comparative analysis of the burning time of each fire source under windy and no wind conditions shows that the shearing wind has a significant influence on the combustion behavior of the fire source. Liu Naian [16] and Liu Qiong of the University of Science and Technology of China and others further developed the BOT analysis method. They also used I(m), A(m,n) and three indexes, but they assumed that the fire source was between The interaction size of is proportional to the square of the distance, and it is pointed out that I(m)=0.5 is the basis for judging flame fusion. In the process of analysis, they put forward the concepts of global average burning rate and fuel surface ratio, and systematically analyzed the complicated competition relationship between the two mechanisms of air entrainment and thermal feedback between the fire sources as the distance between the fire sources and the size of the fire square changes. Established a global macroscopic model describing the overall combustion behavior of multiple fire sources with the change of fire source spacing and array size.

6. WORK VERSION

Multi-oil pool fire source combustion is extremely complicated, not only affected by its own size and the physical characteristics of the fuel itself, but also by external environmental factors such as the distance between the fire point, the flame distribution array, and the shear wind. There is still a lot of work to be done for the research on the fire source of multiple oil pools. The following is a list of some aspects that can be focused on in further research work: (1) A cushion water layer is added under the oil pool to truly simulate the offshore oil spill scene. Find a method to quickly burn oil spills at sea to provide scientific basis and theoretical support. (2) Selection of fuel type. In previous studies, most of the oil fuels are used, and more different types of fuels can be selected to obtain the difference in combustion behavior between different fuels. (3) Distribution type of flame array. Although scholars have proposed many types of symmetrical arrays with multiple fire sources, in actual situations, there will be a large number of asymmetrical arrays. The mechanism of air entrainment and thermal feedback between the fire points is more complicated and needs to be more in-depth. Research.

7. CONCLUDING REMARKS

In recent years, marine oil spills have occurred frequently and the amount of oil spills is huge, which not only caused water pollution and the death of marine life, but also caused irreparable damage to human life and health and the ecological environment. This article summarizes the single oil pool fire source, Based on the main research progress of the multi-oil pool fire source, the factors affecting the burning rate are summarized from the perspective of experimental research, theoretical analysis and numerical simulation, which provides a guiding basis for increasing the burning rate of the oil pool fire.

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REFERENCES

[1] A.A.Putnam,C.F.Speich,A model study of the interaction multiple turbulent diffusion flames.Proceedings of the Combustion Institute,1963,9(1):p,867-877.

[2] P.H.Thomas,R.Baldwin,A Heselden.Buoyant diffusion flames:some measurements of air entrainment,heat transfer and flame merging.Proceedings of the Combustion Institute, 1965, 10(1):p,983-996.

[3] R.Baldwin,Flame merging in multiple fires.Combustion and Flame,1968,12(4):p,318-324.

[4] Sugawa O,Takahashi W,Flame height behavior from multi-fire and materials,1993,17:111-117.

[5] Weng WG,Kamikawa D,Fukuda Y,Hasemi Y,Kagiya K,Study on flame height of merged flame from multiple fire sources.Combustion science and Technology(2004)176:2105-2123.

[6] Wan H,Ji J,Li K,et al.Effect of air entrainment on the height of buoyant turbulent diffusion flames for two fires in open space[J].Proceedings of the Combusion Institute,36:3003-3010.

[7] Byram G,Martin R.Fire whirlwinds in the laboratory[J].Fire Control Notes,1962,23(1):13-7.

[8] Satoh,K.K.T.Yang.Messurements of fire whirls from a single flame in a vertical squre channel with symmetrical corner gaps[J].Fundamentals of Heat Transfer in Flame,ASME HTD,1999,364-4:167-173.

[9] Lei,N Liu.Burning rates of liquid fuels in fire whirls[J].Combustion and Flame,2012,159(6):2104-2114.

[10] Li Zheng, Liu Naian. Experimental and Model Research on the Combustion Characteristics of Heptane Pool Fire with Multiple Fire Sources[M].2006.

[11] Lei,N Liu.Burning rates of liquid fuels in fire whirls[J].Combustion and Flame,2012,159(6):2104-2114.

[12] Liu N,Liu Q,Deng Z,et al.Burn-out time data analysis on interaction effects among multiple fires infire arrays[J].Proceedings of the Combustion Institute,31:2589-2597.

[13] Vasanth S,Tauseef S,Abbasi T,et al.Assessment of the effect of pool size on burning rates of multiple pool fires using CFD[J].Journal of Loss Prevention in the Process Industries,30:86-94.

[14] Huffuman K,Welker J,Sliepcevich C.Interaction effects of multiple pool fires[J].Fire Technology, 1969, 5:225-232.

[15] K.Satoh,M.Shinohara,K.Yang,Experimental observations and analysis of square arrays of equi-distant multiple fires.Fire Safety Science-Proceedings of the 3rd Asia-Oceania Symposium on Fire and Technology,1988,3:p.517-528.

[16] Liu N,Liu Q,Deng Z,et al.Burn-out time data analysis on interaction effects among multiple fires infire arrays[J].Proceedings of the Combustion Institute,31:2589-2597.