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Review of Oil Pool Fire Research

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Abstract

Oil has a very important place in modern industry. However, the safe application of petroleum products is very important for the safety of human life and environmental safety. Therefore, many researchers have conducted extensive research on the combustion properties of petroleum products and the performance of fire extinguishing agents. This paper first describes the progress of several different influencing factors in terms of their impact on the development pattern of oil pool fires, including ambient wind, pressure, tunnel environment, and obstructions. In addition, the progress of research on risk assessment models for oil pool fires is summarized. Finally, the research progress in some new fire extinguishing materials, such as protein foam, two-fluid water mist and modified ultra-fine dry powder, is presented.

Keywords: Oil fire; Fire influencing factors; Fire risk assessment models; Fire extinguishing materials

Introduction

Petroleum is a yellow, brown or even black flammable viscous liquid extracted from deep underground. They are generally less dense than water and have a wide range of boiling points, from room temperature all the way up to 800°C or more. The main components of petroleum are hydrocarbons with different molecular sizes, different structures and large quantities, including alkanes, cycloalkanes and aromatic hydrocarbons [1].

Oil has driven social development and economic growth for more than 150 years since the Industrial Revolution. Today, oil accounts for approximately 30% of total global energy consumption and will continue to be an integral part of the future. However, as the petrochemical industry, which involves large amounts of flammable and explosive materials, grows, environmental and safety issues (such as global warming, fires and explosions) have become primary challenges and are receiving increasing attention from researchers. For example, in the process of oil storage and transportation, some storage and transportation equipment are old and in disrepair. These aging and obsolete equipment cannot meet the needs of high-quality storage and transportation of petroleum products. Therefore, in the process of storage and transportation, a series of safety and environmental protection problems may occur. In addition, the safety awareness problems and irregular operation of oil storage and transportation related staff may also cause fire accidents and leakage accidents [2].

Pool fires, as one of the most serious disasters of flammable liquid spills, are usually associated with the safety of liquid fuels in modern production and life. A pool fire is also defined as a diffuse buoyancy flame in which the fuel is configured horizontally [3]. It is characterized by the establishment of a diffusion flame on a horizontal fuel, where buoyancy is the controlling transmission mechanism. This typical fire usually occurs after a flammable liquid pool has formed (tank or transport pipeline leak) and is then ignited. In such incidents, heat is transferred to surrounding equipment by convection and radiation, and combustion products are released into nearby spaces, posing a direct and significant threat to the safety of people and the environment. Therefore, quantification of oil pool fire combustion parameters plays an important role for fire safety in energy utilization.

Therefore, researchers have thoroughly studied some important parameters of oil pool fires such as flame height, jet frequency, air entrainment, temperature distribution, soot formation and radiation, and have developed many empirical, semi-empirical or theoretical models to explain these parameters [4-10]. However, the hazard level of oil pool fires varies with complex fire scenarios. Therefore, understanding the combustion parameters of oil pool fires under various scenarios is a fundamental area of research for hazard prediction and risk analysis. Such as pool size, initial fuel temperature, pool height (distance from fuel surface to pool edge) and pool geometry. Under different circumstances, the relevant parameters can be affected or even completely changed. In recent years, flame geometry, mass burn rate and temperature distribution under different boundary conditions have been studied by many scholars to provide a better basis for understanding oil pool fires [11-18].

Influence Factors, Risk Assessment and Extinguishing Agents for Oil Pool Fires

Influence of Factors Such as Environmental Wind and Pressure

By the late 1950s, Blinov and Khudyakov [5] conducted experiments on the effect of diameter on the combustion rate of pool fires, showing that the size of the pool is the most important factor in determining its combustion rate in still air. At the same time, the combustion rate increases in equal proportion to the wind speed [6]. However, as the research continued to advance, scholars found that this experimental result was not universal [7-10]. Under wind conditions, the pool fire behavior is driven by the coupling of buoyancy and wind, as shown in Figure 1, and the effect produced by wind is not the same under different conditions. A summary of relevant pool fire studies is shown in Table 1.

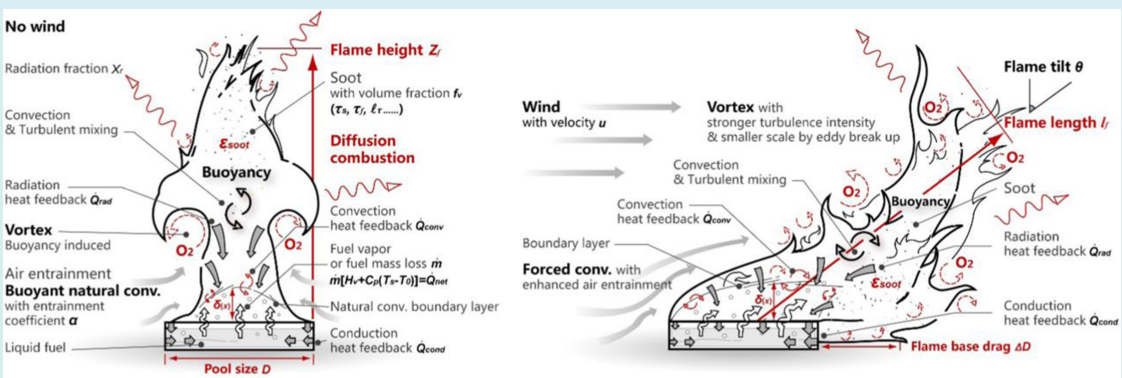

Figure 1: The physics of a pool fire: (a) in still air; and (b) in wind [7].

Reference	Fuel	Wind conditions	Wind speed
[9]	Gasoline	Cross air flow	3 m/s
[10]	Ethanol and heptane	Cross air flow	0–2.5 m/s
[11]	N-heptane	Two-way/indirect	0–4 m/s
[12]	RP-5 aviation fuel and diesel oil	Crosswind	0.15-17 m/s
[13]	Propane	Cross air flow	0–3 m/s
[14]	Heptane	Crosswind	0–8 m/s
[15]	Heptane	Crosswind	0–3.7 m/s
[16]	N-Heptane and ethanol	Crosswind	0–3.7 m/s
[17]	Heptane	Crosswind	0–3 m/s
[18]	Heptane	Longitudinal wind	0–2.49 m/s

Table 1: Summary of pertinent pool fire studies.

To improve the understanding of the combustion characteristics of oil pool fires in open environments with different scales of ventilation, Wang, et al. [11] investigated the mass burn rate and flame geometry of n-heptane pool fires under two-way ventilation conditions and developed prediction models for flame length and tilt angle under different ventilation rates. Lei, et al. [12] conducted an experimental study of the flame geometry characteristics of a large open pool fire under wind controlled conditions. Chen, et al. [13] compared the horizontal lengths of flames in ground pools and elevated pools under cross-flow conditions. Yao, et al. [14] investigated the effect of ventilation on the mass loss rate per unit area of heptane pool fires at different scales and used the results of small-scale pool fires to estimate the mass loss rate per unit area of large-scale pool fires. Tang, et al. [15] investigated the mass burning rate and merging behavior of a double pool fire under the action of crosswind. Shi, et al. [16] studied the evolution of flame height of two adjacent hydrocarbon pool fires under the action of crosswind and revealed the interaction mechanism between adjacent pool fires. Chen, et al. [17] experimentally investigated the joint effect of the presence of sidewall and crosswind on the behavior of heptane pool fires. The effects of sidewall height and crosswind velocity on pool fire combustion rate, flame height and flame tilt angle were obtained. The effect of longitudinal wind on the burning rate was attributed to thermal feedback, flow perturbation and oxidant supply around the flame. Li, et al. [18] investigated the effect of longitudinal wind on the mass burning rate of rectangular heptane pool fires with different aspect ratios.

Zhao, et al. [19] conducted large-scale experiments on n-heptane pool fires at subatmospheric pressure to study their combustion characteristics and use them to assess their thermal hazards. Chen, et al. [20,21] studied the effect of initial pressure on the combustion behavior of ethanol pool fires in closed pressure vessels and the effect of ambient pressure on the oscillatory behavior of pool fires, and proposed a theoretical model to explain the effects of ambient pressure and gravity on the oscillatory frequency. Liu, et al. [22] investigated tunnel oil pool fires and analyzed the mass burning rate of liquid fuels, the temperature variation of the tunnel ceiling, and the vertical temperature distribution around the fire source. Pan, et al. [23] experimentally investigated the change of burning rate and temperature distribution of oil pool fires in curved tunnels with fire location and analyzed the relationship between temperature distribution, tunnel height, and horizontal location of the fire source. Chen, et al. [24,25] experimentally studied the effects of plate barriers on flame morphology, flame radiation and combustion behavior of small oil pool fires. They proposed a new combustion rate correlation to describe the effects of plate barriers. In addition, the relationship between the average radiant heat flow of oil pool fires and the properties of plate barriers was also revealed. Huang, et al. [26] studied the effect of pool height on the combustion performance and heat transfer mechanism of n-heptane and ethanol pool fires. Li, et al. [27] experimentally studied the relationship between flame height and aspect ratio and mass burn rate of rectangular pools. Zhao, et al. [28] experimentally studied the flame length and combustion behavior of pool fires at different heights. Liu, et al. [29] investigated the effect of height on pool fires. Gao, et al. [30] investigated the effect of mixing ratio on the combustion process of layered mixed fuel pool fires using n-heptane-methanol fuel blends with different mixing ratios of mutual insolubility. It was found that the azeotropy of n-heptane and methanol reduced the combustion intensity of the blended fuel compared to the pure fuel.

Risk Assessment Models

The exothermic heat of an oil pool fire may ignite surrounding combustible materials and cause secondary incidents, with a greater potential to trigger a domino event (i.e., higher order accident). Therefore, some experts have developed risk assessment models to quantify the risk of this event. For example, Li, et al. [31] proposed a new CFD-based method to simulate the synergistic effects of tank fires, to simulate the consequences of tank fires, and to more accurately assess the domino effect under synergistic effects. Ahmadi, et al. [32] used FDS to simulate tank and dike fires. The possibility of a secondary fire event in a nearby tank was assessed based on the incident radiant heat flow. The quantitative results obtained by FDS modeling can be used for quantitative risk assessment of tank farms and determination of safe separation distances between tanks. Yuan, et al. [33] proposed a detailed framework for quantitative risk assessment of 0# diesel pool fires based on 0# diesel combustion characteristics. Hou, et al. [34] developed a dual pool fire synergy model that considered the synergistic effect of pool fires to investigate the possibility of dual pool fires triggering domino accidents for quantitative risk assessment.

New Fire Extinguishing Materials

In order to reduce the damage caused by oil pool fires, in addition to studying the combustion characteristics and risk assessment of oil pool fires, the development of new fire suppression materials and the development of fire suppression procedures related to oil pool fires are crucial. Tian, et al. [35] prepared a new gelatinous protein foam material for fighting oil pool fires. After screening tests on the formability and stability of different surfactants, sodium alcohol ether sulfate and hydrolyzed protein were selected as compound foaming agents, and then sodium alginate was used as the gelation agent and calcium chloride ($CaCl_2$) as the cross-linking agent to prepare the new gel-protein foam. The microstructure, foaminess, stability and water retention capacity of gelatin foams were analyzed to identify three optimal formulations, which were then used to evaluate their fire extinguishing and burnback performance against a commercial film-forming fluoroprotein foam. In practice, flame enhancement is evident in the initial application of foam spray fire suppression, which has a significant impact on fire suppression efficiency. Therefore, Tu, et al. [36] comparatively studied the effect of aqueous film-forming foam and water mist on flame intensification during oil pool fire suppression. And Liu, et al. [37] studied the flame expansion mechanism during water mist extinguishing oil pool fires, and established a theoretical model for the interaction of fine water mist with flames and hot fuels by quantitative study of flame structure changes during the expansion process. Dasgotra, et al. [38] conducted a numerical study on the fire extinguishing characteristics of water mist against n-butane oil pool fire and analyzed the effectiveness of water mist fire extinguishing. Jeong, et al. [39] studied the spray characteristics of a two-fluid nozzle containing water mist and the fire extinguishing performance against a pool of heptane oil. The results showed that the airflow of the two-fluid nozzle was an important factor in determining and influencing its fire extinguishing performance. In addition, it was also found that this two-fluid nozzle has a significant potential to significantly improve the performance of water-mist containing fire extinguishing systems. Ultra-fine dry powder, as an effective fire extinguishing agent, has high fire extinguishing efficiency and the ability to inhibit the re-ignition of pool fires after oil rejection treatment. Zhao, et al. [40] used two surfactants, i.e. POTS (1H, 1H, 2H, 2H-perfluorooctyltrimethoxysilane) and OBS (perfluorooctyl sodium benzene sulfonate) to modify fine sodium bicarbonate and studied the effect of POTS/OBS compounds ratios on powders oil repellency. The fire extinguishing experiments showed that the modified dry powder has a high fire extinguishing efficiency, especially after the addition of OBS. In addition, a barrier layer formed by the modified powder was observed on the surface of the extinguished fuel, which would effectively inhibit the re-ignition of the oil pool fire. Rabiei, et al. [41] conducted oil pool fire tests on stainless steel composite metal foam panels. It was shown that one of the potential applications of lightweight S-S CMF could be the replacement of conventional structural steel with excellent insulation, fire resistance, low weight and established energy absorption capabilities in tank cars carrying hazardous materials.

Conclusion

In general, the combustion characteristics of oil fires, control factors, and the study of fire extinguishing materials are still the current research hotspots in this field. However, as the industry has grown and pool size has increased and become more densely distributed, we are unclear about the combustion behavior of these large-scale complex situations. Therefore, the following issues need to be addressed in future research work: 1. combustion characteristics of large pool fires; 2. combustion characteristics of multi-pool fires; 3. effects of higher wind speeds and multi-directional airflow on pool fires. It will be a challenge for all researchers to determine the combustion pattern for large-scale complex scenarios, to quantitatively assess their risks, and to find a more environmentally friendly, economical and effective extinguishing agent due to the influence of environmental conditions, oil composition and equipment diversity.

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