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Experimental study of flame spread over diesel and diesel-wetted sand beds

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HIGHLIGHTS

- 2D flame propagation over diesel and diesel-wetted sand beds is studied.
- Flame spread rate increases with increasing fuel ratio and reduced sand diameter.
- For deeper fuels, flame radiation is dominant after an extensive preheating region.
- Flame spread rate for 2–5 mm fuel ignited from center is greater than from edge.

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ABSTRACT

The experimental study focuses on the behaviors of two-dimensional flame propagation over diesel and diesel-wetted sand beds. Effects of the diesel depth, ignition position, fuel ratio of diesel volume to sand bed weight and sand diameter on the flame spread are analyzed. The results show that for wetted sand beds, the flame spread rate increases with increasing fuel ratio and decreasing sand diameter. The capillary rise effect still plays a significant role with different fuel ratios. Considering the flame spread rate, flame height, temperature distributions near fuel surface and heat fluxes around the fire, the controlling mechanisms of heat transfer are discussed. For the low fuel ratio, the flame spread over wetted sand beds is dominated by the capillary rise effect and heat conduction of sand beds. With increasing fuel ratio, the main controlling mechanism changes from flame radiation to the combined liquid convection and flame radiation. The spread rate for diesel ignited from pan edge is greater than that ignited from pan center for fuel depths (10–20 mm). The flame spread rate increases due to the effect of flame radiation to the unburned fuel surface. For diesel cases ignited from pan center, the dominant mode of heat transfer to the unburned surface is by flame radiation for 2 mm depth, while the controlling mechanism is liquid convection for deep layers (5–20 mm). For diesel cases ignited from pan edge, flame radiation becomes the dominant heat transfer mode for the very thin and thick depths (2 mm and 20 mm), while the controlling mechanism is liquid convection for 5 mm depth. For deeper fuel layers, the flame radiation generates its effect primarily by raising the fuel surface temperature through extensive preheating region. The present experimental results can provide practical guide for the combustion hazard of accidental fuel spills.

1. Introduction

Petroleum fuels, such as diesel, kerosene and crude oil, with multicomponent, high flashpoint and viscosity, are widely used. During the processes of storage, transportation and use, fire accidents resulting from leakage might occur and cause considerable economic losses and environmental pollution. When the oil spilled on a flat plate or soil or sand ground, it would form a certain thickness of fuel layer or wet porous media beds. Flame spread over these surfaces has complex heat and energy transfer mechanisms.

For liquid fuels at sub-flash temperature, most attentions were focused on the liquid convection motion mainly driven by surface tension and the pulsating mode of flame spread [1,2]. The fuel temperature [3–7], fuel depth [4,8,9], ambient pressure [6], pool dimension [9], oxygen concentration and microgravity [8,10] were studied as important factors influencing the flame spread rate which was especially sensitive to fuel temperature. However, these

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studies were mostly conducted in narrow rectangular trays with unidirectional flame spread and the liquid convection was identified as the dominant heat transfer mechanism. For the large area of spilled oil, once ignited the flame will spread radially along with continuously increasing flame volume as time progresses. The work of Mackinven et al. [11] indicated that the radiative heat transfer could play an important role in the flame spreading process in wider trays. For unidirectional flame spread, the tray width which could confine the further enlargement of flame height was proved causing large changes on the spread rate due to the viscous effects along the walls [2,9]. The velocity for radial flame spread over the fuel-soaked porous bed increased with the enlargement of flame volume since the flame radiation began to be dominant [12]. Therefore, it is essential to explore the characteristics of two-dimensional flame spread and understand the heat transfer mechanisms in different growth stages.

In addition, the amount of liquid fuel in porous beds greatly affects the fuel supply and convection and thus the flame shape and spread rate. Despite of the importance, less attention has been paid to the flame spread over porous beds wetted with limited liquid fuel. There were many researches on flame spread over porous media beds with unlimited fuel supply or soaked with liquid fuels, mainly focusing on the effects from the geometry of porous bed [12], bed temperature and inclination angle [13], airflow [14–15] and particle sizes [12,13,16], more referring to the review [17]. Ishida [13] found that the fuel supply rate to the ground surface by the capillary rise effect and the thermal conductivity of the ground surface had great influences on the flame spread rate. Zanganeh and Moghtaderi [18,19] carried out experiments on flame spread over porous beds wetted with the finite amount of liquid fuel with high volatility and revealed the mechanism of unidirectional flame spread. For porous beds wetted with different amount of liquid fuel, the two-dimensional flame spread and heat transfer mode deserve further study.

The purpose of the present study is to examine the phenomenon and mechanism of two-dimensional flame spread over the surface of diesel and diesel-wetted sand beds. The fuel depth, ignition position, fuel ratio and sand diameter are varied. The effect of flame radiation on spread rates is examined in detail.

2. Experimental setup

The experimental apparatus is shown in Fig. 1. The round pan of 1 m in diameter and 5 cm in depth was made of 5 mm thick steel, which was open to quiescent air. A commercial diesel fuel (0#) with flashpoint of 62 °C was used. The detailed experiment conditions are shown in Table 1. A series denotes diesel of various depths ignited from pan center and B series ignited from pan edge. C series denotes flame spread over sand beds wetted with diesel. The quartz sands with average diameters of 0.35 mm, 0.75 mm, 3 mm, were used, respectively. The ratios of fuel volume to the weight of sand bed (referred to Zanganeh and Moghtaderi [18,19] as "fuel ratio") were set to be 0.15, 0.25 and 0.4 L/kg. The fuel-wetted sand beds were kept at the depth of 1.0 cm after initially mixed sufficiently. The selection of sand diameters and bed depth was based on previous studies [12–19]. Two digital Sony cameras (HDR-CX900) with spatial resolution of 1920 × 1080 and frame rates of 50 fps were used to record the flame propagation processes. One was perpendicular to the pan center with 1 m away from pan center and 30 cm in vertical height. Another was about 1.5 m high above the pan edge with 45° angle downwards. The transient flame shapes were obtained by image processing technology [20]. An infrared thermal imager (PYROVIEW 380M, 50 HZ) was used to record the flame temperature from front view. The emissivity was determined as 0.95 after a calibration with a thin thermocouple. Data acquisition instrument was used to record the temperature data of K-type thermocouples with the diameter of 0.5 mm. In order to measure the temperatures near fuel surface, a thermocouple tree including six thermocouples was placed at the position of 0.25 m away from pan center with 0, 5, 10, 20, 30, 40 mm above pan bottom, while for fuel depths less than 5 mm, the thermocouple position of 5 mm above pan bottom was adjusted to fuel surface. Heat flux gauge A of water-cooled was placed vertically facing upward adjacent to pan edge, and heat flux gauge B was placed horizontally facing the flame with 1 m away from pan center. The ambient temperature was around 30 °C and the humidity was 60%. The flame was extinguished when it covered the whole pan. Our tests were repeated three times and the results presented good repeatability with discrepancies less than 5%.

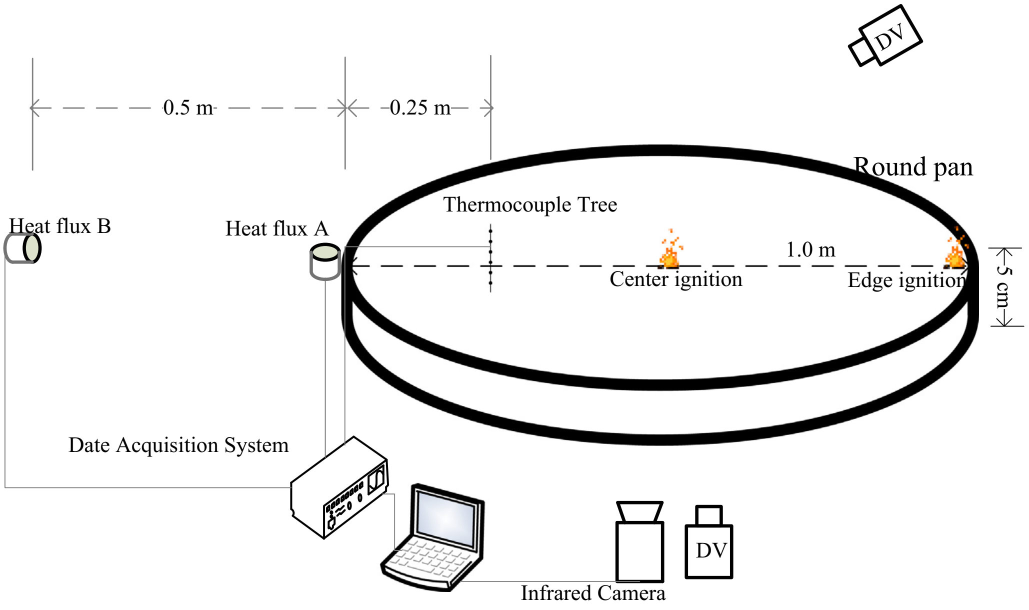

Fig. 1. Schematic of experimental apparatus.