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Research Paper

Experimental study of the mass burning rate in *n*-Heptane pool fire under dynamic pressure

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HIGHLIGHTS

- The higher the pressure rise rate is, the more rapidly the burning rate rises.
- The mass burning rate shows a power function growth with the environment pressure.
- $\dot{m}/D$ has a power exponent relationship with Gr, and the exponent factor is 0.309.

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ABSTRACT

Fire safety is critical for safety of airplane operation. During an emergency landing, airplane goes through dramatic external pressure change from cruise altitude to sea level. The objective of this work is to examine the effect of dynamic pressure on the behavior of a horizontally burning flame over a pool fuel surface based on experimental approach. The experiments were conducted in a large-scale altitude chamber of size 2 m × 3 m × 4.65 m. The pressure rise process was examined under different dynamic pressures from respectively 38 kPa, 64 kPa and 75 kPa to 90 kPa with various pressure rise rates of 100 Pa/s, 150 Pa/s, 200 Pa/s, 250 Pa/s and 300 Pa/s, which is to simulate the airplane landing process from different altitudes with different landing speed. The whole system of the altitude chamber is of unique capability that the pressure in the chamber can be exactly controlled, which are achieved through controlling the air inlet rate and the vacuum pumping rate. A round steel fuel pan of 34 cm in diameter were chosen for the pool fire tests. The fuel pan was filled with 99% pure liquid *n*-Heptane. Parameters such as mass, mass burning rate, chamber pressure were measured. The test results demonstrated the significant impact on fire behaviors caused by high altitude or low pressure atmosphere. The mass burning rate under dynamic pressure increases showed power function growth with the Grashof number, and the exponent factor for all cases is 0.309.

1. Introduction

Fire is one of the most dangerous threats to an aircraft. The cruise altitude of commercial airplanes ranges usually from 39,000 ft to 45,000 ft [1]. Typically, the internal pressure of the cargo compartment of commercial airplanes in flight is maintained equivalent to 0.8 atm. In the case of fire, the airplane descends immediately until it reaches to nearly 20,000 ft, at the same time, the cargo compartment opens the pressure release valve and the pressure inside and outside of the cargo compartment get equal. Then the airplane cruises at this altitude for some time to find a landing place. It will land once the landing place is determined [2–4]. During the descent, the cargo compartment will be pressurized until it matches the ambient air pressure of the destination. The high cruising altitude environment is featured with low pressure and thin oxygen, which would change the physical and chemical reaction of burning process, and will make fire behavior apparently different from those under standard sea level pressure.Understanding the variation law of fire behavior under dynamic pressure (changing pressure, which is not the difference between "total pressure" and "static pressure") is one of the important fundamental premises and theoretical preparations for fire suppression and protection design of commercial air transport. Fire tests under dynamic pressure should be performed to observe the variation of fire behaviors during the cyclic pressurization process. However, few such studies are available due to the constrained experimental conditions. Most research works are focused on the

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combustion characteristics under fixed air pressure. Fire development is generally characterized in terms of mass burning rate vs. time [5,6]. Thus, determining the burning rate is an essential aspect of a fire hazard analysis [5]. Some reported researches under fixed static pressure show that low pressure has significant impact on fire behaviors [7–13]. Wieser et al. [14] firstly conducted the EN54 fire tests in a mobile test platform at four different altitudes (420, 1000, 1800, 3030 m) and obtained the experimental results that the mass burning rate increased with the pressure P approximately as $\sim P^{1.3}$. The burning rate was demonstrated depended on both ambient pressure *P* and fuel pool size D [15] and was summarized as a formal relation $\dot{m} \sim_D P^{\alpha}$, the power exponent factor α was demonstrated varying with the flame heat feedback on fuel surface from flame [15,16]. The burning rate of oil pool was calculated by using the principle of heat transfer and conservation of energy and established the calculation model of average burning rate under steady state burning mode [17,18]. Yin et al. [19] conducted a series of chamber fire tests in an altitude chamber under different pressure levels by constantly replenishing air at a fixed rate and found that the flame shifted from turbulent to laminar during depressurization.

The main objective of this study is mainly to examine the effect of the dynamic pressure on the behavior of diffusion flame over a pool fuel surface. Pool fire test under different dynamic pressures (from 38 kPa, 64 kPa and 75 kPa to 90 kPa) with various pressure rise rates (100 Pa/s, 150 Pa/s, 200 Pa/s, 250 Pa/s, 300 Pa/s) were performed in a large-scale altitude chamber system. 38 kPa, 64 kPa and 75 kPa represent different cruising altitudes of 8 km, 4 km, 2.4 km respectively. The dynamic pressure stage is to simulate the landing process of aircraft from different altitudes to the near ground height. Oxygen concentration is maintained in the chamber by automatically adjusting incoming air and pressure level. The mass, mass burning rate, as well as chamber pressure, were measured and analyzed to reveal the dependence law of fire behavior on the pressure.

2. Experimental platform and setup

2.1. Experimental platform

The experimental platform designed for the surface burning liquid pool fire tests in the altitude chamber is shown in Fig. 1. The experimental system consists of the chamber body, the air supply system, the air outlet system (vacuum pump), the pressure control system and the data acquisition system. The air supply system is used for oxygen concentration control. And the air outlet system is used for the pressure control based on the pressure feedback.

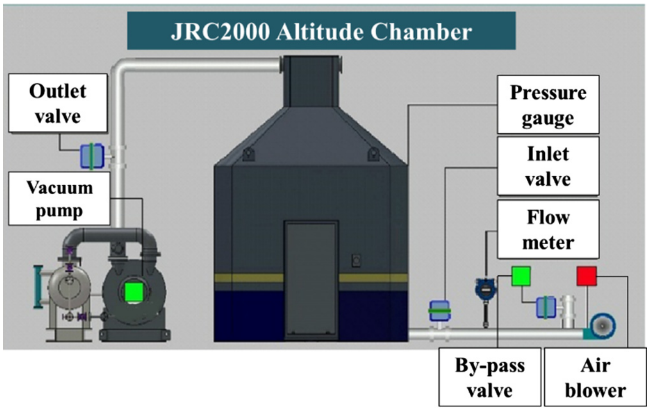

Fig. 1. The sketch map of the experimental platform.

2.2. Experimental setup and procedures

The experimental setup is shown in Fig. 2. For the liquid pool fire, a steel fuel pan of 34 cm in diameter and 15 cm in height are used. The fuel pan is positioned 0.15 m from the ground in the center of the device on top of an electronic scale which is placed on a platform combined by angle steels. A 20 cm-diameter round stool with four feet and a 60 × 60 cm insulation board is placed between the pan and scale to protect the scale, as shown in Fig. 2.

An array of 18 K-Type Nickel Cadmium thermocouples labeled as T1-T5 from the bottom to the top along the centerline above the pan to measure the flame temperature. All the thermocouples are 1-mm-diameter, and the vertical gap between two neighboring thermocouples is 20 cm, where the first thermocouple T1 is 5 cm above the surface of the liquid fuel.

Weight loss rate or burning rate is calculated based on the weight loss measured from an AMPT418 high accurate electronic scale placed beneath the pan. The sampling rate of electronic scale is 1 Hz.

The fuel used in this test is *n*-Heptane with industrial purity above 99% (the impurity contents: volatile $\leqslant$ 0.05%, water $\leqslant$ 0.05%, unsaturated compounds in Br+ $\leqslant$ 0.032%), whose density is 683–685 kg/m3, boiling range is 96.5–98.5 °C, self-ignition temperature is 223.0 °C and the explosion limit is 1.05–6.7%. The ignition source is a length of heating wire with a diameter of 0.65 mm, whose resistance per unit length is 3.28 Ω/m. The heating wire was looped 60 times over a length of 3.937 in. (10 cm) with 0.25-in. (6.35 mm) in diameter. Cold water with a thickness of 10 cm is added beneath the fuel layer to cool the pan and minimize the temperature rise in the fuel. Fire tests are repeated at least three times to ensure repeatability.

The test is designed in accordance with the standard FAA MPS pool fire test procedure [20] for the surface burning liquid pool fire tests in the altitude chamber. During the experiment, the pressure inside the chamber is firstly maintained at the lower level phase, for example 38 kPa, and then ignite the fuel. After a time, the fire develops into the steady burning stage, and the pressure begins

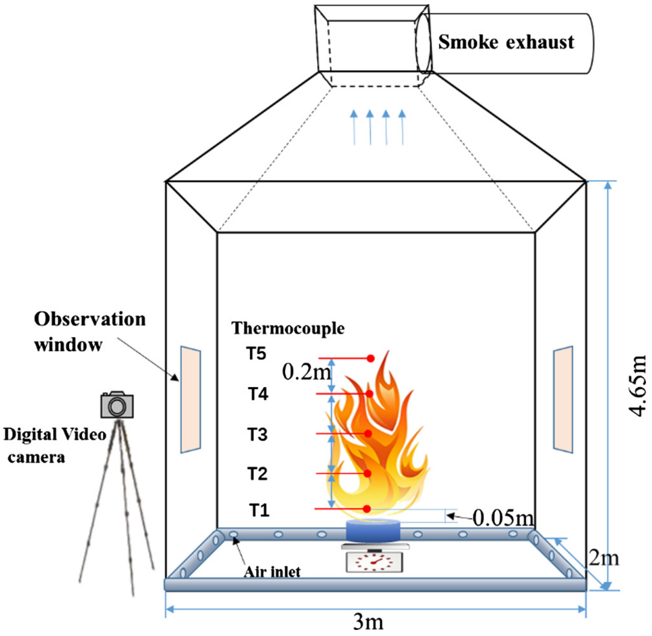

Fig. 2. The schematic diagram of the test setup for liquid pool fire tests.