Fire Safety Journal 95 (2018) 170–179

Contents lists available at ScienceDirect

Fire Safety Journal

journal homepage: www.elsevier.com/locate/firesaf

Heat release rate of wooden cribs with water application for fire suppression

Masaki Noaki [a,*], Michael A. Delichatsios [b,c], Jun-ichi Yamaguchi [d], Yoshifumi Ohmiya [c]

[a] Building Research Institute, Japan, 1 Tachihara, Tsukuba, Ibaraki 305-0802, Japan
[b] University of Ulster, UK, 25-51 York St, Belfast BT15 1ED, UK
[c] Tokyo University of Science, Japan, 2641, Yamazaki, Noda-shi, Chiba, Tokyo 278-8510, Japan
[d] Obayashi Corporation, Japan, 4-640, Shimokiyoto, Kiyose-shi, Tokyo 204-0011, Japan

ARTICLE INFO

Keywords:
Water application
Suppression
Maximum heat release rate
Wood crib

ABSTRACT

A series of experiments was conducted in order to measure the maximum heat release rate of a wood crib ignited at the center of its base after water applications which were not sufficient to extinguish the wood crib fire. The novelty of the present experiments lies in distributing the water uniformly just above the top surface thus ensuring what the exact delivery density is. Uniform water distribution was produced by a system of pipes with holes 5 cm above the wood crib. The variable experimental parameters were the number of layers of wood cribs (6, 9, 12), the water delivered density, and the water activation time. The size of the wood sticks is fixed and they are layered in a fixed staggered way alternating at 9 or 10 sticks per layer. Regardless of the number of wood crib layers, the reduction of the maximum heat release rate by water supplication was proportional to the total water flow rate $\dot{W}$. The constant of proportionality is approximately 12 kJ/g in these experiments for all water delivered densities and all numbers of layers of wood cribs where water was applied either earlier or just when the maximum heat release rate was reached in the free burning wood crib fires. The proportionality factor 12 kJ/g is explained by noting that the heat removed per unit time by the completely evaporated water is proportional to the water application rate times the heat of evaporation and that this leads to the reduction of mass loss rate to be proportional to the water application rate multiplied by the heat of evaporation and divided by the heat of pyrolysis of wood. Therefore, the reduction of heat release rate is equal to the reduction of the mass loss rate multiplied by the heat of combustion of wood. In addition, data for the total heat released and the total mass loss also support the proposition that the reduction in the total heat release is due to the extinction of the wood crib burning area being proportional to the water supply rate. We expect that these results to be applicable as long as the burning of wood crib is fuel controlled.

1. Introduction

Water applications by regular sprinklers can be effective for suppression of fires at a required delivery density and at an early stage of fire growth. Time history behaviors of heat release rate under water application are shown in Fig. 1 [1–6]. In this Figure, behavior (a) indicates that combustible materials are extinguished immediately after sprinkler activation; behavior (b) indicates that the sprinkler system halts the increase of heat release rate even though combustible materials continue to burn at constant burning rate; behavior (c) indicates that heat release rate continues to increase after sprinkler activation reaching a maximum value before decay; finally, behavior (d) indicates that sprinklers are not activated.

Evans [5] proposed evaluation methods for the attenuation of heat release rate for behavior (a). In addition, a lot of researches (e.g. [7–9]) were performed experimentally and theoretically with the aim of comprehending the effect of water application on the extinction of wood cribs. Moreover, Yu [10] proposed an equation for estimating the time history of heat release rate of corrugated cardboard boxes after sprinklers activation for cases (b) or (c), whereas Lougheed [11] proposed equations of the time history of heat release rate of office fuel packages for cases (b) and (c) (Fig. 1). Although these equations have considered behavior (b) or (c), Yu's equation does not calculate the maximum heat release rate after sprinkler activation for behavior in case (c), and Lougheed's equation has not considered the behavior in case (c). We note that an important factor when considering fire engineering analysis is also the maximum value of heat release rate attained in behaviors (b) and (c) whereas the past researches focused primarily on the rate of change of

* Corresponding author. Tel.: +81 29 864 6686.
E-mail address: noaki@kenken.go.jp (M. Noaki).

https://doi.org/10.1016/j.firesaf.2017.10.002
Received 22 May 2017; Received in revised form 28 September 2017; Accepted 17 October 2017

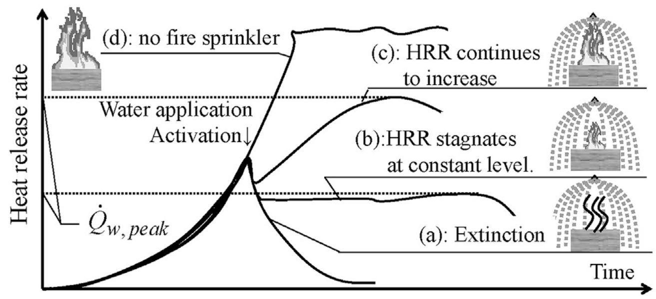

Fig. 1. Representative time history of heat release rate under water applications activated condition.

heat release rate for different water applications. The present research identifies correlations for the maximum value of heat release rate in cases (b) and (c) for a given combustible material at varying water application conditions.

Although different types of materials and geometries are present in practical applications, wood cribs are widely used to evaluate the fire suppression performance of water application systems (e.g. Refs. [7–9]). Furthermore, a wood crib is suitable for analysis because the burning properties of wood crib without water application are well known due to a lot of past researches (e.g. [12]).

In this research, a series of burning experiments using wood cribs and varying water application rates was carried out in order to characterize the maximum value of heat release rate of wood cribs for behaviors (b) and (c).

The specification of the experimental apparatus, the combustible material and the experimental method are explained in Chapter 2. Chapter 3 includes the experimental results and discussion. A theoretical analysis and comparison with previous work are described in Chapter 4. Finally, the summary of this research is in chapter 5.

2. Experiments using water supplying system

2.1. Experimental water application apparatus and procedure

The experiments were conducted at the fire laboratory of Tokyo University of Science using the calorimetry hood shown in Fig. 2. A water supply system shown in Fig. 3 was used for water application. The water application system consists of ten parallel steel pipes having 2 mm diameter holes, 100 mm apart on each steel pipe. Water was fed from a tank via a pump and water flow rate was controlled manually using a water flow meter (manufacturer: Horiba Ltd., Model number: LM20PATAAA-RC) which is connected to the main supply pipe.

The water application system was calibrated away from the crib before the application time. After water flow rate was adjusted at a set value, the water application system was moved 5 cm above the wood crib at the application time. It is important to note that the holes of each pipe were set above the solid sites of the top wood crib sticks so that the water supplied hits the top wood crib sticks and flows downwards (see Fig. 5).

The mean water flow velocity through a hole is calculated by using following equation;

$$v_w = \frac{\dot{W}}{\pi \cdot \left(\frac{d_h}{2}\right)^2 \cdot \rho_w \cdot n_h} \qquad (1)$$

The calculated values are shown in the last row of Table 1. Here, v_w is mean water flow velocity through a hole [m/s], $\dot{W}$ is water flow rate [g/s], d_h is hole diameter [m], ρ_w is density of water [g/m^3], n_h is number of holes [−].

Note that, during the burning experiments, no water passed through the wood crib all the way to the bottom. Therefore, we can assume that all the water evaporates inside the wood crib.

The present water application system guarantees a designed delivered density to the surface of the fuel in contrast to using an overhead sprinkler system where the delivered density depends on the interaction (penetration and evaporation) of the fire plume with the sprinkler spray.

The distribution of the water delivered density was measured before the experiments by using nine (9) water collection pans 316 mm square as shown in Fig. 4. The results are shown in Table 1. Here, water delivered density means the amount of water pooled in a collection pan divided by application time (5 min) and area of the water collection pan (0.1 m^2). According to Table 1, measured values of water delivered density are approximately the same as set values, which are determined from the designed water flow rate and the total area. The standard deviation is about 20% of the average value of the water delivered density.

Heat release rates were measured by the standard oxygen consumption method following ISO 9705 by using O_2, CO_2 and CO concentrations. Water vapor in sampling gas was trapped by a dry agent and cooling system before the sampling gas reached the gas analyzer. K-type sheathed thermocouples having diameter 1.6 mm as well as a bi-directional probe

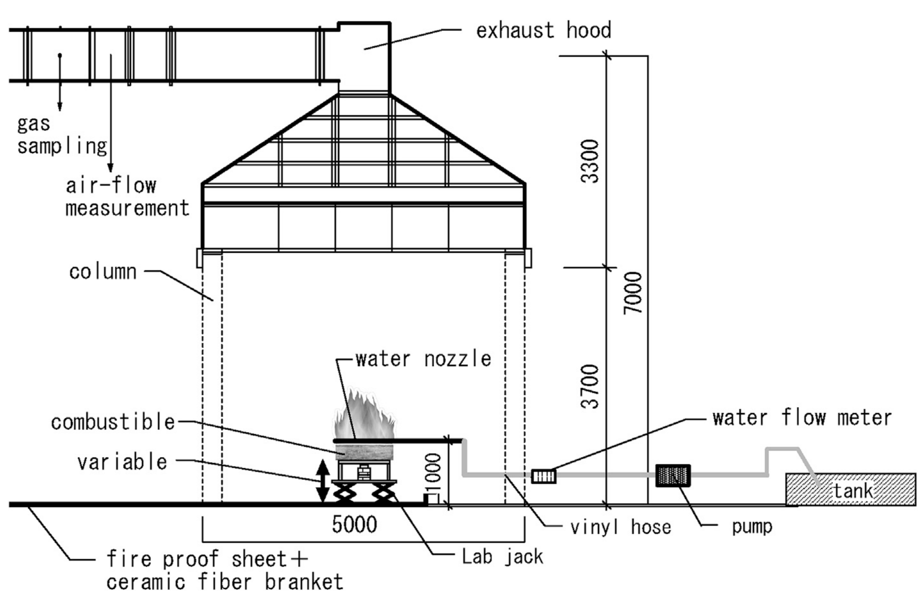

Fig. 2. Schematic of experimental apparatus.