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Effects of storage height on critical delivered flux of representative fuels

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ABSTRACT

Fire suppression experiments were conducted to determine the critical delivered fluxes (CDFs) of representative fuels. The objective was to evaluate the CDF-based commodity classification for sprinkler protection purposes with emphasis on the effects of storage height. The experiments were carried out in 2- and 5-tier double-row, rack storage configurations, which, together with previous 3-tier work, provide a complete set of CDF measurements at different storage heights. The experimental results show that the 5-tier CDFs correlate well with full-scale sprinkler testing experiences. The comparison of CDFs also reveals the storage height effects for different fuels: the CDF values scale linearly for the cartoned commodities, while nonlinearities are observed for the uncartoned plastic commodities. Based on these results, a commodity classification method is proposed to assess solid combustible materials in the real world with separate treatment of cartoned and uncartoned fuels.

1. Introduction

Combustible commodities are stored in various geometries in industrial and commercial facilities. The central issue for fire research is how to define the appropriate protection for a given commodity. This is a very challenging problem since the combinations of material properties and storage geometries are almost unlimited, but only a few representative fuels can be studied systematically. Therefore, a methodology is needed to link the limited research results to the unlimited commodities in the real world. Commodity classification is such a methodology by which commodities are categorized into different classes according to material properties and fuel geometries for fire protection purposes. Once a commodity is classified, the protection recommendations of the representative fuel for that class will be assigned to the commodity of interest. In essence, commodity classification is a mapping scheme that connects the protection recommendations of representative fuels to the commodities in the real world.

Commodity classification was introduced based on full-scale sprinkler test results in the late 1970s. In 1990, Chicarello and Troup [1] developed the first experimental classification method, where fire suppression tests were conducted using two-pallet-load long, two-pallet-load deep and two-tier high (2×2×2) fuel arrays. The water application time was determined based the calculated activation of a hypothetical sprinkler. The measured heat release rates (HRRs) were then used in empirical correlations to determine the commodity ranking. Similar schemes were adopted by Arvidson and Lönnermark [2] and Persson [3] except that a constant HRR was used to determine the water application time. Since the empirical correlations cannot be extrapolated to new commodities, Wu [4] attempted to develop a new commodity classification method by the use of flame heat flux measurements in freeburn fire tests. This approach did not consider the response of burning fuels to water application. As a result, the measured flame heat fluxes showed no correlations with the fire hazards of well-known commodities. Recently, Gollner et al. [5,6] studied commodity burning behaviors using B-number based theories, aiming at classifying commodities using relatively small-scale experiments. These measurements are important to help understand freeburn behaviors, while their applicability for sprinkler protection at large scale still needs to be evaluated. Consequently, it remains important to assess the fire hazards of solid combustible commodities for sprinkler protection purposes.

In previous work, the concept of the critical delivered flux (CDF) was proposed to characterize the response of representative fuels to uniform water discharge simulating sprinkler protection [7]. The CDF for a given commodity is defined as the minimum water flux applied on top of the fuel that can prevent fire growth. Note that the water flux is uniformly and directly applied on top of the fuel. Therefore, the CDF only reflects the fuel response to the amount of water applied, which is independent of any specifics of the sprinkler system. Conceptually, the application of water flux at a CDF level will hold the fire HRR constant for a period of time after water application. Experimentally, two or more intermediate-scale fire tests are required to determine the CDF for a given commodity. Ref. [7] provided the measured CDF values for representative commodities in a 2×4, 3-tier rack storage configuration.

Although the CDF-based ranking of combustible commodities has a sound basis of suppression physics, full-scale sprinkler testing experiences, as reflected in Refs. [8] and [9] have shown that the protection requirements may change with storage height for different commodities relative to one another. For example, the Cartoned Unexpanded Plastic (CUP) and Cartoned Expanded Plastic (CEP) commodities may diverge noticeably in protection requirements at lower and higher

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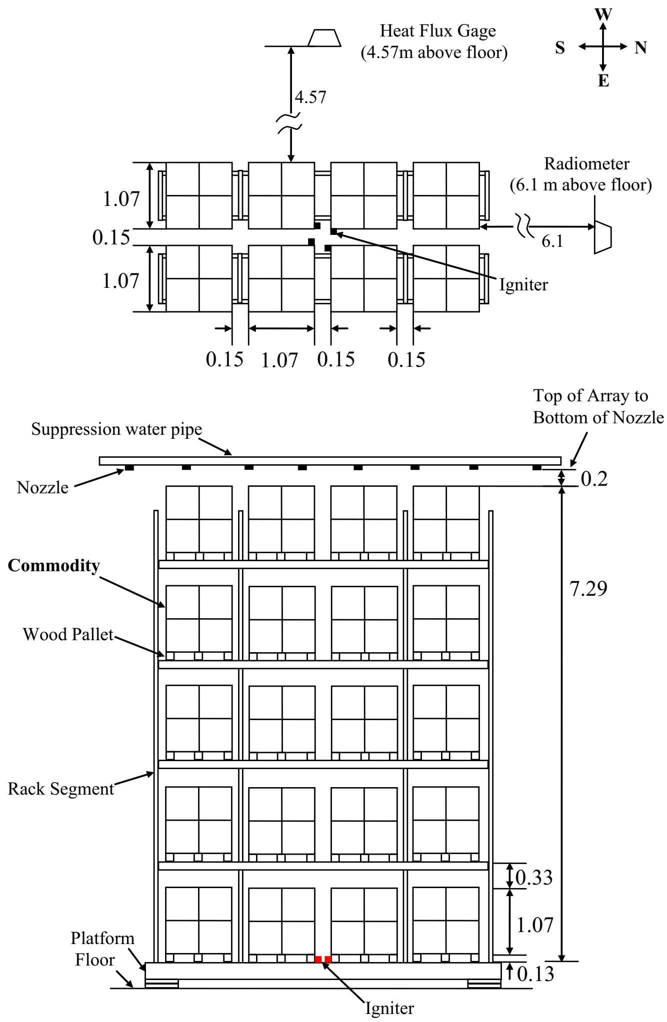

Fig. 1. Top and elevation views of experimental setup for 5-tier rack storage (unit: m).

storage heights [8,9]. This motivated the current work of investigating the impact of storage height on CDFs of all standard commodities. It is expected that the complete data set will help determine the storage height effects over a broad range of commodities and guide the development of a more practical methodology for commodity classification.

2. Experimental method

The CDF values can be determined based on fire tests of representative commodities using a Water Application Apparatus (WAA). The WAA consists of 48 full-cone nozzles installed on six suppression pipes. The separation distance between neighboring pipes and nozzles is 0.6 m. Therefore, each nozzle covers an area of 0.6 m×0.6 m on average where uniform water flux is applied. The details of the WAA were described in previous work [7].

Fig. 1 shows a schematic of the experimental setup for a 2×4, 5-tier rack storage, i.e., double-row, 4 pallet-load long (4.7-m), and 5-tier (7.6-m) high. Another storage configuration included in this work is 2×2, 2-tier rack storage, namely, double-row, 2 pallet-load long and 2-tier high. This smaller fuel array only differs from Fig. 1 in the number of pallet loads of commodities in the longitudinal direction and the number of tiers. The flue space between the commodities is 0.15 m in both longitudinal and transversal directions. These two storage configurations, although limited by the vertical movable distance of the WAA, are substantially different from that in previous work [7] and thus provide good assessment of the storage height effect. Note that the fuel pallet load in Fig. 1 is illustrated using Class 3 commodity; other commodities may differ from the schematic. Seven representative commodities were used in this work, including the Class 2, Class 3, Cartoned Unexpanded Plastic (CUP), Cartoned Expanded Plastic (CEP), Uncartoned Unexpanded Plastic (UUP) and Uncartoned Expanded Plastic (UEP) commodities (see Fig. 2). These commodities are defined in Refs. [10] and [11]. All tests were conducted under the 20-MW calorimeter in the Large Burn Laboratory (LBL) at the FM Global Research Campus, West Glocester, RI, USA.

Each WAA test started with ignition at the center of the fuel array (see Fig. 1). The HRRs during the test were measured by the calorimeter after ignition. The link temperature of a hypothetical sprinkler was calculated during the test based on ceiling flow correla-

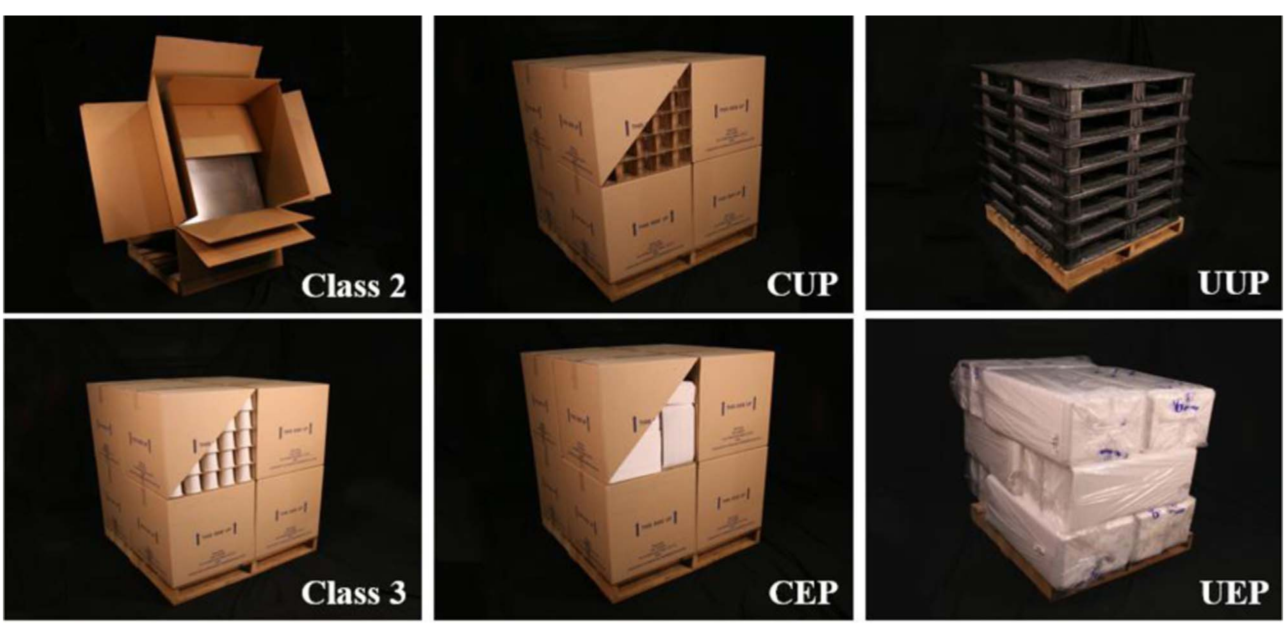

Fig. 2. Representative commodities used in routine sprinkler fire tests.