Applied Thermal Engineering 45-46 (2012) 99–107

Contents lists available at SciVerse ScienceDirect

Applied Thermal Engineering

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

Full-scale experiments of fire suppression in high-hazard storages: A temperature-based analysis of water-mist systems

Paolo E. Santangelo [a,*], Paolo Tartarini [b]

[a] Department of Fire Protection Engineering, University of Maryland, 3106 J.M. Patterson Bldg., College Park, MD 20742, USA
[b] Dipartimento di Ingegneria Meccanica e Civile, Università degli Studi di Modena e Reggio Emilia, Via Vignolese 905/b, 41125 Modena, Italy

ARTICLE INFO

Article history:
Received 15 January 2012
Accepted 5 April 2012
Available online 13 April 2012

Keywords:
Water mist
Fire suppression
Large scale
Thermal transient
Additives

ABSTRACT

Water-mist systems have become quite popular over the last two decades as an innovative technology in fire protection. Moreover, insertion of additives to the flow may be applied to provide additional improvements in terms of suppression effectiveness and temperature control. The present work consists of an experimental approach within a real-scale facility, which has been aimed at challenging water mist against severe fire scenarios. Among them, a high-rise storage has been here explored, being it commonly recognized as strongly hazardous even by technical standards in terms of both nominal fire load and designed physical domain. The system configuration presents high-pressure nozzles at the ceiling; the sole-water flow is compared to water endowed with a commercial additive.

The thermal transient within the test chamber has been evaluated during the fire development as the main quantitative parameter; moreover, the fire evolution has been visualized through a post-fire estimation of the damages. Despite the large amount of released smoke and smoldering materials, water mist is shown to be efficient in fire control, if endowed with the chosen additive. On the other hand, the sole-water flow does not appear suitable for such hazardous conditions under the designed nozzle arrangement.

1. Introduction

Water mist has been considered to be very promising in fire protection for more than two decades: as halogenated hydrocarbons (also known as *halons*) were banned in 1987, this technology has been developed in the quest for alternative agents and systems. From a fundamental standpoint, the related heat-transfer and suppression mechanisms are described by Jones and Nolan [1] and Santangelo and Tartarini [2]; these works are largely based upon the early studies by Rasbash and co-workers [3,4] on extinguishment of liquid fires by water sprays. The recognized review by Grant et al. [5] also provides some insights into suppression physics of water mist within a broader discussion on spray-based systems.

The long-term research promoted by the Naval Research Laboratory features applied studies on water-mist response to various fire scenarios and presents both numerical and experimental approaches; among these latter, the work by Adiga et al. [6] was conducted at large scale (cubic steel-walled compartments of 28 m^3 with heptane and methanol pool fires) and serves as a primary source of inspiration for the present study. The experiments by Back III et al. [7] also constitute a prominent reference for this work: they validated a quasi-steady-state model to predict water-mist effectiveness in extinguishing fuel-spray and pool fires through experimental tests in shipboard machinery spaces. Notably, compartment volumes in the range 100–500 m^3 are here considered and various ventilation conditions are also taken into account. Kim and Ryou [8] focused on methanol and hexane fires within a large enclosure (4.0 m × 4.0 m × 2.3 m), showing some remarkable temperature profiles from K-type thermocouples, which are also employed in the here proposed experiments.

However, the already mentioned studies [6–8] present very simple fire scenarios, even though at large scale, because their main scope is to investigate basic phenomena, as also recently performed by Santangelo et al. [9] to better understand flow/flame interaction; pool fires are the most reliable test cases to firmly control initial and boundary conditions, thus yielding to detailed analyses of a restricted set of parameters. On the other hand, the present work is aimed at challenging a water-mist system within an actual fire scenario to evaluate its performance against a set of real variables.

* Corresponding author. Tel.: +1 301 405 9332; fax: +1 301 405 9383.
E-mail addresses: psantang@umd.edu, paoloemilio.santangelo@unimore.it (P.E. Santangelo).

1359-4311/$ – see front matter © 2012 Elsevier Ltd. All rights reserved.
doi:10.1016/j.applthermaleng.2012.04.011

Nomenclature

A	area (m^2)
H	lower heat value ($J\ kg^{-1}$)
m	mass (kg)
N	total number of combustible materials
q_f	nominal fire load ($J\ m^{-2}$)
t	time (s)
T	temperature (°C)

Greek symbols

ϕ	combustion efficacy
ψ	limiting coefficient to combustion efficacy

Subscripts

Discharge	discharge
FB	free burn
i	index to ith quantity
IF	involved in the fire
j	index to jth quantity
mean	mean value
TC	thermocouple
Test 2	Test 2

To this end, a High-Hazard Storage (HHS) has been chosen: its large size and high fire load make this scenario a recognized hazardous setting for fire-suppression systems, even by international standards (UNI EN 12845).

Rack-storage fires are generally of great interest in fire research. Among the works on flame and plume evolution, the studies by Ingason [10,11] present some experiments and theoretical modeling to describe flame height, mass flow rate and gas properties in a two-dimensional configuration. With regard to sprinkler-based suppression, the investigations conducted by Factory Mutual Research Corporation have provided quantitative insight into the critical water density to achieve suppression [12], water penetration in a rack-storage plume simulator [13] and sprinkler activation as a function of fire size in high-rise compartments [14]. The results obtained in the present work (temperature profiles, response of detection system, etc.) should serve as a guidance for system design in real applications and may also be used to validate numerical simulations, as in previous approaches [6–9].

Furthermore, the effectiveness of additives has been investigated as an additional task. The insertion of additives to enhance temperature control, flame inhibition and suppression performance has been the subject of numerous fundamental studies [15–17]; following a recent industrial trend, some applied contributions have been specifically proposed for water mist [18–20]. Most notably, the study by Ni and Chow [20] shows a similar approach to the present work, even though under a different size scale. In fact, despite some recent preliminary results [21], there is still a lack of experiments on water mist endowed with additives in real fire scenarios, thus strengthening the applicative extent of this work.

2. Experimental facility

The experimental setup consists of the test chamber, the supporting frames of the storage, the combustible materials, the fire-ignition source, the water-mist system (nozzles, piping and pump) and the diagnostics (temperature sensors, thermal-response wire, chronometers and data-acquisition system). Moreover, some mobile and stationary video-cameras have been used to record the fire development.

The test chamber is constituted by a prefabricated box (Fig. 1): the walls are made up by corrugated iron; some air slits are present on the ceiling together with some safety windows, which can be manually opened by fire fighters. The chamber base is rectangular and measures 83.28 m^2; the height is 8 m over the entire ceiling. The doors have been kept closed during the tests, except for emergency operations (unsuccessful suppression by the water-mist system). A picture of the box during a fire test is shown in Fig. 2. This facility is located at *TE.S.I. S.r.l.* in Anagni (Italy).

The High-Hazard Storage (HHS) has been built following a standardized hazard classification (UNI EN 12845). In the present case, three shelves have been placed in the chamber (Fig. 1), each one measuring 5.65 m × 0.8 m in the base and allowing a maximum height of 6.89 m for the commodities. Most notably, each shelf presents eight loading levels (Fig. 1a): the lowest stands at 0.3 m height from the floor, vertically spacing out 0.86 m one to another. Every level has a storage capacity of 4 pallets (Fig. 1b): each of these latter belongs to the *EUR* typology (base: 1.2 m × 0.8 m, height: 0.144 m, mass: 25 kg). The main shelves (Fig. 1a) have a distance of 0.2 m and were involved by fire initiation, while the third one (target shelf) is 1.5 m distant from one side of the former, serving to evaluate potential spread of the fire beyond the initiation region. It should be noticed that the distance between the main shelves was kept constant in these experiments, whereas Ingason's works [10,11] discuss fire-plume vertical development as a function of this parameter (width of vertical flue).

The combustible materials consist of some commodities (*EUR Standard Plastic Commodity* [22]): the already described wooden pallets, cardboard boxes and plastic glasses. Notably, four

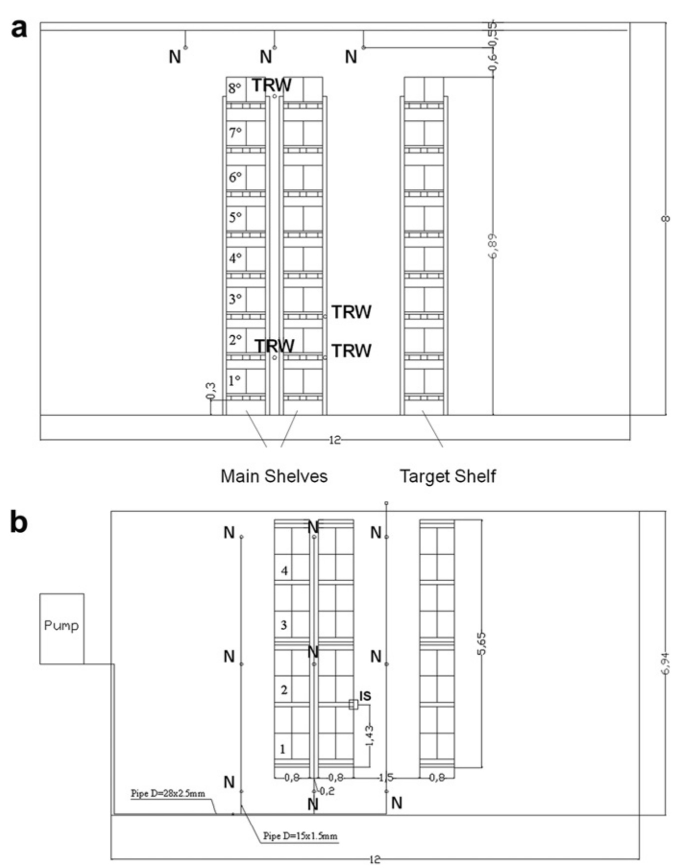

Fig. 1. Technical sketch of the experimental facility: a) view from side; b) view from above (IS: ignition source, N: nozzle, TRW: thermal-response wire; dimensions are in meters, where not specified).