Fire Safety Journal 67 (2014) 1–12

Contents lists available at ScienceDirect

Fire Safety Journal

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

Experimental and numerical study of pool fire suppression using water mist

A. Jenft [a,b], A. Collin [a], P. Boulet [a,*], G. Pianet [b], A. Breton [b], A. Muller [b]

[a] *LEMTA, Laboratoire d'Energétique et de Mécanique Théorique et Appliquée, Université de Lorraine, UMR 7563, CNRS, Vandœuvre-lès-Nancy F-54500, France*
[b] *CNPP, Centre National de Prévention et de Protection, Vernon, France*

ARTICLE INFO

Article history:
Received 12 October 2012
Received in revised form
16 April 2014
Accepted 11 May 2014
Available online 27 May 2014

Keywords:
Fire suppression
Water mist
Fire experiments
FDS

ABSTRACT

Experiments in a real-scale room were done on water mist application to a pool fire. A fire produced with fuel oil in a 35 cm cylindrical pool was used, with a heat release rate reaching 75 kW in stationary conditions. Water application was studied with a nominal flow rate equal to 25 l/min provided by a set of four nozzles, injecting droplets with mean Sauter diameter equal to 112 µm. Observations of fire suppression in these conditions showed two behaviors, which were analyzed and detailed with the help of numerical simulations conducted with FDS.v5. On one hand, a fast suppression (about 10 s required) was observed when water mist was applied to a developed fire. In this case, droplets were injected into a hot environment and thus evaporated strongly, generating a significant vapor concentration and resulting in a fast gas cooling and in an inerting effect. On the other hand, when the mist was applied early, fire growth was controlled, but its suppression required a longer application (about 1 min) and only occurred after a significant cooling of the flame and the liquid pool. These two mechanisms were detailed numerically through mass and energy balances for both the gas and the liquid phases and could help to derive suppression model improvements.

1. Introduction

Fire suppression using water mist is a complex problem, which involves several combined physical phenomena [1,2]. The main effects usually observed in water mist action are gas phase cooling, oxygen displacement, fuel vapor dilution, wetting and cooling of the fuel surface [3]. Two secondary mechanisms have also been identified: radiative transfer attenuation and kinetic effects. When considering the case of water droplet injection, the use of small droplets (an application typically referred to as "water mist") is thought to promote evaporation. For a given water volume, the smaller the droplets are, the larger the exchange surface between the droplets and the surroundings is. This results in a stronger evaporation. This evaporation plays a key role in some of the suppression mechanisms, namely: gas phase cooling, oxygen displacement, and fuel vapor dilution. It is also well known that small droplets promote radiative transfer attenuation (from fundamentals of the Mie theory, absorption and scattering phenomena are higher for a collection of small droplets than for larger droplets given the same water quantity). However, small droplets have a weak inertia which may not allow them to penetrate the flames and the plume, penalizing their ability to reach the fuel surface and thus to cool it. Despite the available literature, work must still be done to better understand and describe interactions among water, fire and smoke depending on the fire type and the conditions of water mist application. The present study was carried out as a collaboration between the CNPP European Security Center and the LEMTA laboratory, aiming to perform tests in a real-scale room and analyze the results with the help of numerical simulations. The objectives are linked to study fire suppression, to better understand the phenomena, to evaluate models at room-scale and to guide toward model improvement. The case of water mist application to a liquid fuel pool fire is addressed. Numerous tests were done with relevant metrology, with attention to accuracy and repeatability. Numerical simulations were carried out with FDS (Fire Dynamics Simulator v.5.5.3, developed by the NIST), combined with home-made post-processing, which deals with detailed balances for mass and energy. The underlying idea is to conduct a detailed study of the influence of the water mist application on the various heat exchanges, the mass balance providing an indicator for water evaporation in particular. Hence, the above-cited effects will be discussed: namely heat sink effects, vaporization, radiative shielding, and exchanges at walls and dilution.

Experimentally, fire suppression tests involving water mist systems have long been reported. Restricting the survey to pool fires with size or configuration similar to the present study, Refs. [4–8] can be cited among others. Conclusions sometimes

---

[*] Corresponding author.
E-mail address: pascal.boulet@univ-lorraine.fr (P. Boulet).

http://dx.doi.org/10.1016/j.firesaf.2014.05.003

seem contradictory since various scales, fuels, nozzle types and flow rates are used. Moreover, the information provided is not complete enough to allow an accurate simulation (data missing regarding the surroundings of the fire, the water mist features, or the heat release itself). Therefore, the present tests were conducted to provide complete input data for numerical simulation, with the aim of validation at the present scale and the further use of numerical simulation towards a better understanding of the suppression phenomena.

Some comparisons can be found in the literature between experimental data and computations carried out with FDS on real-scale building configurations [9–13] or in tunnels [14,15], but few studies have focused on the suppression model (see [16] for a recent and complete contribution to a derivation of a fire suppression model). Water mist/fire interactions will be studied here with the help of the above-mentioned energy and mass balances and the experimental results, investigating in particular the consequences related to the choice between two different times for water mist application: early application or injection after fire development.

The paper is organized as follows: the experimental setup will be described first with related information on metrology, uncertainty, repeatability and analysis of results. Then, the numerical simulation will be presented, with parameter discussion, sensitivity analysis and validation tests. In a final section the emphasis will be put on the influence of mist application time for fire suppression.

2. Experimental setup

2.1. Setup, metrology and uncertainty

A global outline of the experimental setup is shown in Fig. 1 and a detailed description of the different sides of the room in Fig. 2, with dimensions introduced. As can be seen, the tests were carried out in a parallelepipedic room 4.20 m wide, 4.30 m long and 3.05 m high. This corresponds to full scale tests. The room walls are made of concrete (20 cm thick), with two doors (a glass door 5 mm thick on the South side and a steel door 3 mm thick on the East side) and three windows (glass, 5 mm thick), one on the South wall and two on the West wall. The ceiling is composed of plywood (2 cm thick) with two plaster plates near the center of the room above the firepool (1 m × 0.5 m, 2 cm thick). A ventilation device ensures a high level of air renewal to avoid any further complexity due to under-ventilation combustion. This ventilation is provided by dampers on the East side door and a blower on the North wall. Dampers are shown on the sketch of the East wall as a single opening with an equivalent inlet section equal to $0.30 \times 0.40\ \text{m}^2$. The air-renewal was evaluated by measuring the flow rate after the blower ($0.43\ \text{m}^3/\text{s}$, which corresponds to 35 volumes per hour), without fire in the compartment. The same setpoint value was kept for the blower during all the tests and the ventilation was kept active during the fire test and mist activation. A cylindrical pool with a diameter of 35 cm was placed at the center of the room. Fuel oil was burnt. The fire was ignited and the Heat Release Rate (HRR) evaluated through pool weighing or based on O_2 consumption. Water mist can be activated manually at any time and tests were carried out at different activation times after fire ignition. Four nozzles located in the room at a height of 2.45 m produced a water mist with the following characteristics: seven injection holes per nozzle providing as a whole a full cone with an injection angle of 130°, flow rate 6.3 l/min/nozzle, k factor equal to $2\ \text{l/min/atm}^{1/2}$, mean Sauter diameter equal to 112 μm (which corresponds to relatively small droplets fulfilling the water mist standards despite the moderate water pressure feed of 10 bars).

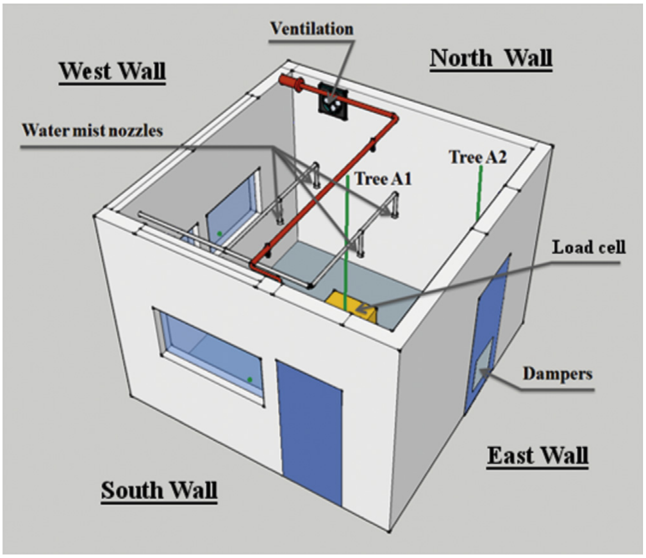

Fig. 1. Sketch of the test room.

A typical run involved a growing phase with a HRR which would reach values of approximately 70–75 kW, according to the preliminary tests conducted without water mist activation (the characteristic evolution of the compartment will be detailed below, together with an assessment of repeatability). The mist activation was studied at a time that was chosen to observe different suppression mechanisms. Some of the fire suppression tests were conducted with early water injection, during the first step of the fire growth, other tests were conducted with injection occurring more than 300 s after ignition.

The metrology involved in the tests is summarized in Table 1, with the devices and their corresponding measurement uncertainties. Two vertical trees each of four K thermocouples were used, one located above the flame (tree A1, cf. Fig. 1), the second shifted 1.40 m towards the north east corner (tree A2). Three other thermocouples were located near the ceiling (2.90 m) to evaluate the temperature in the upper layer of the room. Two thermocouples were fixed onto the windows, to control their temperature for safety concerns. Finally, five thermocouples were placed inside the liquid pool, spaced vertically 0.5 cm from each other, to evaluate the liquid surface temperature in the pool as a function of time during the run. A data logger DAQSTATION DX200 was used for the measurement registration. Video recordings were also made for all runs and these allowed visualization of the flame behavior and its alteration due to water mist application.

Complementary measurements aimed at the fire power assessment were done with a load cell under the pool or a gas analyzer (for O_2, CO_2 and CO) located behind the gas extraction grid. Hence, HRR evaluation could be done thanks to mass loss data or O_2 consumption. Finally, mass loss processing was preferred, due to an observed O_2 evolution time that was not instantaneously related to the HRR variation. A delay was seen between fire development and effective O_2 evolution. When a stationary regime was achieved, data processing for the HRR evaluation according to O_2 consumption and mass loss were observed to be in very good agreement (less than 2% of relative discrepancy, with near zero influence of correction for CO and CO_2 effects on the HRR calculation). Considering the load cell characteristics, uncertainty for the HRR was finally estimated as 3 kW. When water mist is applied, the mass loss can no longer be used because of perturbed