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Radiative shielding effect due to different water sprays used in a real scale application

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ABSTRACT

Thermal radiation attenuation is a well-known positive effect of water sprays applied to firefighting. It was studied here to quantify its real effect on the whole process of fire mitigation. For the demonstration, three different real scale spraying devices were used: a water mist nozzle operating at 85 bars, a sprinkler operating at low pressure (0.3 bars at the nozzle) and a sprinkler operating at a higher pressure (1.3 bars at the nozzle). The radiation attenuation was specifically studied, separately from other actions of the sprays on the fire, using an experimental configuration where water was injected between the radiation source and a detector, but not directly onto the actual fire. Hence, the radiation flux reduction could only be attributed to mixing of water droplets and smoke, not to any reduction in heat release due to water directly cooling the fire area nor to inerting effects occurring simultaneously. The flux was measured using an infrared device combining a Fourier transform infrared spectrometer and a multi-spectral infrared camera. Two radiative sources were used: a high-temperature blackbody for quantification of the radiation transmission with a calibrated source, and a 200 kW heptane pool fire for an application to a realistic radiation source involved in fires. When using a blackbody source for radiation generation, the radiation attenuation of the incident fluxes was 89% for the high-pressure water mist, 62% for the sprinkler at the higher operating pressure and 20% for the sprinkler at the lower pressure. These differences were easily explained by a sensitivity study conducted coupling the Mie theory for the prediction of droplet radiative properties to the Monte Carlo method for radiative transfer simulation. This showed the sensitivity of the radiation attenuation to droplet size and concentration. When the blackbody source was replaced by a pool fire, the flux reduction was even higher for the low pressure sprinkler, i.e. 45%, while being almost unchanged for the water mist. In the present configuration, where smoke stratification was observed before spray activation, this was mainly attributed to the fact that a mixing of droplets and smoke was produced in the measurement area due to the drag effect. The smoke and spray mixing resulted in a stronger attenuation capacity with the sprinkler device. This increased attenuation was not observed through the transmission data for the water mist, perhaps because of compensating effects related to evaporation and the surrounding temperature, or a smoke flow that was highly penalized by the spray activation.

1. Introduction

Radiation attenuation is often cited as one of the expected mechanisms involved in the action of water sprays for fire mitigation (see Refs. [1–5] to name some of the numerous references which addressed this topic), but a clear quantification of this effect in a real fire context cannot easily be deduced from the literature. The radiation effect can hardly be studied separately from other mechanisms in the case of an application to a fire situation, since firefighting is a complex combination of flame cooling, surface cooling, heat sink by evaporation, inerting effects, perturbation of the mixing of reactants and radiation absorption and scattering phenomena. Some numerical studies [1,4–8] and experimental evaluations [8–10] (among other references) have been conducted on radiation attenuation in the past, but these were often in simplified situations: some of the studies took no consideration of fire/spray interactions, or were restricted to parametric

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studies. Relatively minor attenuations were often found in laboratory conditions using reduced-scale devices (of the order of 10% for example in Refs. [5,9] meant considering nozzles with a very low water flow rate of 0.26 L/min/nozzle). These results were promising expecting that the attenuation could increase sharply for very small droplets and higher flow rates. In addition to the droplet size, Försth and Möller [11] investigated the possible enhancement of absorption by using additives in water. On a larger scale, Dembélé et al. [8] conducted tests on water curtains, using a pool fire as a radiation source. With heat flux gauges, they measured attenuation data for particular nozzles up to 70% for water flow rates up to 50 L/min/nozzle. Zhu et al. [12] recently designed a multi-injector nozzle and found 82.7% attenuation when measuring with a total heat flux gauge the heat flux emitted by a large pool fire. Even higher attenuation was expected in some parametric studies, when hypothetical high concentrations of very small droplets were considered. This illustrates the wide discrepancy that can be found in the literature for radiation attenuation. In addition to these studies focused on radiative transfer and hence independent of the fire/spray interactions, fire mitigation was also extensively studied, with water spraying directly applied to the fire (see Refs. [13–17] to name but a few examples of recent studies). However, in this case the role of radiation attenuation cannot be quantified independently from other physical phenomena. Our goal was to restrict the analysis to the radiation effect and to uncouple it from the other mechanisms, while still keeping realistic sprays and radiation sources. Therefore, a specific set-up was designed to allow the use of a fire as a realistic radiation source with real scale sprays. Care was taken not to disturb the radiation measurement by the other mechanisms of spray action on the fire. An additional originality of our work is that the present configuration allowed interactions between spray and smoke, being more realistic of a true fire application than a simple curtain separate from the fire area. Finally the metrology involved a Fourier Transform InfraRed (FTIR) spectrometer and a multispectral Infrared (IR) camera instead of a total heat flux gauge, to provide a fine spectral quantification of the attenuation effects.

Water sprays involve the injection of droplets up to a few millimeters in size when sprinkler systems are considered. When considering water mists, the characteristic size referred to DV90 is below 1 mm (meaning that 90% of the injected volume is composed of droplets with a size below 1 mm). Indeed, a water mist can involve smaller droplets, with diameters of a few hundreds or even a few tens of microns. Such sprays are generally defined based on classes with definitions provided in standards or reference papers, like in Ref. [3] for example. The present tests were done with a water mist device providing a spray corresponding to the so-called Class 1 (i.e. with DV90 below 200 μm) and two sprays with larger droplets. The use of small droplets is expected to reduce the required water quantity for limiting the fire threat. Regarding radiative transfer, it is true from the Mie theory that for the considered range of sizes and given the water quantity, the smaller the droplets are, the higher the absorption and scattering effects should be. As a consequence, radiation attenuation is thought to be a major mitigation mechanism when using water mists, while being less important when using sprinkler systems. Hence, our work was conducted to quantify the radiative part of the problem, considering both injection devices: water mists and sprinklers. It is of primary interest because radiation attenuation may reduce the radiative flux emitted toward the walls or the fuel elements, which could ignite and contribute to the fire propagation. It is also interesting for the safety of the people who escape or for the firefighters who are submitted to the radiation coming from the flames. However, as mentioned above, radiation attenuation is not the only mechanism involved and a complex interaction occurs between water, smoke and fire. In particular, due to the other identified effects (i.e., evaporation, cooling, mixing and inerting effects), the droplet size strongly affects the dynamics and heat transfer around droplets, which may result in various consequences for the fire evolution. An optimized combination of the various mitigation mechanisms should be sought with respect to the droplet size. However, the definition of an optimal diameter for the injected droplet is problematic, without a unique solution, and cannot be considered solely from the radiative point of view. The present study was seen as an opportunity to quantify radiation attenuation, on the same set-up, in the same conditions, using three different types of sprays: generated with a water mist nozzle, a sprinkler operating at a low pressure and the same sprinkler operating at a higher pressure. The goal was not to classify the corresponding techniques by their performances for firefighting, since the fire mitigation results from a combination of mechanisms. This is merely a typical evaluation of the effects related to radiative transfer for three specific different sprays.

In the following sections, the experimental set-up will be described and the radiative fluxes measured, with and without mist activation. The results will be compared for the three different sprays and for two radiation sources: an ideal blackbody and a heptane pool fire allowing spray/smoke interactions to be studied.

2. Experimental setup

The experimental set-up (Fig. 1) involved a room and a corridor (1.40 m wide, 2.40 m high and 9 m long). It had been used in Ref. [18] to study interactions between smoke and water sprays. The radiation source was located in the room. The mist was activated in the corridor, on the room side. The metrology involving a spectrometer and an IR camera was located behind the corridor wall, measuring the radiation that would be received by the wall, via a small hole at a distance of 3.50 m from the source location, on a line of sight 1 m above the ground, as indicated in Fig. 2. This was a directional measurement since the acceptance angle on the spectrometer was 1.7° (full angle). A heptane pool fire (square section 32 cm × 32 cm, 15 cm high) was burning in the room, producing heat, smoke and radiation. The smoke flowed along the corridor toward the exit. A stationary smoke stratification occurred, with a smoke-free layer slightly higher than 1 m. The line of sight was below the smoke layer and a reference measurement was made for the flux received by the wall from the flames without spray (Φ_{ref}). When the mist was activated, radiation attenuation occurred due to the mixing of droplets and smoke generated in the corridor, but the fire kept burning with the same heat release rate (HRR) since it was protected from direct spraying thanks to a lintel between the corridor and the room. The flux measured in this case was referred to as Φ_{spray}. A background measurement was also taken before each test (Φ_0).

Three nozzles provided by the PROFOG company were used, with the following known characteristics:

- A water mist nozzle (hereafter referred to as WM), with flow rate number 2.75 L/min/bar$^{1/2}$, fed with a 100 bar water pressure at the pump exit. This resulted in an 85 bar pressure measured exactly at the nozzle location, which corresponds to a theoretical flow rate of 25.4 L/min. The information related to the droplet size was provided by the manufacturer, indicating a mean Sauter diameter of 23.5 μm measured 1 m below the nozzle at the 100 bar pressure (not exactly at 85 bars).
- An OH1 (Ordinary Hazard, type 1) nozzle, with flow rate number of 80 L/min/bar$^{1/2}$, fed with the standard water network at 2.8 bars, involving an 0.27 bar pressure measured exactly at the nozzle location (hereafter referred to as LPS for low pressure