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Experimental study on radiation attenuation by a water film

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ABSTRACT

Radiative transfer through a water film was investigated. Films with average thicknesses between 100 and 380 μm were studied. The film thickness was measured using an optical method based on the attenuation of a near infrared laser beam. The attenuation of infrared radiation on a wide spectral range was determined simultaneously by using a FTIR spectrometer. A high attenuation efficiency was observed even for such small film thicknesses, which demonstrated the shielding effect of water films. Extension of present observations to high temperature sources allows the evaluation of the film absorption, which was predicted in the range 60–95% for films between 100 μm and 1 mm and for incident radiation from blackbodies up to 1473 K.

1. Introduction

Water is widely used for firefighting, whenever possible [1]. Of course this is because it is an efficient tool for fire suppression or at least fire mitigation. Water is also easily involved and safer for the environment as compared to halogen based suppressing agents (now banned), powders or carbon dioxide for example. When water is used as a dispersed flow, mitigation mechanisms involve cooling of flame and surfaces, inerting effects and radiation attenuation, which are widely studied phenomena. In case of fire in a room (either in buildings, ships, or any confined configuration) injected water may also impact the walls and fall along the surfaces. Hence, impacting droplets may form a water film which will protect the surface, at least partly, from irradiation by flames. This latter phenomenon has received less attention and is the focus of the present work. As radiation is one of the dominant fire propagation mechanisms, it is of primary interest to investigate and to evaluate the true attenuation of radiative heat flux when using water. This helps reducing the heat feed back from flame toward the pyrolyzing fuel surface. Hence, it decreases the heat load on all surrounding surfaces which could become the next fire source in case of propagation. This radiation attenuation has been widely investigated for water droplets used in water curtains or water mists (see [2–5] by the authors of this paper, or well known reference studies [6–9] to name but a few). Absorption and scattering mechanisms have been detailed in these studies, discussing the advantage of injecting very small droplets for an optimal use. Water film can also efficiently contribute to surface cooling and radiation attenuation [10]. This radiation attenuation could be even higher with a film than with a mist. Water is known to strongly absorb infrared radiation owing to its optical indices (which are usually taken from the study by Hale and Querry [11]). Of course, scattering is no more involved but absorption comes from a continuous medium. This good absorption efficiency by a covering film would prevent from radiation propagation mechanism. This was one of the observations reported in [5], with an effective radiation suppression even for very thin films, whose thickness was less than 1 mm. Unfortunately, this was only a guess, as no data were presented on the achievable film thickness obtained with a water spray impacting on a wall, in relation to a simultaneous evaluation of the true radiation attenuation. Similarly Hald and Buchlin [12] also concluded to the high cooling ability of a water film

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Nomenclature

α	absorption coefficient (m^{-1})
e	thickness of the water film (m)
I_0	incident intensity ($W\,m^{-2}\,sr^{-1}\,cm$)
I_R	reflected intensity ($W\,m^{-2}\,sr^{-1}\,cm$)
I_T	transmitted intensity ($W\,m^{-2}\,sr^{-1}\,cm$)
n_i	refraction index of medium i (–)
q_v	volumetric flow rate ($m^3\,s^{-1}$)
R_{ij}	intensity reflection coefficient at the interface between media i and j (–)
$\Re(z)$	real part of z
T_{ij}	intensity transmission coefficient at the interface between media i and j (–)
V	velocity of flowing water ($m\,s^{-1}$)
w	width of the channel (m)

generated by a series of sprays directed toward a target wall. By measuring heat fluxes and with a tentative evaluation of the film thickness they confirmed the film efficiency, but the analysis was restricted to total radiation and the film thickness was not measured. Recently, an experimental study by Aubert et al.[13] was focused on the temperature decrease on a wall submitted to a radiant heat flux and protected by a water film. They measured the changes in the wall temperature and studied the role of the water flow rate. No spectral measurements were carried out but some justifications were provided for their observations and they argued that the semi-transparency of water explains some observed trends when modifying the incident heat flux or the temperature level.

Therefore the present study was carried out in order to relate both experimentally and numerically the water film thickness and its attenuation ability, by conducting a spectral analysis in a wide range of the infrared. Transmissivity measurements were done at a well-chosen wavelength in order to get the film thickness. Then, this information was correlated to flux measurements using a FTIR (Fourier Transform InfraRed) spectrometer in order to evaluate the radiation attenuation in a wide range of the spectra concerned with thermal radiation. In the present paper experimentations are presented first. Then, model and simulations are presented and compared. Data in the form of average absorption coefficients are finally discussed for a simple use by people interested in the film property prediction.

2. Experimental setup

The experimental setup was designed in order to provide a film with a given thickness on a transparent wall, thus allowing optical transmission measurements. A ZnSe window was chosen as this material provides a nearly constant transmission and negligible absorption on a wide spectral range, i.e. between 600 nm and 15 μm. Considering the application of the present work to firefighting problems, a wide range of the infrared must be studied. The Fourier Transform InfraRed (FTIR) spectrometer used allows measuring the radiative properties between 800 and 6000 cm^{-1} (between 1.6 and 12.5 μm) if the emitted signal is sufficiently high in the whole range, as presented in [14,15]. This apparatus was used here for the evaluation of radiation attenuation by the film. In the same time, the measurement of the film thickness was planned to be done on a separate device, possibly developed at any wavelength in the infrared range, searching for the best sensitivity and reliability. Therefore, the ZnSe window, which is also usable with water, provides the right spectral range for the present work.

This window is 400 mm high, 100 mm wide and 6 mm thick. It was integrated in a PMMA (polymethyl methacrylate) wall 2 m high and 1 m wide, in order to provide a wide area for the flow of a developed film in a stationary regime. A special care was brought to the ZnSe window integration in the PMMA plate, in a hole with the required dimensions, checking for a perfectly smooth junction after sticking and polishing steps, hence avoiding any flow perturbation.

The vertical wall (see Fig. 1) has two limiting side rods on its surface, yielding a channel with constant width where the water film is falling down (whereas a free flowing film would exhibit a varying width as a function of the distance from the inlet). Water is introduced from a tank continuously fed on the upper part of the wall. A slot with controlled width allows varying the film flow rates and consequently the film thicknesses, for a given water supply to the tank. The film thickness can be also modified keeping the same slot width, while changing the water flow rate to the tank. Both solutions are used in order to extend the possible film thickness range. The slot length corresponds to the whole plate width and has a regular aperture controlled by a micrometer screw. This water injection type has been preferred to a pulverization or any other impacting solution in order to get the best possible regular film on the widest area of the wall. A flowmeter allows measuring the water flow rate involved in the film. The top of the ZnSe window is located 40 cm below the water inlet.

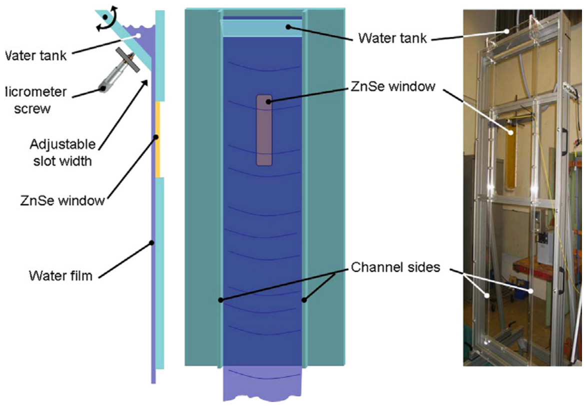

Fig. 1. Schematic view and picture of the experimental setup.