Water sprays used as radiative shield, investigations at laboratory scale.

S. LECHENE[(1)], E. BLANCHARD[(2)], G. PARENT[(1)], Z. ACEM[(1)], P. BOULET[(1)]

(1) LEMTA, Nancy Université, CNRS - Faculté des Sciences et Techniques

BP 70239 - 54506 VANDOEUVRE Cedex

(2) CSTB

84 avenue Jean Jaurès - Champs sur Marne - 77447 Marne-La-Vallée cedex 2

Tel & Fax +33 383 684 686 - mail: Pascal.Boulet@lemta.uhp-nancy.fr

Abstract A study of water curtain used as radiative shield against a strong radiative source has been conducted numerically and experimentally. Comparisons have been carried out between two injection strategies: a classical downward injection of the droplets, and an upward injection keeping the same other conditions (droplet size, water flow rate and nozzle). It is clearly seen that upward injection yields a stronger attenuation (gain with a factor 3) because of the change in the dynamics of the droplets with an increased residence time in the curtain. One remaining problem is a possible weaker stability of the curtain which could be affected by lateral wind or a ventilation device.

Introduction

Regarding radiative transfer, water sprays, water curtains, or mists are semi-transparent media made of droplets injected in air. The typical droplet sizes are in the range from a few micrometers to one millimeter, yielding a dispersed phase in suspension in wet air which interacts in a complex manner with radiation. Owing to the ability of the corresponding dispersed media to absorb and scatter infrared radiation, they are studied in our group for their potential application as radiative shields, against infrared radiation coming from a hot surface or flames. It means that our focus is not on the way to fight against a fire, but rather on a solution to protect some device and to avoid any hasardous propagation from target to target. The goal would be to isolate the heat source and prevent from propagation or rise of a fire.

The main physical phenomena involved in the description of these sprays have been studied and described by present authors in previous contributions [1, 2], using both experimental and numerical approaches. In particular, the dynamics has been described through an Eulerian-Lagrangian approach involving drag and gravity effects, vaporization, convection and coupling with heat transfer, and in particular with radiative transfer. Such problems related to interactions between mists and fire (not only considering the present application of a radiative shield) have received much attention (see among others [3, 4, 5]...).

The present study has been carried out in order to see if a change in the injection direction, downward or upward, could improve the attenuation ability of the curtain. The basic idea with the upward injection is to take benefit from droplets passing twice in the curtain during their up and down trajectory. This investigation is done keeping laboratory conditions (in particular low water flow rate) in order to be able to

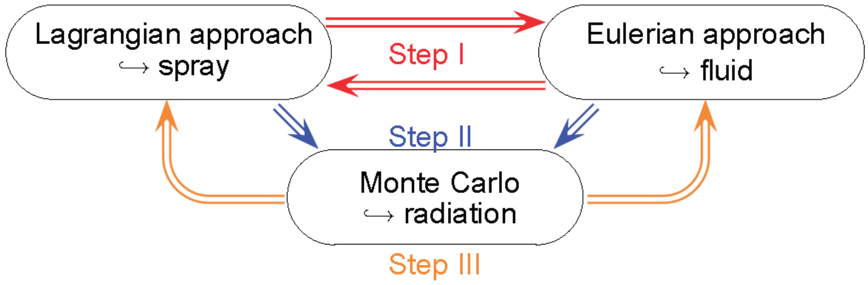

Figure 1: Major steps of the simulation

do some experimentations aimed at the validation of the results.

The following sections give a brief description of the numerical tool and of the experimental setup. Then main results are commented comparing the attenuation obtained in both upward and downward injection cases.

Numerical simulation

The details of the simulation are not recalled here, but the main steps are presented schematically on Figure 1. The whole set of equations corresponds to a two phase flow situation with the simulation of radiative transfer in a participating medium. Three subroutines are involved :

- A Lagrangian step where individual droplets are followed, taking into account the physical phenomena governing their position, velocity, temperature and size evolution. Statistics are performed on a huge number of droplets in order to compute the influence of this dispersed phase on the surrounding air.
- An Eulerian step that simulates the air flow due to the drag effects by the injected droplets. Balance equations are solved for momentum, energy, turbulence and humidity, with source terms devoted to the coupling effects between the two phases.
- A radiative transfer simulation by a Monte Carlo method which predicts the radiation attenuation by the medium of interest, consisting in droplets in suspension in wet air. Radiative properties is a key problem which is addressed with the Mie theory for the prediction of absorption and scattering coefficients of the droplets, and a C-k model for the prediction of the water vapour absorption.

All details regarding the numerical method, validation tests and sensitivity results can be found in [2].

Some typical results are commented below. Simulations have been carried out for a single spray at laboratory scale (meaning for a low water flow rate and a low pressure supply). The emphasis is put in the differences between the two cases of a downward injection and an upward injection. Figure 2 presents the case of the downward injection, with the spray (half of the spray considering the symmetry plane), the emission area and the target area matching exactly the experimental conditions aimed at the validation. In particular the emission is due to a high temperature blackbody. Main numerical conditions are the followings : flow rate is 0.32 L/min corresponding to a feed pressure of 4 bars; size distribution at the injection point is described by a log normal law with mean diameter equal to 110 μm and dispersion parameter of 0.4; angles of the conic spray are 18.5° and 48.0° respectively. These data have been determined by dedicated measurements at the laboratory.

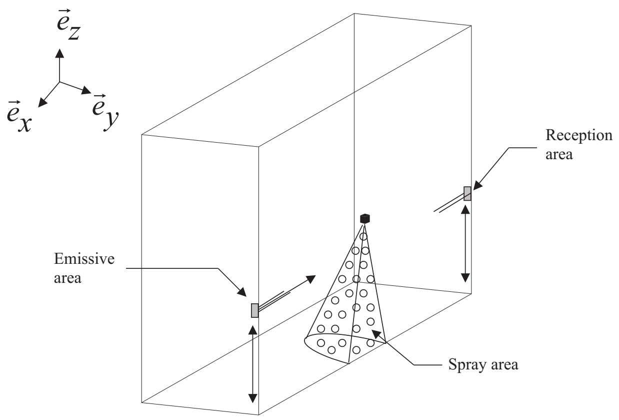

Figure 2: Schematic view of the downward injection case

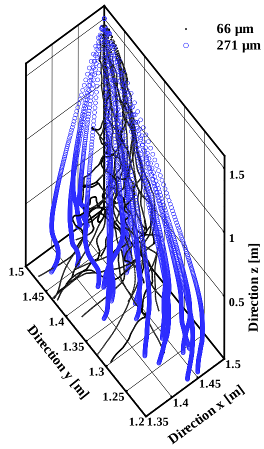

Figure 3: Reconstruction of the spray and visualization of two classes of droplets indicating the various behaviours of small and heavy droplets.

Figure 3 is an illustration of the reconstruction of the spray through the visualization of two classes of droplets, in terms of size. Large droplets are seen to fall with straigthforward trajectories, mainly under gravity influence, whereas small droplets are more affected by turbulence, therefore showing fluctuating motions. Statistics are performed on such reconstructed media, allowing a further study of the radiative transfer step. Our complete predicting tool involves an iterative process which takes into account the coupling between the dynamics of the spray and the radiative transfer. Such reconstruction has been also done in the upward injection case, confirming the expected up and down trajectories in the spray with a more complicated shape, but still with trends associated to inertia and turbulence effects.

Experimental study, validation and analysis

Concerning the experimental part of the study a setup has been built including specific devices for the measurement of radiation attenuation by sprays in the infrared. In particular a Fourier Transform InfraRed spectrometer has been coupled to an infrared camera, both measuring the transmitted radiation with and without spray. The attenuation of potential radiative shields is then evaluated and compared to the numerical prediction. This has been done in various configurations, namely varying the pulverization conditions (flow rate, upward or downward injections, etc...). Typical experimental results are presented in Figure 4, for a single spray in the present case. Experimental data obtained with the spectrometer (line) and the IR camera (crosses), are plotted as a function of the wavenumber (inverse of the wavelength) for given flow rate conditions. The mean level is governed by the droplet influence whereas water vapour is responsible for the attenuation bands at specific wavenumbers. This can be clearly confirmed by our numerical investigations. The case of an upward injection and a classical downward injection are presented, both obtained with the same nozzle, and the same water flow rate (corresponding to the numerical conditions given above). A large gain in attenuation (weaker transmission) is observed when injecting water upward instead of downward. The apparent weak attenuation level (or large transmission values) has to be considered in parallel with the very small water flow rate : around 0.3 L/min. All the experimentations are still carried out at such moderate flow rates, as these small scale conditions allow an easier investigation in a laboratory situation.

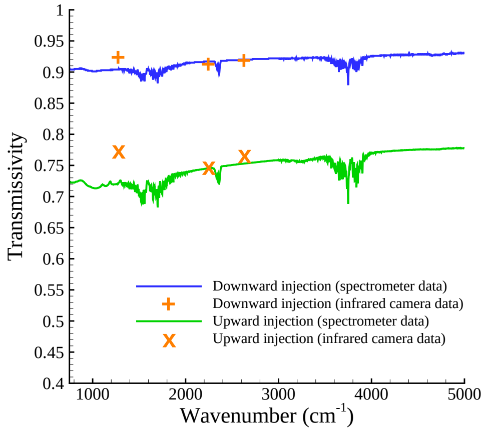

Figure 4: Comparison of transmission levels as a function of wavenumber for downward and upward injections. Experimental results

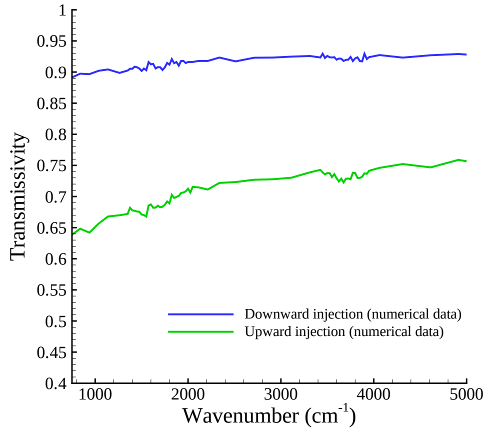

Figure 5: Corresponding numerical simulations, with simulation conditions matching the experimental setup.

However the tools could be soon extended to more realistic conditions in a second step, in particular thanks to the cooperation with the CSTB research center.

Corresponding simulation results are given on Figure 5. The agreement is quite good even if the transmission level is weakly underestimated (or attenuation is over-predicted) in the upward injection case. However, the gain in attenuation is confirmed for upward injection. The numerical tool provides an explanation for this phenomenon through the computation of residence times for droplets, strongly increased when upward injection is considered because of an up and down trajectory for each droplet, with a counterflow situation for the step of down motion. That means that the gain is better than an expected factor two. Instead of falling in a very short time because of a strong initial velocity (24.4 m/s in the present case), droplets are decelerating during their upward trajectory and then they are falling with a zero initial velocity in an upward air flow. This is an illustration of the strong coupling between dynamics and radiative transfer. Beside this apparent optimization of the attenuation for a given water cost, one remaining problem could be a less stable spray when submitted to lateral air flows, produced by convection effects due to a fire, or a ventilation device. This will require further dedicated investigation.

Conclusion, work in progress A possible optimization of systems such as water curtains has been investigated comparing attenuation levels obtained when droplets are injected downward or upward. Both experimental and numerical results indicate that a gain by a factor 3 is possible when droplets are injected upward. The explanation comes from the dynamics since the residence time of droplets is increased in the upward injection case.

Our group now takes benefit from two complementary tools for the characterization of water mists, in particular in what concerns the complex interactions with radiation. Present investigations have been conducted on a single spray but both numerical and experimental tools are ready for the case of a combination of several nozzles in ramps in order to build a realistic water curtain. Further works will be now conducted at larger scales and in situations of use against fire propagation, which rises supplementary problems with combustion phenomena and heat release rate that may induce strong evaporation. Interaction of the curtain with ventilation is another point that has to be addressed.

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