NUMERICAL SIMULATION OF RADIATION PROPAGATION THROUGH WATER MIST

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In the event of fire, thermal radiation plays a very important role. On the one hand, it represents an additional amount of heat which could increase the heat release rate of the fire. On the other hand, it could be a threat to human life and structures. Our group from LEMTA and CSTB is dealing with the interaction between radiation and water mists. Water mist systems, used as protection device against fire, can attenuate radiation by absorption and scattering effects due to the water droplets.

Our current investigations deal with the comparison of two numerical tools dealing with radiative heat transfer through a layer of water spray : BERGAMOTE, a laboratory code developed by LEMTA and FDS, developed at NIST in co-operation with VTT. The objective of this work is to evaluate FDS radiative model by comparing the results yielded by both codes in order to investigate some possible improvements of the models, and finally to use FDS for more realistic applications of water mist systems like in tunnel configuration.

Radiation absorption and scattering are complicated phenomena. The relative importance of these mecanisms depends on the droplet size, the water volumetric fraction in the air and the wavelength of the radiation [4]. As a result, the simulation of the spray dynamics with FDS had to be studied first, especially in the present case of a water mist system whose nozzles are aligned yielding overlappings of the sprays and possible high droplet volume fractions. The predicted characteristics are compared with numerical results obtained by Collin [1] for the same case. Second, a verification should consist in simulating with FDS the radiative energy transfer between two parallel infinitely-long panels in a nonparticipating media and in comparing the radiative flux to analytical values obtained with view factors. At last, the FDS radiative model is evaluated by comparing the FDS and BERGAMOTE attenuation of thermal radiation passing through a water curtain [2], simulating the use of a water spray as radiative shield against a strong radiation source.

1 Brief description of FDS and BERGAMOTE [6, 1]

The water spray in FDS and BERGAMOTE is modeled as an Eulerian-Lagrangian system, where the gas phase is solved using an Eulerian method and the liquid phase is tracked as numerous Lagrangian particles registering their position, mass, velocity and temperature.

The BERGAMOTE and FDS radiative models differ mainly according to the following items:

- BERGAMOTE is based on a Monte-Carlo method combined with a fine spectral approach (43 to 367 bands) and FDS is based on a finite volume method applied on a wide band model (1 to 9 bands) ;
- in BERGAMOTE, the Mie theory yields the radiative properties of the droplets including the phase function handled in its most complex form, whereas, to simplify the scattering computations, FDS approximates the single-droplet phase function with a sum of forward and isotropic components ;
- in BERGAMOTE, a C-K model provides the characteristics of the gas according to water vapor and carbon dioxide concentrations. In FDS, these are computed using the RadCal narrow-band model [5] or are spectrally averaged.

2 Preliminary studies

2.1 Spray dynamics study

The spray is injected in a close infinitely-long room with dimensions 2*l*2 m^3 with $l \to \infty$. The injection is directed downward from a central position in the room at height 1.5 m. The simulated nozzle represents the pattern named TP400067 and manufactured by Spraying Systems & Co. Its pressure feed is 1.5 bars, corresponding to a volumetric rate which has been measured to 0.24 L/min. Droplets are injected with an initial velocity around 18 m/s. Ejection angles are evaluated as 16 ° according to the X-direction and 40 ° according to the Y-direction, yielding an elliptic section perpendicular to the vertical axis.

The polydispersion is injected considering a Rosin-Rammler law in BERGAMOTE and an hybrid law in FDS, it involves 20 classes between 50 and 500 μm, with a mean Sauter diameter at the injection point of 310 μm and a dispersion parameter of 2.66. Spray dynamics can be characterized by the evolution of the mean Sauter diameter in the spray, along the vertical axis below the injection point.

Figure 1 presents the evolution of the mean Sauter diameter as a function of the vertical position. The numerical values have been calculated by integration on cells in a given XY plane.

First of all, the predicted diameter at 20 cm below the injection point can be compared with a value obtained experimentally by PDA : 182 μm. With both distribution

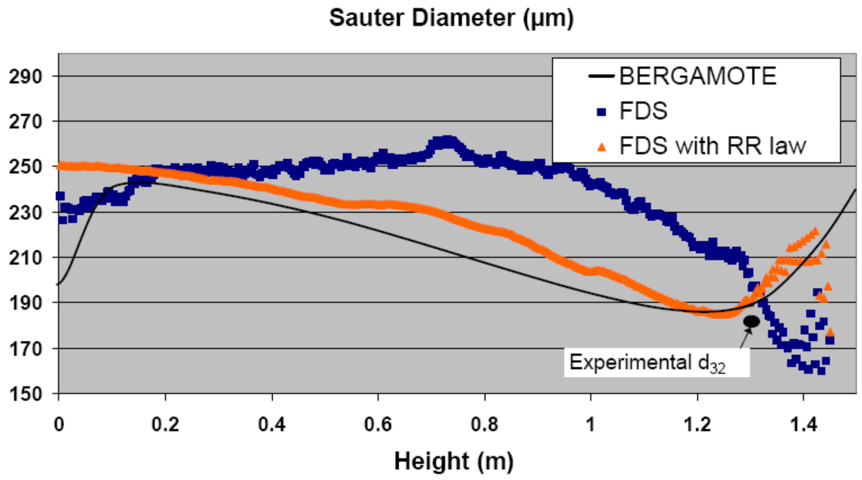


Figure 1: Sauter diameter as a function of a vertical position

laws, the Sauter diameter is predicted to 193 μm at this location. The corresponding offset is equal to 7 %.

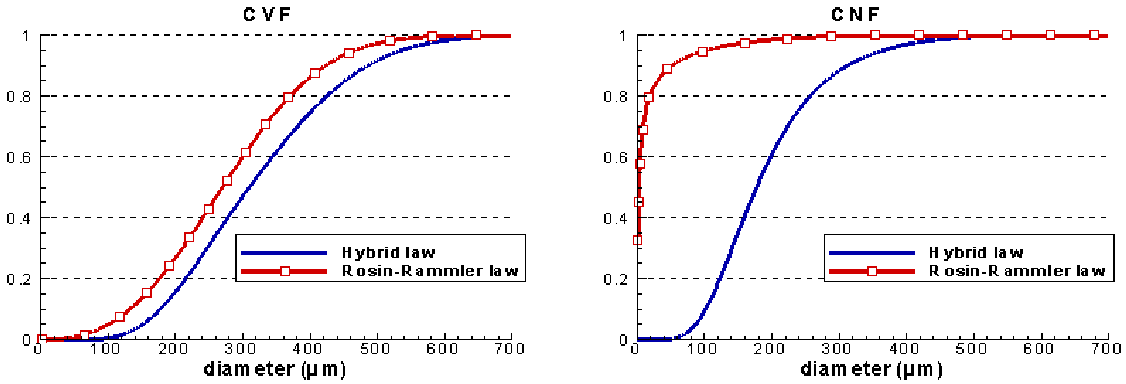
The FDS Sauter diameter evolution along the vertical axis is similar to the BERGAMOTE one [3]. The evolution can be divided in two stages :

- a decrease from the injection point to 30 cm below until 160 μm ;
- an increase till a near constant value, 0.7 m below the injection.

This complex evolution has been explained by Collin by the discrepancy in the droplets behavior as a function of their size. Close to the injection, large droplets fall with a high velocity, contributing in a weak manner to the averaged diameter ; whereas small droplets are already slowed down, bringing a larger weight to the computation of the mean size.

In a given XY plane, the difference between the FDS and BERGAMOTE curves reaches 45 μm and is maximal 50 cm below the injection. The difference is explained by the respective polydispersion models. In fact, as shown on Figure 2, the hybrid distribution favours the biggest droplets over the smallest ones and they do not behave in the same manner in the close room. In fact, if the FDS polydispersion model is modified by implementing a Rosin-Rammler size distribution, the Sauter diameter evolution simulated by FDS is very close to the BERGAMOTE one (cf. Figure 1).

Yang [7] has shown that droplet size influences their ability to attenuate radiation. The smaller the droplets are, the more the radiation is attenuated. Thus, the difference between FDS and BERGAMOTE spray dynamics, even if it is small, could have an impact on the attenuation of thermal radiation in the next section.



(a) CVF

(b) CNF

Figure 2: Cumulative Volume Fraction and Cumulative Number Fraction functions of the hybrid and Rosin-Rammler distribution laws (d_m=310 μm and δ=2.66

2.2 Radiative verification study

To verify the relevance of FDS when addressing radiative heat transfer in a nonparticipating media in a first step, the radiative heat flux between two parallel infinitely-long panels is compared to analytical values obtained with view factors. The radiation is produced by a heated panel at 800 K and is received by a target panel, 4.0 m behind.

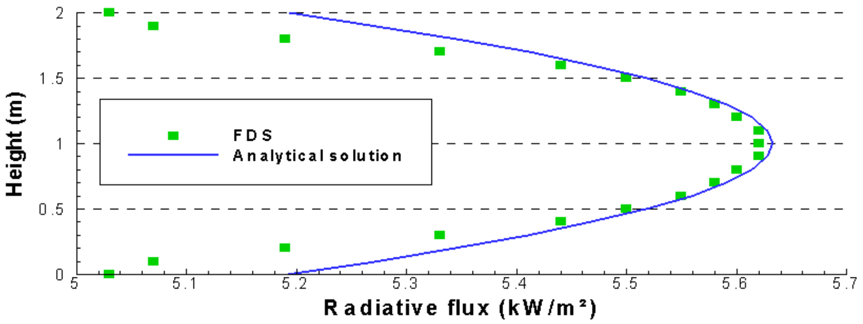


Figure 3: Radiative heat flux versus the vertical position

As shown on Figure 3, the numerical radiative heat fluxes on the target panel are very close to analytical values. The difference at the boundaries can be attributed to the discretization of the solid angle which is required with the finite volume method. The discrepancy can be reduced by increasing the number of angles.

3 Comparison test case

The next comparison test deals with the attenuation of thermal radiation passing through a water curtain, simulating the use of a water spray as radiative shield against a strong radiation source.

The schematic of the experiment is shown in figure 4. The radiation is emitted by a heated panel at 800 K. Then, it passes through a water curtain and it is received by a target panel, 4.0 m behind. This water curtain is produced by a water mist system whose nozzles are aligned. Its characteristics are similar to these presented in section 2.1. This example has been chosen as it could be also conducted experimentally at a laboratory scale. The numerical results have been compared studying the attenuation of thermal radiation at the target panel.

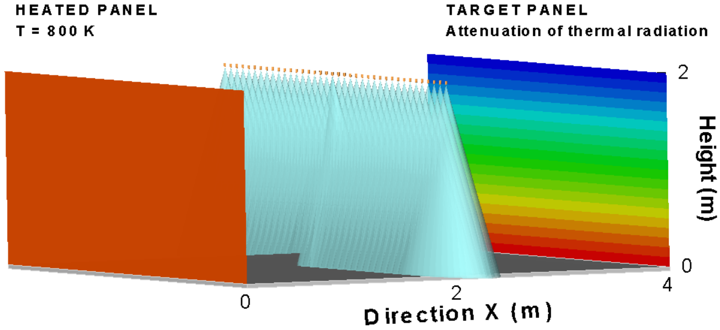
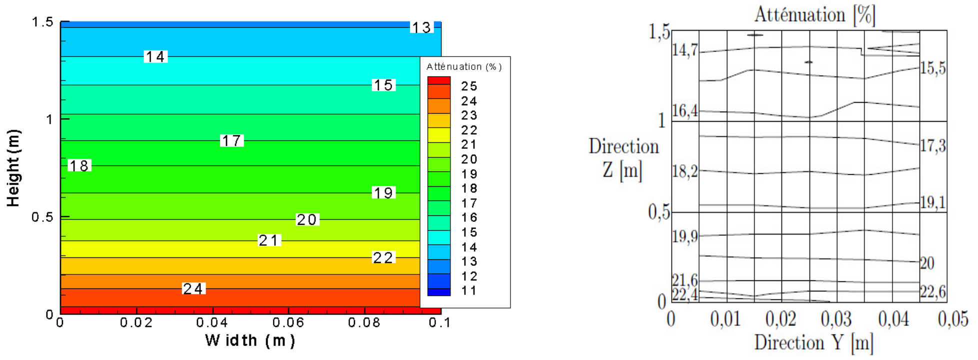


Figure 4: Schematic of the comparison test

As can be seen from figure 5, good general agreement has been found for the results obtained with BERGAMOTE and FDS using only one spectral band (gray gas assumption) :

- the attenuation only depends on the vertical location of the measurement point on the target panel ;
- the attenuation increases near the floor as a consequence of the spray dynamics: the droplets deceleration results in an increase in their residence time when moving away from the injection area ;
- the attenuation values range from 13 and 26% (currently involving moderate flow rates in the simulations in order to allow a possible comparison with experimental data in laboratory conditions).



(a) Values predicted by FDS

(b) Values predicted by BERGAMOTE

Figure 5: Comparison of attenuation of thermal radiation on the target panel, predicted by FDS and BERGAMOTE

4 Conclusion

When the same droplet distribution is injected, the attenuation of thermal radiation predicted by the two codes FDS and BERGAMOTE appears to be in fairly good agreement, even if the radiative models used are rather different. This ensures that radiation predicted by FDS is sufficiently accurate, with a reduced computational cost using the gray medium assumption.

Moreover, the non uniformity of the attenuation through a simple undisturbed water mist curtain clearly illustrates the notable effect related to the variation of water droplet distribution, due to the falling droplet dynamics. This observation highlights the importance of being able to accurately predict the dynamics of the water mist itself.

Complementary work will be conducted in order to couple radiative effect with phenomena encountered in case of fire, especially heat release and related consequences on droplet evaporation and mist dynamics.

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