STUDY ON HOMOGENIZATION OF A PASSIVE SCALAR IN DUCT

Jonathan Alengry[1,2], Thomas Gelain[1], Laurent Ricciardi[1]& Olivier Vauquelin[2]
[1]*Institut de Radioprotection et de Sûreté Nucléaire (IRSN), PSN-RES, SCA, LEMAC, Gif sur Yvette, France*
[2]*IUSTI (UMR CNRS 7343), University of Aix-Marseille, Marseille, France*

Abstract The aim of this study is to propose semi-empirical laws to describe the homogenization of a tracer in a duct and to evaluate the influence of physical parameters (as the ratio between flow and injection velocities) or duct configurations (rectangular section, bend…) on the mixing process.

CONTEXT

Controlling and mastering gaseous releases of nuclear facilities in environment requires performing particulate tracing tests to measure the efficiency of filters constituting the last filtration level. However, if the distance from the injection of the tracer is not sufficient, the tracer concentration can be heterogeneous in the sampling section, leading to an error on the determination of the filter efficiency. Thus, the aim of this study is to determine the "well-mixing length" in order to improve the evaluation of the representativeness of local concentration measurements made in sampling points downstream of the injection.

In the literature, some authors [1-2] proposed models to describe the homogenization of a tracer based on the resolution of the convection-diffusion equation of a passive scalar in a cylindrical and straight duct flow. The main assumptions are: a source point injection in the middle of the duct and uniform velocity and radial diffusion profiles. These studies focused on the influence of the Reynolds number and the roughness in a cylindrical pipe [1], or on the influence of the location of the injection [2]. However, to our knowledge, no data are available on the influence of other parameters on the homogenization such as:

- ratio between flow and injection velocities,
- duct configurations (rectangular section, bend).

METHODS AND RESULTS

In order to assess the influence of these parameters, an experimental bench based on non-intrusive technique has been set up. This bench allows to measure the concentration distribution of a tracer gas seeded with particles based on light scattering of a beam Laser (Fig.1). Smoke is injected through a circular nozzle and during the passing of the particles through the Laser, the light intensity is scattered and recorded by a CCD camera (Fig.2).

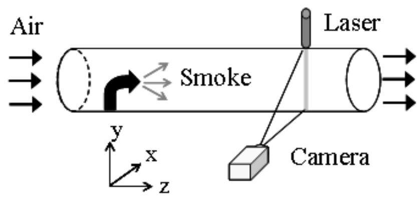

Figure 1. Principle of the measurement technique based on scattering Laser.

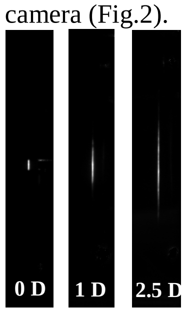

Figure 2. Examples of images obtained at different distances downstream of the injection.

The average value (in time) of the tracer concentration is then measured over the entire diameter of the duct (Fig.3). First, this method was validated by a well-known gaseous tracing in order to fit the grey levels with the concentration. The measurements were also performed to check the validity of the (Gaussian-like) convection-diffusion model. Experiments were carried out for Reynolds numbers of 50,000 and 100,000, respectively, and for an axisymmetric and isokinetic injection, i.e. equal to the flow velocity, in a smooth cylindrical duct of 20 cm inner diameter. The working section is 8 m long. The figure 4 shows the comparison of axial profile of concentration between experimental results and a Gaussian-like model [1].

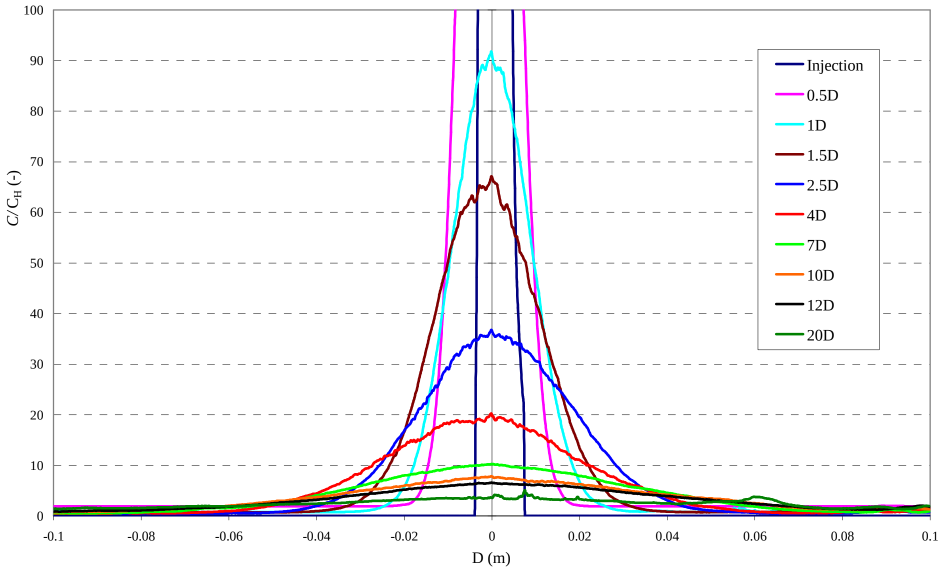

Figure 3. Experimental results of radial profiles of concentration for a Reynolds number of 50,000 in a duct of 20 cm diameter.

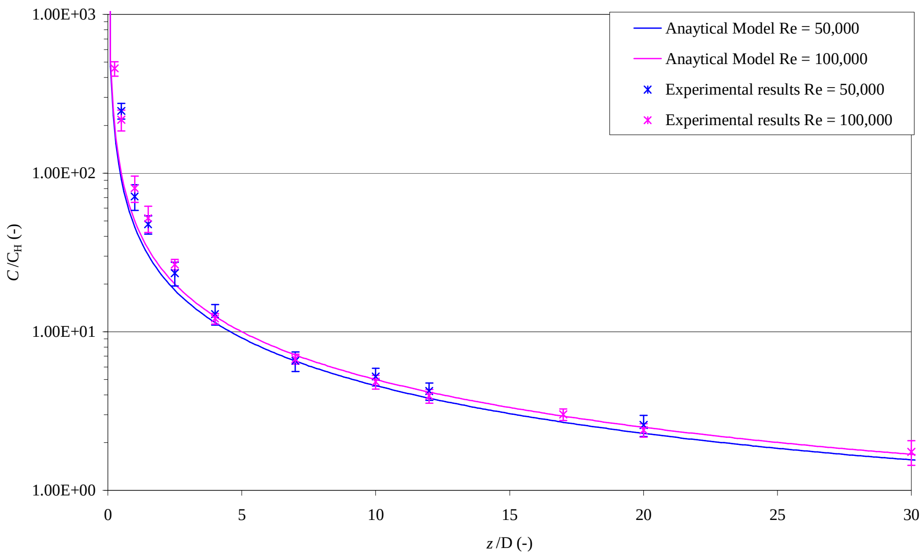

Figure 4. Results of axial profile of concentration for a Reynolds number of 50,000 and 100,000 in a duct of 20 cm diameter.

C is the concentration of the tracer (kg.m^{-3}), C_H the cross-sectional homogeneous concentration (kg.m^{-3}), z the axial coordinate (m) and D the diameter of the duct (m).

The comparison is quite good and allows us to consider the convection-diffusion model as a suitable tool in this case. Secondly, in order to adapt this model for duct configurations, such as rectangular section or bend (to be more representative of a ventilation duct of nuclear facilities), and also injection characteristics (direction, ratio between flow and injection velocities), several experiments have been performed to evaluate the influence of the other parameters on the tracer homogenization. Additionally, numerical CFD simulations are used to get 3-D informations on mixing mechanisms, for the non-axisymmetric cases studied.

The aim is to derive from these experiments and numerical simulations new semi-empirical laws giving the evolution of the concentration downstream of the injection. These new models will be presented and compared to the experimental results at the conference.

References

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