DESIGN OF AN EXPERIMENTAL SETUP TO INVESTIGATE DROPLET EVAPORATION IN A HUMAN-LIKE EXHALED JET

K. Mahjoub Mohammed Merghani[1], B. Sagot[2], E. Géhin[1], and C. Motzkus[3]
[1]Université Paris-Est, CERTES (EA3481), 61 Avenue du General de Gaulle, 94010 Créteil Cedex, France
[2]ESTACA, 12 Avenue Paul Delouvrier, 78180 Montigny-le-Bretonneux, France
[3]CSTB, 84 Avenue Jean Jaurès, Champs-sur-Marne, 77447 Marne-la-Vallée Cedex 2, France

*Courriel de l'orateur : khansa.mahjoub-mohammed-merghani@u-pec.fr

RESUME

Cet article présente un dispositif expérimental pour étudier le transport et l'évaporation de gouttelettes de 40 µm dans un jet représentatif d'émissions humaines telles que la respiration ou la toux. La première partie de l'expérimentation est consacrée à la caractérisation du champ de vitesse de la phase gazeuse du jet stationnaire, et des champs d'intensité turbulente, de température et d'humidité. La deuxième partie est consacrée à l'étude des processus de transport et d'évaporation des gouttelettes dans le jet de gaz, en mesurant la vitesse et le diamètre des gouttelettes à différents distances de la source, en utilisant l'anémométrie laser Doppler et l'anémométrie à Phase Doppler.

ABSTRACT

This article presents an experimental setup designed to study the transport and evaporation of 40 µm droplets in a human-like airflow. The first part focuses on the characterization of the stationary gas jet flow field, turbulence, temperature, and humidity. Then we will study the transport and evaporation processes of the droplets within the gas jet, by measuring the decay of droplets velocity and diameter at different locations from the jet source, using Laser Doppler Anemometry and Phase Doppler Anemometry.

MOTS-CLES : Gouttelettes, jet turbulent, Anémométrie à Phase Doppler, aérocontaminants
KEYWORDS : Droplets, turbulent jet, Phase Doppler Anemometry, airborne contaminant

1. CONTEXT

The emergence of epidemic airborne transmitted diseases like SARS and H1N1 raises crucial questions about the routes of the transmission of these diseases. In literature, both short-range transfer of pathogens by droplets between individuals and long-range transfer by airborne dry residues are reported. However, the results are contradictory on the relative importance of these transmission routes, which could be linked to the lack of quantitative information about the behavior of the droplets. Experimental studies on the exhaled droplet are limited, so far, to the investigation of the size distribution of the initial droplets or the dry residues remain after their evaporation. The evaporation and transport of the droplets released during the breathing, speaking, coughing and sneezing are governed by the complex flow field resulting from the interaction of the exhaled airflow with the ambient environment. Thus, it is important to couple the study of the behavior of the droplets with the characterization of the accompanying airflow field. The objective of this study is to follow the behavior of the exhaled droplets experimentally by analyzing their motion and evaporation in a human-like airflow.

2. EXPERIMENTAL METHODOLOGY

Since it is complex to track a single particle measuring its velocity and diameter in realtime, we chose to generate a monodispersed droplets jet and measure the velocity and diameter of these droplets at different distances from the source. The experiment is composed of two parts; airflow field measurements and droplet measurements. The airflow part comprises generating a human-like jet and characterizes it in terms of the humidity field, the temperature field, the velocity field, and the turbulence. Three reference initial velocities corresponding to coughing, speaking, and breathing exhalation activities are chosen for this study. According to the literature those velocity are 10 m/s for coughing [VanSciver *et al.*, 2011] [Chao *et al.*, 2009] and, 4m/s [Kwon *et al.*, 2012] and [Chao *et al.*, 2009] for speaking, and 1 m/s for breathing [Xu *et al.*, 2017]. The choice of the droplet initial diameter is critical as it determines its settling velocity and evaporation. [Duguid, 1946] documented that the size range of the initial droplets is from 5 µm to 2000 µm, with the maximum droplet count in the range of 25 µm - 50 µm. According to Duguid's results, the chosen diameter of the monodispersed droplets jet is 40 µm. Besides falling in a dominant size range, the 40 µm droplets are of particular interest for the study of the droplet evaporation as small droplets evaporate quickly and get carried by the airflow while the droplets of larger diameters tend to fall at a short distance from the source.

3. EXPERIMENTAL SET UP

A jet generator is designed to produce a steady saturated humid air at a temperature of 34°C and a maximum flow rate of 100 L/min. To adjust the initial velocity to the values of the three above-mentioned initial velocities, a mass flow controller is attached to the inlet of the generator. For airflow measurements, the generator is connected to an oil nebulizer which generates submicroscopic DEHS droplets used as tracer particles. The

DOI : 10.25576/ASFERA-CFA2020-19753

nebulizer is then replaced by a Vibrating Orifice Aerosol Generator (VOAG) to produce the monodispersed 40 µm diameter droplets for the droplet's measurements.

Temperature probes, humidity probes and Laser Doppler Anemometry (LDA) are used to explore the jet temperature field, humidity field, and velocity field, respectively. For the droplet measurements, Phase Doppler Anemometry LPA will be used in addition to the LDA to measure both the size and velocity of the droplets. As the airflow measurements and the droplet measurements will be conducted separately, it is necessary to maintain stable environmental conditions thought the measurements campaign. Therefore, a climatic chamber is built to control the ambient temperature, humidity, and air velocity. A whole-ceiling whole-floor ventilation system is used, and the supply air enters the chamber at a temperature of 20°C and with a flowrate of 50 $m^3.h^{-1}$.

To determine the initial box dimensions the analytical model of Xie *et al.* [Xie *et al.*, 2007] is used to predict the flow shape and direction. This model predicts that for 10 $m.s^{-1}$ initial velocity the radius of the jet is 200 mm at 1 m from the artificial mouth and the deflection of the centerline of the flow was about 500 mm at 3 m from the mouth. According to this information about the flow shape and the optical configuration of the measurement device, the initial box dimensions are 3.0 m x 2.0 m x 2.7 m. In such a kind of experiment, it is important to anticipate the confinement effect so CFD simulations were conducted. For the study of the confinement on the axial direction, three kinds of boundary conditions were applied at the opposite wall; an outlet of a 3 m long room, outlet in a 5 m long room and a wall in a 3m long room. Figure 1.a illustrates the velocity field of the jet obtained by the CFD simulation for an initial velocity of 10 $m.s^{-1}$. The comparison between the decay of the centerline velocity for the three boundary conditions is shown in Figure 1.b and we could observe no significant confinement effect on the axial direction. A similar investigation was carried out to examine the effect of the confinement in the vertical direction as the flow is drifted upward due to the thermal plume and no effect was detected in a room of 2.7 m height.

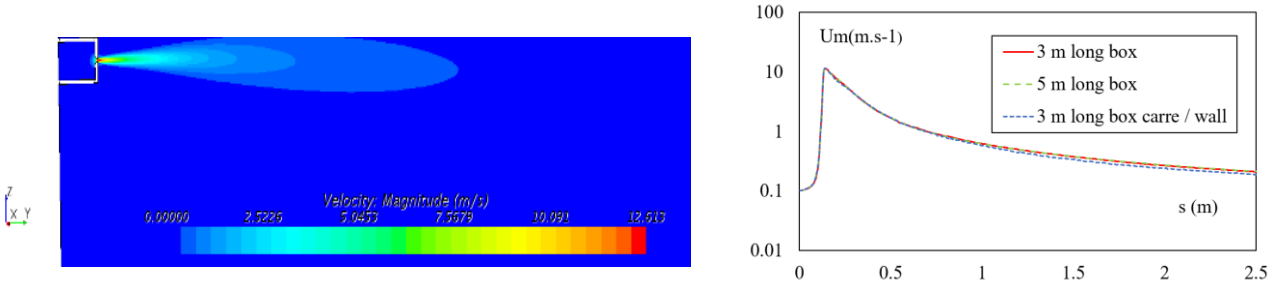

Figure 1. Flow velocity field for an initial velocity of 10 $m.s^{-1}$, at the left. The decay of centerline velocity for three boundary conditions with at an initial velocity of 10 $m.s^{-1}$ at the right.

4. CONCLUSION

In this study, an experimental setup composed of a jet generator and a climatic chamber, is designed for studying droplet's behavior in a human-like exhaled jet. This setup will be used to provide quantitative data and to validate analytical as well as numerical models on the evaporation of the droplet in a steady jet with the same order of magnitude of the human exhaled jet.

[Duguid, 1946] Duguid, J. P. (1946). The size and the duration of air-carriage of respiratory droplets and dropletnuclei. Journal of Hygiene, 44(06):471–479.

[Chao et al., 2009] Chao, C., Wan, M., Morawska, L., Johnson, G., Ristovski, Z., Hargreaves, M., Mengersen, K., Corbett, S., Li, Y., Xie, X., and Katoshevski, D. (2009). Characterization of expiration air jets and droplet size distributions immediately at the mouth opening. Journal of Aerosol Science, 40(2):122–133.

[Kwon et al., 2012] Kwon, S.-B., Park, J., Jang, J., Cho, Y., Park, D.-S., Kim, C., Bae, G.-N., and Jang, A. (2012). Study on the initial velocity distribution of exhaled air from coughing and speaking. Chemosphere, 87(11):1260–1264.

[VanSciver et al., 2011] VanSciver, M., Miller, S., and Hertzberg, J. (2011). Particle Image Velocimetry of Human Cough. Aerosol Science and Technology, 45(3):415–422.

[Xie et al., 2007] Xie, X., Li, Y., Chwang, A. T. Y., Ho, P. L., and Seto, W. H. (2007). How far droplets can move in indoor environments revisiting the wells evaporation falling curve. Indoor Air, 17(3):211–225.

[Xu et al., 2017] Xu, C., Nielsen, P. V., Liu, L., Jensen, R. L., and Gong, G. (2017). Human exhalation characterization with the aid of schlieren imaging technique. Building and Environment, 112:190–199.

DOI : 10.25576/ASFERA-CFA2020-19753