INDOOR AIR QUALITY: A REVIEW OF THE METHODS APPLIED TO STUDY THE SPREAD OF AIRBORNE BIO-CONTAMINANTS

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Abstract. *Indoor cross infection of expiratory contaminants is still an issue for society, govern and authorities, worsened by the recent spread of different influenza strains (avian flu, H1N1, etc), and the outbreak of the virus SARS in 2003. Around the world, various techniques have been applied to help in comprehending the transport of particles, such as tracer gas, solid/liquid particle atomizers and CFD simulations. In this context, the main objective of this study is to present the state of the art of methods applied to evaluate the airborne dispersion of contaminants, more specifically those focusing on cross infection of expiratory droplets. Various studies applied to aircraft cabin, buildings and hospitals are reviewed, and their main aspects related to the experimental techniques and CFD simulation are briefly discussed. Based on the literature review presented, it is possible to define, in a general manner, the main equipment to be used, and the central details related to CFD simulation applied to studies of airborne dispersion of contaminants.*

Keywords*: indoor air, airborne, cross-infection, methodology, review*

1 INTRODUCTION

The outbreak of the virus SARS in 2003 has demonstrated that the spread of indoor air diseases is quite an uncontrolled fact, once it has been fast disseminated through out the world, mainly because infected people have traveled by aircraft between distant cities (Olsen et al., 2003). Mangili and Geandreau (2005) cited several other cases about spread of infectious diseases inside aircraft cabins, such as influenza, tuberculosis and measles, showing that the aircraft cabin might be favorable for airborne cross infection. The Amoy Gardens SARS outbreak in Hong Kong, where 300 residents were infected, has shown that the airborne contamination plays a very important role in building as well (Yu, 2004). In the same direction, Goldmann (2000) has correlated the spread of virus influenza mainly with airborne transmission in homes. In hospitals, some studies have also shown the importance of airborne transmission of biocontaminants (Beggs, 2003; Cole and Cook, 1998; Tang et al., 2006). Inside these different variety of environments, many researchers have focused on understanding the correlation between the type of ventilation system with the transmission of airborne infectious diseases (Li et al 2007; Yang, 2007; Nielsen, 2007; Nielsen, 2008).

Different kinds of methods have been applied by these researchers to simulate particle generation inside experimental chambers and mock-ups, such as tracer gas and liquid/solid particle generators. Additionally, several sort of measurements techniques are required to characterize the particles. In order to simulate particle dynamics, a great part of researchers have been using the CFD Fluent commercial software, with k-epsilon turbulent models, and have considered Lagrangean and/or Eulerean frames to determine the fate of gas or liquid contaminants (Bryant, 2006; Russo et al., 2008; Yan et al., 2009).

The methodologies involved in reproducing and quantifying the dynamics of airborne infection agents is fundamental to fully understand it, and also to comprehend the influence of the ventilation system on it. Therefore, the main objective of this paper is to present and discuss the state of the art of numerical and experimental methods applied so far to evaluate the spread of indoor airborne contaminants, focusing on particles atomized by the expiratory activities such as sneezing, coughing and speaking. Basically, its contribution resides in the fact of gathering the knowledge developed so far in a common source, serving as a guideline for researchers who have acted in this area, which is very incipient in Brazil.

2 METHODOLOGY

This literature review has focused on studies correlated to indoor airborne transport of particles, more specifically, those methodologies related to cross infection of expiratory droplets. The research was done through the Internet, and in the data base available inside USP SIBINET (*Serviço Integrado de Bibliotecas da USP*) during the last 18 months. It was focused more in the aircraft cabin studies, but not only, once there are not sufficient publications in this specific area. Moreover, it is assumed that the methodologies applied to building interiors, a priori, applied to aircraft cabin as well.

3 RESULTS

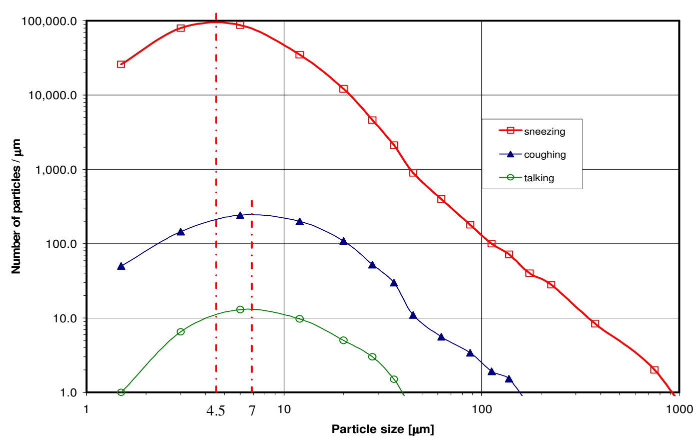
Initially, it is discussed some characteristics of the contaminant of interest, and afterwards, it is presented various studies applied to airborne dispersion of contaminants, including their numerical and experimental aspects.

3.1 Biocontaminants – expiratory droplets

As the wind generates liquid droplets when crosses the ocean waves, the human being produces droplets during the expiratory activities, such as coughing, sneezing, and talking. This process is called atomization, and is defined as the act of generating liquid droplets due to air passage at a specific speed through the surface of a liquid medium (Morawska, 2005). When droplets are produced by expiratory activities of an infected person, pathogenic contaminants present at his expiratory tract are carried outside. Those dispersed contaminants can be directly transmitted to other people via inhalation, or indirectly transmitted via contact with contaminated surfaces, such as seats, walls, objects, and etc.

According to Duguid, 1946, 95% of the expiratory droplets generated by humans have a size between 2 and 100µm, being the most common particles between 4 and 8µm. Based on experimental measurements, this researcher found that the quantity of particles generated by humans are dependent on the type of expiratory activity. As shown in Figure 1, the most generating particle is sneezing, followed by the coughing and talking. Despite of it, the last two occur more often than the first one, and therefore, according to Papineni and Rosenthal, 1997, coughing is in fact the most particle generating activity. In addition, according to Xie et al., 2007, studies have shown that talking for 5 minutes generates the same particle quantity as one coughing.

Duguid, 1946 has sampled human expiratory particles by locating oiled slides nearby their mouths, and then has counted and measured them with microscopy and a micrometer. More recently, Papineni and Rosenthal, 1997, have applied optical counters, reporting that the most quantity of expiratory droplets are lower than 1µm. Nicas et al., 2005, have reviewed these studies, among others, and have concluded that the original studies made by Duguid, 1946 are more consistent. This is why his particle size distribution has being used as a reference in recent studies involving the transport of expiratory droplets (Chao and Wan, 2006, Wan et al., 2007, Sze To et al., 2009, Wan et al., 2010).



Expiratory activity	Number of particles
1 sneezing	1,000,000
1 coughing with mouth closed	5,000
Counting loudly "1" – "100"	250

Figure 1 - Number of particles produced by human expiratory activities as a function of particle size. Based on measuring results obtained by Duguid, 1946.

Once in the air, there exist several chemical and physical processes that modify the physical characteristics and concentration of the droplets, and thus, influence on their fate. According to Morawska, 2005, the most important includes coagulation, where aerosol particles of similar size collide with one another, due to relative motion between them and adhere to form larger particles; the deposition of smaller particles on the surface of greater particles; the size changes due to its moisture content variations (hygroscopic growing or evaporation reduction); the sedimentation, and finally, the deposition on surfaces. Based on the same author, these processes will modify the droplets size, which in conjunction with the initial speed, are the critical variables that most affect the droplet fate.

In general, particles larger than 5µm are deposited on surfaces quickly mainly due to the gravity force (Connor, 2009). The smaller particles instead, probably will remain airborne sufficiently to evaporate completely and form its residue called droplet nuclei. These residues may probably remain airborne for long periods and carry biocontaminants for long distances (Tang et al., 2006).

3.2 Tracer gas

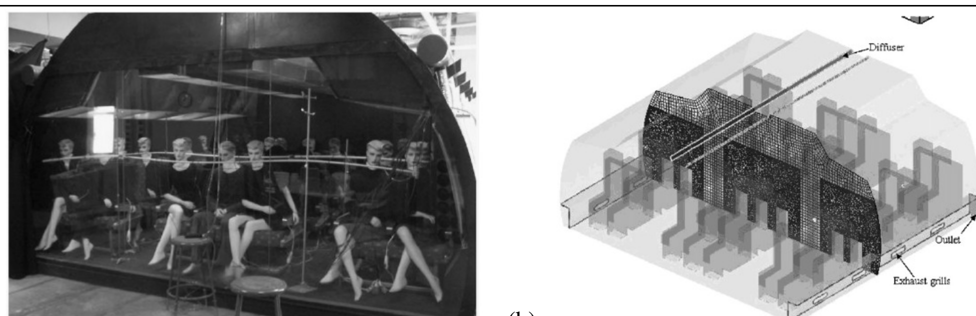
As already mentioned, the droplet nuclei are small particles usually with a medium size less than 5µm, resultant from the evaporation of larger particles. Due to their tiny size, they have a negligible inertia effect and are carried by the airstream as they were in fact gaseous particles. To simulate them, as well as gaseous pollutants, researchers have employed tracer gases such as SF_6 and CO_2, as discussed in the next paragraphs.

Nielsen, 2009, has applied tracer gas to represent experimentally small expiratory particles (less than 5μm), reproducing a case of cross infection inside a mockup of a hospital wards with human dummies (Figure 2). The author has mentioned the tracer gas method is adequate for his study because the target person (dummy on left), is not inside the microenvironment of the infected person (dummy on right). Therefore, the expiratory particles generated by the infected person have a significant distance to evaporate and to become droplet nuclei, which has transport characteristic similar to gaseous particles, as discussed in item 3.1. However, based on human expiratory particles (Figure 1), it is noticed this methodology neglects the effects of particles larger than 5μm, and also the effects of evaporation/condensation processes to the fate of the smaller ones.

Yan et al., 2009, have studied the airborne transport of expiratory droplets inside aircraft cabins, using CO_2 as tracer gas, focusing on droplets nuclei as well (see Figure 3). In this study, 4.5litres/min of tracer gas was injected into the cabin from the mouth of a simulated infected passenger during 5 minutes, and from this time on, the gas concentration around the breathing region of the other passengers was measured with fourteen CO_2 non-dispersive infrared sensors.

Figure 2 – Dummies simulating two persons laid on hospital beds. The right dummy simulates the infected person, and the other is the target (Nielsen, 2009)

CFD transient simulations were applied to model the airflow and CO_2 concentration along the cabin in an Eulerian frame, considering the standard k-ε turbulence model. The cabin was meshed with 1.6 million finite volumes, the passengers modeled as box mannequins, and their thermal dissipation was not considered.



(a) (b)

Figure 3 – Study of the airborne transport of expiratory droplets in a Boeing 767-300 cabin mock-up. (a) General view of the mock-up with the passenger dummies (b) Computational dominium (Yan et al., 2009)

They have got good numerical-experimental correlations for the temperature field, but not so good for the velocities. One limitation is the fact of not considering the mannequin thermal dissipation, and thus, their thermal plume were not captured. As a result, the correlation between numerical and experimental results for the concentration field was quite weak. In fact, as emphasized by Stancato, 2009, the thermal plume promoted by heated mannequins indeed influence the velocities field inside aircraft cabins, and therefore, should not be neglected.

Zhang and Chen, 2007, have applied CFD to simulate the dispersion of CO_2 generated by passengers inside aircraft cabin considering three different kinds of ventilation: mixture ventilation, under floor ventilation, and under floor ventilation with PV (personalized ventilation), as illustrated in Figure 4. It was considered adiabatic seats, box type mannequin with thermal dissipation, and periodicity boundary condition applied on both cabin edges. CO_2 was continuously injected at a rate of 0.3litres/min per passenger, and its concentration modeled with Euler models. The authors have concluded the personal ventilation has improved the air quality of the passengers, but have not shown experimental validation.

Similar study was developed by Gao and Niu, 2007, to evaluate Personalized Ventilation integrated to the aircraft cabin seat armrest (Figure 5). A thermal mannequin scanned from a real detailed mannequin was considered in the simulation, and the pollutant emitted from the floor, and from the occupant skin and nose, considering a constant inhalation rate of 8.4litres/min. The gaseous contaminant dispersion was simulated by injecting CO_2 in a Eulerean frame, and the aerosol dispersion simulated with both Eulerean and Lagrangean models.

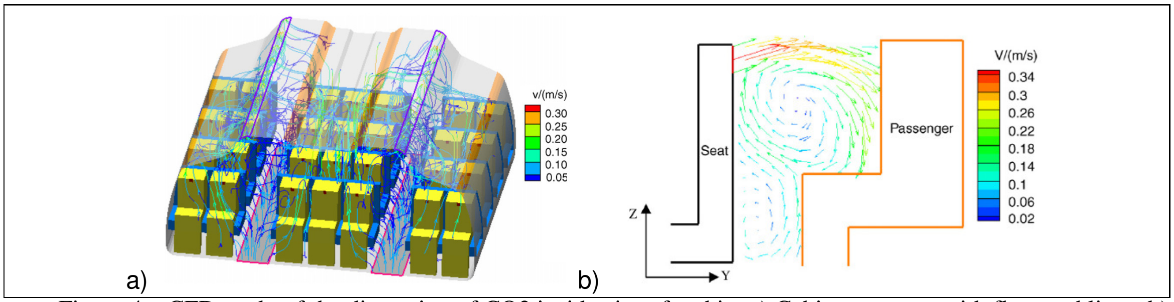


Figure 4 – CFD study of the dispersion of CO2 inside aircraft cabin. a) Cabin geometry with flow pathlines. b) Details of the personalized ventilation integrated to the back of the cabin seats (Zang e Chen, 2007)

At first, the airflow was solved considering RNG k-ε turbulence models with standard wall functions, and after that, the disperse phase equations assuming one way coupling. The dispersed aerosols were considered spherical particles with medium diameter of 1µm and density of 1000kg/m^3, and simulated in a Lagrangean frame. They were injected with an initial velocity of 20m/s during 0.5s, aiming at simulating a horizontal sneezing. The equations applied to model the liquid particles were similar to the applied to simulate the gaseous particles, including the gravitational effect, not considered for the gases. A semi-empirical model was applied to represent the liquid particles adhering effect to solid surfaces, and it was taken into account the thermophoretic, Brownian, and lift Staffman forces. The effects of the turbulence in the pollutants dispersion were considered with the discrete random walk (DRW) stochastic method. Likewise Zhang and Chen, 2007, they have not conducted experimental validation.

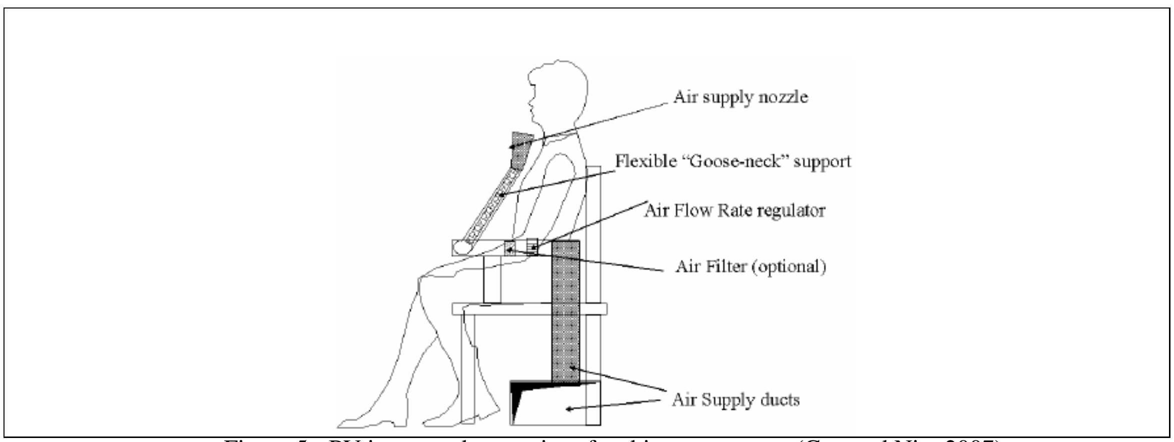


Figure 5 - PV integrated to an aircraft cabin seat armrest (Gao and Niu, 2007)

3.3 Particle generators

In order to generate aerosols, different kinds of atomizers have been applied. These devices can generate unique particle sizes (known as mono-dispersed particles) or multiple (poli-dispersed particles), depending on its atomization principle. Some researchers have applied off-the-shelf mono-dispersed atomizers to study cross infection, such as those used by Zhang et al., 2008, and Jones and Nicas, 2009. On the other hand, the off-the-shelf poli-dispersed particle generators found do not produce particles in the size of interest, as will be discussed on item 3.3.2.

3.3.1 Mono-dispersed particle generators

Shimada et al., 1996, have studied the dispersion of fine particles inside a ventilated experimental chamber and with CFD simulation. The main focus was to investigate the influence of the releasing point location. Around 3.10^10 particles of latex polystyrene per cubic meters of air with a medium size of 0.14µm were released by the emission port into the room with an airflow of 1L/min. An in-house made mono-dispersed particle generator composed basically by a pump, a nebulizer and a drier was used (see Figure 6). Ten cupper tubes with 6mm in diameter were applied to sample air from the room and guide it till two optical particle counters. The sampling tubes suction air was varied from 0.3 to 1 liters/min as well as the tubes length, but no effect to the measurements was found. Three samples per position were taken, and 20% of reproducibility was obtained. They have not obtained good results when the emitter is close to the wall due to its effects on particle dynamics. In the end of the analysis, they have increased the grid by an 8x factor, and have obtained similar results for velocity field, but not so similar for concentration. The authors believe it could be explained by the fact of larger discrete volumes having higher particle numerical diffusion.

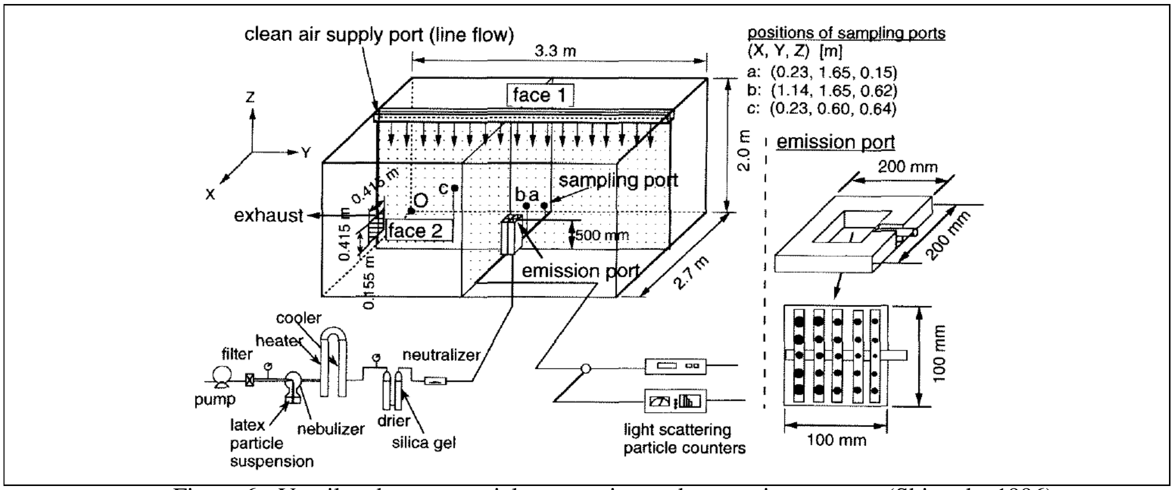


Figure 6 - Ventilated room, particle generating and measuring systems (Shimada, 1996)

Zhang et al., 2008, have studied the dispersion of airborne particles in aircraft mock-up with box type heated mannequins, focusing on the air velocities, temperatures and contaminants concentration fields. Expiratory contaminants were simulated with tracer gas (SF6) and non-evaporative mono-dispersed Di-Ethyl-Hexyl-Sebacat (DHES) particles with medium size of 0.7µm, produced with a TSI model 3475 particle generator. Both gaseous and liquid particles were injected trough tubes into the cabin, and monitored in 48 points, distributed on two measurement planes (see Figure 7). Each measurement took 30 seconds, and was repeated 10 times with a photo-acoustic multi-gas analyzer and an optical particle sizer. The airflow was numerically solved with RANS, applying RNG k-e turbulence model, and the dispersed phase considered in a Lagrangean frame. The method *particle source in cell* (PSI-C) was adopted to calculate contaminant concentration, based on its trajectories. Good numerical-experimental correlations for temperature field was obtained, but not for the velocities and concentration fields, mainly due to diffusers jet air velocity measurement uncertainties. They have observed the velocity measurement process is a key-factor to study the transport of airborne particles, and also a challenge.

Jones and Nicas, 2009, have also applied TSI mono-dispersed particle generator (model 3450) to generate solid contaminants of 3 and 14µm, aiming at to form an experimental data bank to help in the validation process of mathematical models applied to study the airborne transport of particles. Three axes ultrasonic anemometer was applied to measure air velocities inside a ventilated but unoccupied and unfurnished chamber. In order to minimize perturbations to the airflow, the generator was positioned outside the chamber, and the particles injected through 1.8m length polyvinyl tubes, with 3.2cm of diameter, and mixed with airflow of 50litres/min before entering the chamber. They have applied specific methods to assess the particle deposition on the floor and walls, have measured advective and turbulent flow with ultrasonic anemometer and also mixing time with carbon monoxide tracer study. Due to these experimental techniques, they consider their results unique if compared with other studies.

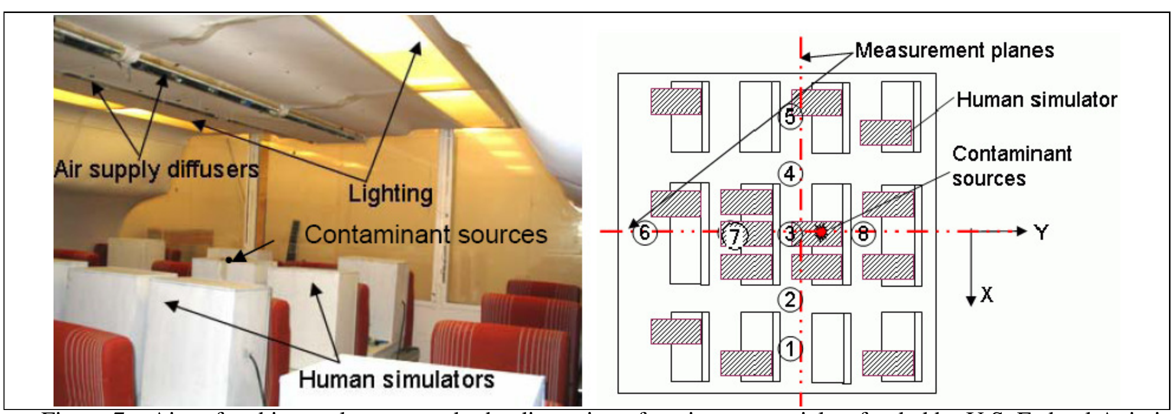


Figure 7 – Aircraft cabin mock-up to study the dispersion of expiratory particles, funded by U.S. Federal Aviation Authority. Left, the interior of the mock-up. Right, top view with measurement planes (Zhang et al., 2008).

3.3.2 Poli-dispersed particle generators

Different kind of poli-dispersed aerosol generators are found in the market (ATI, GRIMM, RR Elektronic, TSI, PIVTEC, Spraying System). As depicted on Figure 8, these poli-dispersed generators usually produce particles having approximately 0.3µm of medium diameter. Unluckily, this size is too small to simulate particles generated during expiratory activities (as shown in Figure 1), but of interest for the filtration industry (MIL-STD-282, 1995), and for Laser Doppler velocimeter (LDV) seeding.

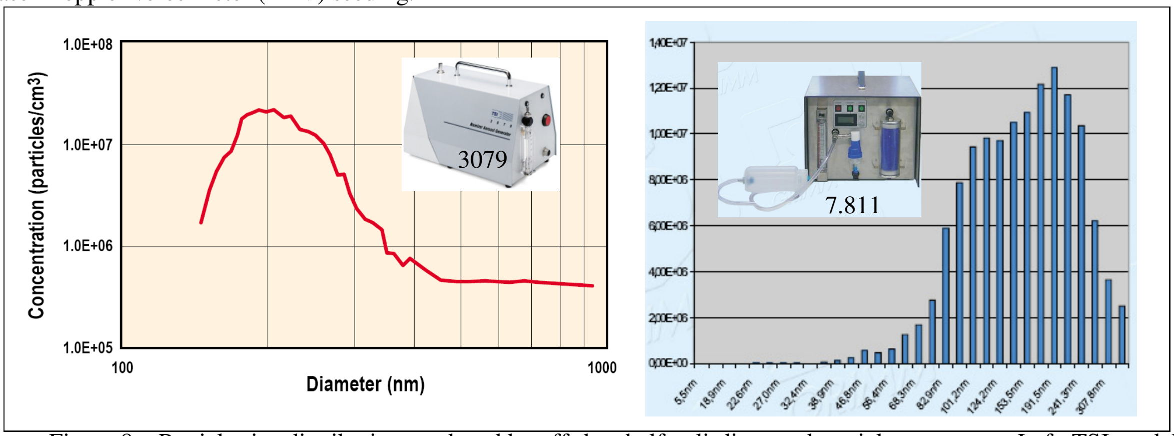


Figure 8 – Particle size distribution produced by off-the-shelf poli-dispersed particle generators. Left, TSI model 3079 particle generator (TSI, 2010). Right, GRIMM model 7.811 particle generator (GRIMM, 2010).

Pennecot et al., 2004, have applied a Laskin type PIVTEC atomizer to generate particles with a medium size of 1µm, but these particles were used for seeding the PIV (Particle Image Velocimetry) system, aiming at measuring airflow velocities inside aircraft cabin.

Even though not found in the literature review, an ultrasonic atomizer was also investigated. Based on the equipment manual (SONICLEAR, 2010) eighty percent of the particles generated by this atomizer are lower than 4µm, which represents the lower particles generated by expiratory activities (Figure 1). Unfortunately, it was not found enough details to characterize the particles in mono or poli-disperse, and also to identify its concentration. It works with total aerosol airflow of 10 to 12 L/min, what seems adequate to simulate expiratory activities airflow rate. However, its fluid recipient is quite little, restricting the total time of nebulization to a maximum of 12 minutes, what could impair experimental studies. General information concerning the operation principles of ultrasonic type atomizers can be found in Hinds, 1999.

The fact of not finding any commercial poli-dispersed particle generator that produces similar particles as those produced during expiratory activities (Figure 1), may have being the main motivation for researchers to develop in-house made particle generator. One example of those is depicted in Figure 9, which if fed with compressed air and liquid similar to human saliva. This particle generator is able to mimic the human coughing, and have been used to study the airborne transport of expiratory droplets by some researchers, such as Wan et al. 2005, Wan et al. 2007 and Sze To et al., 2009.

Wan et al., 2005, have applied the just cited particle generator to evaluate the dispersion of expiratory droplets inside a ventilated aircraft mockup with heated thermal manikins. The particle size distribution was characterized with a light scattering particle spectrometer (PMS Lasair 1002) located 10mm far from the injection nozzle, resulting in a peak concentration of 2.5x10^6 particles/L at a medium size of 6.75µm (Figure 10). 400mL of air was injected as a puff release of compressed air with duration of 1s, producing an air velocity at the generator nozzle of 10,4m/s. Based on the measurement with volunteers conducted by Zhu et al., 2006, this air velocity at the nozzle is apparently adequate to simulate human coughing. The particles were injected at two different points, and its concentration measured at 15 seats, all of them 1.1m above the floor. Particles were detected one row distant from the injection point in the longitudinal direction, and 3 rows distant in the lateral direction, what could be explained by the cabin airflow profile. The relative humidity of the cabin was controlled in the range of 5 to 25%, and the peak of detection occurred for the higher cabin humidity values, explained by the lower droplets evaporation ratio. They have observed also that the cabin contaminant concentration is inversely proportional to the fresh air flow rate.

Similar study was developed by Sze To et al., 2009, where the main objective was to characterize the dispersion and deposition of expiratory droplets inside aircraft cabin, as well as to understand the effects of the cabin air changes on the dilution and removal of these particles. This study was carried in an aircraft cabin mock-up built inside ICIEE (International Center for Indoor Environment and Energy), located at the Technical University of Denmark (DTU) (Figure 11a). The in-house made poli-dispersed particle generator applied on this study was calibrated to generate particles equivalent to the ones produced by human coughing, based on Duguid, 1946, as depicted on Figure 11b.

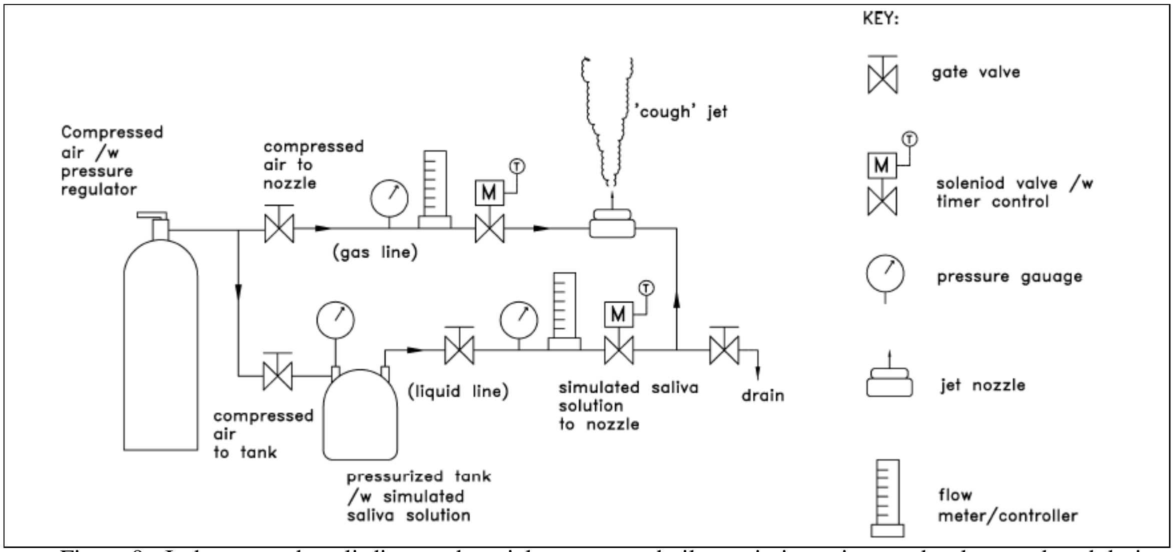


Figure 9.- In-house made poli-dispersed particle generator, built to mimic expiratory droplets produced during human coughing (Wan et al., 2007).

During the experiments, the cabin was kept without recirculation, and pressurized with 7Pa to avoid any kind of infiltration. Heated cylinders were added to simulate passengers thermal dissipation, PIV was used to characterize the particle generator initial jet air velocity during one coughing, and spectrometers to characterize particles. The method called *fluorescence dye technique* was applied to measure particle deposition on internal surfaces. Since there was one spectrometer only, the experiment was repeated several times to measure the various points, and to assess reproducibility. Results have shown that increasing the fresh airflow rate, the particle concentration nearby the injection point was decreased due to the dilution effect. On the other hand, the particle dispersion is increased, which helps to rise the particle concentration around the seats located more distant from the injection point. This study has confirmed the particles fate is totally dependent on their sizes, and it was obtained particles deposition rates of 60 to 70%.

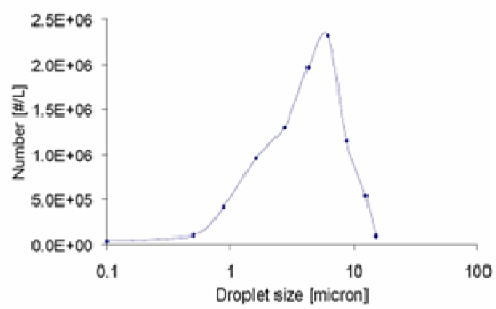


Figure 10.- Droplet size distribution 10 cm far from the nozzle outlet of an in-house made poli-dispersed particle generator (Wan et al., 2005)

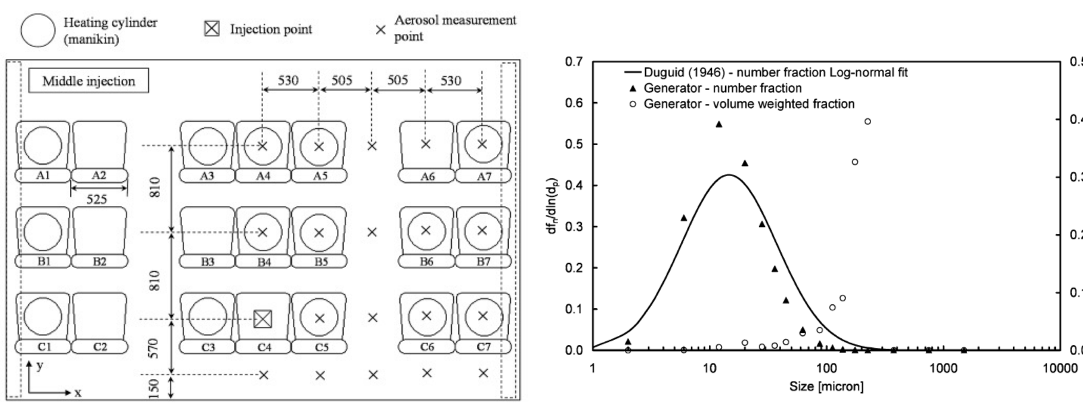
4 DISCUSSION

In a general manner, the reviewed studies have applied tracer gas, and or solid/liquid particle atomizers in order to simulate the transport of expiratory droplets. As already mentioned, the atomizers employed can generate mono or poli-dispersed particles. In some studies, such as Zhang et al., 2008, and Gao et al., 2007, it was applied both methodologies in order to simulate a wider band of particles.

When applying commercially available equipments, such as in Bryant et al., 2006, and in Jones and Micas, 2009, the particle size is usually well characterized by their manufacturers, and this type of data is usually available inside their technical manual. On the other hand, to use in-house made particle generators, such as those applied by Shimada et al., 1996, Wan et al., and Sze To et al., 2009, it is required to characterize the particle size generated with adequate measuring method such as the IMI (Interferometric Mie Imaging) – as shown in Figure 10. A normal particle counter might not be used instead, mainly due to the high particle concentration in the generator outlet jet, which may cause major coincidence losses for this type of equipment (Met One HHPC-6, 2010).

Before choosing the aerosol generator device, it is important to understand the physical process one's intend to simulate in the experiment in order to specify the aerosol main characteristics, such as its airflow, particle number and sizes. Based on Yan et al., 2009, the human average inhalation/exhalation rate is around 4.5litres/min. If the intention is to simulate expiratory activities, for instance, the particle generator used by Zhang et al., 2008, and by Jones and Micas, 2009 (TSI, model 3475) seems adequate, since its operational flow rate is 3.5-4litres/min (TSI 3475, 2010),. Moreover, it generates particles in the range of 0.1 to 8μm, which encloses the most common particle size generated by expiratory activities according to Duguid, 1946. Exploring a little bit more this example, the generator TSI model 3475 produces mono-dispersed particles, but the expiratory droplets are in fact poli-dispersed as shown in Figure 1. Nevertheless, considering its aerosol concentration is around 10^6/cm3, the coagulation effect may be neglected (Hinds, 1999) and therefore, the experiments could be done for different particle sizes independently, and its effects evaluated individually. This discussion is important to show that the particle generator specification should be a detailed process, and is very dependent on each specific experiment details.

Depending on the specific needs, the phenomenon could be treated as steady-state or transient. Thatcher et al., 2002, focused on determining the particles deposition rate after a puff release of compressed air, which is intrinsically transient, and therefore, a Spraying System particle generator with a controlled short duration particle injection was used. Wan et al., 2005, and Sze to, 2009 have considered transient analysis as well, since they have applied the in-house particle generator depicted on Figure 9, which also generates a puff release of compressed air. On the other hand, Zhang and Chen, 2006 have evaluated different types of building ventilation based on the dispersion of contaminants generated by a continuous and mono-dispersed particle atomizer. In such a case, a steady-state approach could probably be applicable. Russo et al., 2008, have checked the efficiency of a patented Personalized Ventilation Device by means of tracer gas generated continuously, and again, a steady-state assumption was also reasonable.



a b

Figure 11 - ICIEE cabin mockup with 21 seats (Sze To et al., 2009).

Regarding particle detection, it has mostly been applied optical counters and spectrometers, which should be specified according to the particle size generated in the experiment. Another important aspect is the equipment sampling time, which should be specified according to the experiments specific characteristics (if steady-state or transient, time scales, etc), as briefly discussed by Wan et al., 2005.

As these equipments sizes are usually considerable, and thus may affect the airflow/contaminant distribution, they have been placed outside the experimental chambers. So, both particle injection and particle sampling have been made by means of small diameter tubes. In this case, as mentioned by Shimada et al, 1996, a sensitivity analysis should be done to evaluate if the applied tubes length and diameter impacts on measurements or not. In addition, the sampling air suction and the relative position between the counter and the airflow should also be investigated in order to guarantee iso-kinetics measurements (Hinds, 1999).

In relation to numerical methods, it was noted that particle 3D transport has been mainly modeled with CFD simulation. Usually, the airflow is solved in a steady-state Euler approach, considering well established turbulence models (mainly k-e RNG), with standard coefficients (Zhang et al., 2008, Yang et al., 2007, Wan et al., 2009). The dispersed phase has been modeled with both Eulerean and Lagrangean frames, always considering one-way coupling only (airflow affects dispersed phase but not the inverse). Zhang and Chen, 2007, have made detailed comparison between both methods for different applications. They have pointed out that the resultant particle concentration distribution calculated with both Euler and Lagrange are similar for steady-state applications, but have recommended Lagrange for intrinsic transient analysis, such as those made by Wan et al., 2007.

In addition, it was identified that the measurement of velocity field is a key-characteristic to obtain good correlations between numerical and experimental results, mainly when it is used to define CFD simulation boundary conditions. Zhang et al., 2008, have applied omni-directional anemometers to measure the velocity magnitude on the cabin diffusers inlet air jet, and smoke to estimate the velocity direction. They believe this might have been the main reason to have differences between numerical results and measurements for contaminants concentration. To avoid this problem, Sze To et al., 2009 have applied PIV to measure aircraft cabin internal air velocities and based on that, Wan et al., 2009 have obtained better numerical-experimental correlations. On the other hand, numerical errors derived from bad-defined boundary conditions for cabin diffusers inlet velocities could be minimized if the upstream ducting parts are included in the CFD simulation (Mazumdar, 2008). However, depending on the complexity of the ducting parts to be included in the simulation, the computational efforts to generate the mesh and solve the airflow could increase too much. Based on all that, it is important to go deeper on each experiment specific details in order to better define the numerical-experimental strategies.

A final important point to be considered when simulating expiratory droplets, is the influence of the relative humidity. As it affects significantly the evaporation/condensation ratio of liquid aerosols, it was observed that some studies have taken its effects into consideration on both experiment and CFD simulations (Wan et al., 2005, Chao et Wan, 2007, and Sze To et al., 2009).

5 CONCLUSIONS

The state of the art of methods applied to study dispersion of expiratory contaminants was presented and discussed, focusing mainly on the experimental and CFD methodologies applied so far. Based on this literature review, it is possible to preliminarily identify the main equipments needed for such a study, a variety of requirements involved, as well as some details about the required computational efforts.

6 ACKNOWLEDGMENT

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