Proceedings of the 4th International Conference on Environmental Science and Applications (ICESA'23)
Lisbon, Portugal- December 04 - 06, 2023
Paper No. 117
DOI: 10.11159/icesa23.117

Design and Construction of a Contact Chamber for Bioaerosol Studies

Lidia Alicia López Vega[1], María Teresa Orta Ledesma[2], Cesar Alejandro Villaseñor Ríos[3], Isaura Yáñez Noguez[4], Ignacio Monje Ramírez[5]
[1,2,4,5]Instituto de Ingeniería, UNAM
Circuito Escolar S/N, Ciudad Universitaria, Coyoacán, Ciudad de México, México
[1]LLopezV@iingen.unam.mx; [2]MOrtaL@iingen.unam.mx; [4]IYanezN@iingen.unam.mx;
[5]IMonjeR@iingen.unam.mx;
[3]Unidad Profesional Interdisciplinaria en Ingeniería y Tecnologías Avanzadas, IPN
Av. Instituto Politécnico Nacional 2580, Ticomán, Gustavo A. Madero, Ciudad de México, México
[3]cvillasenorr@ipn.mx

Abstract – Lately, bioaerosols are gaining importance due to during the last 20 years there have been outbreaks of respiratory diseases caused by different viruses, such as SARS–CoV–2. Which is each time being able to reach more population around the world. For this reason, more studies are necessary about the route of transmission followed by this kind of virus. An important part of airborne transmission studies are contact chambers, these units allow to have an enclosure space to study bioaerosols and are available in a wide kind of models. In this paper, three steps are established to obtain the design and build a contact chamber for studies of bioaerosols: the first step is a mass balance, the second step is a simulation of a proposal design in SOLIDWORKS® software, and finally the construction of contact chamber.

Keywords: Bioaerosol, design, contact chamber, solidworks, construction

1. Introduction

For the last 20 years, there have been different outbreaks of respiratory diseases caused by an airborne transmitted coronavirus, in 2020 was the first outbreak due to the severe acute respiratory syndrome coronavirus (SARS–CoV), in 2012 was the second outbreak due to the middle east respiratory syndrome coronavirus (MERS–CoV) and in 2019 was the latest outbreak due to the severe acute respiratory syndrome coronavirus number 2 (SARS–CoV–2) [1]. The last outbreak due to SARS–CoV–2, its causative agent of the COVID–19 respiratory disease, lead to a worldwide sanitary emergency since its emergence in the city of Wuhan, China. Different changes occurred across countries because of the incessant increment in the number of cases. This led to the implementation of different restricted measures ranging from the use of masks and suspension of classes to mandatory isolation in their homes and even the closure of borders [2]. Although today we count on vaccines to help to reduce severe cases that could lead to death in infected patients, World Health Organization estimated until February 26th of 2023 more than 758 million positive cases and more than 6.8 million people have died around the world [3]. The impact of SARS–CoV–2 over the world population has been greater than outbreaks of SARS–CoV or MERS–CoV, due to it has wide tissue tropism and a larger prodromal period, producing more transmissibility from people infected to people not infected [4]. The transmission routes of SARS–CoV–2 are varied, the main ones are bioaerosols originating in the respiratory airways of infected people, which can enter in direct contact person to person, or indirect contact via fomites or aerosols suspended in ambient. These aerosols are also able to reach people noninfected located far from issuing people, which means airborne; also fecal–oral via was suggested, and a zoonotic pathway which is assumed as the original route by the virus reached humans [4].

Bioaerosol generated by an infected host can come from different areas of the respiratory airway, if bioaerosol comes from a lower respiratory tract, the range of aerodynamic diameter is between 0.1 and 1 micrometer; meanwhile, bioaerosol originating in the upper respiratory tract has a range of aerodynamic diameter between 1 and 100 micrometers [5]. Once in the ambient the size of bioaerosols will define the route which micro drops follow, particles of aerodynamic diameter less or equal to 5 micrometers will be able to stay suspended in the ambient due to its very low sedimentation velocity (3.5 E-05 $m \cdot s^{-1}$) and come to persons located at 1 meter or more. The particles of aerodynamic diameter bigger than 5 micrometers with low sedimentation velocity (3.1 E-03 $m \cdot s^{-1}$) will be able to follow two trajectories: to come to persons located one meter from the emitter, or even deposit over near surfaces too [6]. Furthermore, there is evidence that aims to airborne transmission of SARS–CoV–2, among which are fast propagation of the virus consistent only with characteristic patterns of this kind of route, virus transmission among people in adjacent rooms without direct contact, high rate of transmission in enclosure spaces, detection of infective virus in air samples from rooms of infected patients, in ventilation ducts and filters, and others [7]. In these recent outbreaks of diseases due to airborne viruses and their capacity to reach more populations, it is predominant a need to have protocols or standard studies to allow knowing the behavior that viruses follow in the air [8].

Among the necessary equipment to analyze bioaerosol is contact chambers, used to supply particles of interest, delimit space, and even control environmental conditions such as temperature, relativity humidity, and others. For some years have reported the use of different kinds of contact chambers, there is cylindrical, rotative, and made of stainless steel [9], prefabricated as GenaMini (SCL Medtech Inc, Montreal, QC, Canadá) [10, 11, 12], cylindrical isolated [13] and made of acrylic [14, 15]. Of course, they are available in a lot of dimensions, since almost room size with 1.60m^3 [9], another one of 55.5E-03m^3 [13], one else of 1.848E-03m^3 [14], and one of 0.125m^3 [15]. The approach to the use of a contact chamber could be for biological studies [9, 10, 11, 12, 13] or other types of studies as trials of sensors to measure contaminants [14, 15]. All of them are equipped with sampler ports, additional installations to monitor temperature or relative humidity, and all the necessary connections to set up their tests. According to the bibliography, it is possible to observe that contact chambers can be very diverse and completely focus on the target of study of each one because they use different volumes, flows, and complement equipment.

For this work, the design and construction of a contact chamber for the study of bioaerosols are focused on investigating the inactivation of viral particles in contaminated environments.

2. Objective

Design and construction of a contact chamber that improves the mixing of two aerosol flows with a lower amount of short-circuiting, in order to develop aerosol studies.

3. Methodology

For the design and construction of the contact chamber, the main variable to be considered was the uniform mixing between two aerosol streams. One stream corresponds to the supply of a viral indicator, and the other stream is the supply of disinfectant solution. The purpose is to improve the mixing of aerosols within the contact chamber with a reduced amount of short circuits. An adequate mixture will promote better virus-disinfectant contact, and therefore an effective inactivation of viral particles. The design parameters of the contact chamber contemplated a mass balance by determining the aerosol supply and exit ports and a simulation on SOLIDWORKS®. Considering these design parameters, the construction of the contact chamber was carried out.

In order to carry out the mass balance, inlets and outlets were established in the chamber. Inlets: 1) nebulization of viral particles, 2) nebulization of disinfectant, 3) purge, 4) relative humidity control. Outlets: 1) sampling of viral particles which were not inactivated, 2) purge.

Figure 1 shows a representative diagram including the components of the experimental array that was tested to evaluate the performance of the contact chamber: 1) two nebulizers Single Jet Model 9302 (TSI Inc. Shoreview, MN, US) that would be connected to the contact chamber for supply inlet flows; 2) Button sampler (SKC Inc. Valley View Road, PA, US) equipped with a gelatin filter (SKC Inc. Valley View Road, PA, US) and a suction pump AirCheck® XR5000 (SKC Inc. Valley View Road, PA, US) to collect the sample in outlet flow.

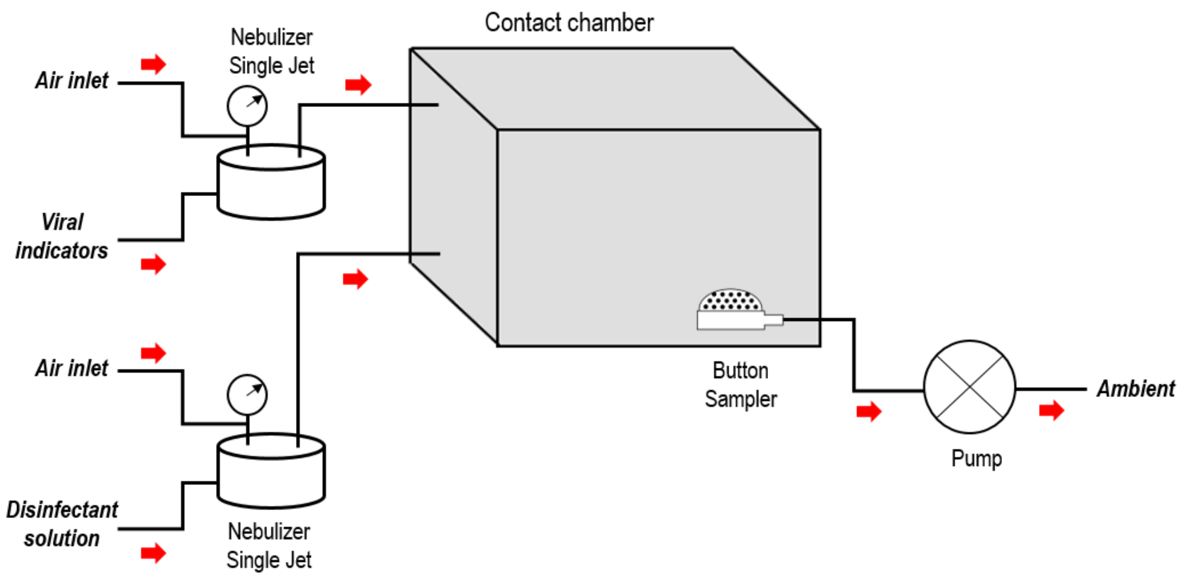

Figure 1: Diagram of experimental arrangement with the contact chamber

For both the inlets and outlets of the contact chamber, the operating conditions of the equipment used were established. Two Model 9302 Single Jet Nebulizers (TSI Inc. Shoreview, MN, US) were used to supply the viruses and disinfectants. The total flow rate was determined by means of inverted graduated cylinder tests, and the amount of nebulized liquid was measured by weight difference before and after two minutes of nebulizer operation. For the sampling of viruses that were not inactivated, we used a pump AirCheck® XR5000 (SKC Inc. Valley View Road, PA, US), the suction flow determined by the manufacturer is 6.66E-02L$\cdot$s^{-1}.

The dimensions of the contact chamber were established, as well as the different arrangements of the inlet ports. Considering the variables described above, SOLIDWORKS® software was programmed to perform simulations and determine the trajectory followed by the flows inside the contact chamber. Subsequently, the conditions that presented the best mixing and the least short-circuit, i.e., the optimum arrangement, were determined.

After of have the simulation of the optimum arrangement, was determined the material and additional characteristics of the contact chamber.

4. RESULTS

4.1 Mass Balance

The characterization of the nebulizer Single JET Model 9302 (TSI Inc. Shoreview, MN, US) showed its capacity to supply a flow of 9.76E-02L$\cdot$s^{-1} operating at 150kPa, as part of these flow 4.46E-06L$\cdot$s^{-1} represent liquid in aerosol dispersed in a continuous gas phase. Two of these flows are supplied by two nebulizers as the inlets to the contact chamber. On another hand, the Button sampler (SKC Inc. Valley View Road, PA, US), according to the manufacturers, works with a suction flow of 6.66E-02L$\cdot$min^{-1}. This flow is considered an outlet. The available space in the lab for the assembly of the contact chamber and its auxiliary equipment is an extraction hood with a 1.27m width, 0.80m tall, and 0.55 depth. With all this information was proposed the next measures for the contact chamber: 0.30m width, 0.25m tall, and 0.20m depth.

4.2 Design Simulation

In the simulation with SOLIDWORKS® software, the conditions to be considered are: the inlet flows are gaseous, the total flow supplied by each nebulizer (9.76E-02L$\cdot$s^{-1}), the area of the orifice through the nebulizer's flow will entrance to the contact chamber (2.83E-05m^2), the speed of nebulizer's flow entrance to the contact chamber ($3.45 m\cdot s^{-1}$), temperature (25°C) and pressure (101,325Pa).Once realized the simulation of different proposed experimental arrays, the optimum simulation showing the best development with better mixing and lower short-circuiting, which was the array with the inlets in countercurrent and difference in level.

Figure 2 shows a front view of the contact chamber's simulation, the speed inside of the contact chamber is approximately $0.64 m\cdot s^{-1}$ and the trajectories followed by flow present mix and few short-circuiting. Meanwhile Figure 3 shows a lateral view of the contact chamber's simulation, where we can see the mix with few short-circuiting.

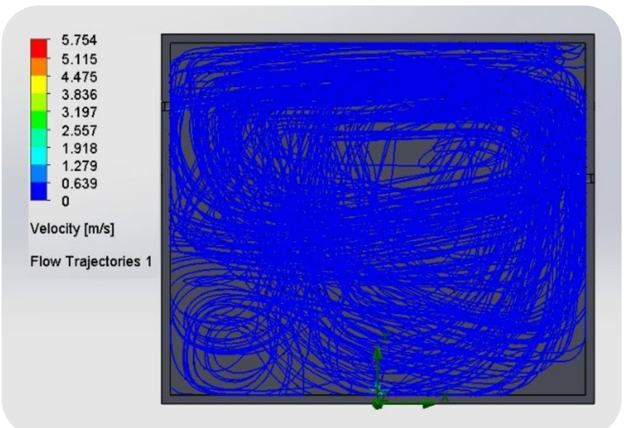

Figure 2: Front view of flows simulation in SOLIDWORKS® software.

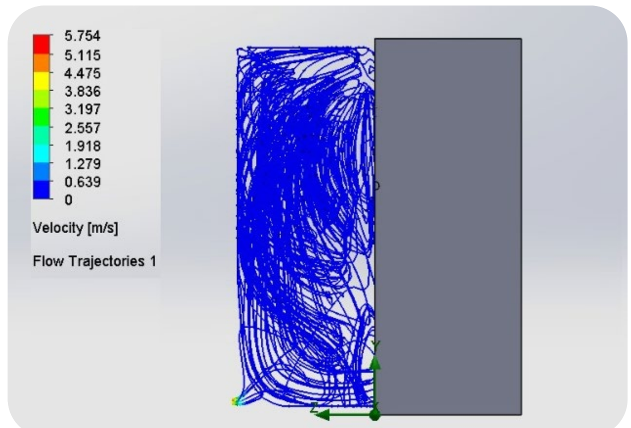

Figure 3: Lateral view of flows simulation in SOLIDWORKS® software.

In the simulation the inlet flow was considered as gas due to the minimum amount of liquid present in it, nevertheless we should consider its presence in some way, and that is why was calculated the drag force (or Stoke's drag) that micro drops in the aerosol experience by the flow inside of contact chamber, the drag force was determined by Stoke's Law as it is expressed by Equation 1.

$$F_d = 6\,\pi\,R\,\mu\,u \qquad (1)$$

To calculate the drag force the next considerations were made: the diameter of a liquid sphere (R) as 5E-06m, a dynamic viscosity (μ) as 1,003E-03Pa·s, and the speed (u) obtained in the simulation $0.64 m\cdot s^{-1}$, yielding a value of F_d = 6.04E-05N.

4.3 Building of Contact Chamber

Although the design with the best performance is the one with the inlets in countercurrent and difference in level, an extra ports was added to get samples in different points as at the top or at the bottom, to even make other supply tests.

The selected material to build the contact chamber was transparent acrylic of 6mm thickness, this material was chosen due to its good properties of chemical resistance, low humidity adsorption, continuous operational capacity in temperatures up to 80°C, and its low costs. The assembling was made with special glue for acrylic and then sealed with silicon. The ports were put in the lateral, top, and bottom faces of the contact chamber, each port was equipped with one gas valve, in the top we collocated a flange with screws and a neoprene gasket to tight seal the contact chamber.

Overall the contact chamber built of transparent acrylic has 5 ports with gas valves to open or close if it is necessary, also it has a flange with screws and a tight seal. In Figure 4 displays the front view, meanwhile, as well in Figure 5 displays the lateral view of the contact chamber.

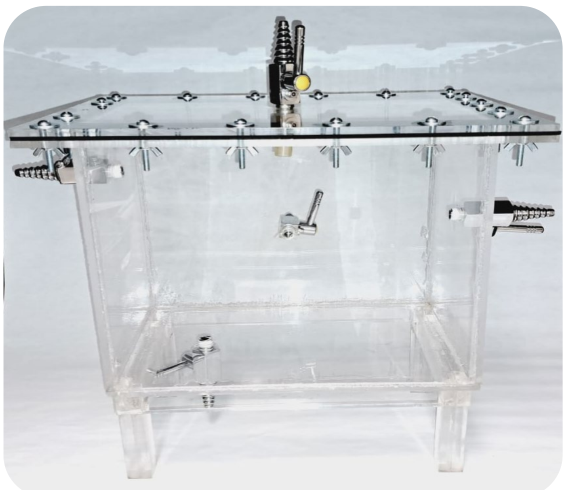

Figure 4: Front view of the contact chamber.

Figure 5: Lateral view of the contact chamber.

5. CONCLUSIONS

Through the approach of mass balance and the monitoring of the different simulations made with SOLIDWORKS® software, adequate design was achieved according to experimental conditions, both infrastructure and operation. The building of the contact chamber was made by the previously established design. This article could be a guide to follow in every case you need to develop a contact chamber, because in all bibliographies there is no manual for this kind of equipment, a lot of them are for water which is not necessarily applicable to this case.

It should be mentioned that this contact chamber already has been used in some tests of bioaerosol sampling to determine recovery percentages, and in tests of inactivation of viral indicators reaching inactivation levels to 98%. But all these data are pretended to be used in a posterior publication.

ACKNOWLEDGMENTS

To the National Council of Science and Technology from Mexico for the sponsorship.

To the Lab of Environmental Engineering of Engineering Institute – National Autonomous University of México for providing the facilities to the assembly of the equipment.

To the National Autonomous University of Mexico – General Academic Personnel Affairs Department, by its support through its Program to Support Research and Technological Innovation Projects No. BG101621 “Design and production of droplets, microdroplets and vapors for the sanitizations environments”.

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