Performance Assessment of COVID-19 Swab Collection Booth (SCB)

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***Abstract*— In the wake of the COVID-19 pandemic, all emergency and routine medical activities have been greatly affected. A safe method of swab collection for PCR testing is deemed necessary for the sake of protection of healthcare workers and patients, and in mitigating the pandemic through timely contact tracing. Given the highly contagious character of the virus, swab collection booths should be aimed at creating a safe environment for the collection of specimens from the patients. This can be accomplished by achieving a desired pressure difference between the chambers containing the patients and the doctors. Quite a few such systems were developed and implemented worldwide, including in Nepal; however, their scientific study is very limited. Thus, with a view to scientifically back the claims of positive pressure mechanisms warranted in swab collection process, in this paper, the airflow into and out of a swab collection booth (SCB) is simulated using computational fluid dynamics (CFD) techniques. The model simulated showed a positive pressure inside the chamber proving that the air carrying droplets cannot enter the chamber stationing the medical staff.**

Keywords—COVID-19, Computational Fluid Dynamics (CFD), Swab Collection Booth (SCB)

I. INTRODUCTION

Since the outbreak of the novel coronavirus disease (COVID-19) and its spread worldwide in early 2020 [1]–[3], many countries have spent their research capacities in combating the virus, be it either through preventive or corrective measures. One of such measures that directly assists in the pandemic mitigation through PCR testing followed by contact tracing is the adoption of swab collection booth (SCB). This system helps achieve safe and economic specimen collection by medical personnel.

As the coronavirus is transmitted through a multitude of media, droplet transmission being the most common, this alternative and specialized method of SCB have been developed worldwide [4]–[6], esp. in the resource-poor countries having Personal Protective Equipment (PPE) shortages to protect the healthcare workers who naturally face serious risks, as well as the suspected patients who might get infected through cross contamination.

Isolation booths are seen as rapid and cost-effective solutions that provide healthcare workers with ample isolation from the patient, while maintaining flexibility so as not to impede their performance [7]. Focus is usually given on airtight sealing, isolation, mobility, ergonomics and regular sanitation in order to prevent transmission of the virus to the doctor and cross-contamination among patients [8]. The frequent and rough use of such booths calls for a technology that can be used in lieu of airtight seals.

A widely accepted theory is that of ventilated chambers providing a difference in pressure. Based on the law of diffusion, these chambers secure the healthcare worker by placing him/her in an environment of higher pressure than the patient, effectively stopping the flow of potentially infected air into the healthcare worker's chamber. Ad hoc solutions such as a negative pressure tent to prevent aerosol transmissions have been developed by the University of Michigan and FlexSys Inc [9]. Similarly, healthy patients are prone to nosocomial infections and contamination from aerosols produced by patients. Such delicate surgeries benefit greatly from a negative pressure environment that lessens exposure and cross-contamination, even those created from readily available medical equipment [10], [11]. Using differential pressure booths in conjunction with a HEPA (High-Efficiency Particulate Air) filter rules out the possibility of aerosol based disease transmission, providing an additional layer of protection for healthcare workers [12]. In the same vein, patients can be accommodated in negative pressure environment for isolation purposes [13], [14]. It is noted that this negative pressure chamber would require proper disinfection following every test [2].

As improvisation to the above theory, in the context like Nepal where suspected patients tended to hesitate entering into the test chamber that was already visited by the preceding patient, is that medical personnel be kept inside the positive pressure chamber with adequate isolation. This would still need disinfection of the areas surrounding the swab collection nevertheless. One of such a swab collection booth was researched and developed by Nepal Academy of Science and Technology (NAST) and donated to Tribhuvan University Teaching Hospital (Institute of Medicine) as depicted in Fig. 1.


Fig. 1 The Swab Collection Booth Developed by NAST

Furthermore, in resource-poor regions, where health facilities are few and far between, testing of the potential virus infection has been performed successfully with a 'mobile swab collection vehicle' – essentially a vehicle carrying positive pressure chambers [15]. Specimen collection booths have been seen to help in reducing specimen collection time, disinfection time as well as cutting down on time that would otherwise be taken to change PPE, increasing the number of tests performed per day at a cost that is cheaper in the long run [16].

The effectiveness of this pressure-based method can either be assessed through physically-based experiment or by simulating airflow inside such a chamber. The physical experiments can be too cumbersome and also expensive for parametric evaluation. Alternatively, Computational Fluid Dynamics (CFD), which is a numerical method employed for mathematically visualizing and analyzing the flow of fluids and has been used to simulate airflows of similar nature, can be employed [8]. In this paper, ANSYS FLUENT, a popular CFD tool, was used to simulate the flow of air inside a swab collection booth in 3 different configurations of inlet and outlet. This parametric study would provide an overview of the pressure distribution inside the booth along with the flow field of air. An overall positive pressure inside the booth would indicate that the concept is verified.

II. METHODOLOGY

The swab collection booth is modelled as a aluminum cuboid, a box of dimensions 1.5×1.5×2.5m with circular inlets and outlets of 0.2m diameter as depicted in Fig. 2. CFD simulations were run in 3 variations of inlet and outlet of the same booth. A constant velocity inlet of 1.768388m/s is considered, corresponding to a discharge of 200 m^3/h. On the other hand, the outlet is modelled as a pressure outlet at atmospheric pressure. The parametric study is done in the aforementioned 3 cases. In each case, a tetrahedral mesh of max size 100mm is used. The simulation is carried out in a steady state model for 1500 iterations in FLUENT. The turbulence is modelled with realizable 2-eqn k-epsilon model and scalable wall function.

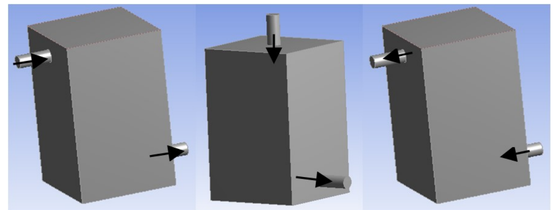
Fig. 2 Diagram Showing Three Configurations of the Booth

III. RESULTS

A. Case I

The inlet and outlet are placed at two opposite faces as shown in Fig. 3. The room has an overall positive pressure with a higher-pressure region in the face across the inlet.

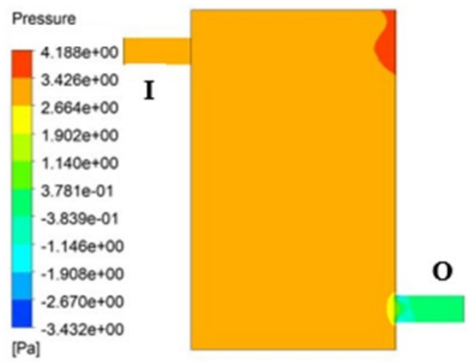

Fig. 3. Pressure Contour (I denotes inlet and O denotes outlet)

B. Case II

The inlet is placed at the top face as shown in Fig. 4. The room has an overall positive pressure without areas of major pressure concentration.

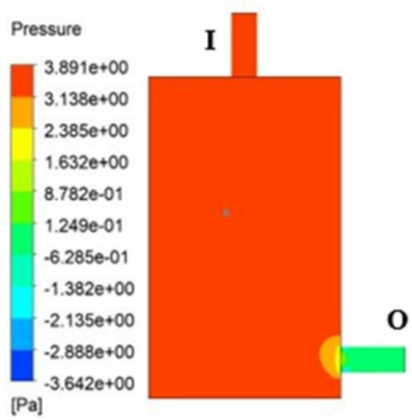

Fig. 4. Pressure Contour (I denotes inlet and O denotes outlet)

C. Case III

The inlet and outlet are placed at two opposite faces as shown in Fig. 5. Similar to *Case I*, the room has an overall positive pressure with a higher pressure region in the face across the inlet.

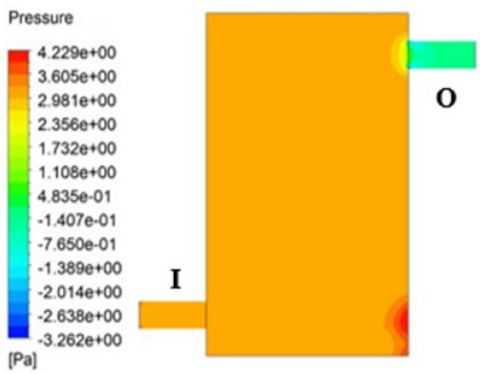

Fig. 5. Pressure Contour (I denotes inlet and O denotes outlet)

IV. DISCUSSION

A. Concentration of Pressure

The three configurations of the swab collection booth showed drastically different pressure distributions across the chamber. Although each configuration maintains a positive pressure inside the booth, the amount, distribution and local concentration of pressure varies between configurations. Case I and Case III had localized areas of high pressure while Case II had a much uniform distribution of pressure distribution as evidenced from Fig. 3, Fig. 5 and Fig. 4 respectively.

To further study the variations of pressure across the booth, certain probing locations were specified. These locations are explained in Table I and Fig. 6.

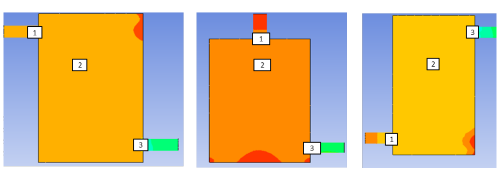

Fig. 6. Position of pressure probing at mid-planes: case 1(left), case 2 (middle), case 3 (right)

TABLE I. PROBING LOCATIONS

Point 1	Inlet mid-plane (entry into the booth)
Point 2	Middle of the booth, mid-plane, at a height of 1.6 m
Point 3	Outlet mid-plane (exit from the booth)

B. Comparative Study of Pressure

The gauge pressures taken at points 1, 2 and 3 along with maximum pressure in the chamber are specified in Table II. Upon plotting them in a graph, a trend is obtained that is uniform for all cases.

TABLE II. PRESSURES AT VARIOUS POINTS

Gauge Pressures (Pa)				
Cases	**Point 1**	**Point 2**	**Point 3**	**Maximum**
Case 1	3.17308	3.1198	1.22259	4.188
Case 2	3.3128	3.24261	1.3201	3.981
Case 3	3.1183	3.08448	1.1578	4.229

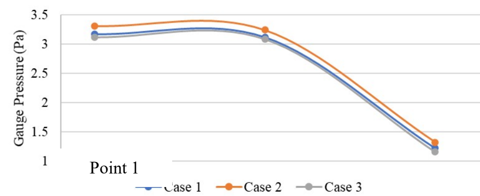

Fig. 7. Pressure Variation at 3 Points in the Simulation

It is evident from Fig. 7 that the trends in pressure are same in all 3 cases. Moreover, the values of pressures at 3 points are nearly identical for Case 1 and Case 3; i.e., it does not matter if the inlet and outlet is exchanged. However, an inlet at the roof of the booth provides for a higher overall pressure in the room although the maximum pressure is less than that observed in Case 1 and Case 2 implying that the configuration with the inlet at the top is the optimal option out of the three. It is to be noted that the pressures in this study do not refer to absolute pressures, but gauge pressures while the operating pressure is considered to be 1 standard atmosphere (101325 Pa).

TABLE III. GAUGE PRESSURES FOR CASE 1

2.2m	**1.9m**	**1.6m**	**1m**	**0.3m**
3.17308	3.11661	3.1198	3.12907	1.22259

Pressures at various heights in Case 1 are probed in the simulation as depicted in Table III. Upon plotting and analyzing these values using a website, an exponential curve (R^2=0.9993) was found to reasonably fit the data [17].

$$P = 3.136626 - 20.16319/2^{(z/0.08831232)}$$

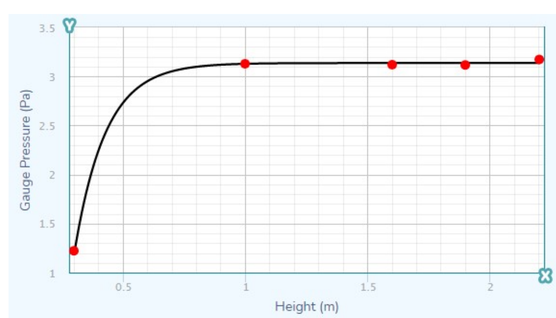

Fig. 8 Exponential Approximation to the Variation of Pressure

In Fig. 8 and the equation associated therewith, P represents the gauge pressure in Pascals, and z represents the height from the ground in meters.

V. CONCLUSION

Healthcare workers are at constant risk of COVID-19 infection as they are exposed to patients every day. Positive pressure isolation booths provide reliable protection to healthcare workers from cross-contamination and ensure rapid, economical sample collection with minimum contact and without wearing expensive PPEs.

The flow of air in a COVID-19 swab collection booth was simulated using ANSYS FLUENT for 3 configurations and the variation of pressure was plotted. Each configuration showed a positive pressure inside the booth with similar trends of pressure variation from inlet to outlet confirming the concept scientifically. Furthermore, more promising results were observed with the configuration having the inlet placed at the top. One of such booths used for combined swab and blood collection modified by NAST and donated to Nepal APF Hospital had the same configuration of inlet and outlet. The variations of pressure with altitude were also approximated using an exponential function.

In the future, a fully equipped large scale swab collection vehicle with disinfecting capabilities can be studied based on this result.

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