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ORIGINAL ARTICLE

COVSACK: an innovative portable isolated and safe COVID-19 sample collection kiosk with automatic disinfection

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Abstract

The Corona VIrus Disease 2019 (COVID-19) is one of the significant medical disaster that changed the life of humankind in the 21st century. The deadly virus is transmittable from infected person, through his nasal droplets, to surrounding people among whom, the healthcare personnel are the utmost affected. The present article brings out an innovative chamber, which is used for collection of throat, or nasal swabs/samples for diagnosis of COVID-19 suspected persons. The chamber, called COVid SAmple Collection Kiosk (COVSACK), eliminates the transmission of the deadly virus to the health care personnel while collecting the sample. The kiosk is designed based on CFD simulations for effective spread of disinfectant in fine droplet form, built with a lightweight composite that is sustainable in extreme weather conditions and the kiosk can be easily sanitized within 3 min after sample collection. The chamber is first positioned in ESI Hospital, Hyderabad, and other hospitals and diagnostics centres across India, extensively being used for testing the COVID-19 patients at a faster rate, with a drastic reduction in use of personal protection equipment (PPE). This technological innovation, to certain extent, has changed the way the testing of COVID-19 patients carried out in the country.

Keywords COVID-19 · Corona virus · Sample collection kiosk · Testing booth

Introduction

The novel coronavirus belongs to a family of viruses that can cause many respiratory symptoms such as fever, cough, shortness of breath and breathing difficulties, and lung contagion (Adhikari 2020 and Lai 2020). In more severe cases, infection can cause pneumonia, severe acute respiratory syndrome, and kidney failure and death (WHO 2020). The coronavirus disease 2019 (COVID-19) is a highly transmittable and pathogenic viral infection, first noticed in Wuhan of China during December 2019, has spread around the world just within two months. The deadly virus has rapidly infected 25 lakhs (Fig. 1) of people and caused death of 1.8 lakhs across the globe by 23rd April 2020 (Fig. 2). The virus is reported to spread among the people through multiple ways. The primary route for the transmission is through aerosolized droplets that are expelled during coughing, sneezing, or breathing, but there are also concerns about possible airborne transmission (Udwadia 2020; Adnan 2020). The COVID-19 affected person may carry the virus in his hand, body, clothes, key chains, mobile phone etc., which are accumulated from his breath. He may leave virus on all the surfaces wherever he touches and sneezes at. The virus gets attached to other person whenever he touches those surfaces (Kampf 2020). The virus takes time from 05 to 14 days to develop the symptoms. Therefore, COVID-19 suspects are usually kept in complete isolation for 14 days.

To impede the rate of infection of COVID-19, many countries have declared lock down. Therefore, across the globe, as crores of people stay at home, health-care workers prepare to do the exact opposite. They go to clinics and hospitals, exposing themselves to high risk from COVID-19. The statistics from China show that more than 3300 healthcare workers have been infected as of early March and, according to local media, by the end of February at least 22 had died. In Italy, 20% of responding healthcare workers were infected, and some have died. Reports from medical staff describe physical and mental exhaustion, the torment of difficult triage decisions, and the pain of losing patients and colleagues, all in addition to the infection risk (Lancet 2020). The healthcare worker may be exposed to

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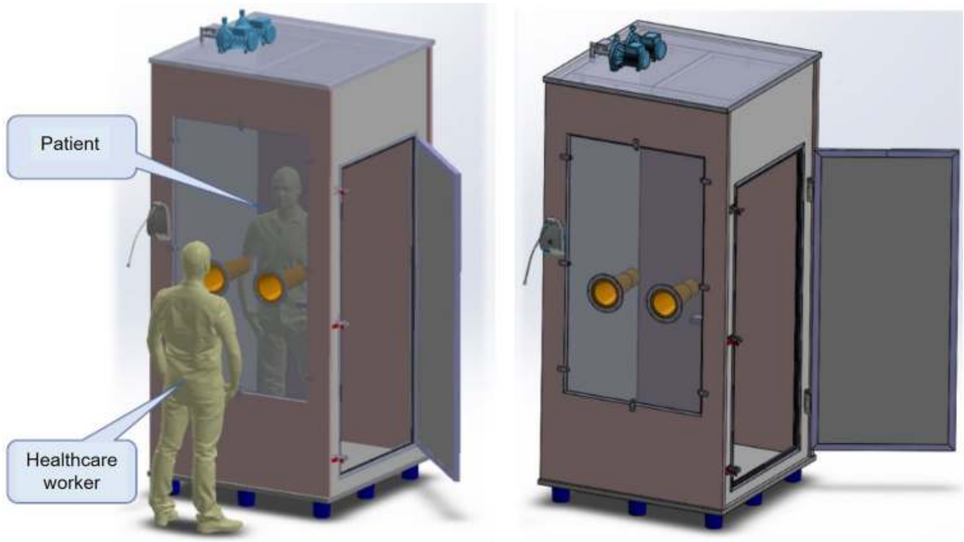

Fig. 1 Pictorial representation of COVID-19 sample collection kiosk

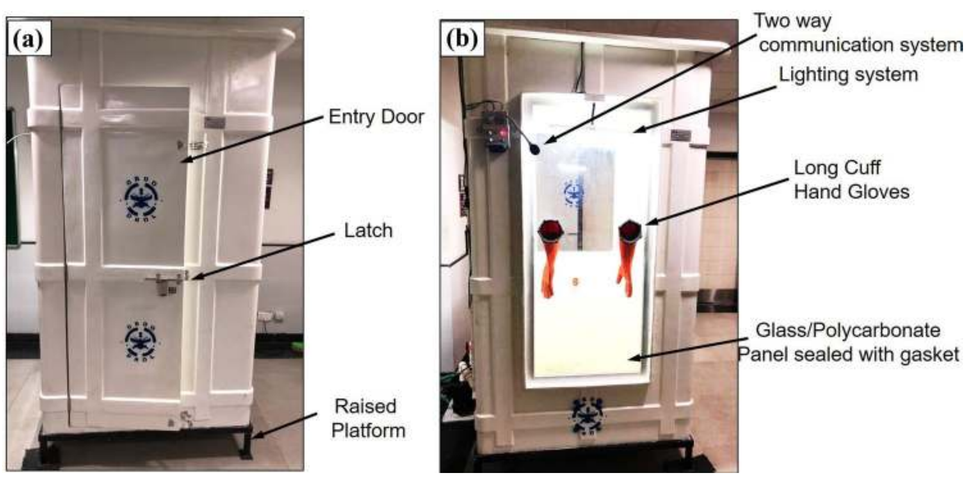

Fig. 2 Major features of CAV-SACK unit **a** view from patient entry door, **b** view from healthcare worker operating panel

the virus during handling, testing and treating the infected patients. The possible reasons for the virus transmission to the healthcare worker could be due to (1) lack of sufficient quantity of personal protective equipment (PPE) at the most infected places; (2) PPE provided not meeting the quality standard requirements; (3) inadequate or unsuitable isolation chambers for testing of suspected patients; and (4) prevailing unhygienic conditions in the facilities where COVID-19 positive patients are treated.

Among these possible sources of transmission, the maximum possible virus exposure is anticipated during the sample collection and testing of the COVID-19 patients, as healthcare worker come across the highest number of patients every day. At present, most testing for COVID-19 targets to identify the infection by molecular detection of the COVID-19 antigen (Lupia 2020). This test involves a RT-PCR (Reverse transcription polymerase chain reaction) of viral RNA in fluid, typically acquired from the swab collected from nose or from throat. Many times, during the aforesaid sample collection, the patients experiences the sensation of coughing or sneezing, which results in jettisoning of aerosol droplets from nose or mouth of patients. Exposure to these kind of aerosol droplets keeps the healthcare workers at the high risk of COVID-19 transmission. Together with concerns for their personal safety, healthcare workers are concerned about passing the infection to their beloved ones. Healthcare systems globally could be operating at more than the maximum capacity for many months. However, healthcare workers, unlike ventilators or wards, cannot be urgently manufactured or run at 100% occupancy for long periods. In the global response, the safety of health-care workers must be ensured. Presently, health-care workers are every country's most valuable resource that needs to be protected from virus infection to safeguard the humankind (Gan 2020). The technologies and tools that the health care workers handle during the process of testing to treatment forms the primary circuit of contamination with the deadly virus. Health care organizations should also consider designing and installing engineering controls to reduce or eliminate exposures by shielding physicians, other health professionals and patients from infected individuals. For example, physical barriers or partitions can help guide patients through triage areas (Sara Berg 2020).The global approach to COVID-19 testing has been non-uniform. In South Korea, testing has been extensive, with emphasis on identifying individuals with respiratory illness, tracing and testing even their contacts. Other countries (e.g., Spain) initially limited testing to individuals with severe symptoms or those at high risk of developing them. Here, we outline the case for mass testing of both symptomatic and asymptomatic health-care workers to: (1) mitigate workforce depletion by unnecessary quarantine; (2) reduce spread in typical, mild, or asymptomatic cases; and (3) protect the health-care workforce. Staff shortages in health care are significant amidst the global effort against coronavirus disease.

There has been many types of systems and gadgets for supporting the healthcare workers during the COVID-19 pandemic (Adams 2020). Very recently in India, particularly in Kerala (Sruthi 2020), telephone booth like chambers are employed for collection of samples from COVID-19 patients, where the healthcare worker is inside the booth, while the patients are outside. This type of sample collection equipment may lead to virus transmission as all the suspected and positively infected patients are nearby in one place. In such situations, it may not be possible to maintain a minimum social distance of 6–7 feet between two persons. In addition, there may be chances of improper removal of virus on all surfaces that are touched in and around testing booth, as the disinfection is done manually. Moreover, there is no automatic and infallible disinfection or sanitization provision in these booths. Keeping in view above all facts, the country is in need of an isolated, safe and airtight kiosk, where automatic disinfection is possible for containment of virus spread during sample collection during these crisis times.

Purpose of kiosk

COVSACK is a kiosk that can help healthcare workers take samples from suspected patients, minimizing the use of the PPE kits. The intention of employing Kiosk is to keep the suspected patient from complete isolation from the doctors and the medical staff while collecting the COVID-19 test sample. The Kiosk is specially built for disinfection automatically without any help of human personnel. The chamber is meant for access to healthcare worker from outside, to take a swab from the suspected patient. Once the sample from patient is collected, the patient as well as the whole inside chamber need to be sanitized first by spray of disinfectant followed by flushing of water for cleaning. The shielding screen of kiosk cabin protects the healthcare worker from the aerosols of the patient while taking the sample. The chamber is kept in a separate room where only the kiosk and medical staff are present. The patients are allowed into this room only for sample collection and sent out of the room immediately after sample collection. This ensures the medical staff who sits outside the kiosk does not need to wear any PPE. Therefore, the kiosk minimizes the use of PPE by the health care worker for each sample taken, which reduces the cost of COVID-19 testing enormously. As the time taken for sample collection and sanitization of the kiosk is around 3 min, it makes it possible to employ in testing the large pool of patients. The maintenance cost of this kiosk is minimal as the dispended amount of disinfectant and water is minimum. This is possible, because atomization of disinfectant liquid through the properly placed spray nozzles. The cost of equipment, installation, operation, manpower, transportation stand to be reasonable when the safety of medical staff is taken into consideration that too while handling hundreds of patients per day.

Salient features of kiosk

A pictorial representation of COVSACK unit is shown in Fig. 1. The chamber is made of lightweight composite material with a wall thickness of 5 mm, which can sustain extreme weather conditions such as outside temperatures ranging from − 20 °C to + 55 °C. This composite material is specially developed for manufacture of weapon system containers. The internal dimensions of the chamber, where COVID-19 patient stands, are 2000 mm height × 1200 mm width × 1200 mm length. The key features of CAVSACK unit are shown in Fig. 2. One wall of the chamber, through which healthcare worker interacts with patient, is made of transparent glass/polycarbonate. The entire chamber and its accessories coated with suitable corrosion resistant coatings. The chamber is designed with good structural rigidity to withstand transportation loads, vibrations and can carry an internal weight of 300 kg after installation and commissioning. The kiosk is equipped with a microphone speaker and public addressing system with two-way communication between patient and sample colleting healthcare worker. It is equipped with electric lighting system to provide sufficient illumination, so that doctors can work in low light conditions or during the night shifts.

Another important feature of the kiosk is that it is fitted with a pair of long cuff gloves in the sidewall of the entry door. A tray is fitted ergonomically on the wall that housed the long-cuff gloves, so that healthcare workers can keep the necessary accessories, vials, and kits while collecting COVID-19 sample. The raised platform of the chamber is designed to withstand the self-weight of the kiosk plus 300 kg, considering the maximum weight of patient. However, when the kiosk is deployed in places of extremely low temperatures less than zero centigrade, there is chance of freezing of disinfectant or water. In such conditions, a closed loop temperature controller can be installed for maintaining ambient conditions inside the chamber and in the storage tanks of disinfectant and water, as an additional accessory. The Kiosk is completely sealed with suitable rubber gaskets near the transparent walls, doors, and gloves, so that the virus transmission does not occur to outside of the chamber. As the total time for sample collection is too short, it does not cause a suffocating experience to a suspected COVID-19 person. Once the door is closed, air does not pass through the chamber to outside or vice versa. The significant disinfection features of CAVSACK unit are shown in Fig. 3. The kiosk is provided with two pumps, one for disinfectant straying and other for water flushing, along with a dedicated plumbing system and drain. Spray nozzles as per details mentioned in next section are fitted in the suitable positions in the plumbing line.

Spray nozzles and its positions

Computational Fluid Dynamics (CFD) simulations are conducted to estimate the particle size and distribution with respect to time during disinfectant spraying with a pressure of 5 bar, by appropriately selecting the type of spray nozzles, their locations on the wall and the number of nozzles required to spray the disinfectant to cover the internal volume of the chamber. The chamber with a size of 1200 mm × 1200 mm × 2000 mm is shown in Fig. 4a. The CFD simulation was conducted, assuming that all the openings on the chamber are closed. The viscosity and the density of the disinfectant are assumed to be that of the water. No ventilation in or out of chamber was assumed. The CFD study is performed for various type and number of nozzles (with diameter = 0.2 mm with 0.06 L per minute mass flow) and their positions on the top and sidewalls to arrive at an optimal solution, so that whole cabin is covered with sanitizer in an optimal time. A well-proven CFD software is used to simulate multiphase flow dynamics. The disinfectant is sprayed into the chamber through the nozzles and its particle size, velocity and distribution is estimated using the simulations (Fig. 4b–e). Particle sizes of around 10 microns with almost negligible velocity are observed in the chamber.

Ten number of nozzles (four on either sidewalls and two on top wall) are required to fully cover the volume of the chamber with disinfectant particles within about 12 s (Fig. 4f, g). Total 10 numbers of spray nozzles are provided as per the location marked in Fig. 4a, for spraying the disinfectant. The selection of location and number of disinfectant spray nozzles are decided, such that the internal walls of the chamber are covered with the mist of the disinfectant in short span of time. Moreover, the positioning and number of nozzles were validated by cross verifying the efficacy of disinfection process, i.e., samples taken from the internal walls after disinfection process tested for null presence of virus multiple times, with a fixed interval of time. Based on this experience, as a standard inspection procedure, periodically, it is recommended to repeat this testing procedure, to ensure the proper functioning of disinfection process.

Sample collection procedure in kiosk

The sample collection kit (comprising a tube and swab) is carried by the patient, which is kept outside the kiosk. The patient picks up a sample collection kit and then enters the kiosk through the door positioned in sidewall, followed by

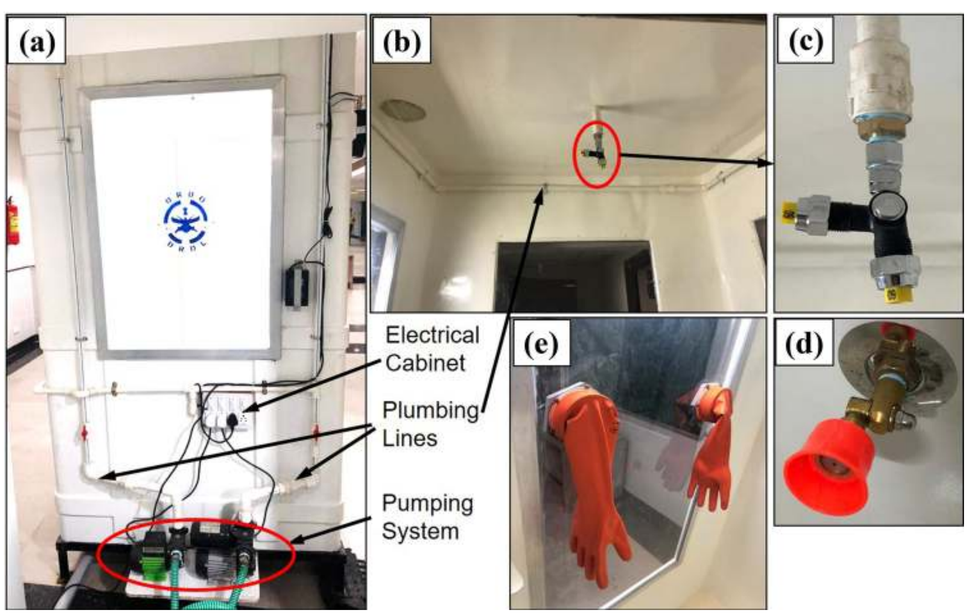

Fig. 3 Disinfection features of CAVSACK unit, **a** details of plumbing lines and pumping system, **b** internal plumbing lines, **c** disinfectant spray nozzle on top wall, **d** disinfectant spray nozzle on sidewall, **e** long cuff gloves with gasket sealing

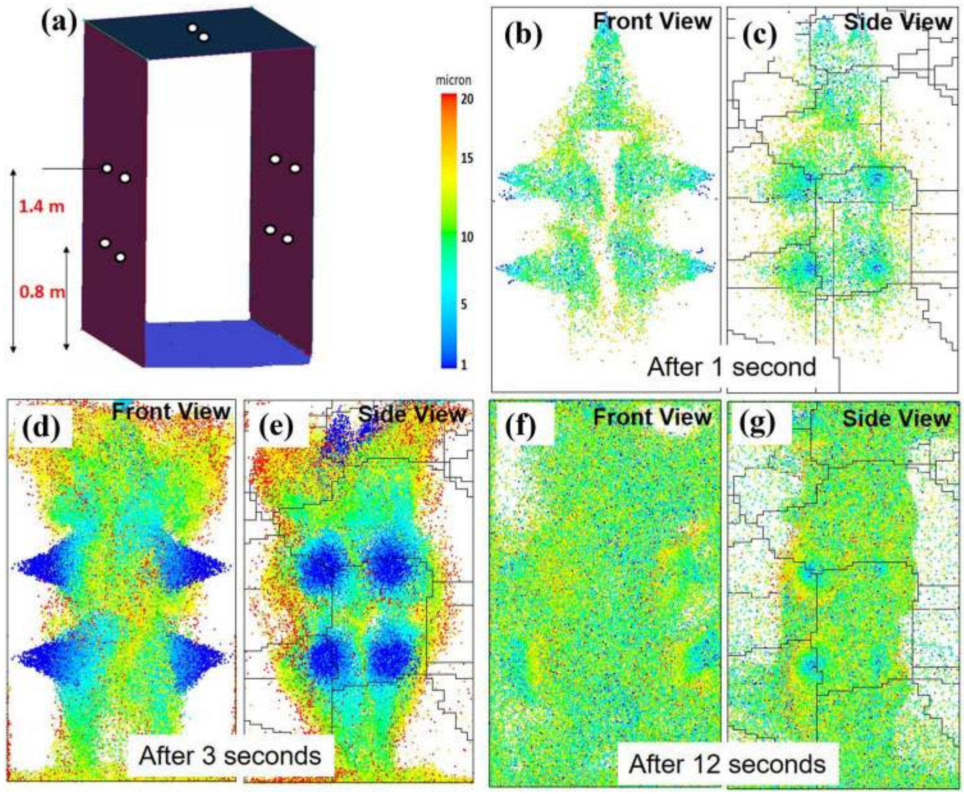

Fig. 4 CFD analysis to estimate the particle size, velocity and distribution during disinfectant spraying in kiosk, **a** schematic sketch of chamber and positions of spray nozzles, **b**, **c** distribution and size of particles in the chamber after 1 s, **d**, **e** distribution and size of particles in the chamber after 3 s, **f**, **g** distribution and size of particles in the chamber after 12 s

bolting of the door by the healthcare workers. The chamber does not have a provision to be bolted from inside as a safety measure. The healthcare worker who is standing outside the chamber inserts his hands through the long cuff gloves and collects the sample from either nose or throat of COVID-19 patient. Then, the sample collection kit is returned back to the patient and he carries back the collected sample to the outside of chamber. Subsequently, all the internal surfaces of the entire chamber, including the long cuff gloves, are sprayed with atomized disinfectant liquid [5% sodium hypochlorite (WHO 2014; Marnie 2020; Storer 2014 and Lineback 2018)] through the nozzles positioned at different places of the chamber. The process of disinfectant spraying takes approximately 30 s time. When the disinfectant is sprayed into very fine particles, it spreads over the surface uniformly and its efficacy of surface disinfection improves. The article by Marnie (2020) indicates the effective disinfection with sodium hypochlorite is possible in 1 min and it is recommended to keep minimum one-minute disinfection time in hospital or diagnostic centers, particularly against COVID-19 virus. This time duration is in line with the works by Storer (2014) and Lineback (2018), but in cases of bacteria and other corona viruses. Therefore, the duration of disinfection is maintained as 2 min in this work. The healthcare worker, who keeps his hands in gloves during the time of disinfection process, also disinfects the hand gloves. The doctor exposes all the fingers, both the sides of palms to the disinfectant, hence, sanitizing the every corner of the gloves thoroughly. Then, the water is flushed through a separate pipeline internally for 60 s to wash of disinfectant from the internal surfaces of kiosk. The water pipeline has closely spaced numerous holes made along the total length so that the complete wall surfaces are flooded with water, washing out all the remnants of disinfectant liquid. In this whole process, the chances of contaminating the sample by disinfectant is almost not possible, thus ensuring the accurate results of testing. Afterwards, the next patient can enter into the kiosk for the next sample collection and this procedure repeats. Therefore, for every patient, on an average, it takes three minutes time for collecting the COVID-19 sample.

First prototype of COVSACK in operation at hospital

The first prototype COVSACK unit is dedicated to the county at ESIC Medical College and Hospital, Hyderabad and is effectively being used for large number of sample collection at faster pace. The kiosk is already under use by several state governments of India. The United Nations Children's Fund (UNICEF) has proposed to procure the kiosk in large quantities for using different parts of the world. The COVSACK is examined for its efficacy in eradication of virus transmission during sample collection, by testing for presence of virus on internal surfaces of chamber walls as well as on long cuff gloves. No traces of viruses are found on all these surfaces after sanitization cycle comprising of disinfectant spraying and water flushing. There is certain scope for improvement in the design of the kiosk and disinfection procedure as well. A suitable air-handling unit, temperature controller unit may be installed on the kiosk, in future versions.

Innovative aspects of the kiosk

The primary difference between the kiosk in the present work and other models under use across the globe is, here the patient is inside the kiosk and healthcare worker is outside. In a closed surroundings and small hospitals or diagnostic centres, this kiosk becomes ideal choice, as the patient is standing inside, and the contamination to external environment in case any by sneezing or coughing at the time of sample collection would be completely limited to the kiosk. If the same patient is positioned outside the kiosk, then, the microorganisms would disperse to external environment and patients waiting for sample collection should be at least distanced more than 10 feet and possibly in open-air settings. Closed room setting or centralized air conditioning would not benefit this second approach, as the contamination into the surrounding air cannot be disinfected due to low ventilation and air circulation in these closed rooms. The kiosk is innovative in the following aspects. The features are not available in the units already under use across the world.

- The kiosk has an automatic disinfection followed by water cleaning procedure to ensure complete sanitization of COVID-19 virus.
- The kiosk utilizes minimum amount of disinfectant with a very small particle size during each cycle, as the number of spray nozzles and their positions are decided based on understanding developed in the CFD analysis.
- The kiosk is completely sealed from surroundings, which eliminates risk virus transmission from patients, across the kiosk, to the health care workers.

Conclusions

The healthcare workers act as primary warriors in the fight against the deadly virus COVID-19. They are exposed to the virus transmission during the testing of patients, due to lack of proper isolated chambers in the country. There is a potential requirement for development of a portable isolated sample collection chamber. COVSACK was designed and developed as a portable, safe and isolated kiosk, which is completely sealed and sanitized after collection of each sample. The kiosk is designed based on CFD simulations for effective spread of disinfectant in fine droplet form, built with a lightweight composite that is sustainable in extreme weather conditions and the kiosk can be easily sanitized within 3 min after sample collection. At the deployed hospital, the first prototype COVSACK unit stands to be highly effective in preventing the transmission of COVID-19 virus to healthcare workers during sample collection from suspected persons, due its in-built features such as air tightness, use of long cuff gloves and automatic disinfectant spraying followed by thorough water flushing after each patient exits the kiosk. The kiosk is innovative for its features such as automatic disinfection process, effective spraying of disinfectant with a very small particle size and reduces the cost COVID-19 testing to a minimum.

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