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CFD Evaluation of Air Conditioning on the Distribution and Dispersion of COVID-19 Virus in a Room

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ABSTRACT

With the beginning of 2020, the Corona virus pandemic began, which negatively affected all of humanity, as medical and engineering research began to solve many problems faced by society during the era of the virus. Those who are exposed to this situation are among the medical staff responsible for treating and quarantining patients with the Corona virus. It has become the responsibility of engineers to develop solutions to the ventilation problem in order to limit the spread of this virus. Where the aim of this research paper was to study the effect of distance between patient and nurse and the effect of ventilation on the spread of the Corona virus. where a simulation model was created a room with real and 3D dimensions was studied with a patient lying down and the nurse treating him next to him. Where the room contains an air conditioner, two outlets for the airflow and an opening for the patient's mouth to simulate the exit of carbon dioxide gas from his mouth. Where the different and high speeds were studied to find out their effect on the spread of the virus abroad and its disposal. The result proves the best flow velocity of the ventilation system is 20 m/s, which led to a large limitation of the waiting for the Corona virus. The best place for the patient and the airway in the room should not be in the same airway, and the best place is between them. where these results serve as a reference for the engineering of medical rooms in terms of the effect of ventilation and distance of the pathogen on the spread of the Corona virus.

1. INTRODUCTION

The main problem of transmission of the Corona virus is convergence, as work has been done to study the convergence between the pathogen and the patient and its impact on the spread of the Corona virus, as well as the importance of ventilation in the room for the purpose of transmitting the Corona virus loaded with air outside.

With the spread of the Corona virus, it became required to limit the spread of this virus, and this study lies through ventilation to get rid of the air loaded with the virus through ventilation holes. SARS-CoVirus may survive lasting more than three hours as an aerosol in the indoor environment, and its distribution may be helped by HVAC systems. To inhibit the spread of SARS-coV-2, it used a novel air circulation strategy backed up with UVGI in combination with a nano porous air filter [1]. Between February 1st and March 20th, 2020, 37 COVID-19 patients were admitted to the ICU at Huang Shi Traditional Chinese Medicine Hospital. From the core airways until the tracheobronchial tree's 4th-5th bifurcation, patient-specific three-dimensional airways were constructed [2]. Aerosol Generating Procedures (AGPs) close to the source provide a number of benefits, including less contamination of protective equipment, neighboring equipment, and space. A prototype device is intended for use during tracheotomies, but comparable machines for other AGPs can be designed using the same principles [3]. The potential for infectious disease transmission in public bathrooms is especially worrying in light of the COVID-19 epidemic. Toilet flushing with an open lid, insufficient handwashing or drying, and blocked drains may all lead to widespread bacterial and/or viral contamination in bathrooms [4]. Air exchange rates were one order of magnitude greater when doors were open than when they were closed. The air exchange rates were not significantly different between autos that were empty and those that were stuffed with 230 commuter mannequins. When 30–300 people rode in a railway car for 7–60 minutes, it was projected that opening all 12 windows would reduce riders' infection risk by 91–94 percent [5]. The location of SARS-CoV-2 infected persons inside hospitals is critical during the Covid-19 epidemic. In the winter, airborne dispersal was restricted to enclosed spaces. In the summer, on the other hand, airflow with potentially toxic air from rooms located on the sun-exposed side of the structure [6]. To successfully prevent virus transmission, A minimum height of 60 cm above the desk top is needed for the barrier. A 70 cm height was suggested for workstations within 4 m of the exit, and with correct ventilation mode, it can lower the risk of infection by 72 percent [7]. The SARS-CoV-2 effect zones were built using a CFD model of sneeze droplet dispersion.

Additive heating/evaporation/boiling laws were used to represent droplets. Larger droplets travel behind the nuclei in front of them and exhibit a greater vertical drop [8]. The influence of indoor airflow on the dispersion and transmission of droplets created when a person with a viral respiratory illness, such as COVID-19, walks or sneezes has been established. The presence of individuals in these settings raises the danger of disease transmission [9]. During a study period, the concentration of pollutants created by road traffic sources in Turin decreased by at least 70% (for PM2.5) and up to 88.1 percent. Concentration maps reveal that concentration decrease varied across the city, according mostly to the types and intensity of the emission sources [10]. Ozone has been suggested as a very effective disinfectant for enveloped and non-enveloped viruses, including those having a morphology similar to SARS-CoV-2. Using 1.76 m nodes and Mentor's shear stress transport turbulence model, a CFD model for an actual tram carriage with dimensions of 28.62.4 m^2 was developed [11]. The COVID-19 epidemic has caused a worldwide health disaster. It was carried out to examine many prospective monohull-unmanned ship prototypes. The Model III's design has exceptional ship stability, hull resistance, and seakeeping characteristics [12]. It addressed the design control points for the inside and exterior settings of the COVID-19 emergency hospital. It analyzed and discussed the site's layout, design, and three distinct zones, & two routes of Wuhan Huoshenshan Hospital [13]. Controlling the interior temperature, relative humidity, airflow pattern, and air quality is facilitated by the heating, ventilation, and air conditioning (HVAC) system. In restricted spaces, HVAC systems may be a source of microbial contamination. To successfully contain the pandemic and reduce infection risks, it is necessary to have a thorough knowledge of COVID19's impacts [14]. The airborne transmission of the COVID-19 infection has been proposed as a significant method of transmission. Ordinary as well as clearly talking apparently was conveying particles to the receptor for some airflow designs in the room. This study shows that the ″rule of thumb based safe distance approach″ can't be an overall technique for disease control [15]. The COVID-19 is an extreme respiratory sickness brought about by an overwhelming Covid family (2019-nCoV). It is an irresistible infection and sends by inward breath or contact with bead cores created during sniffling, hacking, and talking by tainted individuals [16]. The absence of quantitative gamble evaluation of airborne transmission of COVID-19 under reasonable settings prompts huge vulnerabilities and irregularities in our preventive measures. Improper plan can altogether restrict the proficiency of molecule evacuation, make neighborhood areas of interest with significant degrees higher dangers, and upgrade molecule affidavit causing surface tainting [17]. An examination of wind current instigated disease of COVID-19 has shown an amazing direct linkage between areas of high spray openness file and the detailed contamination designs in a café. Utilizing stream structure investigation and reverse time following of spray directions, we can additionally pinpoint the impact of ecological boundaries on the contamination chances [18]. Researchers have fostered a reusable respirator with a little dispensable texture channel. Respirator prerequisites are diminished by 75% contrasted with conventional plans and permit continued cleaning or cleansing. The veil is produced utilizing silicone molds, killing power necessities making it efficient and practical in non-industrial nations [19]. Coronavirus infection can repeat in the tainted person's larynx freely, which is not the same as other. infections that repeat in lungs just, for example SARS. The vulnerable individual experienced a higher openness portion when the infections were let out of the larynx rather than lungs [20].

A treatment room containing a patient and a sick person and a ventilation system will be studied in this paper to get rid of the air contaminated with the Corona virus.

2. METHODOLOGY

Where the process of designing the space was completely done in everything related to the people, the room in it and the ventilation places with the SOLIDWORKS program, Figure 1, the program dedicated to precise engineering design, Figure 2.

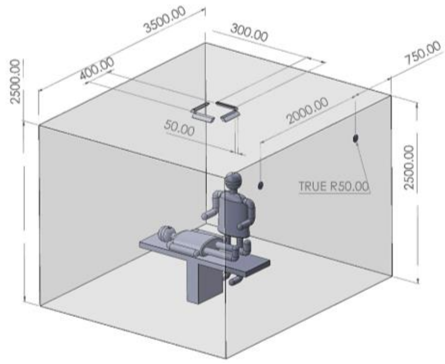


Figure 1. Geometry dimensions

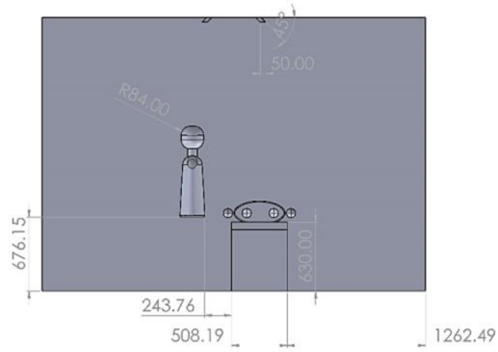


Figure 2. Side view

The simulation process is mainly based on the number of elements that are divided in the mesh, Figure 3, as it greatly affects the studied results, and to know the correct number, we work to increase the number of elements and take one of the data to reach the state of stability when the extracted results are not affected by the increase in the number of elements, Table 1.

Table 1. Mesh independency

Case	Node	Elements	Velocity m/s
1	74556	314678	10.765
2	154675	608457	8.135
3	234670	1063462	7.834
4	307894	1656125	7.826

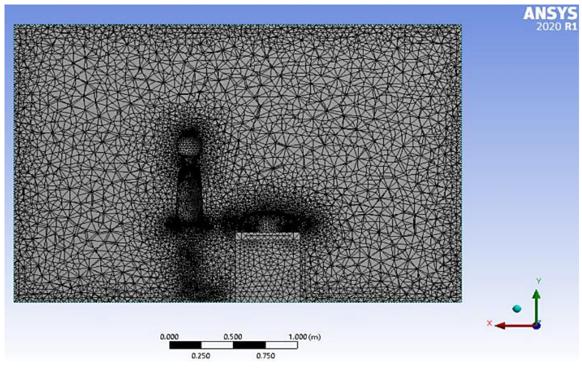


Figure 3. Geometry mesh

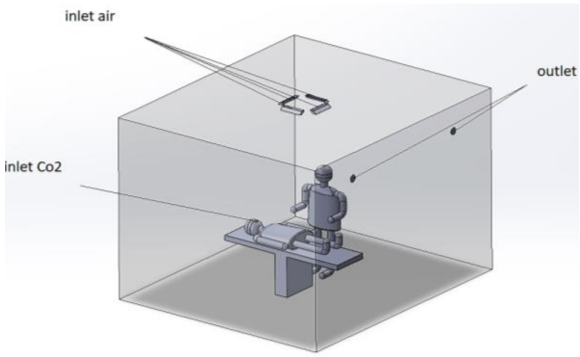


Figure 4. Boundary conditions

Where the internal conditions of the room were taken, where three air flow velocities were used in a different ventilation system to know their effect on the air leaving the mouth. The velocity of air leaving the patient's mouth was 1.5 m/s and the step time was 0.001 and for a period of two seconds. Where is the time required for the process of exhalation and the spread of CO_2 loaded with the Corona virus, Figure 4.

3. GOVERNING EQUATIONS

• Equation of continuity

The equation of continuity for the mixture is in Eq. (1):

$$\frac{\partial}{\partial t}(\rho_m) + \nabla \cdot (\rho_m \vec{v}_m) = 0 \tag{1}$$

where, $\vec{v}_m$ is the mass-averaged velocity:

$$\vec{v}_m = \frac{\sum_{k=1}^{n} \alpha_k \rho_k \vec{v}_k}{\rho_m} \tag{2}$$

and, ρ_m is the mixture density and substitute it into Eq. (1):

$$\rho_m = \sum_{k=1}^{n} \alpha_k \rho_k \tag{3}$$

where, α_k is the phase volume fraction k and substitute it into Eq. (1).

Equation of Momentum The mixture's momentum equation may be found by adding the momentum equations for each phase. It might be stated as:

$$\begin{aligned} &\frac{\partial}{\partial t}(\rho_m \vec{v}_m) + \nabla \cdot (\rho_m \vec{v}_m \vec{v}_m) \\ &= -\nabla p + \nabla \cdot [\mu_m (\nabla \vec{v}_m + \nabla \vec{v}_m^T)] \\ &+ \rho_m \vec{g} + \vec{F} - \nabla \cdot \left(\sum_{k=1}^{n} \alpha_k \rho_k \vec{v}_{dr,k} \vec{v}_{dr,k} \right) \end{aligned} \tag{4}$$

where, n is the number of phases, $\vec{F}$ is a body force, and μ_m is the viscosity of the mixture:

$$\mu_m = \sum_{k=1}^{n} \alpha_k \mu_k \tag{5}$$

$\vec{v}_{dr,k}$ is the drift velocity for secondary phase k and substitute it into Eq. (4):

$$\vec{v}_{dr,k} = \vec{v}_k - \vec{v}_m \tag{6}$$

Equation of Energy The mixture's energy equation is as follows:

$$\begin{aligned} &\frac{\partial}{\partial t} \sum_{k=1}^{n} (\alpha_k \rho_k E_k) + \nabla \cdot \sum_{k=1}^{n} \left(\alpha_k \vec{v}_k (\rho_k E_k + p) \right) \\ &= \nabla \cdot \left(k_{eff} \nabla T \right) + S_E \end{aligned} \tag{7}$$

where, k_{eff} is the conductivity that is effective ($\sum \alpha_k (k_k + k_t)$), when k_t is the turbulent thermal conductivity, as described by the employed turbulence model. Eq. (7) first component on the right-hand side describes energy transfer through conduction. S_E includes any other volumetric heat sources.

In Eq. (7),

$$E_k = h_k - \frac{p}{\rho_k} + \frac{v_k^2}{2} \tag{8}$$

in the case of a compressible phase, and E_k=h_k for a phase that is incompressible, where h_k is the phase's sensible enthalpy k.

Secondary Phase Volume Fraction Equation The volume fraction equation for secondary phase p may be determined from the continuity equation for secondary phase p:

$$\begin{aligned} &\frac{\partial}{\partial t}(\alpha_p \rho_p) + \nabla \cdot (\alpha_p \rho_p \vec{v}_m) \\ &= -\nabla \cdot \left(\alpha_p \rho_p \vec{v}_{dr,p} \right) \\ &+ \sum_{q=1}^{n} \left(\dot{m}_{qp} - \dot{m}_{pq} \right) \end{aligned} \tag{9}$$

4. RESULTS AND DISCUSSION

Three velocities of ventilation were used 10, 15 and 20 m/s and a case without ventilation. It was noted through the extracted results, the clear difference in the amount of spread of the Corona virus.

Through the results of volume fractionation, Figure 5, we note that the effect of ventilation on the spread and concentration of CO_2 gas loaded with the Corona virus through the patient's mouth when exhaled. Where it was found that the maximum value of the volume fraction is 0.96 in all the cases that were studied, but the difference lies in the nature of the spread of the gas loaded with the Corona virus, as at a velocity of 20 m/s was the largest dispersion of the gas diffusion.

The difference in velocity gives a clear concept on the spread and dispersion of the Corona virus in a large way compared to the absence of ventilation, Figure 6. As the results show the effect of the velocity of flow on reducing the impact of the Corona virus and the pathogen's bug. We see in the absence of a ventilation system that the maximum velocity of CO_2 out of the mouth of a patient carrying the Corona virus is 1.45m/s, which is the known exhalation speed when breathing. The velocity of 10 m/s reached the maximum running velocity of 6.32 m/s and the velocity of 15 m/s reached 9.48 m/s. In the latter case, which is considered the best running velocity to disperse the spread of the Corona virus and get rid of it, it was at a velocity of 20 m/s, which reached the maximum running velocity of up to 12.64 m/s, Figure 7.

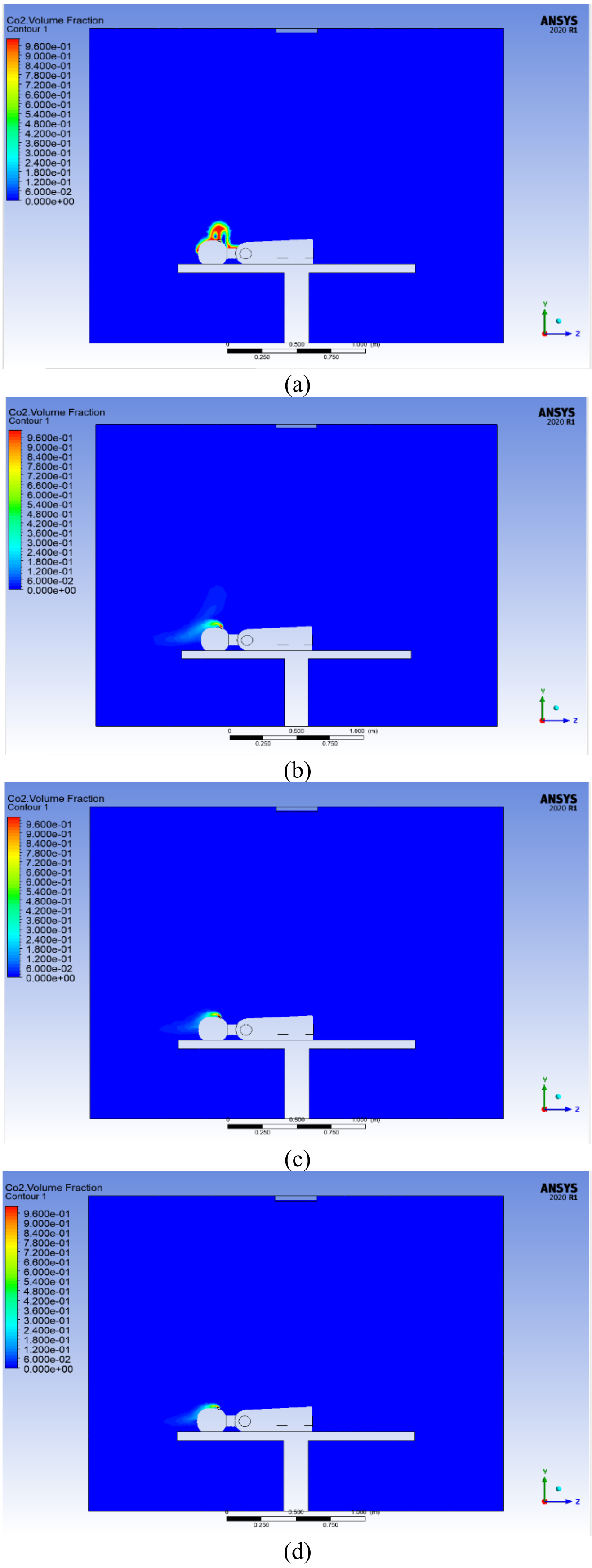


Figure 5. Volume Fraction. (a) without ventilation, (b) 10 m/s, (c) 15 m/s, (d) 20 m/s

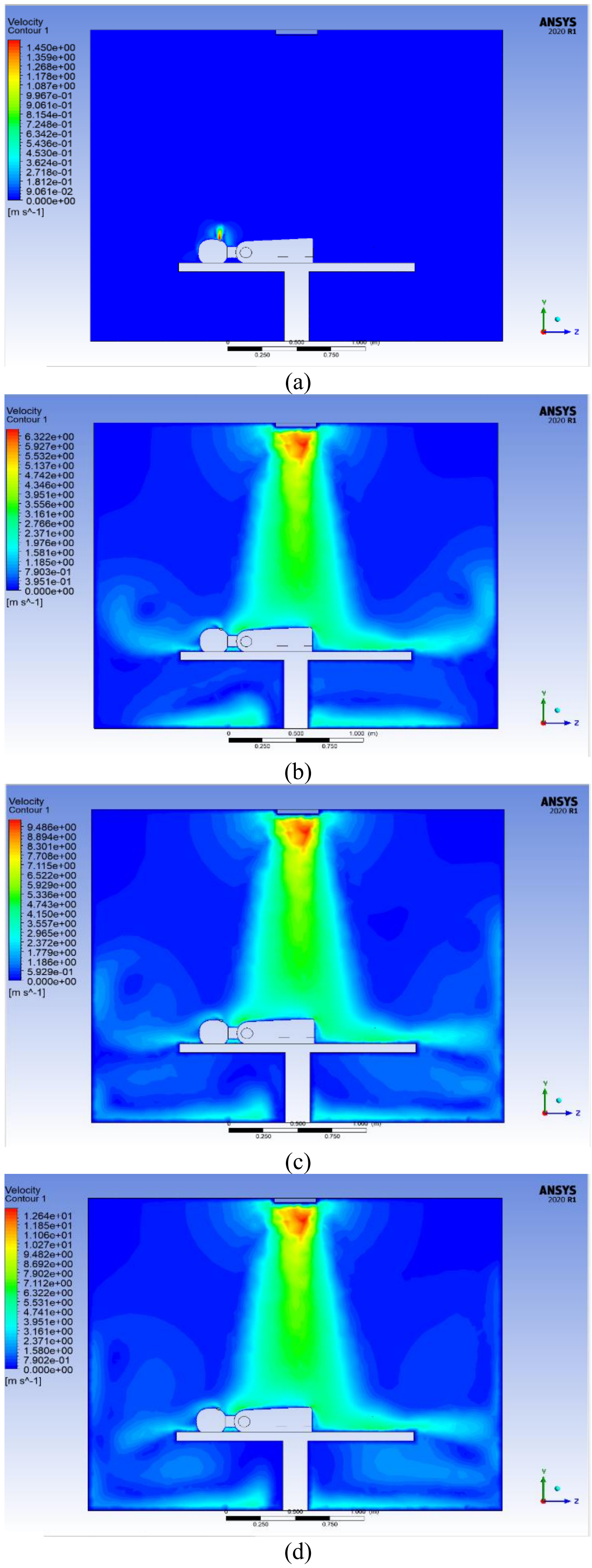
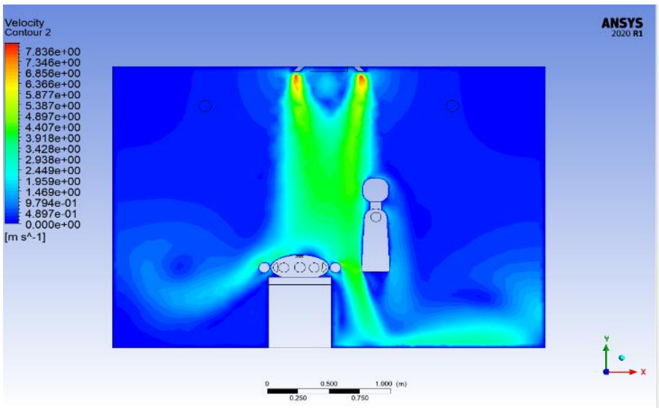
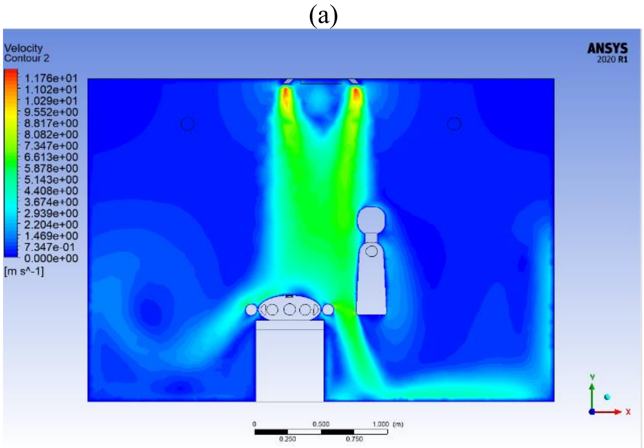


Figure 6. Velocity. (a) without ventilation, (b) 10 m/s, (c) 15 m/s, (d) 20 m/s



(a)



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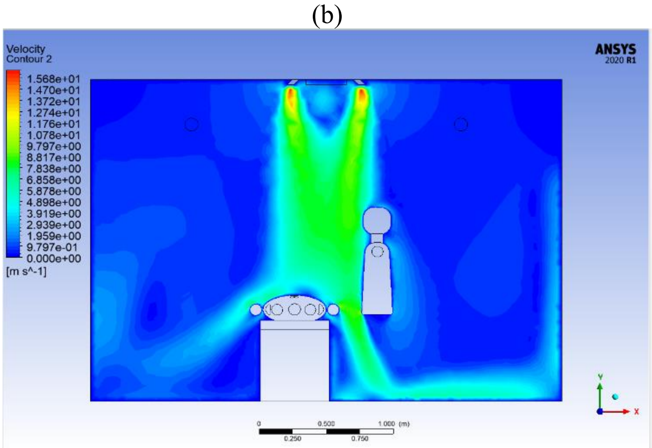
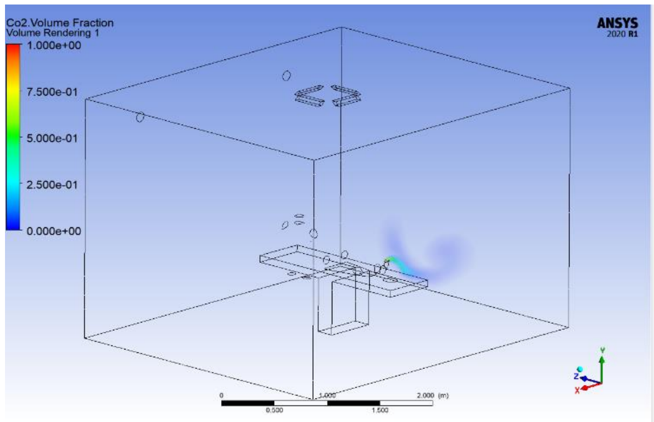
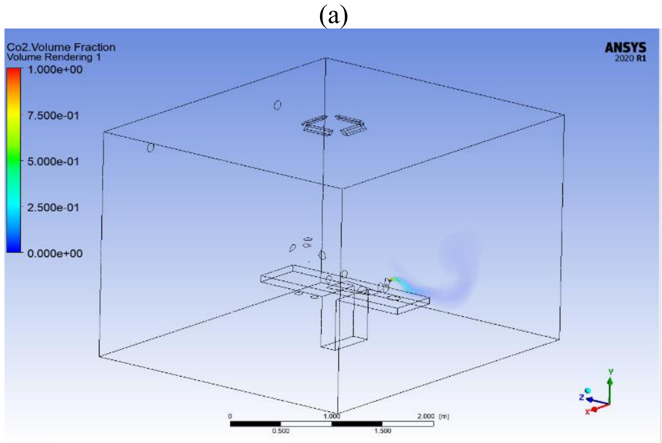


(c)

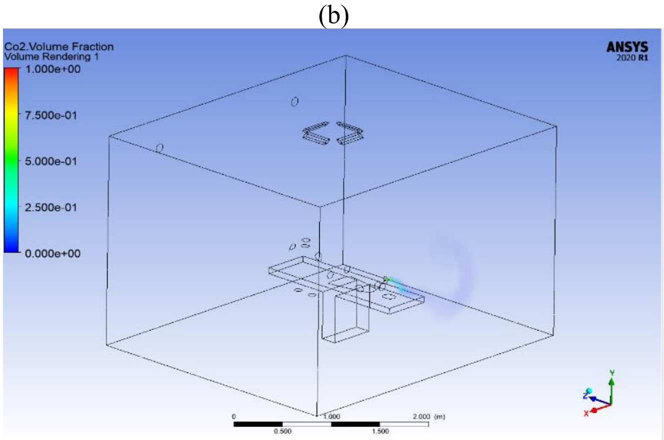
Figure 7. Velocity. (a) 10 m/s, (b) 15 m/s, (c) 20 m/s



(a)



(b)



(c)

Figure 8. Rendering Velocity. (a) 10 m/s, (b) 15 m/s, (c) 20 m/s

Through the previous figures, we note the effect of ventilation on the clear separation between the patient and the pathogen, the removal of the airborne Corona virus from the patient from the pathogen and the limitation of its spread. From another perspective, we can see the difference in velocity, as shown in the previous figures.

The extracted results that preceded indicate the effect of ventilation in terms of moving away from the spread of the virus and its concentration from the patient and its exit from the ventilation openings mainly, Figure 8. As we note that the increase in the velocity of flow increases the effectiveness and usefulness of the ventilation system.

Through the previous scheme, Figure 9, we found the benefit of ventilation significantly, as the results showed the effectiveness of the ventilation system in terms of significantly reducing the average of CO_2 volume fraction.

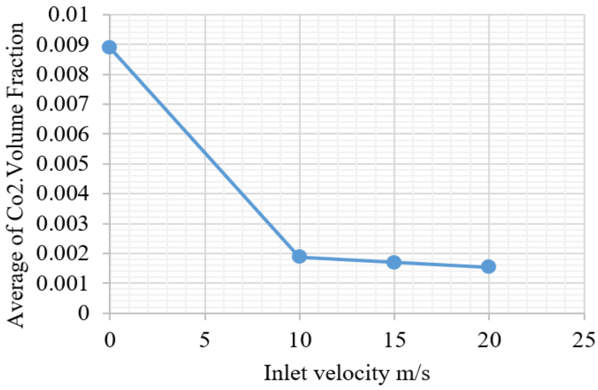


Figure 9. Average of CO_2 volume fraction with inlet velocity

5. CONCLUSIONS

The process of ventilation in nursing rooms in the time of the Corona virus caused many problems of the spread of the virus. As a simulation was used to ventilate the room to see the effect on the spread of the Corona virus and its transmission to the pathogen responsible for the infected disease, as follow:

(1) The results proved through this research that the places where the ventilation system is located is important in the process of spreading where the pathogen and the patient should not be in the same airway in the room and the best place for the ventilation system is between them.

Increasing the flow velocity of the ventilation system increases the limitation of the spread of the Corona virus from the infected disease, as the results proved that the best flow velocity is 20 m/s, which led to a large limitation of the waiting for the Corona virus.

(2) It is mandatory to have conclusions in your paper. This section should include the main conclusions of the research and a comprehensible explanation of their significance and relevance. The limitations of the work and future research directions may also be mentioned. Please do not make another abstract.

6. RECOMMENDATIONS

For future study on the Corona virus and reducing its risks, the case should be studied about the speed of exhalation from the human mouth in the form of a wave to simulate the process of exhalation and inhalation of the patient, and the locations of the air outlet should be studied in places that have a great impact.

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