Original Research Article

Simulation and Analysis of Safe Social Distance under Infectious Disease Epidemic

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Abstract: In this paper, the CFD method is used to study the horizontal distance of the virus infection between the cover and the open opening in the open space. Comparing the spread of virus droplets carrying different particle sizes, the human body's effect on inhibiting virus spread under different forms of protection was studied, and the diffusion concentration of pollutants in the range of 1m before and after the environmental wind speed was studied. The results show that the droplet particles settle when the particle size is larger than 6×10^{-5}m. The KN95 mask can reduce the diffusion distance of exhaled droplets by 50% compared with the working condition without a mask. When the upwind wind speed is greater than or equal to 3m/s, the distance of 1m in front of the human body is set reasonable; regardless of the downwind wind speed, there is a risk of infection directly in front of the human body. When the human body wears a KN95 mask, the distance of 1m is safe when there is no wind; when the wind speed is upwind, it is reasonable for a positive direction of 1m, and there is a risk of infection within 1m behind; when there is a downwind wind speed, the distance of 1m in front should be increased. This article can provide a reference for reducing the risk of infection and determining social distance under different environmental conditions.

Keywords: Droplet diffusion; Mask; Safe distance; Infection risk; Computational fluid dynamics.

1. Introduction

Novel coronavirus pneumonia (COVID-19) is an acute respiratory infectious disease that is highly contagious and prevalent[1]. Beginning in December 2019, novel coronavirus pneumonia spread widely worldwide. As of October 16, 2021, more than 239,437,517 people have been infected with neocoronavirus pneumonia worldwide[2]. This type of respiratory disease is mostly spread with the help of human respiratory activities such as breathing and speaking that are produced as carriers. Exhaled air clouds and droplets and their payloads of droplets carrying pathogens of all sizes can move 7-8 meters[3], and droplets can remain in the air for long periods of time[3], with a healthy person potentially becoming infected by inhaling about a few hundred particles[4]. Wearing masks and maintaining effective safety distances are still the best means of preventing and controlling outbreaks[5][6].

Data suggest that following a social distance of more than 1m reduces the probability of infection from 12 8% to 2 6%. The probability of infection decreased from 17.4% to 3.1% when wearing a mask. With regard to effective social distances, the World Health Organization(WHO) recommends that health care workers and other staff keep a distance of 3 feet (1m) [7] from people who show symptoms of illness such as coughing and sneezing.

The Centers for Disease Control and Prevention recommends a distance of 6 feet (2m) [8][9]. However, these distances are based on estimates of distances and do not take into account the possibility of high-momentum clouds carrying droplets for long distances. The current recommended safe distance is 2 meters[10], and the critical distance results from Daiwai's droplet and airborne studies are 2.5 meters[11]. Accurate study and prediction of air movement, the range of spread of virus-carrying droplets, and the effect of

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masks on the spread of viruses. It is important to determine the social distance for different environmental conditions.

Overall, there is a relative lack of simulations of safe distances for humans wearing masks in different environments. In the normalized prevention and control of epidemics, the question of whether the 1m social distance is safe enough is also worth studying. Therefore, in this paper, ANSYS FLUENT is used to establish the model of human body in public open space places under different wind speeds, and carry out the simulation under different combinations of states such as open face and covered face, in order to determine the safe and effective social distance.

2. Numerical Simulation Methods

2.1 Geometric Modeling

A simplified model is developed, and the human body is placed in an open space with a dimension of $1.5m\times0.5m\times1m$ and an initial temperature of 27 degrees. Since the virus droplets spread horizontally, only the diffusion within 0.5m space below the plane of the person's mouth was studied. The mouth is simplified as a rectangle of $0.05m\times0.02m$. According to Liu[12], the model of the wearing mask was simplified to a rectangle 0.03m away from the mouth with $0.18m\times0.09m$, and the thickness was adjusted with the mask model. Meshing software was used for meshing, the global mesh size was 0.1m, and the number of meshes was 290585, as shown in Figure 1 and Table 1.

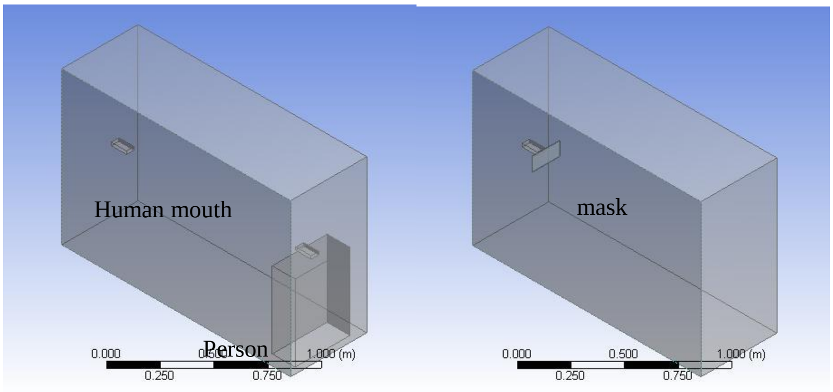


Figure 1 Modeling of open and closed faces of the human body.

Table 1 Mask-related parameters.

Mask name	**Thickness/m**	**Viscous resistance coefficient Number/(m^{-2})**	**Internal inertia resistance Coefficient of internal inertia resistance/(m^{-1})**	**Porosity/ Permeability**	**Resistance/ Pa**	**Average grain size/m**
KN95	0.0027	2.52768E+12	426354.8798	0.9585	120.7	0.0000003
Ordinary mask	0.001	15051086314	21553.3005	0.723	50.96	0.000017
Cotton cloth	0.005	8752372092	18307.66611	0.7769	12.2	0.00002

2.2 Simulation Parameters and Methods

It is assumed that the respiratory state of the human body in the simulation is continuous exhalation, which is consistent with the fully developed turbulent flow, so the RNG K-ε turbulence model is chosen. In this paper, the mixing material is two substances, H_20 and air, and the mass fraction of water at the velocity inlet is 0.011, and the steady state calculation is used, as shown in Table 2.

Table 2 Parameterization of boundary conditions.

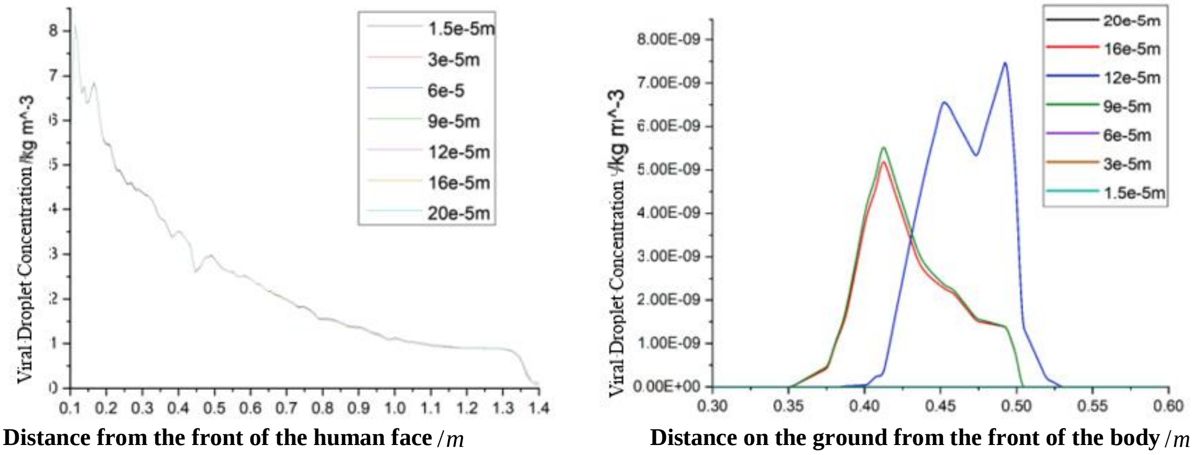
Boundary Name	Mouth	Anterior	Posterior	Left	Right	Upper	Lower
Boundary type	Speed Entrance	Outlet	Outlet	Outlet	Outlet	Outlet	Floor
Velocity m/s	2.76	-	-	-	-	-	-
Return turbulence intensity	5.46%	1	1	1	1	1	-
Hydraulic diameter m	0.0286	1.2	0.7	0.75	0.75	0.75	-
Temperature K	309	298	298	298	298	298	-

3. Numerical Simulation Results and Analysis

3.1 Calculation of Droplet Propagation Distance for Different Particle Sizes

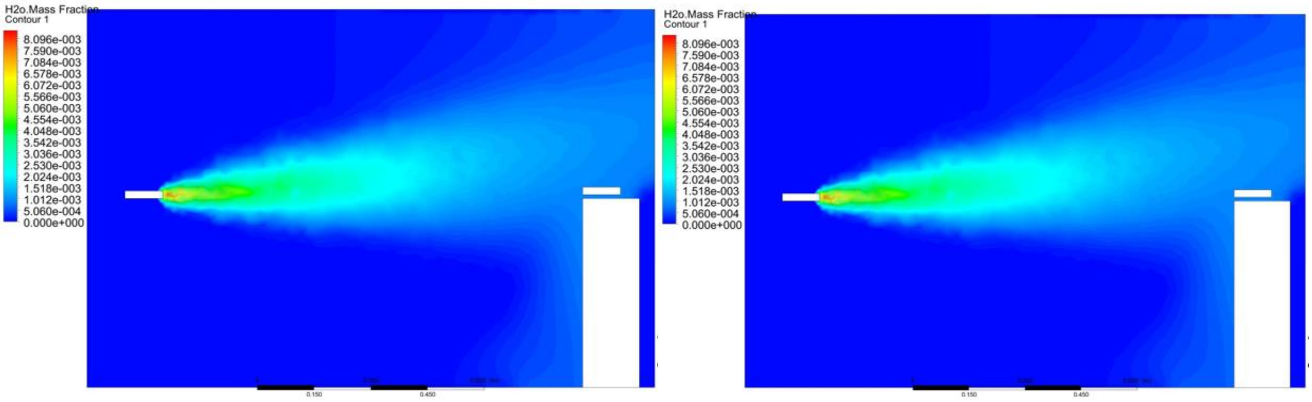
The diameter of the new coronavirus is $60-140nm$[13], combined with the Rosin-Rammer distribution in the discrete-phase model of cough droplets by Zhang eucalyptus Kang et al[14], the minimum particle size of droplets can be set to be $1.0\times10^{-7}m$, the maximum particle size to be $2\times10^{-4}m$, and the average particle size to be$1.6\times10^{-4}m$. In this paper, we simulate that the droplet contaminants with viruses are inert droplets, and considering gravity, we set the diameter to be $1.5\times10^{-5}m$, $3\times10^{-5}m$, $6\times10^{-5}m$, $9\times10^{-5}m$, $12\times10^{-5}m$, $16\times10^{-5}m$, $20\times10^{-5}m$ in order, and the mass fraction of evaporable components to be 0.9.

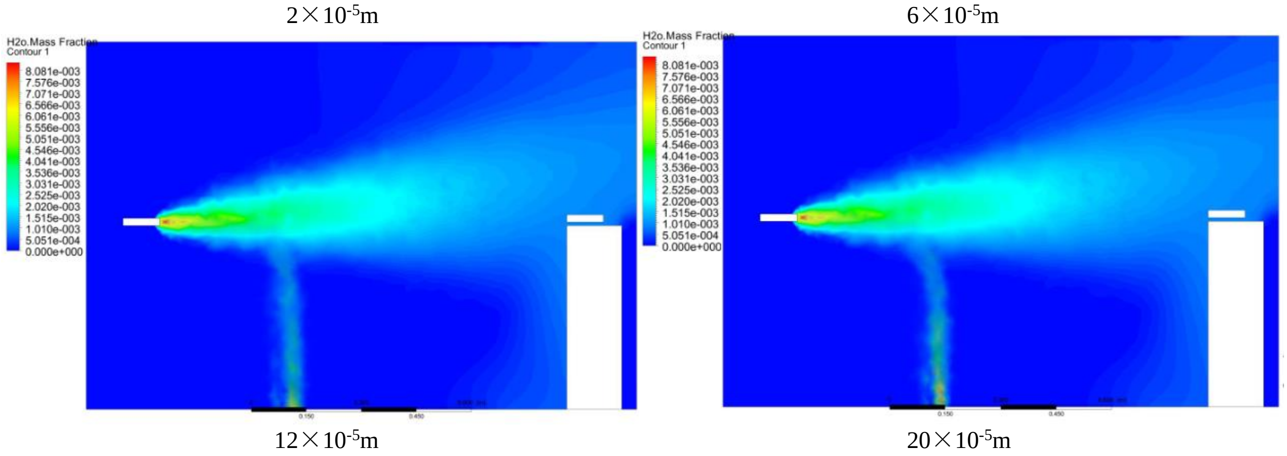
As can be seen from Figure 2(a), the concentration distribution of droplets of different particle sizes is more or less the same in the plane directly in front of the human head. In the plane below the human head, there is a decrease in the deposition of droplets of different particle sizes. From Figure 2(b), it can be seen that $2\times10^{-4}m$ particles are deposited at $0.5m$ from the human body, and $6\times10^{-5}m$ and $9\times10^{-5}m$ particles are deposited at about $0.4m$. The spreading and settling of droplets with different particle sizes are shown in Figure 3.



(a) Mouth plane **(b) Plane 0.5m below the plane of the mouth**

Figure 2 Discounted variation of pollutant concentration with horizontal distance.





2×10^{-5}m 6×10^{-5}m

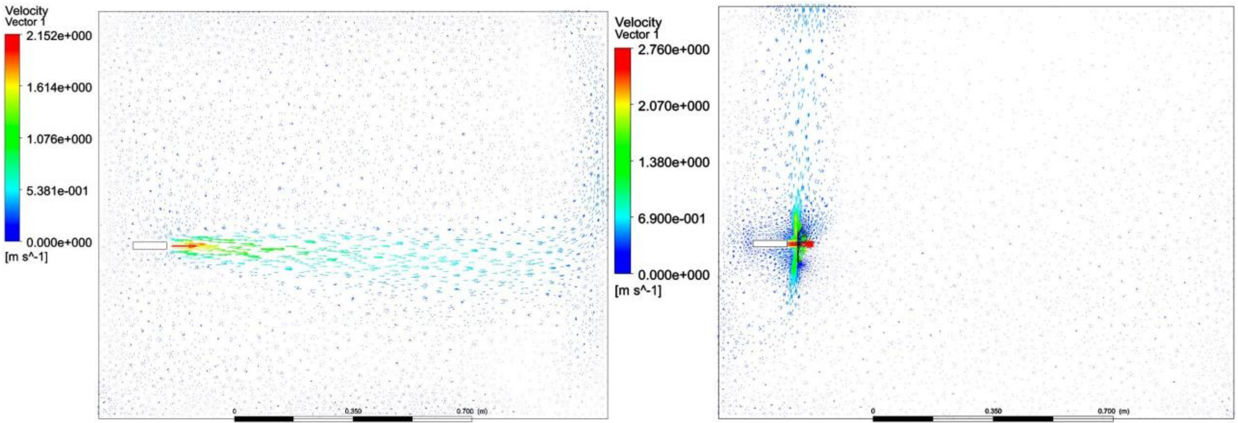
12×10^{-5}m 20×10^{-5}m

Figure 3 Spreading cloud of droplets of different particle sizes.

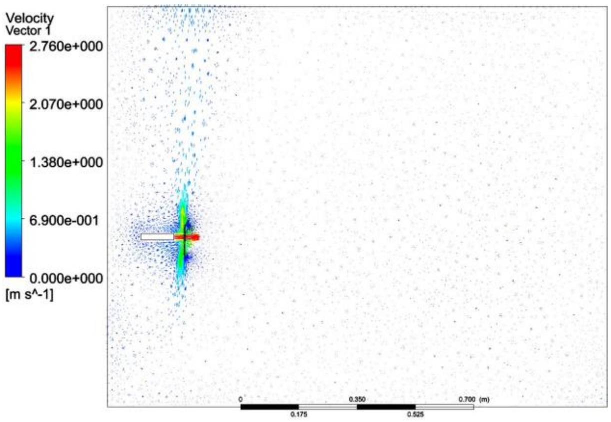
3.2 Comparative Calculation of Protection Effect of Three Mask Types

Droplets with smaller particle size can spread farther, and the contagiousness of small droplets (diameter $<5\mu m$) is farther than that of large droplets[15,16]. Therefore, particles with a diameter of $1.5\times10^{-5}m$ are used for simulation in this paper.

As can be seen in Figure 4, droplets exhaled by people not wearing masks travel farther, so the risk of infection is higher if there are people in front of them.



(a) Not wearing mask **(b) Wearing cotton mask**



(c) Wearing KN95 mask

Figure 4 Vector plot of droplet spreading velocity.

As Figure 5 shows, the droplet diffusion distance in the breathing height $(1.5m)$ of adults under the condition of having a mask is reduced compared with the condition of not having a mask, and the droplet inhibition effect of masks with small porosity is better. That is, KN95 masks have better inhibition of virus transmission than cotton masks, and the droplet spreading distance can be reduced by 50% compared with the no-mask condition.

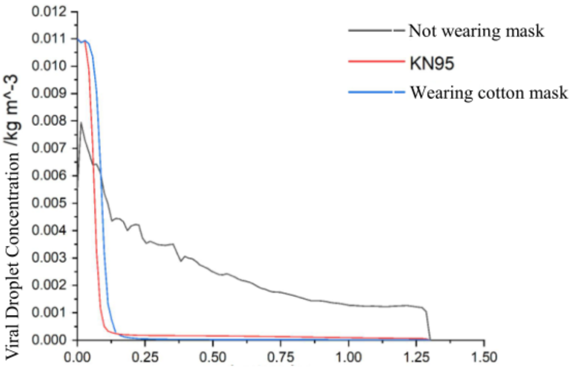


Figure 5 Comparison of safety distances of three types of masks.

3.3 Simulation of Social Distance in Windy Conditions

3.3.1 The human body is not wearing a mask

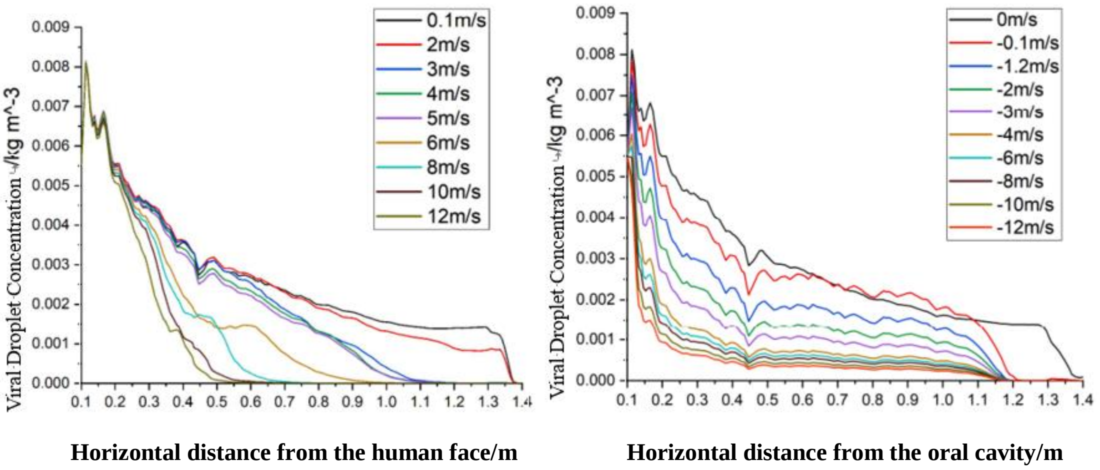
According to the “Wind Level” [17] (GB/T 28591-2012), the wind speed of the environment in which the human body is located is set as follows. When the direction of the external wind flow is opposite to the exhaled gas, i.e. the wind is blowing from the front side of the human body in an upwind manner, the symbol of wind speed is recorded as “+”. When the direction of the external wind flow is the same as the exhaled gas, i.e., the wind blows from the back side of the human body in a downwind manner, the direction of the wind speed is recorded as “-”, as shown in Table 3.

Table 3 Wind Rating Scale.

Wind Rating	Name	Land-based phenomenon	Wind speed m/s	Specific value m/s
0	Windless	Quiet. Smoke is going up.	0-0.2	0
1	Soft breeze	Smoke indicates wind direction.	0.3-1.5	2
2	Light wind	Feel the wind	1.6-3.3	3
3	Breeze	The flags unfurl.	3.4-5.4	4
4	Harmonious wind	Blowing the dust	5.5-7.9	6
5	Fresh wind	The trees are swaying.	8.0-10.7	8
6	Strong wind	The wires sound	10.8-13.8	12

The socialization distance is usually set to $1m$ during the epidemic control period. From Figure 6 (a) we can see that when there is no wind or the wind speed is small ($0.1m/s$, $2m/s$), the virus-carrying pollutants exhaled by the human body without a mask can spread to $1.3m$ directly in front of the human body, and at this time the social distance should be increased by $1m$.

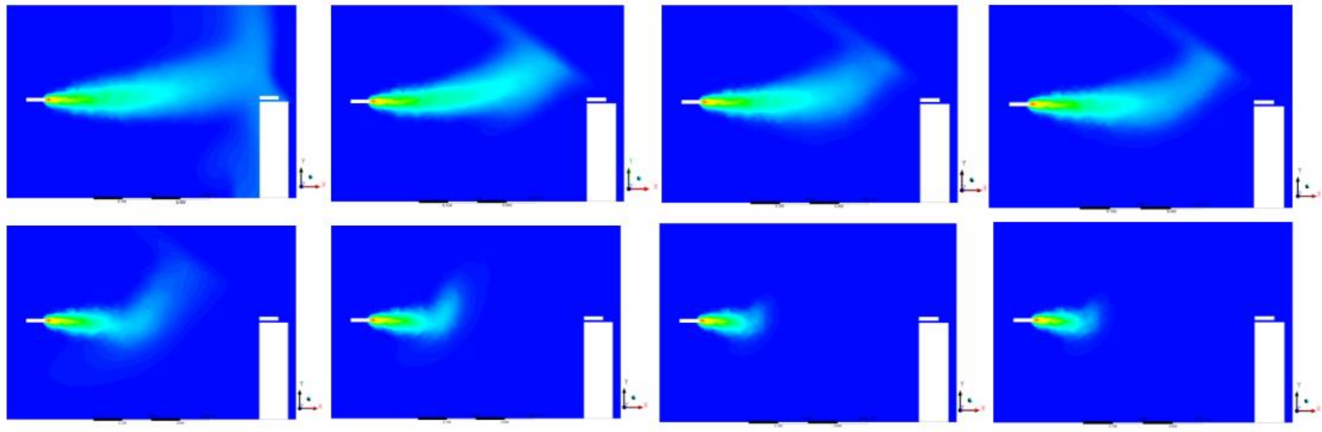
As seen from the windward plot in Figure 6(a), when the wind speed reaches $+3m/s$, the concentration of pollutants at $1m$ in front of the human body decreases significantly. When the wind speed is $+6m/s$, the pollutant concentration at $0.85m$ in front of the human body decreases significantly. When the wind speed is $+10m/s$, the pollutant concentration at $0.5m$ in front of the human body decreases significantly to almost zero, but there is still a risk of infection at $0.5m$ at lower wind speeds. A distance of $0.5m$ is generally considered to be an intimate distance, mostly between couples, parents and children, and therefore contact should be minimized during the control phase of an outbreak.



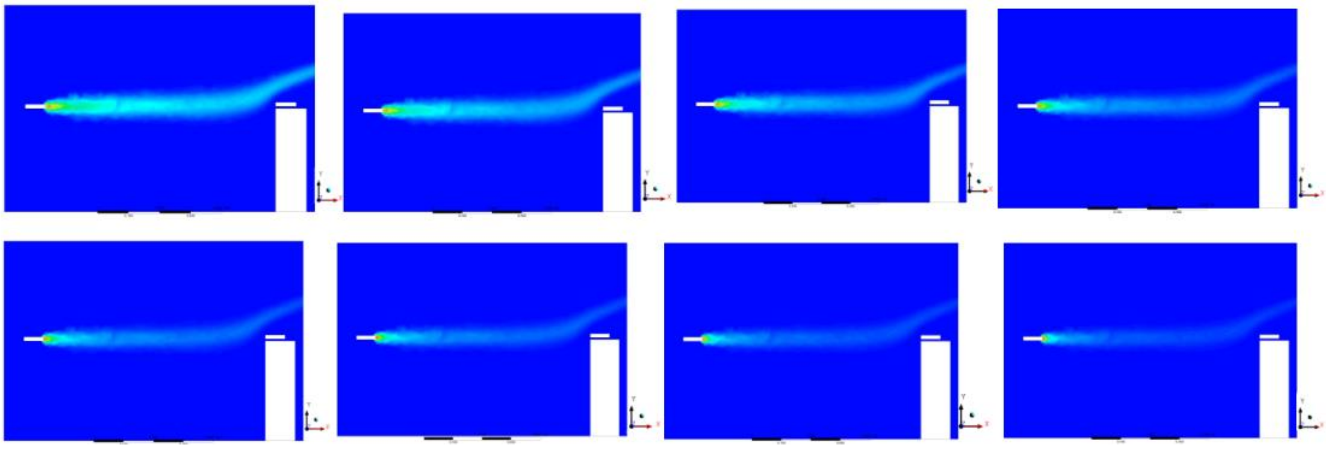
(a) Upwind (windward) **(b) Wearing cotton mask**

Figure 6 Comparison of pollutants exhaled by humans without masks.

Figure 7 (a) shows the cloud diagram of droplet dispersion under different wind speeds. When people are in a windy environment, with the gradual increase in wind speed, the diffusion of pollutants forward becomes more and more difficult, and it is easier to be deposited on the human face and clothing, and the viruses carried by the objects will also cause a certain risk of infection, so in the phase of prevention and control of the outbreak, attention should be paid to the cleanliness of clothes, skin, and wash hands more often, and be diligent in disinfecting.



(a) Upwind (windward)



(b) Wearing cotton mask

Figure 7 Cloud view of droplet dispersion under different wind speeds in the same direction opposite to the exhaled airflow of the human body.

Figure 6 (b) can be obtained, downwind ambient wind speed makes the airflow of the oral expiratory airflow to the human body in front of the environmental space to a greater extent, although it makes the human body directly in front of a certain distance at the pollutant concentration is reduced, but regardless of the value of the wind speed is greater than the pollutant concentration of the human body directly in front of the $1m$ is greater than zero. $1m$ of the social distance in the case of that case should also be increased.

In order to explore the scenarios for which the $1m$ socialization distance is applicable, the effect of different environmental conditions on contaminant concentrations was plotted (Figure 8). From the figure, it can be seen that the concentration of viral contaminants in front of the human body is larger when the human body is in a space with no wind or wind speed less than $1m/s$. When the person-to-person spacing is $1.2m$, the $1m$ socialization spacing applies to scenarios with windward wind speeds greater than $+2.5m/s$. When the downwind wind speed is greater than $2.5m/s$, the concentration of pollutants reduces to less than $2\times10^{-4}kg/m^3$, with a lower risk of infection. When the person-to-person spacing is $1m$, the $1m$ social spacing applies only when the headwind wind speed is greater than $7m/s$. When the person-to-person spacing is $0.5m$, the $1m$ social spacing does not apply to environments below strong winds.

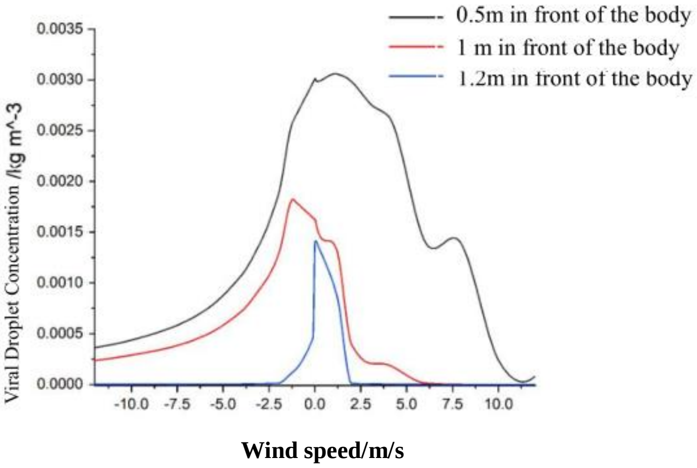


Figure 8 Effect of different environmental flow states on pollutant concentrations.

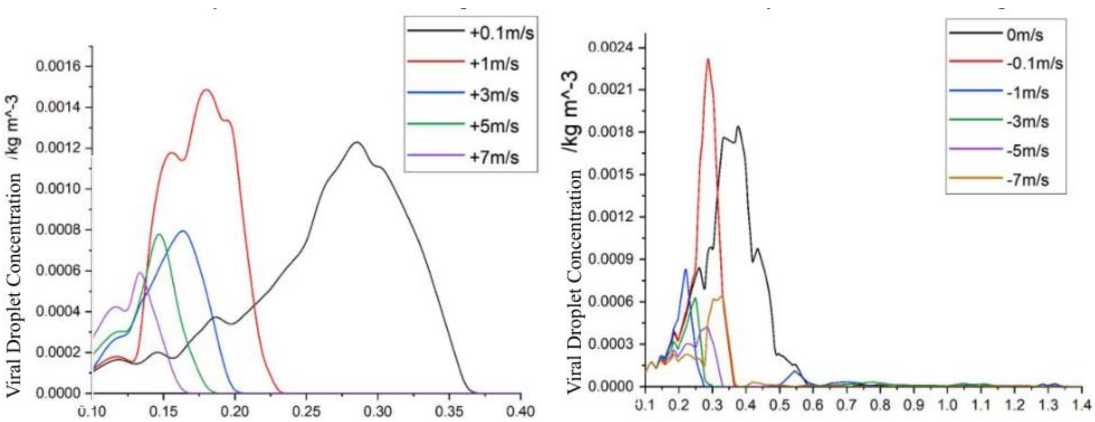
3.3.2 Human Wearing of KN95 Masks

When the human body wearing the best protective effect of KN95 mask, no wind conditions droplets spread to the front of the face from the distance of $0.5m$, so $1m$ safe social distance can effectively protect the front personnel safety.

As obtained from Figure 9(a), both the mask and the headwind enhanced the effect of blocking virus transmission. When the headwind wind speed is small ($0.1m/s$), the concentration of droplets spreading to 0.28m directly in front of the human body is reduced to zero. When the windward wind speed is greater than $1m/s$, the concentration of contaminants at $0.25m$ directly in front of the human body is zero. In this case, the $1m$ socialization distance is set reasonably.

In Figure 9(b) downwind, regardless of wind speed, the effect of the mask causes the distance at which the pollutant concentration is first reduced to $0kg/m^3$ to be shorter, but there are a small number of inert droplets spreading to a distance of $1m$ away in the same direction of the wind, which still poses some risk of infection. The distance at which the pollutant concentration is first reduced to $0kg/m^3$ is not much different from the usual $1m$ safe social distance. Therefore, when humans wear masks and are in downwind environments, the $1m$ social distance should be maintained along with other disinfection efforts for outbreak prevention and control.

When the human body wears a KN95 mask and is in a windy environment, the droplets escaping from the top, bottom, left and right sides of the mask are dispersed to the rear of the human body by the action of the head wind.



Horizontal distance/m **Horizontal distance from the front of the human head/m**

(a) Upwind (windward) **(b) Downwind**

Figure 9 Effect of air on droplets when humans wear masks.

As can be seen from Figure 10, when the wind speed is $+3m/s$, the pollutant concentration at the position of $0.55m$ directly behind the human body is the largest. When the wind speed is $+5m/s$, $7m/s$, there are pollutant concentrations greater than zero at different heights within a safe distance of $1m$ directly behind the human body, and the distribution of pollutant concentrations directly behind is shown in Figure 11.

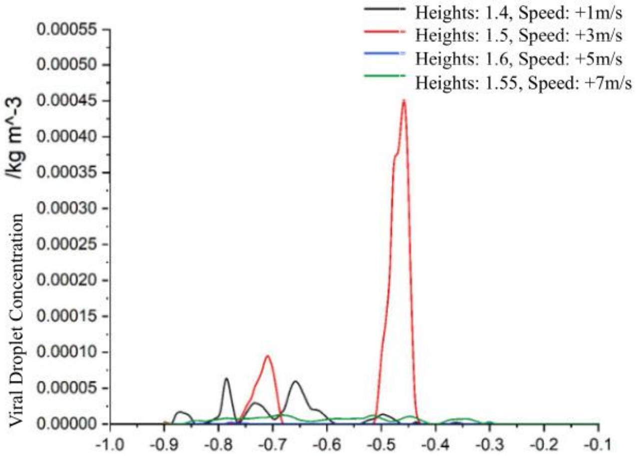


Figure 10 Distribution curves of pollutant concentrations at different heights directly behind the windward side of the human body.

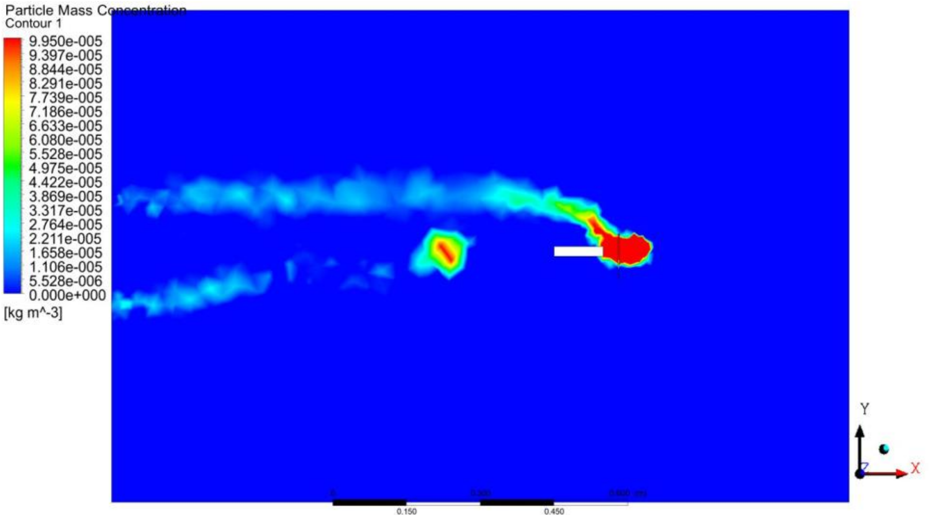


Figure 11 Pollutant concentration clouds directly behind the windward side of the human body.

4. Conclusion

(1) In this experimental simulation, diffusion and deposition of particles of seven particle size dimensions were studied. Significant deposition of virus-carrying droplet particles occurs when the particle size is larger than $6\times10^{-5}m$.

(2) mask protection, small porosity of the KN95 mask protection effect is greater than the gauze mask, and greater than not wearing a mask, and wearing a mask can make the pollutant transmission distance is reduced by about 50%.

(3) To study the safety distances in different environments for different levels of protection for the human body. In windy conditions, the concentrations of pollutants at locations on the downwind side of the human body are greater than those in the absence of wind, so the safety distance should be increased appropriately. While maintaining a social distance of $1m$ on the upwind side is theoretically safe. The conclusions of the study lay the foundation for epidemic prevention and control, and has important guiding significance for ensuring the life, health and safety of personnel.

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Conflict of Interest

The authors declare no conflict of interest.

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