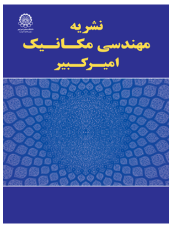

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Numerical Simulation of the Dispersion of Human Sneeze Droplets In The Surrounding

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ABSTRACT: The important feature of viral respiratory diseases is the rapid transmission and spread of these viruses through respiratory processes. In this study, computational fluid dynamics and heat transfer have been used for the airflow inside the human Airway and the surrounding environment, as well as the penetration and spread of droplets from sneezing for a 65-year-old non-smoking man. In the current study, about one million drops from sneezing with an initial temperature of 35 degrees Celsius were injected inside the mouth, and the majority of these drops are small drops with a diameter of 4 to 16 microns. In this study, the k-ω SST turbulence model was used to investigate the flow, and the Euler-Lagrange approach with a one-way view was used to investigate the forces acting on the droplets and also the phase change of the droplets. For a human sneeze with a maximum flow rate of 553 liters per minute through the respiratory system with a temperature of 35 degrees Celsius and a relative humidity of 95% in an environment with an air pressure of one atmosphere, a temperature of 24 degrees Celsius and a relative humidity of 65%, it was determined that the maximum amount of penetration belongs to large drops equal to 3 meters. While the highest amount of spread belongs to small drops equal to 1 meter and the results of droplet evaporation indicated that more than 95% of the droplets injected during sneezing evaporated at the end of 5 seconds.

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1- Introduction

The rapid spread of viruses is always one of the problems that affect people's lives. Viruses such as Covid-19 have the highest rate of spread and people with the disease. The velocity of spreading the virus through inhalation of air containing the virus is very high; because droplets containing the virus can enter the air through an exhalation process such as sneezing, coughing, and even talking, and by entering the respiratory system of a healthy person, a person becomes ill. The amount of penetration and spread of droplets from sneezing depends on many parameters. Environmental conditions such as temperature, humidity, and wind velocity affect the spread and penetration of droplets. Exhalation conditions such as sneezing, coughing, or talking can also affect the initial velocity of the droplets and as a result their spread and penetration [1,2]. Nunn and Gregg [3] were able to develop a maximum flow curve during sneezing based on age and gender with an experimental study on maximum outflow during sneezing. Busco et al. [4], with an experimental study of the pressure on the mouth during sneezing, were able to develop a curve of pressure changes on the mouth and concluded that the duration of the entire sneezing process is about 0.5 Sec and in 0.23 Sec At the beginning of the sneeze, the sneeze drops come out of the mouth along with the air jet, and in the remaining time (after 0.23 Sec), only the air jet is discharged from the mouth and nose. Gupta et al. [5], with an experimental study of changes in flow rate during coughing, were able to develop a curve of changes in flow rate during coughing and record the flow rate behavior during one cough as well as two consecutive coughs. Fontes et al. [6] investigated the distribution of droplets with a numerical study of sneezing considering an ideal respiratory system. Considering the importance of the spread and penetration of viral droplets from sneezing and coughing, as well as the many differences between numerical and experimental results and even experimental results with each other; in this research, considering the human respiratory system, the sneezing process was simulated and the structure of the flow inside the respiratory system during sneezing was investigated.

2- Methodology

In the present study, the actual geometry of the upper respiratory tract was used to simulate airflow during sneezing. In order to produce the upper respiratory tract, CT scan images of a 65-year-old healthy and non-smoking adult man was used. The distance between consecutive CT scan images used in the present study to pass the imaging process was 0.625 mm. The dimensions of the environment around the

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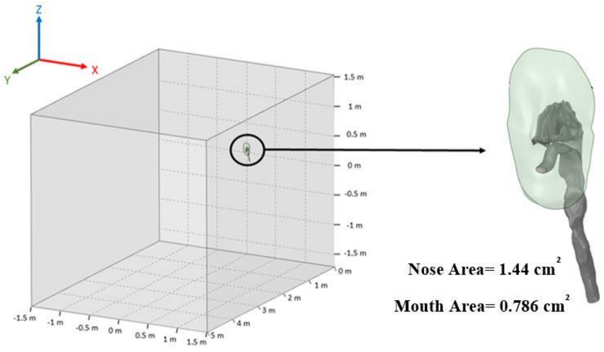


Fig. 1. The computational domain

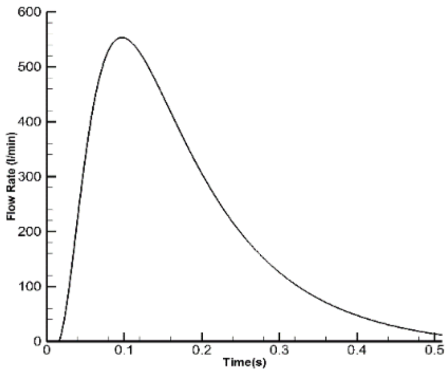


Fig. 2. Changes of flow according to time during sneezing

subject are 3m (height) × 3m (width) × 5m (length). Fig. 1 is a view of the computational environment of the present study.

A non-uniform mesh was used to mesh the upper respiratory tract and the surrounding environment. To properly simulate the interactions between the airflow and the wall of the upper respiratory tract, four prism layers with a height of the first layer of 0.01 mm and a growth coefficient of 1.2 were used, and the mesh with 1.7 million cells has been selected as the appropriate mesh in terms of accuracy and efficiency.

In the present study, by determining the maximum flow rate of 553 liters per minute and considering the flow rate changes according to the studies of Busco et al. [4] and Gupta et al. [5], the flow rate changes from the beginning of the trachea are according to Fig. 2. The formulation of flow rate changes in terms of time is expressed in Eq. (1).

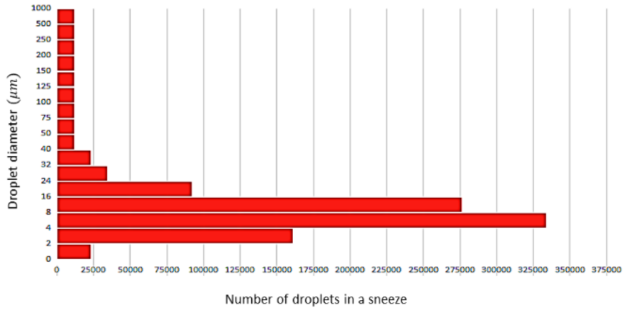


Fig. 3. Distribution of the diameter of droplets resulting from sneezing

$$FlowRate(t) = a + \frac{b}{t} exp\left(-0.5\left(\frac{Ln\left(\frac{t}{c}\right)}{d} \right)^2 \right) \tag{1}$$

Using the results of Nunn and Gregg [3] to calculate the maximum flow rate of 553 liters per minute and the results of Busco et al. [4] and to calculate the volume flow rate change trend in the sneezing process, the values of constants *a*, *b*, *c* and *d* presented in Eq. (1) are equal to -17.1430, 69.5510, 0.1535 and 0.6780. In this study, the diameter distribution of droplets resulting from sneezing is considered according to Doguid’s experimental data [23] (Fig. 3).

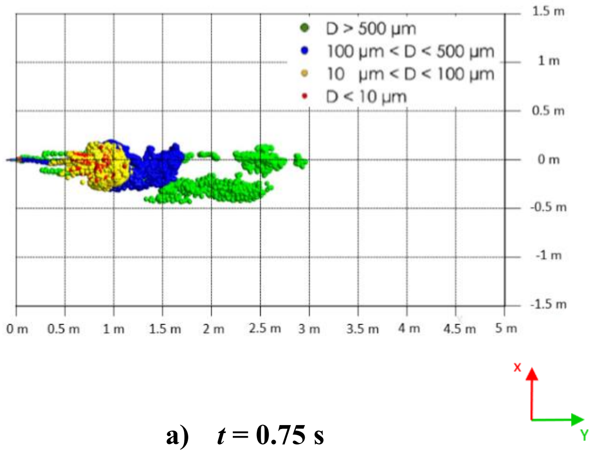
The equations governing the fluid domain can be expressed as Eqs. (2), (3), and (4). The equation of forces affecting a droplet is expressed as Eq. (5).

$$\frac{\partial \rho}{\partial t} + \frac{\partial \rho \hat{u}_i}{\partial x_i} = 0 \tag{2}$$

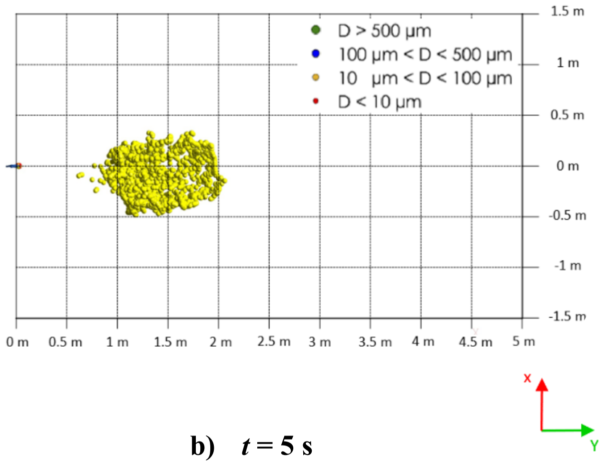
$$\frac{\partial \rho u_i}{\partial t} + \frac{\partial \rho u_i u_j}{\partial x_i} = -\frac{\partial p}{\partial x_i} + \frac{\partial}{\partial x_i}\left[\mu\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} \right) - \rho\, \overline{u'_i u'_j} \right] \tag{3}$$

$$\frac{\partial \rho c_p T}{\partial t} + \frac{\partial \left(\rho c_p u_i T\right)}{\partial x_j} = k \frac{\partial^2 T}{\partial x_j^2} \tag{4}$$

$$m_p \frac{dv}{dt} = F_{Drag} + F_{Gravity} = \frac{\rho_c \pi C_d d_p^2 |U - V| \left(U - V\right)}{8 C_c} + m_p g \tag{5}$$



a) *t* = 0.75 s



b) *t* = 5 s

Fig. 4. Diameter contour, expansion, and penetration of droplets caused by sneezing in (a) t= 0.75s and (b) t= 5s

In this study, the ANSYS Fluent 2020 commercial solver package was used for simulation and CFD-Post 2020 for the post-processing of the results, the finite volume method was used to solve the governing equations, and the pressure-based solver was used. The Pressure-Implicit with Splitting of Operators (PISO) algorithm is also used to solve the equations.

3- Results and Discussion

The diameter contour of sneeze droplets provides a good picture of the transient nature of droplet locations of different sizes. A total of 1045133 drops have been injected into the solution domain at a distance of 8 mm from the mouth (inside the respiratory system). According to Fig. 4, the maximum amount of droplet penetration in the surrounding environment for large drops is equal to 3 meters. But the maximum diffusion of droplets in the surrounding environment belongs to small droplets, which is equal to 1 meter.

4- Conclusion

The diameter contour of sneeze droplets provides a good picture of the transient nature of droplet locations of different sizes. A total of 1045133 drops have been injected into the solution domain at a distance of 8 mm from the mouth (inside the respiratory system). According to Fig. 4, the maximum amount of droplet penetration in the surrounding environment for large drops is equal to 3 meters; but the maximum diffusion of droplets in the surrounding environment belongs to small droplets, which is equal to 1 meter.

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