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Review Article

The Major Role of Fluid Mechanics in Respiratory Drop Dispersion

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Abstract

The covid-19 pandemic has caused unpredictable damages to economy, trade, tourism, aviation, etc. In addition, lockdowns have led to social isolation, depression, loss of income, mental health problems, etc. On the other hand, this pandemic is more deadly than the previous ones, such as SARS and MERS. Unfortunately, according to the latest report of the World Health Organization (WHO), as of 14 August 2021, there have been more than 206 million confirmed cases of COVID-19 patients, including up to 4.3 million deaths globally. Although medical researchers have developed and mass-produced some useful therapies, like drugs and vaccines for control of its spread, engineers have presented some methods, as non-pharmacological solutions, to reduce disease transmission. In this context, some engineers have taken part in assessing the dispersion of respiratory drops. Due to still unknown and non-deterministic medical approaches, Computational Fluid Dynamics (CFD) has been extensively used to study the formation and dispersion of respiratory drops, which leads to infectious disease transmission.

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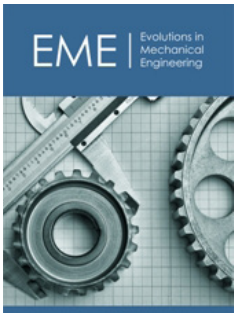

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Objectives

Over the past four decades, development and application of CFD have changed the study of fluid dynamics drastically, especially in multiphase flows. Of course, it has also been used to simulate in details formation, spread, and deposition of coronavirus carrying drops. According to recent studies, respiratory drops are the principal factor in transmission of infectious respiratory diseases [1-4]. Thus, WHO has recommended maintaining social distance, wearing facemasks together with regular hand washing, and some use of appropriate personal protective equipment by medical staff in patient care places [5-7]. In addition, some engineers have investigated the mechanisms of formation of respiratory drops and their motion after exhalation [8]. Formation and dispersion of respiratory drops include all processes related to such complex fluid flow, e.g., turbulent jet flow, fluid instability due to high-velocity air, mucus/saliva breakup, and then drop formation [9]. Analysis of each process from the interaction between air and mucosa to the fragmentation of the liquid sheet, evaporation/deposition of drops, and virus transmission is possible by CFD as a powerful tool for analyzing various physical situations. CFD has revolutionized numerical studies of physical phenomena related to complex fluid flows in about the past 40 years. Not only does it collaborate in design and manufacturing of high-quality medical equipment or in high ventilated indoor spaces by analyzing the behavior of bio-aerosols, but it also helps relevant organizations and institutions in updating their social rules during the pandemic [10]. Unfortunately, all processes such as sneezing, coughing, talking, laughing, and breathing induce respiratory drops [11]. During exhalation, these drops are transferred to outside environments.

Larger drops deposit on the ground, and the rest can remain suspended in air for many hours. Human respiratory exhalation is a multiphase turbulent jet flow which is sometimes referred to as a respiratory cloud [12]. This cloud includes particles containing saliva and mucus covering the surface of the respiratory system. It can move several meters downstream of the patient face due to the effects of temperature gradient, buoyancy, air current, humidity, ventilation, shear force due to the shear layer developed, etc. Different sizes of respiratory drops are such that their diameters vary from about 1-2000 [13]. Although these drops are so small that they cannot be seen with naked eyes, they are large enough to carry the coronavirus along [14]. Note, drops larger than about 100 deposits on ground or on nearby surfaces under the influence of gravity up to about 1 meter from mouth after a ballistic motion [15]. However, smaller drops are suspended in air and can move much farther downstream. In addition, some respiratory drops evaporate during their transport. Note, such drops consist of 10.4% NaCl and 89.6% water [16] and so their evaporation processes continue until their diameters become about 30 to 20% of their original sizes [17]. These particles are called droplet nuclei, which are the most significant factors in transmitting disease from an infected person.

Many numerical studies have been performed to evaluate the factors affecting drop evaporation. According to previous studies, evaporation rate depends on the differences between saturated vapor pressure of the drop surface and that of ambient vapor pressure, mass diffusion coefficient, and relative velocity between drop and surrounding air [18]. Of course, evaporation is also affected by ambient temperature and relative humidity [19]. The dependence of evaporation on temperature and relative humidity in different climates and different geographical areas lead to various respiratory drop transmission rates [20,21].

According to previous studies, airborne particles move further distances in higher relative humidity if air temperature is kept constant [22]. Also, an increase in temperature will lead to increase in evaporation rate, which causes respiratory drops to travel less distances (for constant environmental relative humidity). Ambient airflow can also affect respiratory particles directly. Some previous simulations have considered wind flow and examined its effects on drop transmission and thus social distancing [23,24]. They found that if wind blows in the respiratory process direction, the resulting particles transfer to much greater distances [25]. Therefore, air current can increase the number of people exposed to respiratory drops. In addition, high airflow velocity can cause turbulence and thus, more particle dispersion leading to an increase in chance of new infections. Besides, motion and temperature of human bodies also affect spread of respiratory drops [26]. Thus, in closed and crowded places, such as in airplane and in trains suitable air-conditioning is very crucial [27]. Another word, by designing proper ventilation, indoor air can be kept fresh such that particle dispersion can more easily be controlled [28].

Future Outlook

So far, many numerical studies have been performed on respiratory processes and some features of respiratory events have been almost entirely investigated. For instance, factors affecting formation of drops, such as Kelvin-Helmholtz/Rayleigh-Taylor/Rayleigh-Plateau instabilities, secondary drop breakup, and viscoelasticity of mucus and saliva in their breakup, factors affecting the number of particles such as gender and age, factors affecting drop displacement and dispersion, such as air temperature, airflow, ventilation system, relative humidity, and impact of facemasks have been previously studied. However, some problems such as effects of vocal loudness, distribution of respiratory drops related to healthy and infected individuals, importance of atmospheric stability in drop dispersion, transmission of drops during days or nights and their effects on social distances, factors affecting deposition of respiratory drops during cleaning and laboratory activities, and repetitive sneezing/coughing have not received enough attention. So, several related projects can still be proposed.

References

1. Beggs CB (2003) The airborne transmission of infection in hospital buildings: Fact or fiction? Indoor Built Environment 12(1-2): 9-18.
2. Dwosh HA, Hong HL, Austgarden D, Herman S, Schabas R (2003) Identification and containment of an outbreak of SARS in a community hospital. CMAJ 168(11): 1415-1420.
3. Vuorinen V, Aarnio M, Mikko A, Alopaeus V, Nina A, et al. (2020) Modelling aerosol transport and virus exposure with numerical simulations in relation to SARS-CoV-2 transmission by inhalation indoors. Saf Sci 130: 104866.
4. Bourouiba L (2021) The fluid dynamics of disease transmission. Annu Rev Fluid Mech 53(1): 473-508.
5. Sakharov AS, Zhukov K (2020) Study of an air curtain in the context of individual protection from exposure to coronavirus (SARS-CoV-2) contained in cough-generated fluid particles. Physics 2(3): 340-351.
6. Riediker M, Tsai DH (2020) Estimation of viral aerosol emissions from simulated individuals with asymptomatic to moderate coronavirus disease 2019. JAMA Netw Open 3(7): e2013807.
7. Przekwas A, Chen Z (2020) Washing hands and the face may reduce COVID-19 infection. Med Hypotheses 144: 110261.
8. Scharfman B, Techet A, Bush J, Bourouiba L (2016) Visualization of sneeze ejecta: Steps of fluid fragmentation leading to respiratory droplets. Exp Fluids 57(2): 24.
9. Vadivukkarasan M, Dhivyaraja K, Panchagnula MV (2020) Breakup morphology of expelled respiratory liquid: From the perspective of hydrodynamic instabilities. Phys Fluids 32(9): 1-8.
10. Shafaghi AH, Talabazar FR, Koşar A, Ghorbani M (2020) On the effect of the respiratory droplet generation condition on COVID-19 transmission. Fluids 5(3): 113.
11. Tang JW, Noakes C J, Nielsen P V, Eames I, Nicolle A, et al. (2011) Observing and quantifying airflows in the infection control of aerosol- and airborne-transmitted diseases: An overview of approaches. J Hosp Infect 77(3): 213-222.
12. Bourouiba L, Eline D, Bush JW (2014) Violent expiratory events: On coughing and sneezing. J Fluid Mech 745: 537-563.
13. Duguid J (1946) The size and the duration of air-carriage of respiratory droplets and droplet-nuclei. Epidemiol Infect 44(6): 471-479.
14. Asadi S, Bouvier N, Wexler AS, Ristenpart W (2020) The coronavirus pandemic and aerosols: Does COVID-19 transmit via expiratory particles ? Aerosol Science and Technology 54(6): 635-638.
15. Kumar V, Sravankumar N, Sourabh S, Harshrajsinh J, Pravin N, et al. (2020) On the utility of cloth facemasks for controlling ejecta during respiratory events. Medical Physics pp. 1-19.
16. Feng Y, Marchal T, Sperry T, Yi H (2020) Influence of wind and relative humidity on the social distancing effectiveness to prevent COVID-19 airborne transmission: A numerical study. J Aerosol Sci 147: 105585.
17. Chaudhuri S, Basu S, Kabi P, Unni VR, Saha A (2020) Modeling the role of respiratory droplets in Covid-19 type pandemics. Phys Fluids 32(6): 063309.

18. Mittal R, Ni R, Seo J (2020) The flow physics of COVID-19. J Fluid Mech 894: 1-14.
19. Bourouiba L (2020) Turbulent gas clouds and respiratory pathogen emissions: Potential implications for reducing transmission of COVID-19. JAMA 323(18): 1837-1838.
20. Maggiore E, Tommasini M, Ossi PM (2020) Propagation in outdoor environments of aerosol droplets produced by breath and light cough. Aerosol Sci Technol 55(3): 340-351.
21. Wang H, Li Z, Zhang X, Zhu L, Liu Y (2020) The motion of respiratory droplets produced by coughing. Phys Fluids 32(12): 125102.
22. Dbouk T, Drikakis D (2020) Weather impact on airborne coronavirus survival. Phys Fluids 32(9): 093312.
23. Dbouk T, Drikakis D (2020) On coughing and airborne droplet transmission to humans. Phys Fluids 32(5): 053310.
24. Sandoval M, Vergara O (2021) Drops in the wind: Their dispersion and COVID-19 implications. Fluid Dynamics pp. 1-9.
25. Li H, Leong FY, Xu G, Ge Z, Kang CW, et al. (2020) Dispersion of evaporating cough droplets in tropical outdoor environment. Phys Fluids 32(11): 113301.
26. Berrouk AS, Lai AC, Cheung AC, Wong SL (2010) Experimental measurements and large eddy simulation of expiratory droplet dispersion in a mechanically ventilated enclosure with thermal effects. Build Environ 45(2): 371-379.
27. Zhang L, Li Y (2012) Dispersion of coughed droplets in a fully-occupied high-speed rail cabin. Building and Environment 47(1): 58-66.
28. Liu H, He S, Shen L, Hong J (2021) Simulation-based study of COVID-19 outbreak associated with air-conditioning in a restaurant. Phys Fluids 33(2): 023301.