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Modeling the evaporation and dispersion of airborne sputum droplets expelled from a human cough

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ABSTRACT

This study contributes a new model to simulate the evaporation and dispersion of sputum droplets from human coughs or sneezes. It is the first time different chemical components have been included in order to estimate the transport of sputum or similar biological droplets. This modified model demonstrates the ability to describe real-world phenomena that the widely used single droplet model lacks. Evaporation and dispersion of airborne sputum droplets originating from a human cough are simulated using this model combined with an initially buoyant turbulent jet. Constituents of sputum droplets such as NaCl, amino acids, carbohydrates, and lipids are included. Effects of these chemical components on evaporation rate, velocity, and temperature of droplets are investigated in detail. The results obtained for sputum droplets will provide a perspective of what conditions the viruses within a droplet might face upon being ejected from the mouth during a cough. Finally, computational fluid dynamics (CFD) and probability density function (PDF) techniques were used to complement the new model with a simulation of a cough jet and the dynamics of droplet nuclei in confined spaces. Numerical results indicate that a 10 microns sputum droplet will evaporate to become a droplet nucleus (3.5 microns) in 0.55 s at 0.8 or 80% RH, in 0.3 s at 0.5 or 50% RH, and in 0.25 s at 0.2 or 20% RH. The droplet temperature decreases rapidly from human body temperature to room temperature, which may affect the viability of any carried virus.

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1. Introduction

The main motivation for this work comes from great concern about airborne transmission of avian and 2009 H1N1 influenza to the health care community. Bio-aerosols such as sputum droplets [24] have been referred to as an important mode of transmission of influenza by many researchers [3,6,7,11,17,21–23,38–40,48,55]. The virus-laden bio-aerosols can originate from respiratory activities such as coughing, sneezing, and speaking from infected individuals. It is important to note that dried nuclei of aerosols may remain suspended in air and be transported with the airflow due to air-conditioning or other negative pressure-ventilation systems. In recent years, emphasis on and improvement of physical and clinical processes have helped to limit the spread of airborne transmission of diseases. However, there is not always consensus among experts on the range over which particles are transported and the size of droplets that are truly airborne in the engineering context. Furthermore, how the composition of the droplet affects its transmission is not well understood.

The transport properties of aerosols are strongly dependent on droplet diameter. Particles with an aerodynamic diameter of less than 10 microns ($D_a < 10$ μm) remain suspended for a sufficient time to permit dispersion throughout the room [55]. Larger droplets ($D_a > 10$ μm) are removed from the air more rapidly by gravitational settling. For aqueous droplets, the evaporation process affects the drifting velocity of the droplets and the concentration of solutes within the droplets [15]. Numerical simulations have shown that the evaporation of 50 μm droplets occurred in several seconds as their diameter was reduced to less than 5 μm under the condition of 0.6 or 60% relative humidity [9,46]. Recent experimental measurements have shown that the geometrical mean diameter of droplets was about 13.5 μm for coughing and 16.0 μm for speaking. The estimated total number of droplets expelled was in the range of 947–2085 per cough [11]. Laboratory experiments have shown that 90% of large size ($D_a > 50$ μm) water droplets rapidly settled at a distance of 1–2 m from the point of emission. Only about 4–10% of droplets remain suspended in room air ($D_a < 10$ μm), and the evaporation time of

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