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Evaporation of Emitted Droplets Are An Important Factor Affecting the Lifetime of the Airborne Coronavirus

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Abstract

There is a lot of discussion underway with conflicting opinions examining the airborne nature of the SARS-CoV2 virus. Surprisingly, important phenomena prevalent with respect to aerosols (suspended droplets) have not been considered. In this Technical Note, we propose a methodology for the coupling of aerosol phenomena (such as evaporation, particle transport accounting for drag) to accurately establish the lifetimes of the droplets. A characteristic time analysis illustrates the time scales for evaporation and settling: for example, the characteristic time for evaporation of a 10 µm droplet is 0.036 s at a relative humidity of 25%; compared to a settling time of about 500 s. For any particle smaller than ~ 100 µm, the evaporation of the emitted or exhaled droplet has to be considered. Coupling evaporation of the droplet as it settles, we estimate the horizontal distance traversed. Trajectories of a 10 µm and 100 µm particle emitted with a typical initial velocity of release associated with coughing and sneezing indicates the greater spread in the horizontal direction when evaporation is accounted for. The life time of the 10 µm particle increases from 8.3 min to 12 hours (will be intercepted prior and the actual airborne time will then be shorter); and for a 100 µm particle from 4.9 s to 39.4 s.

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Introduction

The highly infectious SARS-CoV-2 novel coronavirus has resulted in a pandemic leading to the Corona Virus Disease 2019 (COVID-19). More than a million people are already impacted, with infected numbers expected to go up. There are three possible pathways conjectured for infection: direct contact (e.g. handshaking, kissing) with an infected individual; indirect mode via fomite (e.g. contact with objects contaminated with the virus and then entry through the nose or mouth); and airborne mode where an individual inhales aerosols containing the viable virus followed by deposition in the respiratory tract. While there is a clear understanding of reducing the spread by physical distancing and hand washing, there is not a clear mechanistic understanding of the airborne spread of this virus and remains a point of contention. The first clarification is on the use of the term aerosol: by definition it is a suspension of particles (including droplets) in a gaseous medium, in this case, air. Both large particles or droplets (e.g. from coughing or sneezing) and smaller particles (e.g. resulting due to evaporation) are both aerosols as long as they remain airborne. Large particles or droplets will have a shorter lifetime and deposit (due to aerosol phenomena of settling), whereas smaller particles or droplets will remain airborne longer. The fate and transport, and resultant lifetime of the airborne particles and droplets are to be determined by using concepts of aerosol physics.

There are many studies conducted on the airborne spread of viruses causing diseases such as SARS and measles, however none of the studies (Tellier et al., 2019; Kutter et al., 2018) couple the transport characteristics with the aerosol dynamics of the droplet. Modeling studies have ranged from simplistic to complex ones using CFD to unravel the airborne spread (Yu et al., 2004). While several have reported potential airborne transmission (Service, 2020) and reasonably long airborne life times of 3 hours of the SARS-CoV2 virus in laboratory studies (van

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Doremalen et al, 2020), others have reported disagreements by experts (Lewis, 2020). A glaring omission in all these studies is a coupling of the aerosol phenomena (such as evaporation, particle diffusion) to accurately establish the lifetimes of the droplets. This technical note presents the results of those calculations

Methodology

The governing equation for particle diameter (dpi) change is given by

$$\frac{dd_{p,i}}{dt} = \frac{4D_v v_m}{d_{p,i} k_B T} \left(RH * P_{sat} - P_{d,i}\right) F(Kn)$$

$$P_{d,i} = P_{sat} * \left(1 - x_{solute,i}\right) * \exp\left(\frac{4\sigma v_m}{d_{p,i} k_B T}\right)$$

where D_v is the diffusivity of the vapor (water), v_m the molecular volume, RH the relative humidity, P_{sat} the saturation pressure of water vapor, $P_{d,I}$ the vapor pressure at the droplet surface, and Kn is the Knudsen number. The settling time is calculated by using the settling velocity expression

$$\boldsymbol{u_{ext}} = \frac{F_{ext}}{f} = \frac{m_{droplet}(g)}{3\pi\mu d_p C}$$

Where μ is the viscosity of the medium (air) and C is the Cunningham slip correction factor. The two equations are coupled (as the diameter of the droplet is changing) and is used to solve for the trajectory of the particle.

Results

The characteristic time for evaporation of a 10 µm droplet is 0.036 s at a relative humidity of 25%; compared to a settling time of about 500 s. Figure 1 (left) outlines a comparison of the evaporation time and the settling time for droplets ranging from 0.1 to 1000 µm; and as illustrated, for any particle smaller than ~ 100 µm, the evaporation of the emitted or exhaled

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droplet has to be considered. Coupling evaporation of the droplet as it settles, we estimate the horizontal distance traversed (Dhawan and Biswas, 2020). The emitted particle (or droplet) will decrease in particle size, thus increasing the horizontal distance traversed and its airborne lifetime (Figure 1(right)).

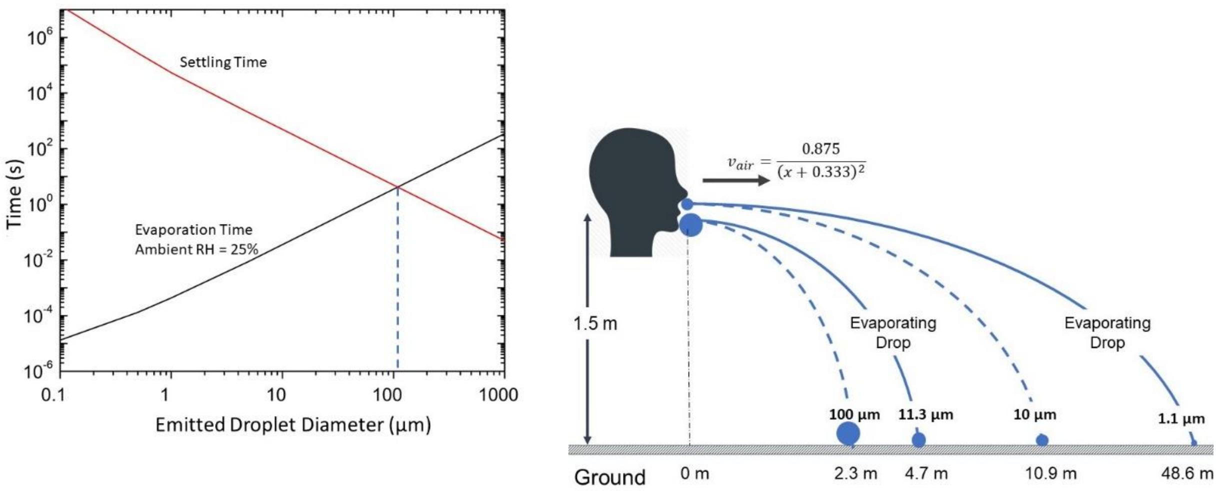

Figure 1 (Left). Representative evaporation time and settling time calculated for droplets of different initial sizes. A guideline is that for any droplet less than 100 µm, evaporation cannot be neglected. (Right) Trajectories of a 10 µm and 100 µm particle emitted with a typical initial velocity of release indicating the greater spread in the horizontal direction when evaporation (solid line) is accounted for. The life time of the 10 µm particle increases from 8.3 min to 12 hours (will be intercepted prior); and for a 100 µm particle from 4.9 s to 39.4 s.

There are three conditions, sneezing, coughing and exhaling(breathing) under which a symptomatic or asymptomatic individual will release droplets potentially with the virus. The following are typical size distribution parameters of the droplet size distributions

	Particle Size Distribution of Emitted Droplets		
	Speaking (Breathing)	Coughing	Sneezing
	Chao et al (2009)	Chao et al. (2009)	Duguid (1946)
N_{total} (# / m^3)	1.51×10^5	2.37×10^6	2.74×10^8

Geometric Mean Size(μm)	16.3	13.4	8.86
Geom. Std Deviation	3.6	3.48	2.21

From the resultant size distributions of all three cases, it is clear that evaporation of the droplet has to be considered. The aerosol dynamics (such as droplet evaporation) coupled to particle transport models (settling, diffusion) will provide accurate estimation of lifetimes and help propose strategies to minimize the spread of this highly communicable disease. The governing equation which gives the size distribution function, n is (Bai and Biswas, 1990)

$$\frac{\partial n}{\partial t} + \nabla.(\overrightarrow{v_p} n) - \nabla^2(D\, n) = -\frac{\partial(Gn)}{\partial v} + I(v^*)\delta(v - v^*) + \frac{1}{2}\int_0^v \beta(v-\hat{v},\hat{v})n(v-\hat{v},t)n(\hat{v},t)d\hat{v} - n(\hat{v},t)\int_0^v \beta(v,\hat{v})n(\hat{v},t)d\hat{v}$$

The second term on the LHS is the transport due to the fluid flow and gravity, the third accounts for diffusional transport. The RHS terms account for evaporation, nucleation (formation), and coagulation terms, respectively. Models that also account for the survivability of the virus during transport of emitted droplets has to be considered (Hogan et al, 2006); and controlled experiments to validate them with robust measurement tools (Li et al., 2017) have to be conducted (Dhawan and Biswas, 2020).

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