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Living in Still-air Environment can Increase the Risk of Contracting COVID-19: A Physics View

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Abstract:

COVID-19 is regarded as the greatest global challenge since World War II. Consequently, the global scientific community unites to track the progress of COVID-19 research and development. In many researches, aerosol droplets were identified as the major carriers of certain pathogens that are responsible for respiratory ailments, including the global pandemic of SARS-CoV-2. To complement their efforts, this paper aims to estimate the terminal velocity and the settling time of aerosol droplets from either coughing or sneezing healthy subjects at standing position, in a closed space. The settling time determined could be used as an analogy to the real COVID-19 patients. The heights of the subjects as well as the size of each droplet were modelled. The terminal velocity and the settling time of the aerosol droplets were estimated using the Stokes' model equation. The results showed a direct relationship between the settling time and the height of the subjects and inverse relationship between the settling time and the size of the droplet. The results further revealed the prolonged time taken by droplets of lower sizes to settle down. This study is believed to have given a technical insight about this subject.

Keywords: droplet, aerosol, COVID-19, settling time.

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I. INTRODUCTION

Wuhan, China has been the first place where the SARS-CoV-2 initially manifested, as an acute respiratory syndrome, in the late 2019 and, eventually, metamorphosed into a global pandemic [1]. The presence of this pandemic has affected every aspect of life, including economy, health, education, sport, etc., and resulted in thousands of deaths. Consequently, the global scientific community unites to track the progress of the COVID-19 research and development, to identify new research priorities and critical gaps [2].

In view of this, many studies have been conducted with regards to identification, transmission and stability of the disease [3, 4]. Many studies have shown that aerosol droplets, which happened to be the major culprits for transmitting COVID-19 virus, are in the range of 5 µm and above, and those below that are considered as droplet nuclei [5]. Aerosols have been defined by many authors as tiny particles (solid or liquid) suspended in air [6, 7]. Studies revealed that the size distribution of aerosol droplets produced from coughing have a relatively wide spectrum of size, ranging between 0.58 µm and 5.4 µm, and 82 % of the droplet nuclei were found to centralize between 0.74 µm and 2.12 µm [8]. Moreover, [9, 10] have suggested that sneezing may produce as many as 40, 000 droplets with diameter range between 0.5µm and 12µm. Furthermore, [9]; [10] and [11] have reported that coughing may produce up to 3000 droplet nuclei, about the same number when talking for five minutes.

Despites the contributions by many authors, much information about how long typical droplets linger in the surrounding air still remains vague. As a carrier of the virus, the time the droplets take to linger in the surrounding air may reveal significant information on how readily and quickly can the virus be transmitted to a susceptible host. In the light of this, the present study, utilizes the Stokes's law to estimate the terminal velocity and the settling time of the droplets after they have been emitted from a coughing or sneezing subject.

A. *Theoretical Background*

For a particle of constant mass, m, released in quiescent air with an initial velocity, v=0, at any time t > 0, Newton's second law holds thus:

$$\sum \vec{F} = m\frac{d\vec{v}}{dt} \quad , \qquad (1.0)$$

This equation is used, assuming that the particle droplet neither grows, nor shrinks due to evaporation and the surrounding air is assumed to be still, no ventilation. In this case, the droplet is under the influence of two forces, namely; constant force of gravity and a drag force [8].

In this case, therefore, the instantaneous drag force is given by Stokes' law [8]:

$$\sum \vec{F} = mg - \mathrm{F_D} \qquad (1.1)$$

Where, $\mathrm{F_D} = \frac{3\pi\mu v d_p}{C_c}$. When we substitute this into 1.1 we get:

$$m\frac{d\vec{v}}{dt} = \mathrm{mg} - \frac{3\pi\mu v d_p}{C_c} \qquad (1.2)$$

Ignoring the Buoyant force, given the fact that the density of the droplets is much greater than that of air, we set v = 0, t = 0. When we integrate, we get:

$$\frac{3\pi\mu d_p}{mC_c}\int_0^t dt = -\int_0^v \frac{dv}{[v-\left(\frac{mgC_c}{3\pi\mu d_p}\right)]} \qquad (1.3)$$

$$-\frac{t}{\left(\frac{\rho_{pd_p^2}C_c}{18\mu}\right)} = \ln\left(\frac{\frac{g\rho_p d^2 C_c}{18\mu}-v}{\frac{g\rho_p d^2 C_c}{18\mu}}\right) \qquad (1.4)$$

Taking $\tau = \frac{\rho_p d^2 C_c}{18\mu}$ (1.5), we get, v_t at any time, t as:

$$v_t = g\tau[\,1 - e^{-\frac{t}{\tau}}\,] \qquad (1.6)$$

Equation 1.6 shows that as t approaches infinity, the settling speed of the aerosol particle approaches a constant, which is the maximum speed that the particle can reach. In aerosol dynamics, this maximum speed is called terminal setting velocity, denoted by V_{ts}. This occurs as t approaches infinity. Thus:

$$V_{ts} = \frac{\rho_p D^2{}_p g C_c}{18\mu} \tag{1.7}$$

Note that when the system is in non-continuum regime, Cunningham correction factor, C_c is used to correct the drag force. The C_c is given as:

$$C_c = 1 + \frac{2.52\lambda}{D_p} \tag{1.8}$$

Equation 1.7 is used to determine the terminal velocity of the aerosol particles. To get the settling time of the particles, equation 1.9 below is used.

$$\Delta t = \frac{H}{V_{ts}} \tag{1.9}$$

II. METHODS

Five sets of five (5) different samples of droplets were modelled. Each set was assumed to have been emitted by a subject of height, h_i, where h_i= 0.5 m, 1.0 m, 1.5 m, 2.0 m, and 2.5 m; where i=1,2,3,4,5.The five modeled size of the droplets emitted by the subjects were 1 **µ**m, 2 **µ**m, 3 **µ**m, 4 **µ**m, and 5**µ**m respectively. This is consistent with the finding of [8], that the total average size distribution of droplets by coughing was 0.58–5.42 µm. All the droplets were assumed to have been discharged from the mouth horizontally in air, in a closed space, having similar shape and density (1,000 kg/m^3).

Having the data for the height and the diameter of the droplet equations 1.7- 1.9 were utilized to simulate the settling times of the droplets. This procedure is adopted from [8].

The simulation was done under the following assumptions: $\boldsymbol{\rho}_p$ = 1000kg m^{-3}, which is the density of the droplet, g is acceleration due to gravity, 9.8m/s, $\mu = 1.81 \times 10^{-5}$ Pa, C_c is the Cunningham correction factor for aerosol particles.

The simulation was done in two phases. Firstly, settling time of 5 µm droplet was determined as emitted by each of the five subjects, so in this case, size of the droplet was fixed at 5 µm, whereas, height of the subjects were varied. Secondly, for each subject of h_i, we investigated variation of the settling time with change in the aerosol's diameter.

III. RESULTS AND DISCUSSION

A. *Variation of Settling time with the Subjects' Heights*

Fig. 1 presents the height of the subjects, measured in meter, from 0.5 to 2.5 at 0.5m interval, the calculated terminal velocities of the droplets and the corresponding settling times. According to the Fig. 1, the settling time was found to be directly dependent on the height. This implies that smaller droplets emitted by a standing patient or a patient of greater height exhibit greater tendency to linger in the surrounding air and eventually caught by a susceptible host in the neighbourhood. From Fig. 1 it is clear that the settling time of droplet emitted by 2.5m high patient was found to be 55 min., whereas that of droplet emitted by the 0.5m high patient was only 11minutes.This does not deviate from the findings of [12], that droplets of size~ 5 µm were found to remain in the air for approximately 10 minutes. From this, we can deduce that the virus-carrying droplet can linger up to close to an hour in the surrounding air. In a recent paper by [4], it has been demonstrated that SARS-COV-2 can remain active and infectious in aerosol for hours [4]. Based on this, it is evident that small droplets with longer settling times can contain coronavirus for even longer than it remains in the air. This really explains why SARS-CoV-2 is fast-spreading and can be regarded as airborne. Similarly, another study has shown that airborne transmission of SARS-COV-2 may also occur besides close distance contacts [13]. This may be attributed to the transportation of the live droplets.

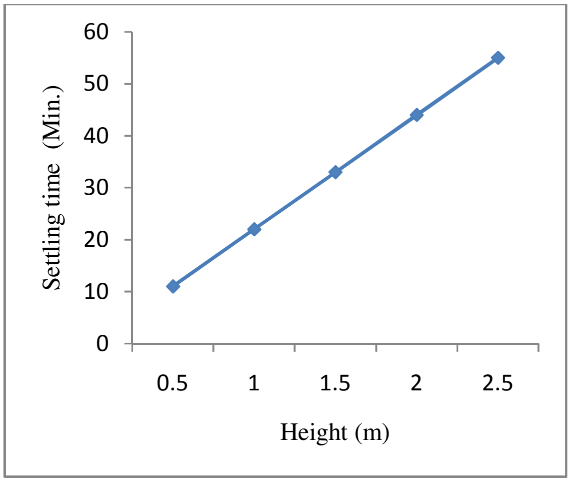

Fig. 1: Presentation of the Settling time dependence on the Height of the Subjects at a fixed diameter of droplet.

B. ***Variation of Settling time with the Size of the Droplets***

Another important thing to note is the dependence of the settling time on the size of the droplet. This can be observed in Figs.2a-2e.The carefully chosen diameters disclosed significant increase of the settling time as the diameter decreases. Moreover, more striking effect is observed when a subject of greater height emits droplets of lower diameter. For instance, the settling time of the 1 µm droplet emitted by a subject of 0.5m high amounted to only 245 min. whereas, same size of the droplet emitted by a subject of 2.5 m high amounted to over 1300 min, more than four times greater. This may explain why transmission rate of COVID-19 among children is very minute.

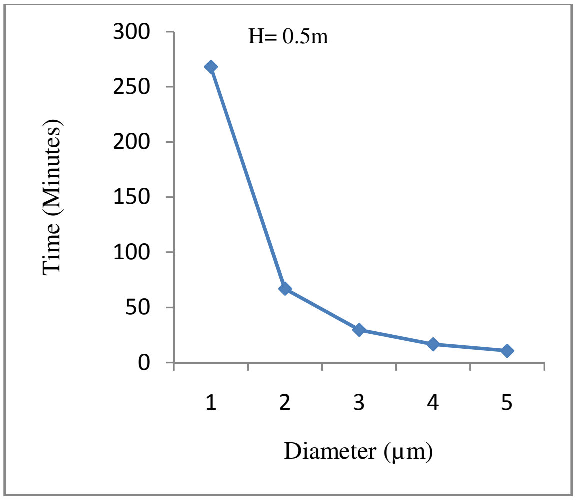

Fig. 2a

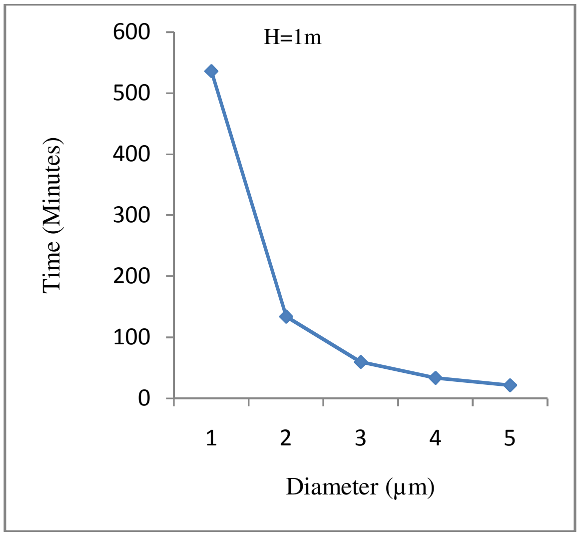

Fig. 2b

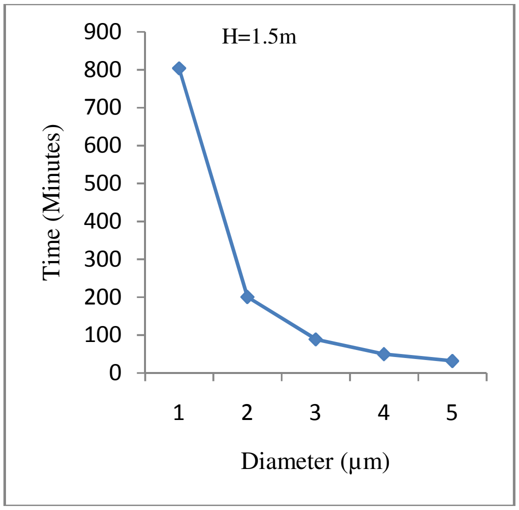

Fig. 2c

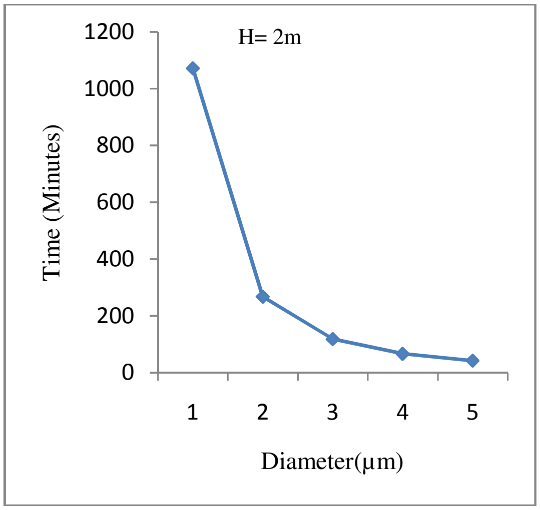

Fig. 2d

Figs. 2a-2d present Variation of the settling time with the diameter at different emission heights.

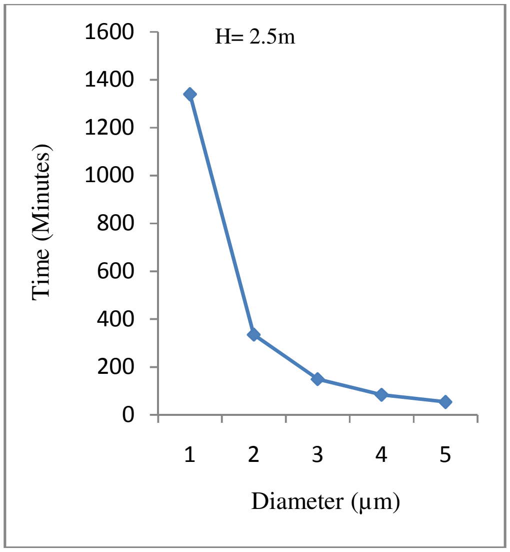

Fig. 2e

Fig. 2e reveals a quite prolonged settling time of the droplet. The particle was found to take more than 1200 minutes to settle. This is almost a day. This occurs at diameter 1 µm and the time can be even more at diameters <1 µm. However, the prolonged time taken by the droplets can be shortened if ventilation is allowed in the area. The ventilation could cause rapid evacuation of the droplets via transportation mechanism. So it is recommended that isolation centres, especially those located in rural and remote areas, where air conditioners and fans could not be in place should have their doors and windows open to allow adequate ventilation in the rooms.

IV. CONCLUSION

In conclusion, the results showed a direct relationship between the settling time and the height of the subject and inverse relationship between the settling time and the size of the droplet. The long period that was found to be taken by the smaller particle droplets is an indication that SARS-CoV-02 and other infectious diseases can remain active in still air and can infect any potential susceptible host in the surrounding.

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