SARS-CoV-2 transmission: The cigarette smoke analogy

N Ghadiri[1], m.ali[1], and M Ghadiri[1]

[1]Affiliation not available

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Abstract

Despite the current presumption that SARS-CoV-2 is transmitted by droplets, the reported evidence of the presence of the virus in air suggests that droplets dry fast producing clusters of virus, which are most penetrative through commonly available fabric filters to the public.

We consider droplets corresponding to a typical bimodal distribution of droplets of sneeze and calculate the time taken for them to evaporate to their ultimate size for two virus loadings. The dry virus clusters resulting from fine droplets of the first mode have a size distribution comparable to cigarette smoke. There are currently no masks available to the public which can filter these aerosols efficiently, and even FFP grade masks have low filtration efficiency for these particle sizes.

The implications are that safe distance is considerably greater than the generally-recommended two metres, as the virus remains fully suspended in the air. Secondly, mask filters available to the public are inefficient in preventing SARS-CoV-2 spreading, as it could penetrate through them. The rapid spread of the virus is indicative of the ease with which it spreads through the air, and apart from wearing a high efficiency mask, the only safe prevention is to self-isolate at home.

Authors

Nima Ghadiri[1], Muzammil Ali[2,3], Mojtaba Ghadiri[3]

[1] *Moorfields Eye Hospital, London, UK*

[2] *Fluid Comp Ltd, Leeds, UK*

[3] *School of Chemical and Process Engineering, the University of Leeds, Leeds, UK*

Introduction

A Historical Approach to Pandemic

In 1025, Avicenna (A Persian polymath) completed his Canon of Medicine, within which he speculated that some diseases are spread by microorganisms. He suggested the method of isolating people for 40 days to prevent transmission of diseases. For this, he was reprimanded by religious authorities, but his recommendations were taken up by Venetian traders who were travelling on the Silk Road. They took his knowledge back to Italy and from this the word "quarantena" ("*the forty* ") was born. A similar situation prevails today, as economic and financial pressures are thwarting science and logic recommendations, increasing the likelihood of a devastating second phase.

Transmission of the SARS-CoV-2 Virus

The transmission of SARS-CoV-2 virus is regarded to take place mainly through droplets generated when an infected person coughs, sneezes, or speaks. It is commonly considered that these droplets are too heavy to remain suspended in the air and fall quickly on to grounds and surfaces. On this basis, the infection is considered to take place by breathing in the virus in the vicinity of an infected person (typically within 1 metre) or by contact with contaminated surfaces and then touching eyes, nose or mouth. However, the recent study of Wuhan hospitals(1) reports the airborne virus cluster size is in the range 0.01 to 10 µm, with the mode of the distribution in the range 0.25 to 1 µm, depending on the hospital zone. This strongly suggests that SARS-CoV-2 virus could spread primarily through dispersion, as an aerosol which travels through air at a size of less than a few micrometres. For the fines fraction corresponding to the mode of the size distribution reported above, there are currently no masks commonly available to the public which can filter out these aerosols efficiently. In laboratories, particle technologists use FFP1, FFP2 and FFP3 grade filters when handling benign powders. However, all three FFP grade masks have low filtration efficiency for the particle size range around 0.09-0.16 µm(2). There is extensive literature on filter performance evaluation, and as commonly available filters are all fabric filters, they all suffer from poor performance for the most penetrative particle size. This depends on the filter material, but is typically in the sub-micrometre range. So, considering the average size of a single virus, measured by transmission as well as by scanning electron microscopy(3), ranging from 0.08-0.22 µm, they could penetrate through filters even when in clusters if they are suspended in air.

The Cigarette Smoke Analogy

Cigarette smoke provides an analogue for spreading of the SARS-CoV-2 virus, as its particle size distribution is in a similar range of 0.1-0.4 µm(4). So virus particles can travel in a similar way when emitted from an infected person by sneezing or coughing. The current two-metre social distancing is presumably based on droplet size and principles of droplet spreading. However, droplets evaporate quickly and it is evident that we are facing a most penetrating aerosol. The particle size distribution of droplets coming out of the nose and mouth has been extensively characterised. Both unimodal and bimodal distributions have been reported with the modes around 500 µm for the former and 90 µm and 600 µm for the latter, and with geometric mean values of 72 and 386 µm(3). An early report indicates an even much finer distribution in the range 4-8 µm(5). So it is of interest to estimate how long it takes for the droplets to shrink to their ultimate size encasing the virus.

Considering the uncertainty about the viral load which causes infection, and the number of copies of virus prevailing in the droplets, we consider a number of cases and investigate the size of virus clusters on drying: (1) a load of 1000 virus particles inside each droplets; (2) a concentration of $10^{7.2}$/ml of virus particles in respiratory liquid which is sprayed out on sneezing or coughing(6); (iii) an infectious dose in the range of 1.95×10^3 and 3.0×10^3 viral particles, based on Influenza A virus(7).

Results

(i) Constant load of 1000 virus particles per droplet

We consider two droplets corresponding to the bimodal distribution with the corresponding geometric mean sizes of 72 µm and 386 µm for the two modes(3), with 1000 virus particles inside. The droplets are ejected into quiescent air at 50 m/s (as commonly reported for sneezing) at an average relative humidity of 65%, common in the UK and an ambient temperature of 50°F (10°C). The time taken for the droplets to evaporate to their ultimate size is calculated(8), considering no internal resistance to mass transfer and drying rate controlled by the external mass transfer film. Water is considered as the evaporating material and assuming that the presence of the virus does not hinder the drying of droplets. The drying rate of the two droplets sizes is shown in Figure 1. The evaporation time is 20 and 510 s for the two droplet sizes, respectively, and the ultimate cluster sizes in both cases are around 1μm. Considering a smaller virus loading of 100 viruses, the ultimate size will be obviously smaller and is around 0.46 μm.

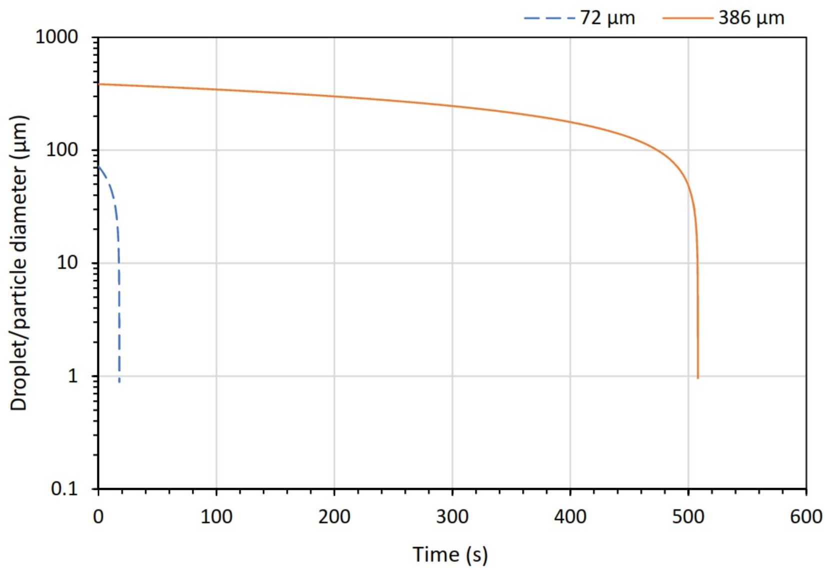

Figure 1: *Drying profile of two droplets each containing 1000 viruses.*

(ii) Constant concentration of $10^{7.2}$/ml of virus particles in respiratory liquid

As the droplets originate from a pool of liquid inside the body, this concentration corresponds to viral load of an infected person with common flu. In this case a constant volume fraction of the virus is considered for all droplets. The number of viruses in each droplet then depends on the droplet size. Taking the above virus concentration (corresponding to a virus volume fraction of 4.2×10^{-9}) and the bimodal droplet size distribution reported by Han et al.[(3)], as shown in Figure 2, this represents about 1 virus in the lower droplet size (50 μm) and 6900 in the largest droplet size. Following the drying time shown in Figure 1, the size distribution of the dried virus clusters shifts drastically to the left and is in the range 0.1 to 1.8 μm, as shown in Figure 2. Reports on the droplet size distribution produced by sneezing, coughing, shouting and speaking show a great variation. If we consider an earlier study by Duguid[(5)] in which he reports the most common droplet size is in the range 4 to 8 μm, then the time taken to reach the same ultimate size is even much shorter, around 0.05 to 0.22 s. So the calculated size range of the virus clusters formed by the smaller droplets is very similar to that of the size distribution of cigarette smoke particles.

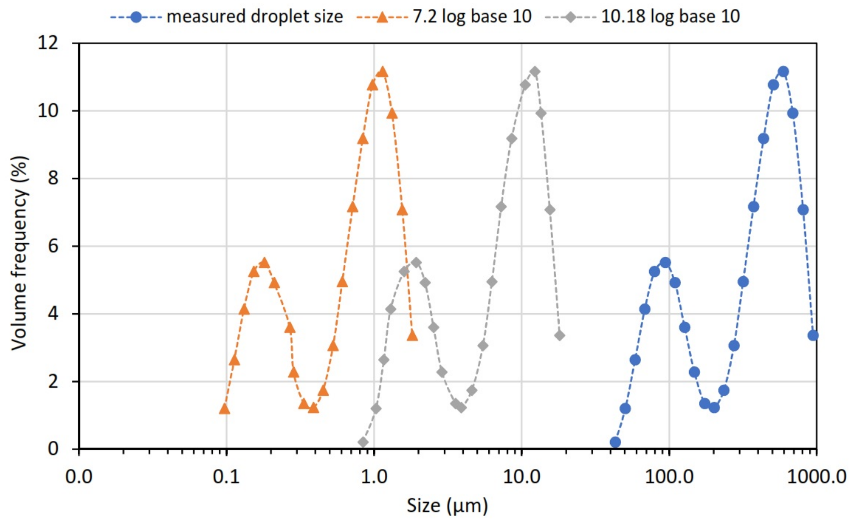

Figure 2: *Measured droplet size distribution of sample sneeze reported by Han et al.*[(3)] *and calculated dry particle size distribution considering different virus loadings in droplets.*

(iii) Infectious dose in the range 1.95 × 10^3 - 3.0 × 10^3 viral particles based on Influenza A

Here we consider the upper limit, i.e. 3000 particles in 72 µm droplet (giving rise to $10^{10.18}$ virus copies per ml), as this produces larger clusters of virus and hence less penetrating through filters. Applying the drying kinetic model to droplet size distributions given by Han et al.[(3)], the resulting particle size distribution of the dried particles are predicted to be in the range 0.84-18 µm, as also shown in Figure 2.

These particles are actually so fine they remain airborne due to ambient air turbulence. The trajectory of an initial 72 µm droplet is shown in Figure 3, considering gravity settling under quiescent air conditions. The droplet is ejected horizontally at 50 m/s at 1.6 m above the ground level into the stationary air. The terminal velocity of the particle after reaching a virus packing volume fraction of 0.6 is 8×10^{-5} m/s and at 20 s the dry particle is 0.38 m above the ground, having a diameter of 1.36 µm. It reaches the ground asymptotically with time, and will require further 1.3 hours before settling onto the ground. In contrast, a droplet with an initial size of 386 µm (corresponding to the larger mode of the droplet size distribution shown in Figure 2) settles onto the ground after 1.2 s of ejection from 1.6 m height and under the same conditions as above, and travels a horizontal distance of about 2.3 m. The diameter of the droplet when reaching the ground is 384.3 µm, i.e. very little drying takes place for droplets of this size before settling.

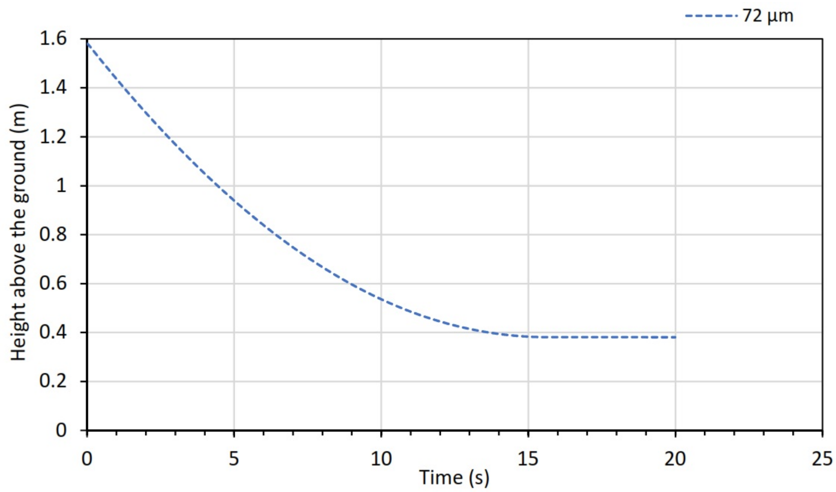

Figure 3: *Plot of height above the ground versus time for an initial droplet diameter of 72 µm with a load of 3000 viruses.*

Conclusion

In summary, large droplets settle quickly in the vicinity of the ejection point with little drying, whilst small droplets, less than about 100 µm, quickly dry and remain airborne. This has two major implications for public health: firstly, safe distance is considerably longer than the generally-recommended two metres, as the virus remains fully suspended in air. Secondly, mask filters available to the public are inefficient in preventing SARS-CoV-2 spreading, as it is most penetrative through fabric filters. They can retain the droplets from nasal and throat secretions on coughing and sneezing, but cannot protect a person from inhaling nearby viruses released into the atmosphere. The deadliness of this virus has drawn deservedly great attention of the scientific community on its spreading mechanism, with the latest re-evaluation of the basis adopted by the World Health Organization and other agencies [(9)].

Declarations

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Contributorship statement

NG and MG first conceived the study. MG was in charge of overall planning. MA carried out the calculations and data visualization. MG and MA analysed the data. NG and MG wrote the manuscript with input from all authors.

Conflict of Interest Disclosures : None reported.

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