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Page: 40-45

A Review of Evidences of Aerosol Transmission of SARS-CoV-2 Particles

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Abstract: *Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2) causes COVID-19 disease through multiple transmission routes and understanding the mode of transmission is utmost importance for its containment and prevention. Consequently, adequate attention has been given to the control of the spread of respiratory droplets in outdoor conditions under microclimatologic turbulent wind promoted by aerosol from talking (loud), coughing, sneezing, toilet flushing of isolation room, leading to resuspension of settled virus from the surfaces. To this end, this study is presenting review of the early process and evidence of aerosol transmission of SARS-CoV-2 particles. There are significant results from many studies including those under peer review that support the aerosol and airborne transmission which government agency should consider for reducing the transmission chain.*

Keywords: *Aerosol transmission, SARS-CoV-2, Pandemic, Air recirculation, Respiratory droplet*

INTRODUCTION

The rate of spread of Coronavirus disease (COVID-19) caused by Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2) through transportation of respiratory droplet (aerosol) over a wide geographic area gives the reason to be declared a global public health emergency or pandemic by the World Health Organization (WHO) (Sun *et al.*, 2020). The hazards of the pandemic greatly increase morbidity and mortality globally and causes significant economic, social, and political disruption (Madhav *et al.*, 2017). As of October 27th 2020, the total confirmed cases of COVID-19 has exceeded 44 million doubling the figure recorded as of August in 215 countries of the world with over 1.1 million mortality (WHO, 2020). Nigeria has been one of the countries affected by the pandemic with over 62 thousand cases recorded as at the ending of October, 2020 and over 1 thousand deaths cut across the country. The first confirmed case in Nigeria was announced on 27th February 2020, when an Italian citizen in Lagos tested positive for the virus (NCDC, 2020). The multiple routes of transmission of COVID-19 disease which include respiratory droplet, contact, fomite, or air makes it difficult to independently investigate each route of transmission. Evidences have shown that in addition to the mentioned modes of spread, transmission of SARS-CoV-2 through aerosol is imminent especially in closed indoor settings with poor ventilation and high probability of air recirculation (CDC, 2020; NHC, 2020; Song *et al.*, 2020; WHO, 2020). The aim of this study is to review the mechanism of aerosol suspension and transportation and the evidence of aerosol transmission of COVID-19. Based on the established evidences of aerosol transmission, infection control methods were adopted to mitigate aerosol transmission of the respiratory particles (SARS-CoV-2).

AEROSOL SIZES, SUSPENSION, AND DEPOSITION

Atmospheric aerosol is a suspension of fine solid and/or liquid matter which are emitted directly into the atmosphere by anthropogenic and biogenic sources or formed indirectly in the atmosphere by gas-to-particle conversion processes. It encompasses a wide range of particle types having different sizes, shapes, compositions, and optical properties (Seinfeld and Pandis, 1998). Generally, its typical diameters range over four orders of magnitude, from a few nanometres to a few tens of micrometres otherwise referred to aerodynamic diameter. Based on size, aerosol can be classified into monodisperse synthesized in the laboratory for experiment and polydisperse synthesize which occur naturally with different sizes usually represented with a relative term particle size distribution. It has two distinct categories, namely, the fine and coarse particles. The fine particles are generally referred to as having their diameters less than 2.5 μm, while coarse particles have diameters above 2.5 μm. These categories can be regrouped into modes and in the domain of coarse particles, there is usually only one mode which is called coarse mode. The domain of fine particles are usually of three modes: nucleation (<20 nm in diameter), Aitken (≈20 nm to ≈100 nm in diameters), and accumulation modes (≈0.1 μm to ≈2 μm in diameters) (Seinfeld and Pandis, 1998).

The Size and composition determine the ability of particles to serve as nuclei upon which other droplets in the atmosphere react and settle. These aerosol processes involve different stages of formation, Nucleation, Condensation, and Coagulation. During nucleation gas molecules or ultra-fine particles (nanoparticle- e.g. SARS-CoV-2) aggregate and can form a cluster that can condense in a small liquid particle. This can be of the same molecules nucleating together (Homogenous) or the nucleation happens on the surface of foreign particles (Heterogeneous e.g. SAR-CoV-2 and Mouth Aerosol). When a lot of nucleated particles are formed and super saturation becomes low, condensation takes place instead of nucleation (Figure 1). After this, there is no further formation of new particles, but instead, already existing particles start to grow. Coagulation occurs when two aerosol particles come in contact with each other, collide and stick together. Collision can happen due to Brownian motion of the particles in air, gravitational, phoretic, electrical, or other forces and depend on the aerosol diameters. In the process externally mixed particles become internally mixed and a number of small particles are lost due to the formation of larger particles, while the volume of the particle is preserved (Jacobson, 2005).

Suspension of aerosol in the atmosphere greatly depends on aerosol type and modes of emission. The coarse mode aerosols are mechanically disintegrated parts of soils and its formation and emission greatly relies on wind through the dragging of the particles on and off the surface (Saltation) at a wind velocity referred to erosion threshold velocity. Anthropogenic aerosols are directly emitted into the atmosphere due to human activities and propelled by the force of emission such as coughing, talking, sneezing as in the case of SARS-CoV-2 with the mouth aerosol. Once suspended in atmosphere, there are many factors that determine the residence time in air such as physical properties, size, type, altitude range. The suspension period (Residence times) of aerosols vary significantly from a few seconds for very large particles that soon after emission fall back to the ground, to years for sulphate aerosols stable at high altitudes in the stratosphere going through many phases during the cause of staying (Chazette *et al.*, 1995, 2009) in air.

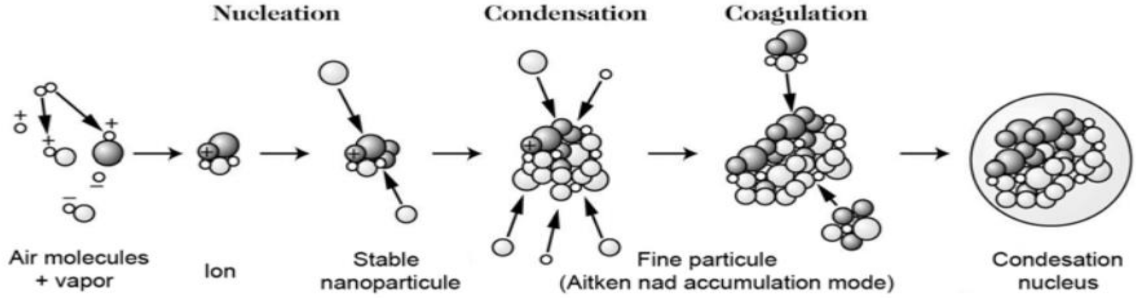

Figure 1: Possible Path of Evolution of a Particle, from Nucleation to Coagulation
(Source: (Delmas, Mégie and Peuch, 2005)

During the residence time, aerosol can be transported from emission sources to sink areas. Some of the aerosols e.g. desert dust can be transported over very long distances horizontally, commonly over several thousands of kilometres or more which have been proven by several studies with Sahara and Asian dust over Atlantic ocean, Mediterranean sea, and other part of the globe (Carlson and Prospero, 1972; Prospero, 1999; Uno *et al.*, 2009). Some can be transported vertically in layer plumes into the stratosphere such as volcanic ash particles while others reside very close to the sources of emission such as Sulphur dioxide (SO_2) (Liousse *et al.*, 2010). The removal mechanism of aerosol is what is referred to as deposition. Its mechanism is complex and depends on location and properties of the aerosol particles. It can be divided into dry and wet deposition. Dry deposition are the deposition at the surface and gravitational sedimentation while wet deposition are in-cloud and below-cloud scavenging (Bojan, 2014).

The dry deposition at surface is an aerosol deposition process in which particles are removed from the atmosphere by the interaction with surface, or more precisely with the atmospheric surface layer and a thin layer of air next to the surface (quasi-laminar sublayer) The dry deposition flux directly depends on the aerosol concentration:

$$F_{dd} = \upsilon_{dd}\eta \qquad (1)$$

Where η is the aerosol concentration and υ_{dd} is the deposition velocity in ms^{-1}. The deposition velocity depends on size, shape, density of particles, properties of the surface, and the turbulence in the surface layer. The smallest particles in Aitken mode (e.g. SARS-CoV-2) are subjected to Brownian motion, collision with the surface and deposition while bigger size and coarse mode particles can be deposited through interception and impaction respectively (Slinn, 1988a). Coarse mode particles can also be subjected to the gravitational settling due to gravitational force that makes the particle fall and because they are of bigger sizes, it makes their atmospheric lifetime very short. Wet removal mechanisms are processes that act on aerosols via atmospheric hydrometeors (cloud droplets, rain, snow, fog) and depose them unto the surface. Both in-cloud and below-cloud mechanisms can be efficient in the aerosol removing and are reversible, because all hydrometeors that scavenged aerosols can also evaporate, releasing aerosols back into the air (Bojan, 2014).

VIRAL AEROSOL TRANSMISSION

It has been established by many studies that body fluids can be aerosolized through daily activities such as coughing, medical procedures. Deposited particles can be aerosolized through re-suspension due to floor cleaning, and biological specimens can be aerosolized through improper laboratory procedures into infectious virus-containing particles that can be easily suspended in atmosphere (Song *et al.*, 2020 and some ref therein). The suspended infectious aerosol particles (SARS-CoV-2) can then be transported as either homogenous nucleated, heterogeneous nucleated, condensed, or coagulated aerosols and later been deposited on the any surface by either dry or wet deposition and can be directly inhaled with the fine aerosol in air. Experimental research has demonstrated variety of respiratory viruses including Middle East Respiratory Syndrome coronavirus (MERS-CoV), Severe Acute Respiratory Syndrome coronavirus (SARS-CoV), norovirus, and influenza virus could be transmitted by aerosols under different climatic and environmental conditions (Mustaffa-Babjee, Ibrahim and Khim, 1976; Johnson *et al.*, 2013; Khare and Marr, 2015; Zietsman, Phan and Jones, 2019).

EVIDENCE OF AEROSOL TRANSMISSION OF SARS-CoV-2

According to Jones and Brosseau (2015), three criteria were set for aerosol transmission of virus to be imminent (1) the mouth aerosol containing virus must be from an infectious person, (2) the virus must be able to exist and infective in aerosol for its residence time, and (3) the target tissues must be accessible to aerosol with required viral load. Several studies have shown in the case of first criterion that SARS-CoV-2 particles are discharged into the atmosphere through respiratory droplets of infected person (NCDC, 2020; WHO, 2020), and it has been frequently detected in throat, conjunctival, and anal swabs. When a person coughs, talks or breathes, they throw anywhere between 900 to 300,000 liquid particles from their mouth which range in size and a cough can send them traveling at speeds up to 60 mph which keeps them suspended in air for some time (Miller, Nazaroff and Jimenez, 2020). Since breathing and speaking occur more frequently than coughing and sneezing, they have critical role in viral transmission, particularly from asymptomatic cases and from bigger size droplet (>50 μm) have higher probability of containing the virus than smaller size droplet before dehydration (Wölfel, Corman and Guggemos, 2020). One minute of loud speaking could produce thousands of oral droplets per second, of these, at least 1000 virus-containing droplet nuclei could remain airborne for more than 8 minutes and hence have high chances of likely been inhaled by others and thus triggering new infections (Stadnytskyi *et al.*, 2020).

The viability of SARS-CoV-2 virus in aerosol according to the second criteria has been investigated experimentally by several authors. Van Doremalen, et al., (2020) demonstrated that SARS-CoV-2 can survive for more than three hours in air under a controlled condition of temperature 21 ^{o}C-23 ^{o}C and relative humidity of 65%. Also, a UK variant of SARS-CoV-2 is said to be capable of remaining viable in aerosols for at least 90 minutes under experimental conditions (artificial saliva and tissue culture media) and another investigation revealed that SARS-CoV-2 in respire-able-sized aerosols could persist and maintain infected for up to 16 hours (Fears *et al.*, 2020). These are just few of many studies pointing out the persistence and viability of coronavirus in aerosols. According to Song *et al.*, (2020) Epidemiological studies are difficult to interpret with respect to role of transmission unless other routes can be ruled out. Different recent studies of Lu, et al., (2020); Miller, et al., (2020); Read, (2020); Shen, et al., (2020) have investigated the role of air transmission of SARS-CoV-2 ruled out other routes and showed that Airborne route appeared to be a major contributor for super spreading of the virus in an air recirculation environment.

CONTROL AND ELIMINATION OF AEROSOL TRANSMISSION

One of the main measure to contain the aerosol transmission of infectious disease is ventilation. This promotes the air dilution around a source dispersing the aerosol, and the removal of respiratory viruses through Brownian motion in open atmosphere (Francisco and Emmerich, 2014; Stein *et al.*, 2015; Rolph, Stein and Stunder, 2017). The use of face mask which is recommended by the Nigeria Centre for Disease Control (NCDC) will block some aerosol from leaving the mouth and also reduce the chances of inhaling the aerosol contaminated with virus in air (Miller, Nazaroff and Jimenez, 2020; NCDC, 2020; Song *et al.*, 2020).

CONCLUSION

Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2) particles have been established as an aerosol based on its size, shape, and state. As an aerosol particle it can nucleate, condense, and coagulate with either its type or other aerosol particle types which can be suspended, transported, and deposited on various surfaces or straight into nasal or mouth passage. Studies have shown with significant number of evidences that SARS-CoV-2 is transmissible through the inhalation of aerosol particles present in air, most especially in air recirculated environment as the source air of the virus. The chain of transmission through aerosol could be broken with full ventilation of air tight environment and face masking. It is also recommended that frequent hand washing will reduce the chance of transmission through extra-body surface contacts with virus aerosol infected surface.

REFERENCES

Bojan, S. (2014) *Improvement of aerosol representation in a chemical-transport model: Modelling and data assimilation*. University of Toulouse.

Carlson, T. and Prospero, J. (1972) 'The Large-Scale Movement of Saharan Air Outbreaks over the Northern Equatorial Atlantic', *Journal of Applied Meteorology*, 11, pp. 283–297.

CDC, C. for D. C. (2020) *Interim Infection*

Prevention and Control Recommendations for Patients with Suspected or Confirmed Coronavirus Disease 2019 (COVID-19) in Healthcare Settings. Available at: https://www.cdc.gov/coronavirus/2019-ncov/infection-control/control-recommendations.html).

Chazette, P. *et al.* (1995) 'Comparative lidar study of the optical, geometrical, and dynamical properties of stratospheric post-volcanic aerosols, following the eruptions of el chichon and mount pinatubo', *Journal of Geophysical Research: Atmospheres (1984–2012),* 100(D11), pp. 23195–23207.

Chazette, P. *et al.* (2009) 'Vertical structure of aerosols and water vapor over West Africa during the African monsoon dry season', *Atmospheric Chemistry and Physics*, (September 2000), pp. 8017–8038.

Delmas, R., Mégie, G. and Peuch, V.-H. (2005) *Physique et chimie de l'atmosphère*. Belin.

van Doremalen, N. Bushmaker, T. and Morris, D. (2020) 'Aerosol and surface stability of HCoV-19 (SARS-CoV-2) compared to SARS-CoV-1', *medRxiv*, (2020). doi: 2020.03.09. 20033217.

Fears, A. C. *et al.* (2020) 'Persistence of severe acute respiratory syndrome cor-onavirus 2 in aerosol suspensions', *Emerg. Infect. Dis.*, 26(9). doi: 10. 3201/eid2609.201806.

Francisco, P. W. and Emmerich, S. J. (2014) *ASHRAE Position Document on Airborne Infectious Diseases*. Georgia.

Jacobson, M. Z. (2005) *Fundamentals of atmospheric modeling*. Cambridge: Cambridge University Press.

Johnson, D. *et al.* (2013) 'Aerosol generation by modern flush toilets', *Aerosol Sci. Technol.: J. Am. Assoc. Aerosol Res.*, 47, pp. 1047–1057.

Jones, R. M. and Brosseau, L. M. (2015) 'Aerosol transmission of infectious disease', *J. Occup. Environ. Med.*, 57, pp. 501–508.

Khare, P. and Marr, L. C. (2015) 'Simulation of vertical concentration gradient of influenza viruses in dust resuspended by walking', *Indoor Air*, 25, pp. 428–440.

Liousse, C. *et al.* (2010) 'Updated African biomass burning emission inventories in the framework of the AMMA-IDAF program , with an evaluation of combustion aerosols', pp. 9631–9646. doi: 10.5194/acp-10-9631-2010.

Lu, J., Gu, J. and Li, K. (2020) 'COVID-19 outbreak associated with air conditioning in restaurant, Guangzhou, China', *Emerg. Infect. Dis.*, 2020(26), pp. 1628–1631.

Madhav, N. *et al.* (2017) 'Pandemics: Risks, impacts, and mitigation. In Disease Control Priorities: Improving Health and Reducing Poverty', in *The International Bank for Reconstruction and Development: Washington, DC, USA,*. Washington, DC, USA: The World Bank.

Miller, S. L., Nazaroff, W. W. and Jimenez, J. L. (2020) 'Transmission of SARS-CoV-2 by inhalation of respiratory aerosol in the Skagit Valley Chorale superspreading event', (2020). doi: 2020.06.15.20132027.

Mustaffa-Babjee, A., Ibrahim, A. L. and Khim, T. S. (1976) 'A case of human infection with Newcastle disease virus. Southeast Asian', *J. Trop. Med. Public Health*, 7, pp. 622–624.

NCDC, N. C. for D. C. (2020) *FIRST CASE OF CORONA VIRUS DISEASE CONFIRMED IN NIGERIA.*, *NCDC.*

NHC, N. H. C. (2020) *Diagnosis and treatment plan of COVID-19 (trial version 7). (in Chinese)*. Available at: http://www.nhc.gov.cn/yzygj/s7653p/202003/ 46c9294a7dfe4cef80dc7f5912eb1989/files/ce3e6945832a438eaae415350a8ce964. pdf%0AOng,.

Prospero, J. M. (1999) 'Long-range transport of mineral dust in the global atmosphere: Impact of African dust on the environment of the southeastern United States.', in *Proceedings of the National Academy of Sciences*, pp. 3396–3403.

Read, R. (2020) *A choir decided to go ahead with* *rehearsal. Now dozens of members have COVID-19 and two are dead.* Available at: www.latimes.com/ world-nation/story/2020-03-29/coronavirus-choir-outbreak.

Rolph, G., Stein, A. and Stunder, B. (2017) 'Real-time Environmental Applications and Display sYstem: READY', *Environmental Modelling and Software*. Elsevier Ltd, 95, pp. 210–228. doi: 10.1016/j.envsoft.2017.06.025.

Seinfeld, J. and Pandis, S. (1998) *Atmospheric Chemistry and Physics: From Air Pollution to Climate Change*. New York: John Wiley and Sons.

Shen, Y., Li, C. and Dong, H. (2020) *Airborne transmission of COVID-19: epidemiologic evidence from two outbreak investigations*, *ResearchGate*.

Slinn, W. (1988) 'Predictions for particle deposition to vegetative canopies', *Atmospheric Environment*, 16(7), pp. 1785–1794.

Song, T. *et al.* (2020) 'Aerosol transmission of SARS-CoV-2? Evidence, prevention and control', *Environment International*, 144(January), pp. 1–10. doi: doi.org/10.1016/j.envint.2020.106039.

Stadnytskyi, V. *et al.* (2020) 'The airborne lifetime of small speech droplets and their potential importance in SARS-CoV-2 transmission', *PNAS*, 117, pp. 11875–11877.

Stein, A. F. *et al.* (2015) 'NOAA's HYSPLIT atmospheric transport and dispersion modeling system', *American Meteorological Society*, 96, pp. 2059–2077.

Sun, J. *et al.* (2020) 'COVID-19: Epidemiology, evolution, and cross-disciplinary perspectives.', *Trends Mol. Med.*

Uno, K. *et al.* (2009) 'Asian dust transported one full circuit around the globe', *Nature Geoscience*, 2(8), pp. 557–560.

WHO, W. H. O. (2020) *Coronavirus disease 2019 (COVID- 19) Situation Report.* Available at: https://www.who.int/docs/defaultsource/%0Acoronaviruse/situationreports/%0A20200323-sitrep-63-covid-%0A19.pdf?sfvrsn=b617302d_4.

Wölfel, R., Corman, V. M. and Guggemos, W. (2020) 'Virological assessment of hospitalized patients with COVID-2019', *Nature*, 581, pp. 465–469.

Zietsman, M., Phan, L. T. and Jones, R. M. (2019) 'Potential for occupational exposures to pathogens during bronchoscopy procedures', *J. Occup. Environ. Hygiene*, 16, pp. 707–716.

