COVID – 19 Spreads Through Respiratory Droplets: A Review of Modelling and Simulation

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Abstract- *In the realm of diseases, epidemic disease plays a dynamic role that leads to a detrimental rise of health risks within a society and increasing the mortality rate over the past several decades. Currently, COVID-19 plays a remarkable role due to its high mortality rate. Its impact ruins the economy of many countries around the world.The WHO (World Health Organization) states that COVID-19 is transmitted through respiratory droplets. These droplets are produced because of activities such as sneezing, coughing, talking, etc. Under certain environmental conditions, the above droplets tend to reduce in smaller droplets (i.e., aerosol). These smaller droplets will lead to the spread of diseases in suspension in the air. In this paper, provides the basic understanding airborne disease transmission, droplet transmission and its risk, environmental factors influencing to airborne transmission, models (mathematical & numerical) used for predicting the risk of droplet transmission. It also helps us to provide an in-depth understanding about disease transmission and to establish guidelines for determining social distance between two people.*

Keywords- Airborne disease transmission, COVID – 19, respiratory droplets, mathematical models, numerical models

I. INTRODUCTION

In reviewing the history of pandemics, the health burden of respiratory infectious diseases has a notable impact among other diseases. Some of the infectious respiratory diseases that threaten the world population include influenza, SARS (severe acute respiratory syndrome), MERS-COV (Middle East respiratory syndrome coronavirus), tuberculosis, etc. [1] At the beginning of the 1960s, the coronavirus was known as a cold virus and was considered a non-lethal virus.[2].But after the outbreaks of SARS-COV-1 and MERS-COV which cause the death of many people around the world.[3] This prompted many scientists and researchers to delve deeper into the virus. Therefore, many scientists report that it is a **deadly virus** due to its mutagenic nature. In December 2019, a novel strain of coronavirus was an outbreak in China and it is similar to a SARS-COV-1 virus. As the rate of infection and mortality grows faster than other coronaviruses. On March 2019, World Health Organization and health agencies declared that COVID-19 virus as a pandemic disease and also found out the mode of disease transmission is through respiratory droplets.[4]

Airborne disease transmission is the transmission of diseases by droplet nuclei or aerosols that remain in the air for a prolonged period of time. The aerosol particles are produced during activities like talking, coughing, sneezing etc from an unhealthy person. Since these aerosol particles are heavily contaminated with pathogenic organisms, they remain in suspension in the air for a longer period and generally create a highly contagious environment. [5] To reduce this harmful potential adequate supply of ventilation, controlling environmental factors like temperature, humidity etc should be maintained. The purpose of this review is to summarize the basic understanding of Nature of coronavirus, droplet transmission, environmental factors that affect droplet transmission, Models are used to predict the risk of droplet transmission.

II. DISCUSSION

Nature of Coronavirus

The coronaviruses belong to the corona viridae family. It affects the respiratory, digestive and nervous systems causing diseases in both humans and animals. In General, corona virus is classified into 4 broad types they are α, β, γ and δ. SARS-COV-2 is the part of β group. [6] The genetic development of SARS-CoV-2 results in the formation of a number of variants with different characteristics. Every variant has a different transmissivity ratio. SARS- CoV-2 is highly lethal because it has high reproductive rate and transmittivity rate compared to other viruses. [7] In comparison to the cell culture environment, the growth and development of the COVID-19 virus is more prevalent in the epithelial cells of the human respiratory system. [8]

Droplet Transmission

Aforesaid when an infected person coughs or sneezes, the contaminated droplets emerge out and spreads disease to other people. This process of transmitting disease through droplets is called **Droplet transmission**. Respiratory Droplet is normally classified into respirable droplets and insuperable droplets. Respirable droplets are also called as **smaller droplets or respiratory aerosol** which easily enter into the respiratory tract through inhalation process. Its size is about **d < 5µm**. Inspirable droplets are also called as **larger droplet** are transmitted to healthy person by close contact with an infected person. Its size ranges from **d > 5µmto 100 µm**. [9] Figure 1 shows the schematic diagram of classification of respiratory droplet.

Under the influence of gravity, the larger droplets settle down at a fast rate within a distance of about 1 or 2 m from source person.These droplets evaporate quicker and turn into smaller aerosol particles. Evaporation time is a function of temperature and relative moisture. When the temperature is higher and the relative humidity is small, the evaporation rate is high. [10] Smaller aerosol particles have a neutral buoyancy force which can be suspended in the air over a longer period of time. It also tends to cover greater distances. [11]

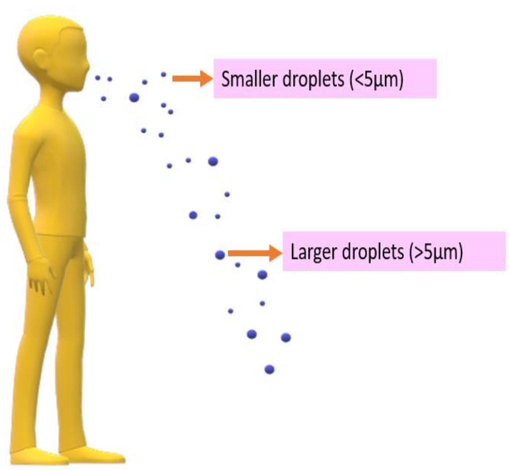

Figure 1 Classification of respiratory droplet.

The possibility of healthy person to be affected by this disease depends upon certain factors such as host community, aerosol concentration, period of exposure to these droplets, confined spaces with limited ventilation.

Environmental factors that affect droplet transmission

There are three major parameters that plays a significant role in predicting the distribution of droplets and its trajectory path. Figure 2 shows important parameter involved in distribution of droplets.

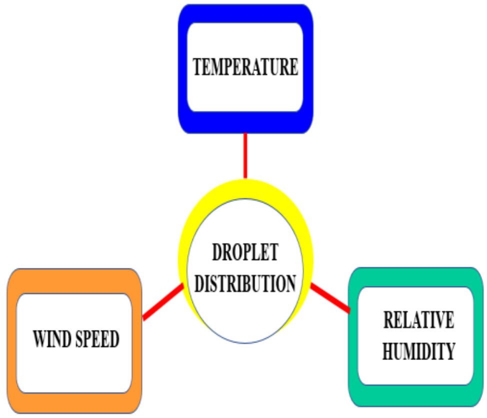

Figure 2 Important parameter involved in distribution of droplets.

Temperature is the most important factor affecting the evaporation of droplets. The mean evaporation time required to shrink 22 µm particle diameter of its half is approximately 0.8 sec. Therefore, it takes very little time to transform the bigger droplet into smaller aerosol particles [12]. The lifetime of the droplets is dependent on environmental conditions (e.g., temperature and relative humidity). [13]

Relative humidity is inversely dependent on temperature. When relative humidity is lowered, the size of the droplet is reduced from its initial size. These small droplets (i.e., aerosol particles) tend to penetrate into a healthy person's lungs and make them infected. [14]

Wind speed is also an important parameter to facilitate the spread of respiratory droplets. *Feng et.al* divulge that when the ambient air speed is zero, the larger droplet area retains its initial momentum and kinetic energy. Furthermore, it is less affected by the viscose dissipation force acting on these droplets. But in the case of smaller droplets, the viscous dissipative force is more dominant and thus produces more dispersal in static air. [15] When the velocity of the ambient air flow is high, the convective effect on the air influences the narrowing of the particle. Therefore, increasing wind velocity causes a high convection effect and also contributes to the evaporation process.

Models used to predict the risk of droplet transmission.

Modelling and simulation help us predict solutions to unforeseen problems. It also mimics an actual scenario for a complex problem. The disease transmission model involves a more secure environment to study the behaviour of the pathogen, its response to the surrounding environment and the rate of disease spread, etc.

a) *Mathematical Models*

The mathematical model uses a mathematical notion to represent the system. It also helps us better understand the dynamics of the system and how the system responds to a specific issue. [16] Mathematical model is widely used in disease transmission model. Mathematical model can be used to evaluate the growth rate of pathogens pathogen evolution in particular place and timeusing statistical method, correlation with the environmental factors, vaccine responses with pathogens. [17]

Individual based models (IBM) are developed to determine infectiousness of each individual. [18]. *Mittal et al.*developed CAT inequality model to predict the risk caused due to airborne transmission. It is mathematical based model. [19] The viability of virus and its relationship of thermodynamics framework were also studied by using mathematical model. [20] Mathematical models are also used for predicting the social distancing [21]

b) *Numerical Models*

Fluid dynamics play an important role in disease transmission. Fluid dynamics can assist us in understanding the fundamentals of transmission, the trajectory path followed by droplets, the spatial pattern of respiratory droplets, thermodynamics relationship with the environmental condition, effectiveness of barrier (ie mask) etc. Computational Fluid Dynamics is the method of analyzing the fluid flow and provides solutions to the problem. [22].

The 5 minutes of talking can produce nearly **3000** droplets which are equivalent to single cough.Its droplet size is about **0.62 to 15.9 µm** (average mode size 8.35 µm) with velocity of **10 - 15 m/s.** It produces **10 to 100 times** fewer droplets than sneezing

Similarly, a single sneeze can generate **40,000 droplets/s** of size **0. 5-12 µm** in diameter with velocity of **20 m/s to 100 m/s**. Speaking can also generate nearly **50to 100** droplets. Its droplet size is about **0.3 - 5 µm** in diameter with a velocity of **5 m/s** [23] High velocity and concentration of particles can contaminate an enclosed area.

Droplet distribution can be estimated by numerical simulations. In an indoor environment where the wind velocity of the surrounding air is zero, if a person coughs or sneezes the turbulent movement of the droplets prevail more. [24] And the motion of the droplets can occur randomly with wide diffusion. The cough cloud can also forecast using CFD. The small aerosol particle may travel over 6 m at high wind speeds. Therefore, maintaining the social distancing of 2m is not sufficient and varies depending on the wind speed. [25]

To provide a successful model, it is necessary to compare the results of the model to the experiment performed. The initial velocity of the droplet is an important parameter for droplet distribution. *Nicholas et al.* performed an experiment to measure droplet velocity during cough using particle image velocity (PIV). [26] In addition to it, *Prateek Bahl et al.* conducted an experiment using PIV measuring droplet movements. Furthermore, it has been observed that almost 80% of the particle speed are less than 5 m/s. [27]*Xiaojian Xie et al.* states that particle size has a dominant role in the spread of infectious diseases. They carried out an experiment to observe the motion of the droplets using food dye. The motion of the droplet is monitored through an aerosol spectrometer. [28]

III. CONCLUSION

Based on the literature review, it is clear that certain parameters must be taken into account in the development of a disease transmission model. The following are set out below.

- The effect of an infectious disease depends on host immunity, gender, age, use of illegal drugs such as smoking, alcohol use, etc.,
- The angle of coughing and droplet cloud formation that arises during coughing or sneezing indicates the direction of the droplet movement.
- The particulate concentration of the droplets indicates the level of contamination within an area.
- Velocity is an important parameter for calculating the droplet distribution.
- Temperature and relative humidity determine the evaporation rate and lifespan of a droplets.
- Wind velocity is the main parameter influencing the spatial dispersal of droplets.

There are research gaps and conflicts that need to be explored further.

- Simulation of the model is required for both indoors and outdoors. Because every location has a distinct flow dynamic.
- A different model should be designed according to the concentration of the particles.

- Separate social distance measurements should be performed according to their corresponding zones, such as inside a room with ventilation, at hospital, bank, in schools, etc.

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