Filtration efficiency analysis of cotton cloth-based mask for reducing transmission rate of COVID-19 using PM2.5 detection methods

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Abstract. The spreading or transmission rate of COVID-19 caused by SARS-Cov2 infection is extremely fast and now almost all countries around the world reported the case of the disease. As a new type of coronavirus, it was identified that the size of SARS-Cov2 is about 100 nm (nano-meter). The spreading droplet from coughs is between 1 meter to another person around him. Therefore, the important task is to make a physical distancing more than 1 meter from the infected person. The transmission model of COVID-19 is different from other virus disease transmission such as through airborne or direct touch. The common transmission of COVID-19 is from the spreading of the droplet through the air as well as the other media surface. The transmission of respiratory infection via droplet will have different dimensions or sizes. When the droplet size of particles in diameter is less than 5μm (<5μm), this size will be referred to as droplet nuclei and it can be the residue of dried respiratory aerosol that results from evaporation of droplet coughed or sneezed into the atmosphere or by aerosolization of infective material. Another droplet size is 5 to 10μm or more, it can be referred as a respiratory droplet or respiratory aerosols. One of the causes of the very fast-spreading transmission rate of COVID-19 is coming from droplet transmission through the air which contain virus in small droplet size type. It is recommended that airborne precautions for any situation involving the care of COVID-19 patients and consider the use of medical masks as an acceptable option in case of shortages of respirators (N95, FFP2 or FFP3). The other medical mask for general purposes in hospitals or clinics is a surgical mask. A surgical mask, also known as a procedure mask, medical mask, or simply as a face mask. Because of very rare and limited production volume of masks for ordinary people as well as special mask for medical also becomes very limited. Some homemade small industry tries to develop their own mask type and design by their own self. The use of homemade cloth base masks is becoming a new industry or an alternative for society to protect their health and activity from COVID-19. PM2.5 refers to atmospheric particulate matter (PM) that have a diameter of less than 2.5 micrometers. In the present study, the filtration efficiency of cloth cotton mask type by using detector particle type of PM2.5 is evaluated for reducing transmission of COVID-19. N95 mask type was used to be compared as special medical mask application with the cotton type mask for general use of people when the mask was very limited in the market. The analysis focused on the filtration efficiency of the mask that can reduce the particles entering the detector especially for particle size 2.5 micrometers or less to be used for droplet size of COVID-19 with the size of around that number.
1. Introduction

Coronaviruses are a large family of viruses that may cause illness in animals or humans. In humans, several coronaviruses are known to cause respiratory infections ranging from the common cold to more severe disease, including Middle East Respiratory Syndrome (MERS) and severe acute respiratory syndrome (SARS) [1]. The most recently discovered coronavirus causes coronavirus disease, called COVID-19. As a worldwide pandemic disease, an emerging disease caused by the new coronavirus, is the one of scariest diseases among the infectious diseases. As shown in Figure 1, the spreading or transmission rate is extremely fast and now almost all countries around the world reported cases of this disease.

![Figure 1. Map of reported case of coronavirus (COVID-19) [2].](image)

The transmission model of COVID-19 is different with other virus disease transmission such as through airborne or direct touch. The common transmission of COVID-19 is from the spreading of the droplet through the air as well as the other media surface. The transmission of respiratory infection via droplet will have different dimensions or sizes. When the droplet size of particles in diameter are less than 5μm (<5μm), this size will be referred to as droplet nuclei and it can be the residue of dried respiratory aerosol that results from evaporation of droplet coughed or sneezed into the atmosphere or by aerosolization of infective material. Other droplet size is 5 to 10 μm or more, it can be referred as respiratory droplet or respiratory aerosols [3]. Figure 2a and 2b illustrate the structure of SARS-Cov2.

PM2.5 refers to atmospheric particulate matter (PM) that have a diameter of less than 2.5 micrometers, which is about 3% the diameter of a human hair (Figure 2c). Commonly written as PM2.5, particles in this category are so small that they can only be detected with an electron microscope. They are even smaller than their counterparts PM10, which are particles that are 10 micrometers or less, and are also called fine particles. Since they are so small and light, fine particles tend to stay longer in the air than heavier particles. This increases the chances of humans and animals inhaling them into the bodies. Owing to their ultra tiny size, particles smaller than 2.5 micrometers are able to bypass the nose and throat and penetrate deep into the lungs and some may even enter the circulatory system [4]. The use of home-made cloth base masks are becoming a new industry or an alternative for society to protect their health and activity from COVID-19. This alternative mask not only can be used easily and access to buy and production, but also in price is relatively affordable for people. There are several studies aimed to evaluate the efficacy of cloth based mask in filtering the aerosol and droplets [5]. For example, Konda et al. reported that respiratory cloth masks have an aerosol filtration efficiency of >80% (for
particles <300 nm) and >90% (for particles >300 nm) [6]. Further, Asadi et al. revealed that it is likely the cloth masks provide some reductions in emitted expiratory particles, in particular the larger particles (> 0.5 μm). Their observations are consistent with suggestions that mask wearing can help in mitigating pandemics associated with respiratory disease [7].

In this sense, spreading rate of alternative mask become high and the other advantages is more cloth based mask can be easily use and re-used again by ordinary cloth cleaning process and dry it. Increasing the use of mask will have some advantages and raising some problem if there is no regulation or standard to be made in this crisis. It will need some evaluation for this alternative masks and some regulations.

Figure 2. (a) Illustration and (b) microscopic image of SARS-Cov2 structure [8]. (c) The size comparison of human hair, PM2.5, and PM10 [4].

Herein, the particulate matter filtration efficiency of cloth cotton mask type was evaluated using particle detectors of PM2.5 and PM10. In this study, the droplet sizes that can carry SARS-Cov2 were assumed to be less than 10 and 2.5 micrometers. There are two mask types that were employed for the evaluation, i.e., N95 and cotton cloth mask type to reduce the detected particles by filtration and compared with no mask covering the detector. The analysis focused on the filtration efficiency of the mask that can reduce the particles entering the detector especially for the particle with the size of 2.5 micrometers or less as well as 10 micrometers or less.

2. Experimental Details

2.1. Pocket PM2.5 sensors
Pocket PM2.5 sensors (Yaguchi Electric Co., Ltd., Japan) was utilized for the measurement of particles with the size of 2.5 micrometers or less which not filtered by the masks. The working principles of pocket PM2.5 sensors is shown in Figure 3a. The device consists of a light emitting diode (LED) laser, a photodiode (PD) sensor, a fan, amplifier, and universal serial bus (USB) encoder. The device can generate log data in comma-separated values (CSV) of Google KML (Keyhole Markup Language) format including global positioning system (GPS) data. The device is portable and should be connected to an Android smartphone (Figure 3b). The apps on the Android smartphone displays the PM2.5
concentrations in microgram per cubic meter. Further, the apps screen color varies from blue, yellow, red, purple to black with increasing PM concentrations. The detailed specification of the device is shown in Table 1. The pocket PM2.5 sensors were also calibrated with constantly observed PM2.5 counter (PM-712, Kimoto Electric Co., Ltd.) of Air Quality Research Station, National Institute for Environmental Studies (NIES), Tsukuba, Japan [9].

![Figure 3. Schematic diagram of (a) the Pocket PM2.5 Sensor device (Yaguchi Electric Co., Ltd.) and (b) evaluation two types of mask and without a mask with Pocket PM2.5 Sensor connected to an Android smartphone. The apps color varies for different levels of PM2.5 concentration.](image)

### Table 1. Basic specifications of Pocket PM2.5 and PM10 Sensors

| No | Parameter                     | Value                                      |
|----|-------------------------------|--------------------------------------------|
| 1. | Measurement parameters        | PM2.5, PM10                                |
| 2. | Measurement range             | 0.0 - 999.9 μg/m³                           |
| 3. | Rated voltage                 | 5V                                         |
| 4. | Rated current                 | 60mA ± 10mA                                |
| 5. | Sleep current                 | <4mA Laser & Fan sleep                     |
| 6. | Temperature range             | Storage environment: -10 ~ +50°C            |
|    |                               | Work environment: -20 ~ +60°C              |
| 7. | Humidity range                | Storage environment: Max 90%               |
|    |                               | Work environment: Max 70%                  |
| 8. | Air pressure                  | 86KPa~110KPa                               |
| 9. | Corresponding time            | 1s                                          |
| 10.| Serial data output frequency  | 1Hz                                        |
| 11.| Minimum resolution of particle| <0.3μm                                     |
| 12.| Counting yield                | 70%@0.3μm 98%@0.5μm                        |
| 13.| Relative error                | Maximum of ± 15% and ± 10μg/m³             |
|    |                               | 25°C, 50%RH                                |
| 14.| Product dimension             | 42.5 x 32 x 24.5mm                         |
2.2. Masks type
Cotton cloth-based masks and N95 respiratory masks were employed in this study. An N95 respirator is a respiratory protective device designed to achieve a very close facial fit and highly efficient filtration of airborne particles (Figure 4a). For ordinary people who does not have any sufficient mask to protect their respiratory or mount and nose from the bacteria or virus as well as COVID-19 in a form of droplet or any other particle form, to use N95 respiratory mask as well as surgery mask are very limited. Those medical mask is used only for medical purposes or nursing condition in the hospitals or clinics but not for ordinary people. In term of N95 mask is little bit expensive than surgery mask in term of price. But now, when the pandemic and transmission become worldwide spreading condition, those masks become rare and very limited amount and at the same time the price becomes much more expensive. Because of very rare and limited volume of mask for ordinary people as well as special mask for medical also becomes very limited. Some home-made small industry tries to develop their own mask type and design by their own self. The masks are made from cloth-based mask such as cotton from T-shirt regular used or some other cloth-based production (Figure 4b). This small industry makes two advantages for industry and small enterprise still alive when this pandemic condition and at the same time more people who need the mask can be helpful and the rare and limited condition of mask to protect the people can be in some way fulfilled [10, 11, 12].

![Figure 4. The masks type employed in this study, i.e., (a) N95 respirator and (b) cotton cloth mask type.](image)

2.3. Filtration efficiency evaluation methods
The schematic of filtration efficiency evaluation methods depicted in Figure 3b. Pocket PM2.5 sensors were operated to measure the PM2.5 and PM10 concentration with and without mask covering the sensors inlet. The sensors inlet was covered with two types of masks. The measurements were carried out at different time, i.e., morning, afternoon, and evening time. Filtration efficiency (%) is calculated through an equation (1) as follows,

\[
\text{Filtration Efficiency (\%)} = \frac{\text{PM2.5}_{\text{without-mask}} - \text{PM2.5}_{\text{with-mask}}}{\text{PM2.5}_{\text{without-mask}}} \times 100\%
\]

where PM2.5_{without-mask} is the concentration of PM2.5 detected by the Pocket PM2.5 Sensors when the sensors inlet was not covered with any mask. Meanwhile, PM2.5_{with-mask} is the concentration of PM2.5 detected by the Pocket PM2.5 Sensors when the sensors inlet covered with mask either N95 respirator or cotton cloth mask. The flow condition was not controlled both at the presence and absence of mask covering the PM2.5 Sensors inlet thus the inlet airflow was solely regulated by the mini fan operated inside the sensors.
3. Results and Discussion

3.1. Measured particles by PM2.5 and PM10 Sensors for different detection times

The time-series measurements of PM2.5 and PM10 particles concentration at the different detection times (morning, afternoon, and evening) are shown in Figure 5. The measurement duration at each detection time was around 1 – 1.5 hours. Figure 5a measured particle by PM2.5 and PM10 in the morning about 7:30-9:00 am. It can be estimated that the concentration of PM10 particles were detected higher than PM2.5 during detection time. It is shown that about 50 micro-gram/m³ in average levels are detected by PM2.5 and about 66 micro-gram/m³ in average levels by PM10. It shows some fluctuates values for detected particle during the time.

Figure 5b shows measured PM2.5 and PM10 concentration in the afternoon during 12:00-13:00. The measured PM2.5 and PM10 concentration was about 27 micro-gram/m³ and 30 micro-gram/m³ in average, respectively. Figure 5c shows measured PM2.5 and PM10 concentration in the evening around 17:30-19:00. The measured PM2.5 and PM10 concentration was about 25 micro-gram/m³ and 26 micro-gram/m³ in average, respectively. Although the values fluctuate, the level of measured particles shows a constant average and trends. Based on those results, it can be estimated that measured particles are varied and depend on the period of detection time. Therefore, three different detection period times in the morning, afternoon and evening can be used to evaluate the dependence of time for PM2.5 and PM10 detection condition.

![Figure 5](image_url)

**Figure 5.** Measured PM2.5 and PM10 particles concentration at different detection times: (a) morning, (b) afternoon, and (c) evening time.

Those variation of detection time which show some various level of measured particle will affect to the filtration efficiency of cover mask which employed in this evaluation. To understand the efficient filtration level of mask or cover mask, the N95 respirator and non-medical mask such as cloth cotton made mask were employed. Those was used for evaluation of PM2.5 and PM10 when the detector was covered by mask to filter the particle entering the detector. Assuming those particles are filtered by mask when the detector was covered by the mask.

3.2. Measured particles by PM2.5 and PM10 Sensors with masks

Figure 6a and 6b show the PM2.5 and PM10 measurement at the morning detection time with the cover of N95 respirator and cotton cloth masks, respectively. Both PM2.5 and PM10 have dropped immediately as the inlet of the sensor was covered by both mask types.
Figure 6. Measured PM2.5 and PM10 without and with mask (a) N95 respirator and (b) cotton cloth mask at morning detection time.

Figure 7a and 7b show the PM2.5 and PM10 measurement at the afternoon detection time with the cover of N95 respirator and cotton cloth masks, respectively. Both PM2.5 and PM10 have dropped immediately as the inlet of the sensor was covered by both mask types.

Figure 8a and 8b show the PM2.5 and PM10 measurement at the evening detection time with the cover of N95 respirator and cotton cloth masks, respectively. Both PM2.5 and PM10 have dropped immediately as the inlet of the sensor was covered by both mask types.
3.3. Filtration efficiency for N95 respirator and cotton cloth type masks

The filtration efficiency comparison between N95 respirator and cotton cloth mask type towards PM2.5 and PM10 at the different detection time, i.e., morning, afternoon, and evening, are shown in Figure 9a, 9b, and 9c, respectively. At the three different detection time, N95 shows an excellent filtration efficiency for PM2.5 and PM10 which is around 96-98%. Meanwhile, the cotton cloth mask type shows a filtration efficiency around 87-91%.

4. Conclusions

The filtration efficiency comparison towards PM2.5 and PM10 by N95 respirator and cotton cloth-based mask type has been evaluated. The utilization of pocket PM sensors could assist the evaluation of
particles filtration efficiency of different mask types. According to the study, the cotton cloth mask type shows quite good filtration efficiency as of 87.45-90.49% and 88.68-91.01% for PM2.5 and PM10, respectively. While, N95 respirator shows an excellent filtration efficiency as of 96.59-98.42% and 96.88-98.74% for PM2.5 and PM10, respectively.

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