Performance and the Protection against COVID-19 and Their Efficiency Degradation by Sterilization to Reuse the Masks

Peter P. Tsai

Abstract

Medical masks and N95 respirator are widely used to protect against airborne diseases such as tuberculosis, SARS, MERS, avian and swine flues, and the recent emerging COVID-19. The filtration layer of these masks is made of meltblown (MB) PP (polypropylene) nonwoven electret – electrostatically charged media.

Medical masks have Bacteria having 3 µm in size Filtration Efficiency (BFE) of > 95-99%, and > 78-87% Filtration Efficiency (FE) of suspended NaCl submicron particles having number media diameter of 0.075 µm. The N95 has > 95% FE of the above NaCl particles and >> 99% of BFE and it has perfect edge seal that prevents the particles from entering between the face and the respirator edge thanks to the respirator contour structure that conforms the human facial outline. Medical masks play a critically important role in stopping the big size saliva droplets carrying airborne diseases from entering by direct inertial impaction on the mask surface. However, quite a little aerosol – air with suspended submicron particles - enter from the leakage between the mask edge and the face without going through the mask body.

Sterilization using radioactive such as gamma rays has the potential to decompose the PP materials, using alcohol will erase the charges. However, charges are retained by exposing the masks in the hot air at elevated temperatures such as 70°C for 30 minutes, which kills the coronavirus according to a report. But be sure to suspend the masks in the hot air without contacting or being too close to a metal surface because the metal temperature is much higher than that of the hot air leading to a severe charge decay or to the damage of the masks.

Introduction

There has been a dire shortage of face masks since the emerging of COVID-19 originated from Wuhan. Numerous erroneous news has been reported about the performance and the reuse to reduce the consumption of the face masks.

There are quite a few types of face masks for a variety of applications. Two types are used to protect against airborne diseases, i.e., medical masks (also known as flat three-fold face masks) and N95 respirator or the like. The FE of these masks is basically contributed by the electrostatic charges embedded inside the fibers of the filtration layer(s), the interior part of the masks. This paper will briefly describe the performance, the quiescent charge decay in shelf time, in use, and the reuse of these masks.

Key words: Face masks, Respirators, Medical masks, N95, NIOSH, FDA, Nonwovens, Meltblowing (MB), Spunbonding (SB), Polypropylene (PP), Electrostatic charging, Electret, Charge decay.

Background

Medical face masks are classified into three categories, General Use (for outpatient clinic), Sub-Micron Filtering (for aseptic room), and Fluid Resistance (for surgery room) according to ASTM F2100. The BFE for General Use is greater than 95% - named BFE 95, Bacteria Filtration Efficiency - tested according to ASTM F2101 using Staphylococcus aureus, which has a particle size of 3 µm. Respirator
N95 is one of the nine types of particulate filtering face masks. It is certified by NIOSH (National Institute for Occupational Safety and Health) to have a FE greater than 95% according to 42 CFR Part 84 at a flow rate of 85 lpm using NaCl as the testing particles having a number median diameter of 0.075 μm, a mass mean diameter of 0.26 μm, and a geometric standard deviation of 1.83. The particle is not a monodisperse but a polydisperse size distribution. Using this testing aerosol, a General Use medical mask has FE of 78% at 32 lpm.

Filter media

Both the medical masks and the N95 respirator are made of three plies of media, an outer veil made of SB PP facing outside, a filtration layer made of charged MB PP electret in the middle, and an inner veil in contact with the face made of needle-d or thermal bond nonwovens for N95, and SB, thermal bond or paper tissue for medical masks. There is only one ply of the filtration layer for medical masks. The N95 is composed of two plies of MB PP electret having higher FE each ply than the filtration layer of the medical masks. The filtration layer solely plays the role of the mask’s FE accordingly contributing to almost the whole mask’s breathing resistance (or pressure drop). Therefore, N95 is much less breathable than the medical masks due to two plies of the filtration layer and much higher FE each ply. The material weight and therefore the breathing resistance in N95 respirator can be tremendously reduced if made using the MB electret charged by a novel technology recently developed and assigned to UTRF.

The increase of the FE is ten folds compared to that not charged, e.g., the efficiency will go up to 95% for an uncharged media having FE of 25% suggesting that ten plies of the uncharged have the same FE as that of one ply of charged of the same media. The increase is 20 folds to 99.8% by the above novel charging technology.

There is always a charge decay of an electret. However, it was investigated by Tsai that the charge loss (or the FE degradation) is only in the range of 0.5%, i.e., the retained FE is 98.5% for N95 having an initial FE of 99% after the heat treatment at 70C for 24 hours according to EN 143 and EN 149 (European respirator standard). This elevated temperature and treatment time simulate the FE degradation (charge decay) in quiescent shelf storage time for five years at room temperature (25C). The humidity in the storage environment is not a critical issue in causing the charge decay because PP is a hydrophobic material, which has a zero-moisture content. The embedded charges inside the fibers are quasi-permanent, different from the surface charges in our daily, will not be affected by the humidity in the environment and nor be neutralized by the naturally ionized air (10⁹ out of 10²³ of air molecules per cubic meter) from radioactive elements or cosmic rays. Respirator N95 is commonly made with an initial FE of 99% to guarantee that its efficiency is still well above the required 95% after the quiescent shelf storage time of five years.

The FE loss is 3% using NaCl aerosol at the above elevated temperature and treatment time to test the General Use medical mask having an initial NaCl FE of 78%. It is commonly made with an initial FE of 82% to guarantee maintaining an NaCl FE of 78% corresponding to 95% of BFE after their quiescent shelf storage time for five years (usually 3 years for medical masks).

Figure 1 shows the FE of the uncharged, charged, and the charge decay after the heat treatment at 70C for 24 hours.
Protection against COVID-19 and sterilization to reuse the masks

Medical masks serve as a barrier by the impaction of large saliva droplets coming from the other person, especially by talking, sneezing and coughing. They are not an ideal equipment to protect against submicron particulate airborne diseases because they do not have a high submicron FE on one hand and on the other hand, they quite a little leakage from the lack of edge seal. In such a case, respirator N95 is recommended to protect against suspended submicron virus to stop them from penetrating through the respirator body as well as from the edge leakage. The size of a corona virus is 0.08 - 0.12 µm (or 80 - 120 nanometers). However, it is always survived with a host, which is bigger than the virus per se. But the host can be a suspended submicron droplet/particulate.

The efficiency of NIOSH N95 is monitored and audited by NIOSH and of medical masks by FDA. A N95 respirator, not a NIOSH N95, is not being monitored or audited.

Polymer PP has a surface energy of 35 dynes/cm, a hydrophobic material, much lower than the surface tension of room temperature water, 71.2 dynes/cm. Alcohol has a lower surface tension, 20 dynes/cm, than PP. Alcohol will penetrate into the MB PP fabric and erase the charges. Therefore, face masks cannot be sterilized using alcohol because the charges are erased by either liquid or vapor alcohol. The testing standards to test a filter efficiency after erasing the charges by alcohol include ASHRAE 52.2 Appendix G, EN 776, and EN 16890.

Shown in Figure 2 is an example of the marking of qualified/certified medical masks and N95 respirators.
Q’s&A’s:

**Q1: Can the masks be treated by heat?**

**A:** Yes as indicated in Figure 1, it is reported (if it is true) that COVID-19 cannot survive at 65°C for 30 minutes. Therefore, it is safe to treat the masks in hot air at 70°C for 30 minutes and this process can be repeated multiple times to reuse the masks without a noticeable loss of efficiency. But be sure to suspend the masks in the hot air in the oven **without contacting or putting the masks too close to a metal surface.** The respirator can be hung in the oven using a wood or a plastic clip on its edge of non-breathing zone or put on a wood grill at least 6” away from a metal surface. Similarly, hold the edge of non-breathing zone when doffing the mask. Don’t touch the inside part of the mask because your hands might be contaminated at this time if the mask was. Wash your hands thoroughly using soap with water for at least 20 seconds according to CDC after donning the masks.

The first web link in Q3 had the similar insignificant charge decay results in treating the mask at 70°C for 30 minutes.

**Q2: Can the masks be treated using alcohol?**

**A:** No, face masks cannot be sterilized using alcohol because the charges will be erased by either alcohol liquid or its vapor as described in a previous section.

My friend, Dr. Cai, a retired filtration testing scientist, had experimental data conducted in February 2020 as in the below table that support my above results in the past.

<table>
<thead>
<tr>
<th>Treatment using alcohol or soap water</th>
<th>Experimental</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial Filtration Efficiency (3-fold medical mask)</td>
<td>93.2%</td>
</tr>
<tr>
<td>After Immersion in medical alcohol</td>
<td>67.0%</td>
</tr>
<tr>
<td>After treatment with saturated IPA vapor (ISO)</td>
<td>47.4%</td>
</tr>
<tr>
<td>After washing by hand with soap/water for 2 minutes</td>
<td>54.0%</td>
</tr>
</tbody>
</table>

The first web link in Q3 had the similar results of charge decay in sterilization using alcohol.

**Q3: Can the masks be treated using radiation or UV?**

**A:** Not sure, it depends on the intensity and the exposure time. Radioactive such as gamma rays or UV light are commonly used for the sterilization of material but they have potential to decompose the PP material by the attacking of the lone pair electrons pairs in its CH₃ side group on its backbone of the molecular chains leading to the dissipation of the charges. However, the degree of PP decomposition depends on the radiation and UV intensity as well as the exposure time. For example, the PP will be totally degraded and become brittle under sunshine in summer for three months. Experiment needs to be conducted to expose the masks to the UV or the radioactive intensity for the time that can kill COVID-19 and then measure the mask filtration efficiency to know.

Three web links below were provided regarding the loss of strength but insignificant charge decay of UV sterilization at a certain dose and exposure time.

[https://t.co/8aPfLMEskF?amp=1](https://t.co/8aPfLMEskF?amp=1)
A paper to be published but not available to public at this time was provided shows that the strength and charge loss was significant using gamma irradiation to sterilize the mask.

Q4: Can the masks be reused after hanging dry?

A: Not sure. According to a study published in New England Journal of Medicine (NEJM), The COVID-19 can survive in the air for three hours, four hours on a copper surface, 24 hours on a cardboard, two-three days on a stainless or a plastic surface. It is reported from CDC that the possibility of infection from a package being shipped for a few days from China is very slim, which is a similar result as in the NEJM. PP is a hydrophobic plastic material with zero moisture content. The virus needs a host - a cell - to survive. A respirator can get dry in less than two-three days in a dry air environment. Based on the above reports, three-four respirators can be numbered, let them get dry, and reuse in the numbered sequence.

Q5: Can the masks be treated using steam?

A: Yes, our investigation showed that the charge loss on the electret is unnoticeable by sterilization using 125°C steam for three minutes.

My friend, Dr. Cai, a retired filtration testing scientist, had experimental data conducted in February 2020 as in the below table that support my above result in the past.

<table>
<thead>
<tr>
<th>Steam treatment</th>
<th>Experimental</th>
<th>Theoretical Prediction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial FE (3-fold medical mask)</td>
<td>93.2%</td>
<td>N95 (99%)</td>
</tr>
<tr>
<td>Steam for 5 minutes</td>
<td>91.7%</td>
<td>98.5%</td>
</tr>
<tr>
<td>Steam for 30 minutes</td>
<td>85.2%</td>
<td>97.5%</td>
</tr>
</tbody>
</table>

The first web link in Q3 had similar insignificant charge decay as above sterilized using hot water vapor.

Q6: Can the respirator be treated by boiling water?

A: Yes, our investigation showed that the charge loss on the media is unnoticeable in boiling water for three minutes but stirring on the mask is not recommended to avoid its physical damage.

My friend, Dr. Cai, a retired filtration testing scientist, had experimental data conducted in February 2020 as in the below table that agree with my above result in the past.

<table>
<thead>
<tr>
<th>Boiling water treatment</th>
<th>93.2%</th>
<th>92.4%</th>
<th>83.6%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial FE (3-fold medical mask)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Boiling for 5 minutes</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Boiling for 30 minutes</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Q7: Can the respirator be in contact with water?

A: Yes, the charges of an electret, embed deep inside the fibers, are quasi-permanent. Different from the surface charges encountered in our daily life, they will not dissipate in the air or in contact with water.
Our investigation showed that this electret had little charge decay after being immersed in water for three days. However, laundering should be avoided for its action will physically damage the masks.

In Q5, Q6 and Q7, to be sure that the inner or the outer veil of the mask is not made of paper-like tissues – paper pulp or nonwovens bond by water soluble binder, which will either dissolve in water resulting in loose fibers in the veil or the loss of its strength after exposing to water.

References

1. ASTM F2100 “Standard Specification for Performance of Materials Used in Medical Face Masks”, West Conshohocken, PA 19428, 2019
2. ASTM F2101 “Standard Test Method for Evaluating the Bacterial Filtration Efficiency (BFE) of Medical Face Mask Materials, Using a Biological Aerosol of Staphylococcus aureus”, West Conshohocken, PA 19428, 2019
4. EN 143 “Respiratory protective devices – Particle filters, Requirements, testing, marking” rue de Stassart, 36 B-1050 Brussels, 2000
5. EN 149 “Respiratory protective devices - Filtering half masks to protect against particles Requirements, testing, marking,” rue de Stassart, 36 B-1050 Brussels, 2001

The author’s brief bio

Education: Ph.D. Retired faculty, Joint Institute of Advanced Materials, The University of Tennessee
Expertise: Development of meltblowing (MB) system and the electrostatic charging (EC) of materials for making air filter electrets. The MB and the EC developed by Tsai have been used in the industries worldwide making tens of billion pieces of N95 or above face masks. He receives three most prestigious awards from UT in recognition of his contribution in technology innovation and transfer. Tsai is a Fellow Member of American Filtration and Separation Society and a member of Electrostatic Society of America.

https://utrf.tennessee.edu/ut-researchers-nonwoven-fabrics-protect-the-health-of-more-than-a-billion-people/


This document is for informational and educational purposes only. The information contained therein, in whatever form, does not constitute medical advice, is not intended to be a substitute for medical advice and should not be used as a substitute for medical care and treatment. Any use of this information is at the user’s own risk.
Dr. Tsai, the University of Tennessee Research Foundation, and the University of Tennessee DISCLAIMS ANY AND ALL EXPRESS OR IMPLIED REPRESENTATIONS OR WARRANTIES REGARDING this information.