Information and FAQs on the Performance, Protection, and Sterilization of Face Mask Materials

Article by Dr. Peter P. Tsai, inventor of the electrostatic charging technology that makes the filter media of face masks including medical and N95. Dr. Tsai is a material scientist not a virologist and as such his advice is on possible sterilization techniques and how the materials perform. He does not give any advice on the performance of the re-sterilized N95 or mask against the virus.

Latest Update in FAQ's as of 4:30P EDST, April 7, 2020

Abstract

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

Bacterial filtration efficiency (BFE) is a measure of the effectiveness of a material to filter bacteria 3.0 µm in size, whereas filtration efficiency (FE) is a measure of the effectiveness of a material to filter submicron (median diameter of 0.075 µm) particles of NaCl. Medical masks have a BFE of >95–99% and a >78–87% FE. The N95 respirator has an FE of >95% and a BFE of >>99% along with a perfect edge seal and contour structure that conforms the human face, preventing particles from entering between the face and the respirator edge. Medical masks play a critically important role in preventing large-sized saliva droplets, some of which may carry airborne diseases, from entering by direct inertial impaction on the mask surface. However, some particles in aerosol form may enter from gaps between the mask edge and the face without going through the mask body.

There has been a dire shortage of face masks since the emergence of COVID-19, and many questions about the sterilization and reuse of these masks have been raised. Sterilization using ionizing radiation such as gamma irradiation may decompose the PP materials, while using alcohol will erase the charges. However, exposing the masks to air at elevated temperatures such as 70°C for 30 minutes allows the charges to be retained. With this method, it is important to suspend the masks in air without contacting or approaching a metal surface because the metal temperature is much higher than that of the hot air leading to a severe charge decay or damage of the mask material.

Introduction

There has been a dire shortage of face masks since the emergence of COVID-19 from Wuhan, China, in late 2019. In response, there have been numerous erroneous reports about the performance and the reuse of face masks.

There are a number of types of face masks available for a variety of applications. Two types are generally used to protect against airborne diseases: surgical masks (also known as flat three-fold face masks) and N95 respirators. The FE of these masks is influenced by the electrostatic charges embedded within the fibers of the filtration layer(s) in the interior part of the masks. This paper will briefly describe the performance and the quiescent charge decay in shelf time in the use and reuse of these masks.

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

Background

While the N95 respirator is one of nine types of particulate filtering face masks, medical face masks are classified, according to ASTM F2100, into three categories: general use (for outpatient clinics), sub-micron filtering (for aseptic rooms), and fluid resistant (for surgery rooms). The bacterial filtration efficiency (BFE) of FDA-certified general use masks is 95% and is evaluated according to the ASTM F2101-19 standard testing protocol using a biological aerosol of Staphylococcus aureus contained in 3 micron-sized droplets. On the other hand, a mask's filtration efficiency (FE) is measured per 42 CFR 84 criteria using an NaCl polydispersed test aerosol with a median particle diameter of 0.075 µm, a mass mean diameter of 0.26 µm, and a geometric standard deviation of 1.83 discharged at a flow rate of 85 liters per minute (lpm). N95 respirators are certified by the National Institute for Occupational Safety and Health (NIOSH) and must have an FE of at least 95%. In comparison, a general use medical mask has an FE of 78% at 32 lpm using this FE testing protocol.

Shown in Figure 1 is an example of the marking of qualified/certified medical masks and N95 respirators.

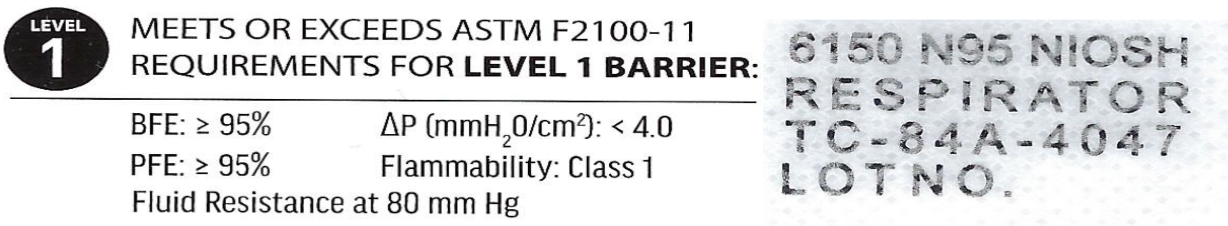

Fig. 1. An example of the marking of qualified/certified medical masks (L) and NIOSH N95 respirators (R).

Filter media

Both medical masks and N95 respirators are made of three plies of media: an outer veil made of spunbond (SB) PP facing outward; a filtration layer made of charged MB PP electret in the middle; and an inner veil in contact with the face made of needled or thermal bond nonwovens for the N95 and SB thermal bond or paper tissue for medical masks. Medical masks have only one ply of the filtration layer for medical masks while the N95 is composed of two plies of MB PP electret each having a higher FE than the filtration layer of the medical masks. The filtration layer solely determines the mask's FE and, accordingly, contributes almost entirely to the mask's breathing resistance (or pressure drop). For these reasons, the N95 mask is much less breathable than medical masks. The material weight and therefore the breathing resistance in the N95 respirator can be tremendously reduced if made using the MB electret charged using a recently developed novel method.

Typically, the increase in the FE of a charged media is tenfold compared to that of an uncharged media, i.e., the efficiency increases from 25% to 95% for an uncharged media, suggesting that ten plies of the uncharged media have the same FE as one ply of the same charged media. Using the novel charging technology, the FE is further increased 20-fold, to 99.8%.

There is always a charge decay of an electret. However, Tsai found that the charge loss (or FE degradation) is about 0.5%, i.e., the retained FE is 98.5% after heat treatment at 70°C for 24 hours according to EN 143 and EN 149 (European respirator standards) for an N95 mask having an initial FE of 99%. This elevated temperature and treatment time simulate the FE degradation (charge decay) for a five-year period of quiescent shelf storage time at room temperature (25°C). The humidity in the storage environment is not a critical issue in causing the charge decay because PP is a hydrophobic material, which has zero moisture content. Moreover, the embedded charges inside the fibers are quasi-permanent, as opposed to surface charges, and will not be affected by the humidity in the environment nor neutralized by the naturally ionized air (10^9 out of 10^{25} of air molecules per cubic meter) from radioactive elements or cosmic rays. The N95 respirator 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.

In the case of the general use medical masks having an initial FE of 78%, the FE loss is 3% using the above elevated temperature and treatment time. These masks are commonly made with an initial FE of 82% to guarantee maintenance of a 78% NaCl FE (which corresponds to a BFE of 95%) after a quiescent shelf storage time of five years (usually three years for medical masks).

Figure 2 shows the FE of the uncharged, charged, and the charge decay after the heat treatment at 70°C for 24 hours.

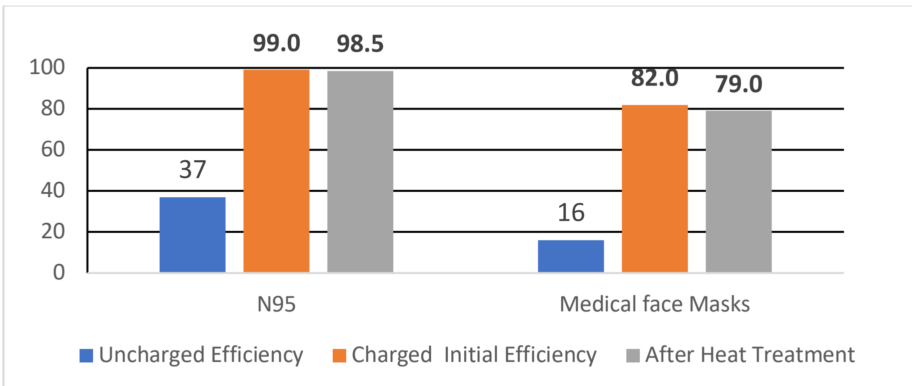

Fig. 2. Efficiencies of uncharged, charged, and after heat treatment at 70°C for 24 hours.

Protection against coronavirus and the effect of sterilization methods on mask media

Medical masks serve as a barrier to the impaction of large liquid droplets expelled from the nose and mouth, especially through talking, sneezing and coughing. Because they do not have a high submicron FE and because the edges are not tightly sealed, these masks allow leakage and are not ideal equipment to protect against submicron particulate airborne diseases. In such cases, N95 respirators are recommended to prevent suspended submicron viruses from penetrating through the respirator body as well as from the mask edge. The size of a coronavirus is 0.08–0.12 µm (or 80–120 nanometers), which is smaller than the NaCl polydispersed test aerosol used to measure FE, but it is always transported via suspended submicron droplets/particulates that are much larger than the virus.

Polymer PP is a hydrophobic material with a surface tension of 35 dynes/cm, which is much lower than the surface tension of room temperature water at 71.2 dynes/cm, whereas the surface tension of alcohol is 20 dynes/cm. Because the surface tension of alcohol is lower than that of PP, alcohol can 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.

FAQs:

Q1: Can the masks be treated by heat?

A: Yes. As indicated in Figure 1, masks can be treated in hot air at 70°C for 30 minutes, and this process can be repeated multiple times without a noticeable loss in FE. But be sure to suspend the masks in the hot air **without contacting or nearing a metal surface**. The respirator can be hung in the oven using a wood or a plastic clip on the edge of a non-breathing zone or put on a wood grill at least 6" away from any metal surface. Hold the edge of non-breathing zone when doffing the mask, and do not touch the inside part of the mask because your hands might become contaminated at this time if the mask was. After donning the masks, wash your hands thoroughly using soap and water for at least 20 seconds according to CDC guidelines.

A number of sources, including medical journals, television, and Chinese media, have reported that heat treatment at 56–75°C for 30 minutes can kill coronavirus. However, these experiments were done using SARS-CoV, MERS-CoV, and/or H1N1 and NOT SARS-CoV-2 (the novel coronavirus that causes COVID-19). So far, no data have been reported on the use of heat sterilization to kill SARS-CoV-2.

The first web link in Q3 shows similar insignificant charge decay results after treating the mask at 70°C for 30 minutes. This link also shows the results of killing E. coli using the above treatment protocol.

Q1.1: Does human exhalation through the respirator cause it to lose efficiency?

A: No. Studies conducted by my colleagues, Juan and Jenny, from an N95 manufacturer, human exhalation vapors coated on the electret fibers will not cause the N95 respirator to lose its efficiency. As shown in the following table, heat treatment at 70°C for 30 minutes on a respirator that had been worn for 8 hours and dried for 24 hours did not degrade its efficiency.

N95	**Before donning**		**After donning**		**Dried and heat treated**	
Respirators	FE (%)	R (mmH2O)	FE (%)	R (mmH2O)	FE (%)	R (mmH2O)
Person 1	99.787	9.3	99.757	9.4	99.746	9.3
Person 2	99.774	7.4	99.767	7.4	99.742	7.3
Person 3	99.869	8.2	99.770	8.2	99.715	7.9
Person 4	99.852	7.5	99.787	7.6	99.710	7.2

Before donning – unused N95
After donning – four samples worn for 8 hours
Respirators dried at ambient environment for 24 hours then heat treated at 70°C for 30 min.
Tested using TSI 8130 according to CFR 42 Part 84 at 85 lpm

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 above.

My colleague Dr. Cai, a retired filtration testing scientist, collected experimental data in February 2020, shown in the table below, that support my past results.

Table 1. Measured FE after treatment with alcohol and soap/water (Cai et al., Feb. 2020).

Treatment using alcohol or soap water	**FE**

Initial filtration efficiency (3-fold medical mask)	93.2%
After immersion in medical alcohol	67.0%
After treatment with saturated IPA vapor (ISO)	47.4%
After washing by hand with soap/water for 2 minutes	54.0%

The first web link in Q3 shows similar charge decay results after sterilization using alcohol.

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

A: Radiation sources such as gamma rays or UV light are commonly used for the sterilization of materials, but they have the potential to degrade the PP material by the attacking the lone electrons pairs in the CH_3 side group on the backbone of its 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, PP will be totally degraded and become brittle after three months of exposure to sunlight during the summer. More experimentation is needed to determine the effect of ionizing radiation on the filtration efficiency of mask media at the duration and intensity needed to kill coronavirus.

The three web links below provide evidence of some small degree of strength loss but insignificant charge decay after UV sterilization at a certain dose and exposure time.

https://t.co/8aPfLMEskF?amp=1
https://pubmed.ncbi.nlm.nih.gov/25806411/

https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4699414/

The following link shows the loss of charges and strength after using gamma irradiation to sterilize the mask.

https://www.medrxiv.org/content/10.1101/2020.03.28.20043471v1

Q4: Can the masks be reused after hanging dry?

A: Possibly. According to a study published in the New England Journal of Medicine (NEJM, March 17, 2020; https://www.nejm.org/doi/full/10.1056/NEJMc2004973), and summarized by Dr. Pascal S.C. Juang, M.D., as follows:

Viral Particle (Fomite) Survival Time (tested at 70–73°F and 40% humidity)

- Up to 3 hours post-aerosolization (median half-life 1.1–1.2 hours)
- Up to 4 hours on copper (median half-life 1.1–1.2 hours)
- Up to 24 hours on cardboard (median half-life approximately 3.5 hours - estimate from graph)
- Up to 2 days on stainless steel (median half-life 5.6 hours)
- Up to 3 days on plastic (median half-life 6.8 hours)

The CDC reported in February that the possibility of being infected from a package received after a few days from shipment is very slim, which agrees with the NEJM article. PP is a hydrophobic plastic material with zero moisture content, and a respirator can dry out in less than two to three days in a dry air environment. Therefore, the above reports suggest that respirators can be numbered, dried, and then reused in the numbered sequence.

Q5: Can the masks be treated using steam?

A: Yes. Our investigation showed that sterilization using 125°C steam for three minutes has an unnoticeable effect on the charge loss on the electret. Note that it is important 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.

My colleague Dr. Cai, a retired filtration testing scientist, collected experimental data in February 2020, shown in the table below, that support my past results.

Table 2. Measured FE after steam treatment of a 3-fold medical mask and predicted N95 FE (Cai et al., Feb. 2020).

Steam treatment	FE	Theoretical Prediction
Initial FE (3-fold medical mask)	93.2%	N95 (99%)
Steam for 5 minutes	91.7%	98.5%
Steam for 30 minutes	85.2%	97.5%

The first web link in Q3 reports a similar insignificant charge decay after sterilization with hot water vapor.

Q6: Can the respirator be treated by boiling water?

A: Yes. Our investigation showed that sterilization in boiling water for three minutes has an unnoticeable effect on the charge loss on the electret. However, to avoid physically damaging the mask, stirring is not recommended. Note that it is important 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.

My colleague Dr. Cai, a retired filtration testing scientist, collected experimental data in February 2020, shown in the table below, that support my past results.

Table 3. Measured FE after boiling water treatment of a 3-fold medical mask (Cai et al., Feb. 2020).

Boiling water treatment	FE
Initial FE (3-fold medical mask)	93.2%
Boiling for 5 minutes	92.4%
Boiling for 30 minutes	83.6%

Note: The above experiments were carried out with the masks placed above boiling water, not submerged into the boiling water. Because of their material composition and construction, boiling water will alter the shape of N95 respirators, possibly affecting fit. So far, we have not found that the fit is affected by heat treatment at 70°C for 30 minutes or by steam for 3–5 minutes.

Q7: Can the respirator be in contact with water?

A: **Yes.** In contrast to the surface charges encountered in our daily life, the charges of an electret, embedded deep inside the fibers, are quasi-permanent and will not dissipate in the air or after 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 because its action will physically damage the masks. Note that it is important 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.

Q8: What material is suitable or better for homemade masks?

A: Basically, any cloth barrier helps to prevent the spread of the droplets from an infected person and to intercept the droplets before entering a healthy person. A hydrophobic nonwoven layer such as shop towel made of PP or PET between two thin layers of fabric such as handkerchief or scarf is an ideal structure for a homemade mask because 1) the droplet will not penetrate through the hydrophobic media to contaminate the wearer's mouth or nose and 2) nonwoven fabrics have a better filtration efficiency than a woven fabric because nonwovens are composed of fibers with each individual fiber serving to capture particles. Woven fabrics, on the other hand, are composed of yarns or threads, in which fibers are bundled together. Only the fibers exposed on the yarn or the thread surface have the ability to capture particles.

Hydrophilic materials such as wipes, tissues, paper towels, or coffee filters are not ideal for the middle layer of the mask because the droplets in contact with these materials will spread out, penetrate through, and contaminate the wearer's mouth and nose. A drop of water on the material can show if a material is hydrophobic or hydrophilic: it is hydrophobic if the drop beads up, hydrophilic if it spreads out.

References

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The author's brief bio

Education: Ph.D. Research faculty, Joint Institute of Advanced Materials, The University of Tennessee

Expertise: Development of meltblowing (MB) systems 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 billions of pieces of N95 respirators or face masks. He has received three prestigious awards from UT in recognition of his contribution to technology innovation. Tsai is a Fellow Member of American Filtration and Separation Society and a member of Electrostatic Society of America.

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