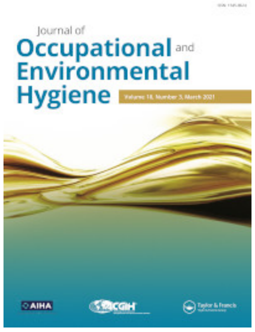

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Factors influencing the filtration performance of homemade face masks

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ABSTRACT

The outbreak of the COVID-19 pandemic is causing a shortage of personal protective equipment (PPE) across the world. As a public health response to control the pandemic, wearing homemade face coverings has been proven as a resort to protect both the wearer and others from droplets and aerosols transmission. Although aerosols and droplets can be removed through these non-medical materials with a series of filtration mechanisms, their filtration performances have not been evaluated in detail. Moreover, many factors, such as the fabric properties and the method of usage, also affect filtration performance. In this study, the size-dependent filtration performances of non-medical materials as candidates for face coverings were evaluated comprehensively. The flow resistance across these filter materials, an indicator of breathability, was also examined. The effect of materials properties, washing and drying cycles, and triboelectric effect on particle filtration was also studied. Results showed that the filtration efficiency varied considerably from 5–50% among fabrics materials due to the material properties, such as density and microscopic structure of the materials. Microfiber cloth demonstrated the highest efficiency among the tested materials. In general, fabric materials with higher grams per square meter (GSM) show higher particle filtration efficiency. The results on washing and drying fabric materials indicated decent reusability for fabric materials. The triboelectric charge could increase the filtration performance of the tested fabric materials, but this effect diminishes soon due to the dissipation of charges, meaning that triboelectric charging may not be effective in manufacturing homemade face coverings.

KEYWORDS

Aerosols; COVID-19; fabrics; filtration performance; homemade face mask

Introduction

During the ongoing coronavirus disease 2019 (COVID-19) pandemic, millions of people have confirmed infections across the world. Severe illness and death rates have caused massive disruption to daily life. In addition to droplet and fomite transmissions, it is currently believed that the coronavirus (SARS-CoV-2) can be transmitted via the inhalation of aerosols, although more evidence needs to be collected (Allen and Marr 2020; Prather et al. 2020). Given this situation, medical respirators, which are designed to protect people against particulate matter and pathogens, are vital to prevent virus transmission. However, these medical supplies have gone through a high global demand and severe shortage at the initial stage of the pandemic when these are supplies are mostly needed. As a compromise, the Centers for Disease Control and Prevention (CDC) recommends the wearing of face masks or face coverings in general public settings where social distancing measures are challenging to maintain (Centers for Disease Control and Prevention (CDC) 2020).

Although face masks are not designed to filter aerosols suspended in the ambient environment, they may still be able to provide some level of protection against airborne particles if sufficient sealing between the mask and the wearer can be achieved (Abd-Elsayed and Karri 2020; Tcharkhtchi et al. 2021). Recent studies indicated the effectiveness of face coverings on lowering the spread of COVID-19 (Aydin et al. 2020; Chu et al. 2020; O'Dowd et al. 2020; Wang et al. 2020). Due to COVID-19's high infection rate, face masks are crucial in general public places and closed indoor environments. Homemade face masks made of household materials are regarded as a last resort to help prevent the emission of large respiratory droplets, per the guidance of the CDC and the World Health Organization (WHO) (CDC 2020; WHO 2020; World Health Organization and United

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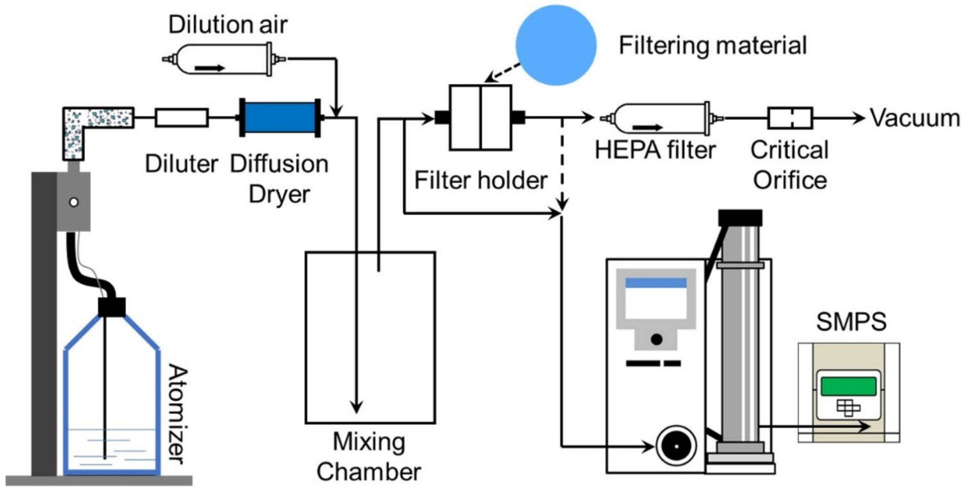

Figure 1. Schematic diagram of the experimental setup.

Nations Children's Fund 2020). The types of household materials used for homemade masks affect their filtration performance. Thus, it is necessary to use easily accessible household materials with higher filtration performance to make face masks.

Household fabrics have been evaluated in a few studies before the COVID-19 pandemic, and these studies provide useful guidance on the choice of household materials that can be used to manufacture face masks. Jung et al. (2014) compared the filtering efficiencies of masks and handkerchiefs commonly used by the general public to protect against particulate air pollution, and found that the average filtration efficiency per mask type ranged from 99% for quarantine masks to 2% for handkerchiefs. In a similar study, Mueller et al. (2018) discovered that the filtration efficiency for folded bandana range from 18–40%, while that of handkerchief is around 23%. To address particle leakage associated with different mask-wearing configurations, studies also used a mannequin head for testing: filtration efficiencies of 33–78% were reported for surgical masks, 65% for cloth masks and 10–60% for household fabrics (Bowen 2010; Rengasamy et al. 2010; Shakya et al. 2017). A concern associated with these studies on fabrics as homemade face mask material is that the specifications of the fabrics are not directly comparable. According to the mechanism of filtration, the fiber diameter, fiber material, and filter permeability determine the interactions between the fibers and particles. Parameters need to be identified to isolate the influence of different fabric specifications on their filtration performance.

Under the COVID-19 pandemic, more studies examining the filtration performance of face masks materials have become available. Konda et al. (2020) found that the combination of different types of fabric materials could enhance filtration efficiency significantly, which is likely due to the combined effect of mechanical and electrostatic-based filtration, because electrostatic interactions are commonly observed in various natural and synthetic fabrics (Frederick 1986; Perumalraj 2015). Hao et al. (2020) examined a wide range of household fabric and fibrous materials in their filtration performance, and found that layers of fibrous filters can create filtration performance similar to that of N95 materials. Zhao et al. (2020) showed that although the filtration efficiencies of single layers of common fabrics such as cotton, polyester, nylon, and silk are relatively low, the efficiency can be enhanced by triboelectric charging without increasing the flow resistance. Asadi et al. (2020) discovered that surgical masks and N95 respirators are effective in blocking supermicron particles even without fit-tests, but friction shedding of supermicron particles from cloth face coverings may confound the filtration measurements. Mueller et al. (2020) determined that the particle filtration efficiency of cloth masks ranged from 28–91% when the masks were worn correctly, and a nylon overlayer improved the particle removal efficiency due to a better fitting. New low-cost techniques using air quality sensors (Fischer et al. 2020) or laser scattering (Schilling et al. 2020) to examine the performance of face masks have also become available, and are applied to evaluate the filtration efficiencies of medical PPE and common face masks.

Existing studies on filtration performance have not yet covered many household materials available to the general public, and such a dataset of the filtration performance of common household materials is needed. Moreover, factors influencing the filtration performance of these materials need to be examined so that the performance can be optimized. The main factors of the fabric materials include material density (grams per square meter, GSM) and microscopic structure. Regarding homemade face masks, reusability without compromising the filtration performance is crucial, but no existing studies have examined the influence of cleaning cycles on face mask filtration performance. Existing studies have found that triboelectric charging induced by rubbing fabrics against other materials may enhance the filtration efficiency, but the duration of this enhanced effect has not yet been examined (Konda et al. 2020; Zhao et al. 2020).

The aim of this study is to examine the filtration performance of a variety of homemade face mask materials and investigate the effect of influencing factors. The size-dependent filtration efficiencies and flow resistances across the materials were measured. Representative fabric materials were selected to study the effect of cleaning cycles and triboelectric charging on the filtration performance. The results can be used as a guidance for choosing common and useful materials for manufacturing the face coverings to meet the urgent demand and mitigate the shortage of medical supply in the pandemic. These low-cost homemade face masks can also help mitigate the exposure to wildfire smokes when certified face masks and respirators or air purification systems are not available.

Methods

Experimental setup

Figure 1 shows a schematic diagram of the experimental setup, including the aerosol generation and filtration assessment sections. The test aerosols were generated by a constant output atomizer (Model 3076, TSI Inc., Shoreview, MN) nebulizing a NaCl-water solution with a mass concentration of 0.1%. The atomizer generated aerosols at a flow rate of 3.0 liters per minute (lpm). The aerosols were first diluted by an inline diluter and then dried by a custom build diffusion dryer. Afterward, the aerosols, together with a stream of filtered make-up air, were introduced to a mixing chamber. The homogeneous aerosols were then directed into a 37-mm filter cassette (Air Sampling Cassette, Zefon International Inc., Ocala, FL), where the disc-shaped filter material was firmly pressed onto mesh support and sealed at the edge. The filter material was cut to disks, which can be fitted tightly in the filter cassette.

In general, the breathing flow rate varies from 10–60 lpm depending on the age, gender, and motion status of a person (Becquemin et al. 1991; Hinds 1999; Janssen et al. 2005; Grinshpun et al. 2009; EPA U 2011). In the study of filtration process, the variation of flow rate is determined by the face velocity through the filter material area (Stafford and Ettinger 1972; Leung et al. 2010). The testing condition employed by the National Institute for Occupational Safety and Health (NIOSH) was performed at a constant flow rate of 85 L min^{-1} (NIOSH 2007). The resulting face velocity is 17.3 cm s^{-1} at maximum depend on a 102 mm diameter sheet of the filter. Moreover, given the variabilities of breathing flow rates, common materials have been tested under a wide range of face velocities, ranging from 5.3–26 cm s^{-1} (Rengasamy et al. 2010; Li et al. 2012; Konda et al. 2020). This study examined the filtration performance of the tested materials under face velocities of 9.2 cm s^{-1} which correspond to a flow rate of 6 lpm through the 37 mm filter material and the effect of face velocity on the filtration performance can be found in an earlier study (Hao et al. 2020).

A scanning mobility particle sizer (SMPS, Model 3936, TSI Inc., Shoreview, MN) measures the mobility size distributions of aerosols upstream and downstream of the filter holder. This system is equipped with a differential mobility analyzer (DMA, Model 3081, TSI Inc., Shoreview, MN) that classifies particles in the range between 30 and 600 nm, and a condensation particle counter (CPC, Model 3750, TSI Inc., Shoreview, MN) that measures the concentration of the mobility-classified particles. The size distribution of aerosols ($n(D_P)$) is obtained by scanning the voltage that is applied to the DMA. Therefore, the filtration efficiency (together with standard deviation) was measured at the range of 30–600 nm and the overall number of particles with the SMPS. As the flow resistance across the filter material is a critical component to assess the breathability of the material, a two-digital manometer (RISEPRO, 365BG947677, measuring range ± 13.79 kPa, 0.001 kPa resolution) was used to monitor the flow resistance of the materials. A digital microscope (Dino-Lite Edge 3.0) with the magnification of 10–200 times was used to examine the microstructure of these common materials. A four decimal place-electronic analytical balance (Denver Instrument Co., A-160) was used to weigh the fabric materials. A standard washing machine (Crosley brand, CAWS9234VQ) and dryer (Kenmore brand, 80 series) with detergent (Purex Liquid Laundry Detergent) were used to study the effect of wash and dry cycles on the filtration performance of fabric materials.

Filtering materials

A wide range of common household materials were evaluated, including five types of paper materials and

Table 1. Properties of household materials tested in this study.

Material	Brand	GSM, g m^{-2}	0.3 µm FE, %	Overall FE, %	P, kPa	q_F
Surgical (earloop)	Walgreens	71.52	50.07 ± 0.18	66.37 ± 0.33	0.09	7.72
Paper Materials						
Shop towel	ToolBox	76.92	33.48 ± 2.59	45.58 ± 1.86	0.24	1.7
Coffee filter paper	ZengerGroup	51.08	26 ± 3.15	43.17 ± 2.61	0.78	0.39
Toilet paper towel	Great Value Ultra Strong	41.76	19.62 ± 4.99	27.05 ± 4.27	0.12	2.18
Kitchen paper towel	Check This Out	35.36	3.69 ± 2.84	8.57 ± 2.34	0.16	0.23
Wax paper	Cut-Rite	34.24	5.23 ± 2.49	6.57 ± 1.20	0.90	0.06
Fabric Materials						
Lycra cloth	N/A	372.68	20.13 ± 0.17	37.45 ± 0.48	0.63	0.36
Microfiber	Rubbermaid	343.6	45.69 ± 1.59	64.27 ± 1.09	0.75	0.81
Knit (60% cotton 40% polyester)	N/A	232.6	13.32 ± 3.27	35 ± 2.99	0.12	1.19
Knit (97% cotton 3% spandex)	N/A	228.56	4.6 ± 3.66	19.85 ± 3.37	0.09	0.52
Velvet	Stretch Velvet	221.32	12.29 ± 1.18	19.78 ± 0.28	0.03	4.37
Suede cloth	SyFabrics	196.12	9.57 ± 1.63	16.53 ± 0.77	0.45	0.22
Jersey (100% polyester)	ProCool Jersey Mesh	164.68	4.14 ± 0.43	13.23 ± 0.14	0.06	0.70
Flannel	Comfy Cozy	158.36	13.96 ± 2.68	25.61 ± 2.4	0.16	0.94
Cotton print pattern	Joann Fabric brand	144.88	3.92 ± 2.88	8.91 ± 2.31	0.05	0.80
Bamboo cleaning cloth	Kitchen + Home	128.76	10.97 ± 2.09	27.04 ± 2.1	0.19	0.61
Quilt (100% cotton)	Quilter's showcase	116.96	9.42 ± 0.87	18.85 ± 2.54	0.11	0.90
Muslin	Roc Lon	106.44	12.52 ± 2.21	21.8 ± 2.5	0.06	2.23
Knit (100% cotton)	Fabric Wholesale Direct	105.44	8.08 ± 1.37	30.32 ± 2.36	0.11	0.77
Non-woven polypropylene bag	N/A	83.84	2.86 ± 2.88	19.3 ± 2.44	0.14	0.21
Bamboo diaper	Unscented	38.48	8.23 ± 2.46	3.91 ± 2.89	0.16	0.54
Silk	Tony and Candice	28.08	10.14 ± 1.4	12.63 ± 1.79	0.02	5.35

16 types of fabric materials (Table 1). The results were compared against the surgical mask (earloop, ASTM F2100-19 Level 1) material. In addition to the information of the tested and common materials, Table 1 also lists the grams per square meter (GSM), filtration efficiency (FE) particle size of 0.3 μm, overall FE particle sizes, flow resistance (ΔP), and filter quality (q_F). In this study, GSM was evaluated as an indicator for material filtration performance because it correlates with the thickness and packing density of the garment. The particle size of 0.3 μm is essential, because it is within the most penetrating particle size (MPPS) and it is used as an indicator for the filtration performance in similar studies (Podgorski et al. 2006). It is possible that the virus-containing aerosols may penetrate the materials within this size window and further transmit through the human respiratory system. However, it should be noted MPPS is also affected by many factors such as flow rate and particle charge (Rengasamy et al. 2012). Moreover, the microstructure of the materials in this study was observed. Eight fabric materials: microfiber, flannel, bamboo, velvet, jersey, silk, cotton, and muslin materials, were further examined in the effect of washing and drying cycles. The decay of triboelectric charging of polypropylene fabrics was also discussed.

Data analysis

The filtration performance of the materials is mainly determined by the filtration efficiency and flow resistance. The filtration efficiencies are not directly obtained from the size distributions measured by the SMPS. Similar to previous work (Li et al. 2018; Hao et al. 2020), size-dependent filtration efficiency ($\eta(D_p)$) was calculated by Equation (1):

$$\eta(D_p) = 1 - \frac{n_o(D_p)}{n_i(D_p)} \tag{1}$$

where $n_o(D_p)$ and $n_i(D_p)$ are the particle number concentrations for each particle size measured at the outlet (downstream) and inlet (upstream) of the filter holder. Based on the size distributions, the overall number-based filtration efficiencies can also be evaluated. The particle size distributions were first integrated over the measured size range to calculate the total number (N) in Equation (2):

$$N = \int n(D_p)d(D_p) \tag{2}$$

The overall number-based filtration efficiencies (η_N) were calculated by Equation (3),

$$\eta_N = 1 - \frac{N_o}{N_i} \tag{3}$$

where N_o and N_i are the total number of concentrations of aerosols at the outlet and inlet of the filter holder.

Size-dependent particle number concentrations were measured for a minimum of three times at the outlet and inlet of the filter holder. The standard deviation (σ) was considered to include downstream and upstream

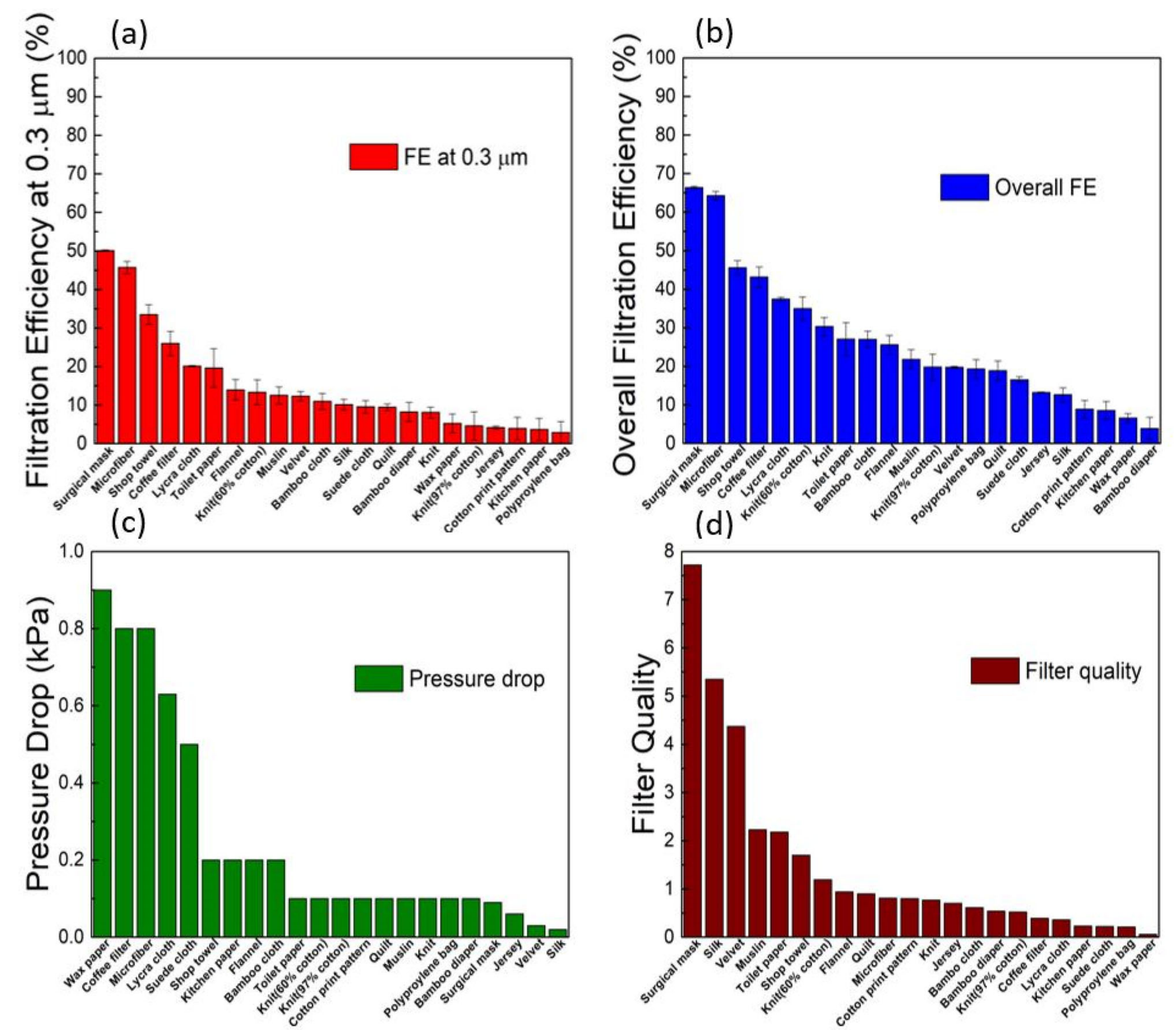

Figure 2. The filtration performance of all tested materials: (a) Filtration efficiency at 0.3 μm. (b) Overall efficiencies. (c) Pressure drops. (d) Filter quality.

conditions in Equation (4).

$$\sigma = \frac{n(D_{p,o})}{n(D_{p,i})}\sqrt{\left(\left(\frac{\sigma_o}{n(D_{p,o})}\right)^2 + \left(\frac{\sigma_i}{n(D_{p,i})}\right)^2\right)} \tag{4}$$

where σ_o and σ_i are the standard deviations at the outlet and inlet of the filter holder.

The performance of the filter material is a function of the filtration efficiency and the flow resistance through the filter. Better filter materials have a higher filtration efficiency (lower penetration efficiency) and a lower flow resistance. Pleats are also used to reduce in air filters to reduce the flow resistance by increasing the surface area of the filters. Therefore, this study used the filter quality, following the convention of Hinds (1999), to further evaluate the performance of the materials (Hinds 1999). It is calculated with Equation (5):

$$q_F = \frac{ln(1/P)}{\Delta P} \tag{5}$$

where P is the penetration efficiency of particles $(P = 1 - \eta)$ and ΔP is the flow resistance across the filter. In the fabric industry, GSM is a standard measurement and benchmark specification for different comparisons of fabrics. In our tests, Equation (6) was used to evaluate the GSM of the materials

$$\mathrm{GSM} = \frac{4m}{d^2\pi} \tag{6}$$

where m is the mass of the sample materials, d is the sample diameter of 37 mm.

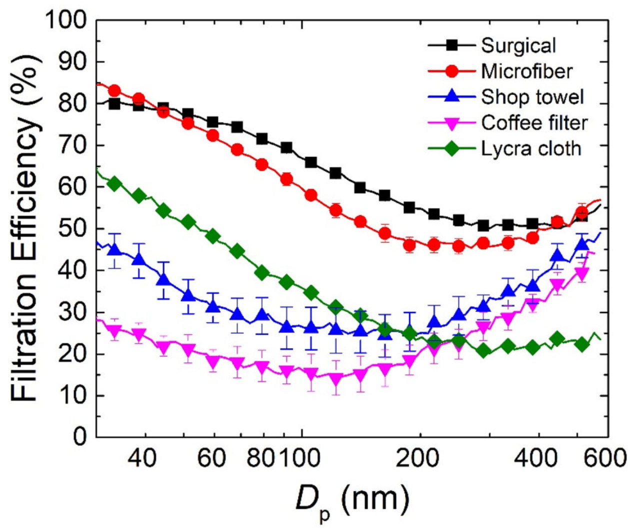

Figure 3. Size-dependent filtration efficiency for the best four materials and surgical mask material.

Results and discussion

Overview of filtration performance of commercial and homemade masks materials

The tested materials were examined in their filtration efficiency in the size range between 30 and 600 nm and flow resistance. The filtration efficiency at 0.3 μm, overall efficiencies, and flow resistance of all tested materials are shown in Table 1, Figure 2(a–c). The filter quality, which evaluates the overall filtration performance as a function of filtration efficiency and flow resistance, is shown in Figure 2(d). The results showed that four of 21 samples have filtration efficiency above 20% at 0.3 µm, which include microfiber, shop towel, coffee filter paper, and lycra cloth. Figure 3 displays the particle size-dependent filtration efficiency curves for these four materials with the surgical mask material as a reference. As expected from filtration mechanisms (Hinds 1999), smaller particles below 40 nm are filtered more efficiently due to diffusion, and larger particles above 500 nm are filtered more efficiently due to impaction and interception. The particle size corresponding to the minimum filtration efficiency, or, the most penetrating particle sizes (MPPS) (Shaffer and Rengasamy 2009), ranged between 100 nm and 300 nm.

In effect, it should be noted that surgical face masks and homemade face masks are not presumed to have a perfect fit on the face compared to N95 respirators. Some studies found that the filtration efficiencies of face masks under actual conditions for surgical masks and N95 respirators are significantly lower than those for the materials testing (Grinshpun et al. 2009; Chu et al. 2020), due to the leakages

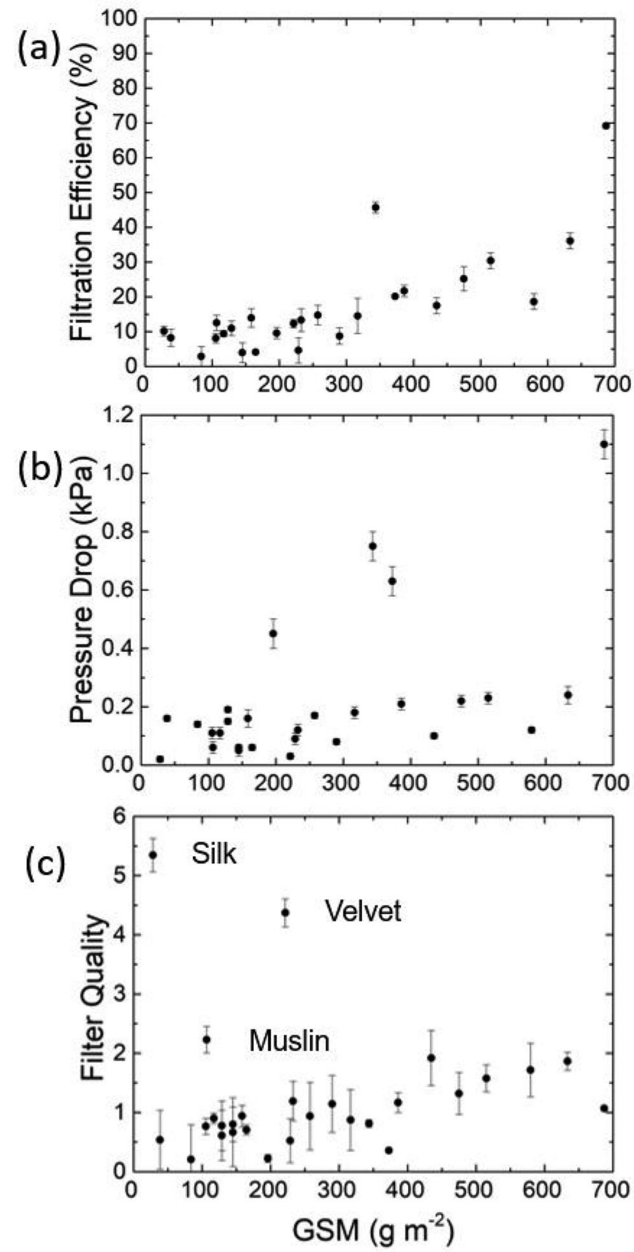

Figure 4. The relationship between filtration efficiency at 0.3 um, flow resistance, and filter quality *vs.* GSM.

between the mask materials and the face. They also showed that small leaks in the order of one percent of the total sample area can substantially reduce the overall filtration efficiency of a mask down to half or even less compared with the value of the material itself (Drewnick et al. 2021).

Influence of material properties on filtration performance

In general, the mask materials differ in their specifications, such as fiber diameter, thickness, density, and porosity, and their filtration performance strongly

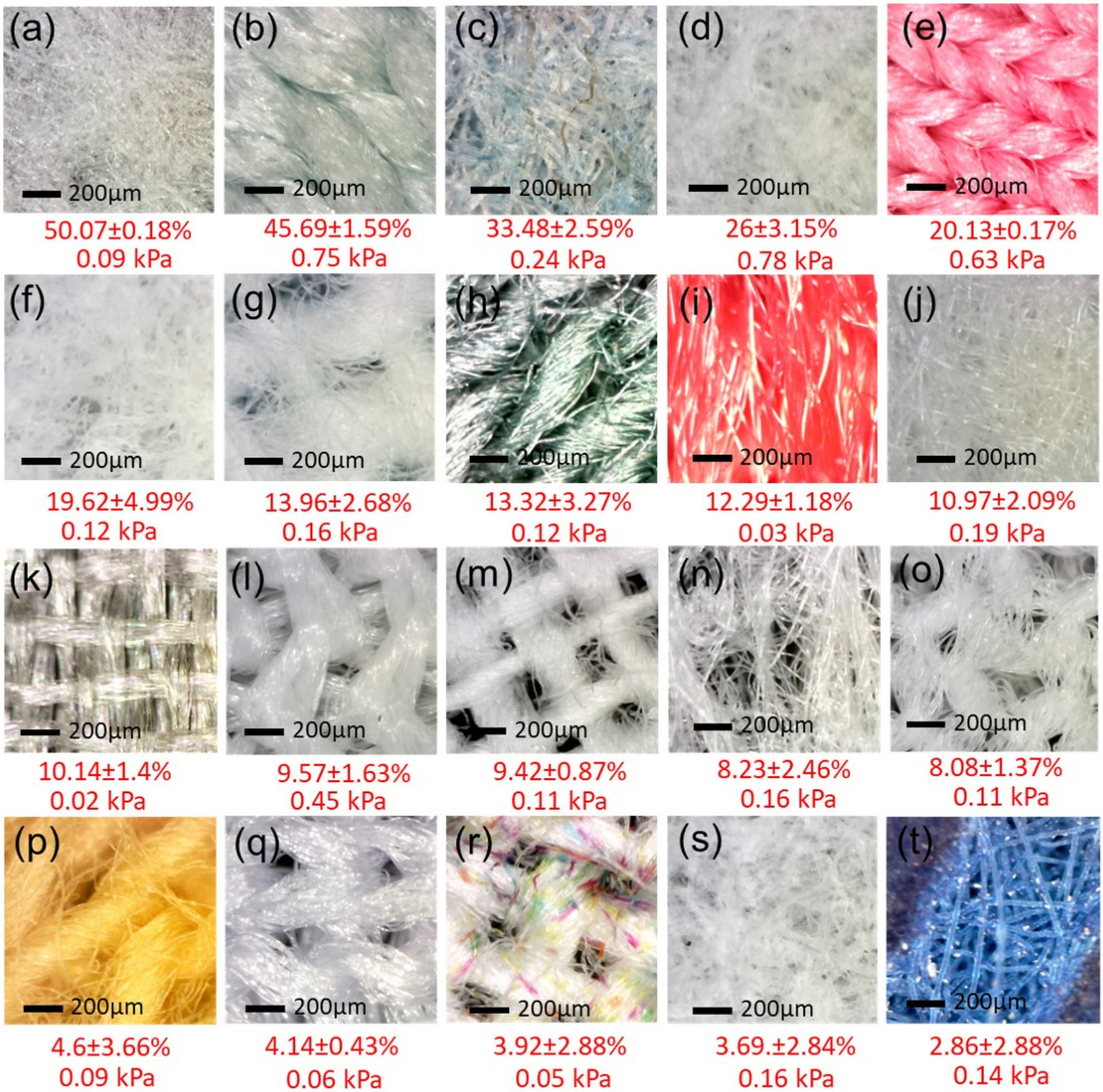

Figure 5. Images of microscopic structures of surgical mask and tested materials corresponding filtration performance: (a) Surgical mask, (b) Microfiber, (c) Shop towel, (d) Coffee filter, (e) Lycra cloth, (f) Toilet paper, (g) Flannel, (h) Knit (60% cotton, 40% polyester), (i) Velvet, (j) Bamboo cleaning cloth, (k) Silk, (l) Suede cloth, (m) Quilt (100% cotton), (n) Bamboo diaper, (o) Knit (100% cotton), (p) Knit (97% cotton, 3% spandex), (q) Jersey (100% Polyester), (r) Cotton, (s) Kitchen paper, and (t) Non-woven reusable bag.

depends on the fabric types and fabric construction. In this study, GSM was used as a parameter for the material filtration performance. Also, better quality and reusability generally correlates with fabrics with higher GSM, which means that they can serve as good candidates for homemade face masks. In Table 1, the paper and fabric materials were ranked according to the GSM values, and it showed that the filtration efficiency generally increased with GSM for both the paper and fabric materials. The filtration efficiency, flow resistance, and filter quality as a function of GSM were plotted in Figures 4(a–c), which showed enhanced filtration efficiency and flow resistance at higher GSM values in general. Theoretically, quality factors should be constant with respect to filter thickness, since filter quality is more related to the fiber properties instead of GSM. In this study, it was found that silk and velvet generally have higher filter quality but the filtration efficiencies are relatively low. In this case, multiple layers of the materials should be used

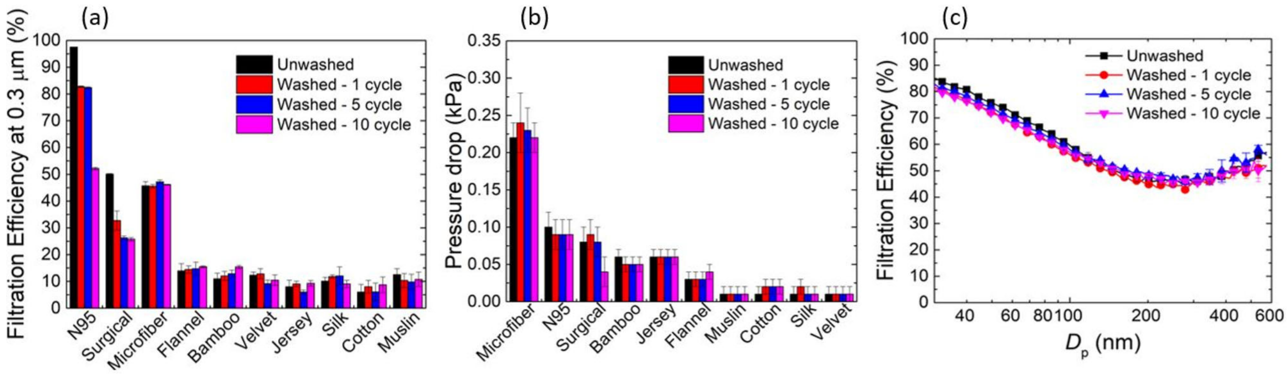

Figure 6. (a) The filtration efficiency at 0.3 um of all fabrics and surgical mask under unwashed and washed conditions. (b) The pressure drops of all fabrics and surgical mask under unwashed and washed conditions. (c) The size-dependent filtration efficiency of microfiber cloth under unwashed and washed conditions.

in manufacturing homemade face masks, as the filtration efficiency of a single layer is relatively low. To identify the commonality of household materials that are efficient in particle filtration, the microstructure of the materials (Figure 5) was examined further. Similar to the surgical mask material (Figure 5(a)), many of the high-filtration efficiency materials are composed of a fine mesh of nonwoven fabrics. Woven materials may also generate high particle filtration efficiency if they are tightly packed with low porosity.

Influence of washing and drying on the filtration performance

Compared to medical PPE, homemade face masks offer the advantages of low-cost and reusability to the general public. According to the guidance of cleaning cloth face coverings from the CDC (2020) the fabric face masks can and should be cleaned with regular household laundry after each use. However, one needs to confirm that reusing the homemade face masks would not compromise the filtration efficiency due to washing and drying.

In this study, eight fabric materials were chosen and examined the filtration efficiency before and after 1, 5, and 10 cycles of washing and drying. The data was further compared to surgical masks and N95 respirator materials. The samples were cleaned by an actual washer and dryer using detergent with the usual laundry settings. Figures 6(a and b) show the filtration efficiency and pressure drops of all washed fabrics, mask, and respirator materials. At the same time, the size-dependent filtration efficiency of microfiber cloth after different cleaning cycles is shown in Figure 6(c). The findings show that the filtration efficiency of medical masks and respirator materials degraded drastically after cycles of cleaning, with the sharpest drop occurring in the first cycle. This decrease of filtration efficiency may be due to the loss of charges attached on the electret fibers of the mask and respirator materials. Compared to the surgical mask and N95 respirator materials, there is no obvious impact on the fabrics, which is mainly due to the unchanged structure of fabric materials. However, one should still note that even after cycles of cleaning, the filtration efficiency of N95 respirator and surgical mask materials are still higher than many fabric materials. The pressure drop of medical masks and respirator materials has a slight decrease after cleaning cycles, while there is no obvious impact on the fabrics. This is likely due to the change of fiber structure for mask materials.

Influence of triboelectric charging on the filtration performance

Based on the filtration mechanisms, another factor that would affect the filtration efficiency is the electrostatic interaction between the filter material and particles. The particles are able to be trapped by the charged filter materials due to the existing charges or induced dipoles on the particles. A few recent studies show that triboelectric charging of the face mask material can enhance the filtration performance (Konda et al. 2020; Zhao et al. 2020). As opposed to the permanent charging effect created by the electret materials used in the medical masks and respirators, triboelectric charging may decay rapidly and become a crucial issue after a period of usage. This study further examined the decay of triboelectric charging and the associated filtration efficiency of silk materials, since it can be easily charged by moving against the polypropylene fabric. Two different brands of polypropylene fabrics were used to generate triboelectric charging. The filtration efficiency of uncharged materials and that of charged materials over time are

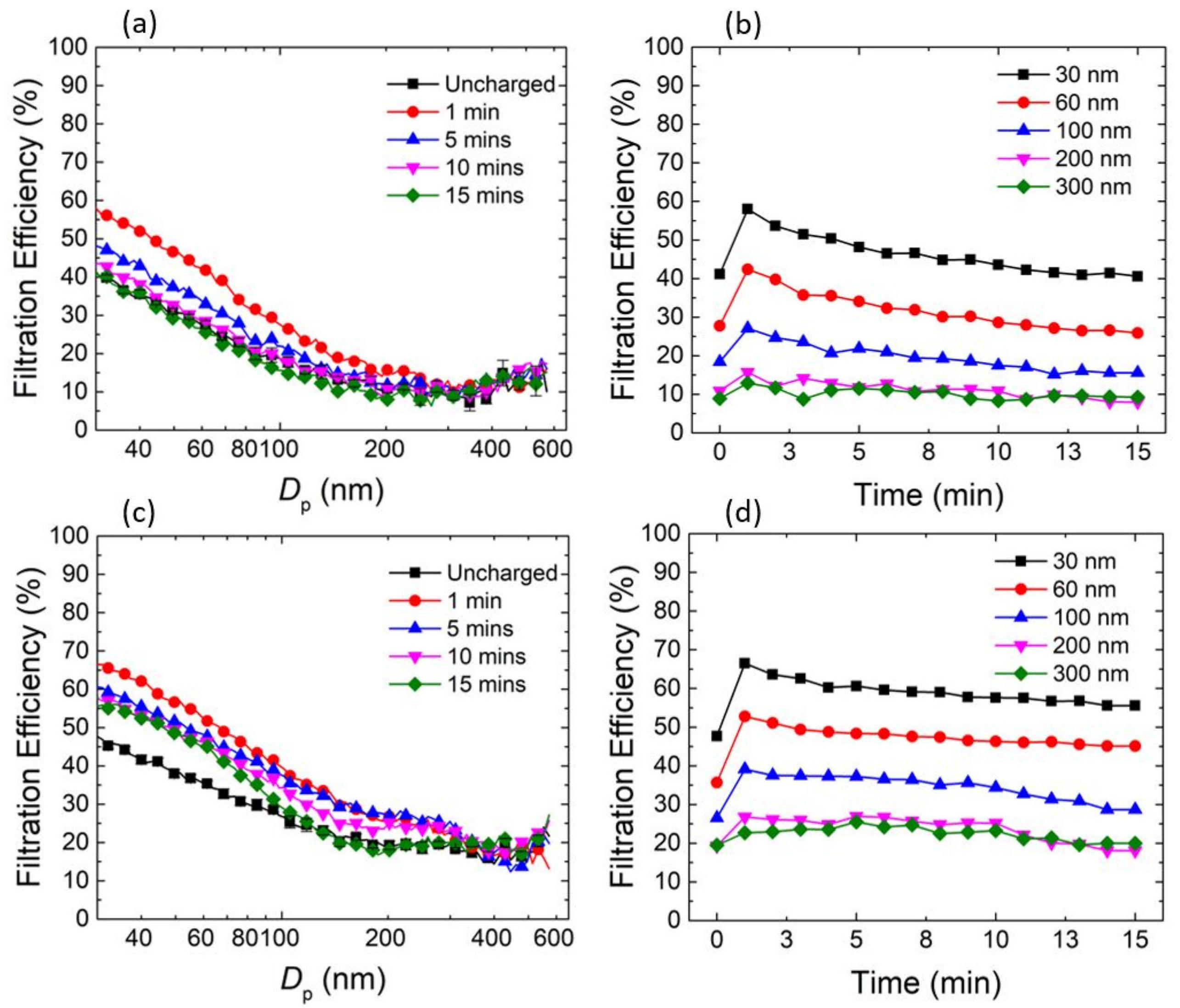

Figure 7. Panels (a) and (c) show the size-dependent filtration efficiency of uncharged materials and charged materials in two brands of polypropylene materials. Panels (b) and (d) show the filtration efficiency varies over time in two brands of polypropylene materials.

shown in Figure 7(a and c). The results showed an enhancement of filtration efficiency due to the triboelectric charging, but the filtration efficiency quickly diminished to uncharged condition after 15 min of testing.

The evolution of filtration efficiency during a period of 15 min is further examined at various particle sizes. Immediately after the materials were charged, static charges built up, and the filtration efficiency increased significantly. However, the filtration efficiencies decreased over time, and the enhancement of filtration efficiency from triboelectric charging becomes minimal. Figures 7(b) and 7(d) also displayed that triboelectric charging and its decay showed a stronger impact on smaller particles than the larger particles.

Conclusions

Face masks play a vital role in preventing the spreading of the virus, and common household materials can work as a candidate for surgical masks for the general public. This study evaluated the performance of a wide range of common household materials as candidates for an alternative to commercial face masks. Several factors related to filtration performance were also comprehensively studied. By evaluating 21 types of materials, it was found that material properties such as GSM and microstructures are able to indicate the filtration performance. The higher efficiencies are generally accompanied by higher GSM, finer mesh, and lower porosity. Washing and drying have a significant effect on medical masks and respirators, but not so for fabrics materials, meaning that they can be reused after cleaning cycles. Also, triboelectricity can improve the filtration efficiency for a short period of time, but this enhancement diminished rapidly.

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