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N-Halamine-Modified Antimicrobial Polypropylene Nonwoven Fabrics for Use against Airborne Bacteria

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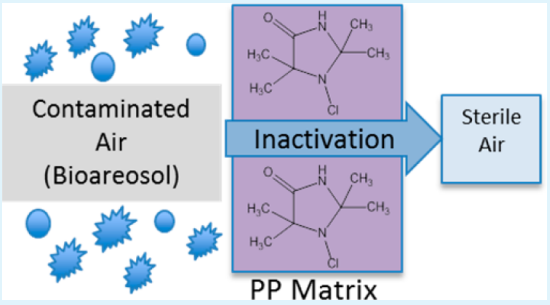
Supporting Information

ABSTRACT: Disinfecting, nonbleaching compound 1-chloro-2,2,5,5-tetramethyl-4-imidazolidinone (MC) was uniformly coated onto polypropylene melt-blown nonwoven fabrics having basis-weights of 22 and 50 g/m^2 in order to impart antimicrobial properties via a pad-dry technique. The antimicrobial efficacies of the tested fabrics loaded with MC compound were evaluated against bioaerosols of *Staphylococcus aureus* and *Escherichia coli* O157:H7 utilizing a colony counting method. It was determined that both types of coated fabrics exhibited superior antimicrobial efficacy upon exposure to aerosol generation for 3 h. The effect of the coating on air permeability was found to be minimal. Samples were stable for a 6 month time period when they were stored in darkness. However, when the fabrics were exposed to fluorescent light, partial chlorine loss was observed. The MC-coated fabrics exhibited great potential for use in protective face masks and air filters to combat airborne pathogens.



KEYWORDS: *N-halamines, antimicrobials, bioaerosols, air filters, protective face masks, nonwovens*

INTRODUCTION

Antimicrobial materials have gained utility due to the increasing concerns about health care associated infections that can be transmitted through direct or indirect contact. One vector for these infections occurs through exposure to environmental airborne pathogens, which could cause mortality.[1,2] Exposure to airborne pathogens can cause many infectious diseases including severe acute respiratory syndrome (SARS) and H1N1 influenza.[3] Airborne microorganisms can reproduce in large quantities especially in heating, air-conditioning and ventilation systems, and they are able to live in the surrounding environment for hours, even days, with increasing resistance to drying and usual cleaning methods.[4,5] In addition, the rapid mutation of the bacteria, as well as vaccination difficulties, due to rapid multiplication and propagation, can also create treatment problems.[6] Thus, protection of humans against host-to-host transmission of airborne pathogens has become a very important issue. Filter face-piece respirators (FFRs) are one of the most beneficial protection devices that are used to reduce aerosol transmission. For example, it has been recommended to use NIOSH approved FFRs to protect patients and health care workers by the Occupational Safety and Health Administration (OSHA) and the USA Centers for Disease Control and Prevention (CDC) during a pandemic influenza outbreak.[7] The N95 respirator is the most common type of approved particulate FFR; it filters at least 95% of airborne particles.

Therefore, there is a need for developing antimicrobial surfaces for face masks and air filter devices that can reduce the risk of infection from airborne pathogens, especially for health care workers. This need can be approached by incorporating antimicrobial agents into face mask and air filter materials. Quaternary ammonium salts,[8,9] metals (especially silver ions),[10,11] copper oxide,[12,13] synthetic mimics of antimicrobial peptides,[14,15] and N-halamines[16−18] are the most common antibacterial agents which have been used in general infection control.

Carbon nanotubes (single-walled (SWCNT), multiwalled (MWCNT)) and silver nanoparticles are the most studied antimicrobial agents, which have been used in antimicrobial air filter and face mask applications.[19−22] Rengasamy and co-workers investigated antimicrobial efficacy of different types of commercial face pieces, which were modified by TiO_2, iodinated resin, silver−copper, and EnvizO_3-Shield technologies.[23] Other different antimicrobial agents such as copper oxide[24] and various natural products[25] have been investigated in order to develop antimicrobial filter and face-piece applications. However, many of these materials did not provide a significant and rapid antimicrobial action.

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N-halamines are generally the most effective antimicrobial materials due to their superior antimicrobial efficacy against a broad spectrum of microorganisms (Gram-positive and Gram-negative bacteria, yeasts, fungi, and viruses), nontoxicity, stability, and rechargeability.[26−28] N-halamines have been extensively studied in these laboratories, and they have been applied to numerous materials in order to provide antimicrobial coatings on a variety of surfaces.[28] Sun and co-workers applied N-halamines onto surfaces via covalent bonding using grafting techniques.[29,30] Cerkez and co-workers synthesized and coated an N-halamine polymer onto polypropylene nonwoven fabrics.[31] Water-soluble N-halamine compounds have also been prepared and demonstrated utility in general disinfection applications.[32]

Among N-halamines, monochlorinated compounds tend to have higher stability to loss of oxidative halogen in both aqueous and dry forms. As a consequence of high stability, the rate of antimicrobial activity is generally lower compared to dichlorinated N-halamines, though it is still rapid enough for most applications. The mechanism of action of N-halamines involves the direct transfer of oxidative halogen to a cell upon contact.[16] The transferred halogen penetrates the cell and oxidizes the amino acids in the cell membrane of the microorganism and inactivates it within contact times dependent upon the rate of halogen transfer by the N-halamine.[28] Generally, Gram-negative bacteria are inactivated more slowly than are Gram-positive bacteria because of an extra protective outer layer of lipopolysaccharides for the former.[28] It is to be emphasized that during the mechanism of action of stable N-halamines, a direct contact of the N-halamine with the bacterial cell is necessary. The molecule does not dissociate into free oxidative chlorine before the transfer.[28]

Currently employed protective face masks are either prepared utilizing expensive materials and methods, or tend to have poor antimicrobial activity. To address these problems, there is a need for a superior material, which can inactivate the pathogens rapidly and effectively, and can be obtained with simple and inexpensive techniques. Therefore, in this study, commercially available surgical and N95 types of polypropylene nonwoven fabrics were modified with 1-chloro-2,2,5,5-tetramethyl-4-imidazolidinone (MC, Figure 1) in order to provide a rapid and effective antimicrobial face-piece material. Biocidal efficacies against *Staphylococcus aureus* and *Escherichia coli* O157:H7 bioaerosols, air permeabilities, and chlorine stabilities have been determined.

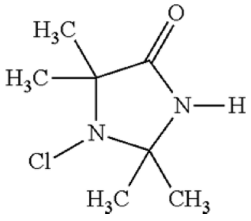

Figure 1. 1-Chloro-2,2,5,5-tetramethyl-4-imidazolidinone (MC).

EXPERIMENTAL SECTION

Materials and Instrumentation. Electrostatically charged polypropylene melt-blown nonwoven fabrics were kindly donated by Hollingsworth & Vose Company (East Walpole, MA) with basis weights of 50 and 22 g/m^2, which are produced to use as substrates for N95 type respirator and surgical face mask applications, respectively. The polypropylene nonwoven substrate meets the U.S. government NIOSH and European EN 149 standards for N95 and surgical respirator applications. Millipore filters (0.45 μm pore size) were purchased from VWR Inc. (Radnor, PA). Clorox brand (Clorox, Inc., Oakland, CA) household bleach was used for chlorination. Bacteria cultures of *S. aureus* ATCC 6538 and *E. coli* O157:H7 ATCC 43895 were purchased from American Type Culture Collection (Rockville, MD), and Trypticase soy agar was obtained from Difco Laboratories (Detroit, MI).

The effect of the coatings on air permeability of the fabrics was tested on a Frazier Precision Instrument (Hagerstown, MD) air permeability tester (using Meriam red oil), both on 22 and 50 g/m^2 polypropylene nonwovens, at 21 °C and 65% relative humidity. The pressure drop was adjusted to 0.5 in. of water. Air permeability was recorded in cubic feet of airflow per min per square foot (ft^3/min/ft^2).

Synthesis of 1-Chloro-2,2,5,5-tetramethyl-4-imidazolidinone (MC). The synthesis of MC compound has been described elsewhere.[32] Briefly, 2,2,5,5-tetramethyl-4-imidazolidinone[32] (14.2 g, 0.1 mol) was dissolved in 100 mL of 1 N sodium hydroxide solution (0.1 mol). The mixture was stirred at 10 °C, and chlorine gas was bubbled into the solution until the pH reached 7. The precipitated white solid product was obtained by filtration and was recrystallized from a hexane/ether mixture. The yield was 95%. The melting point was 157.0−157.5 °C. The ^{1}H and ^{13}C NMR spectra of the compound are presented in the Supporting Information. The IR (KBr) spectrum contained prominent bands at 3200, 2986, 2939, 1730, 1676, 1477, 1436, 1388, 1368, 1224, and 1177 cm^{-1}.

Coating Procedure. 1-Chloro-2,2,5,5-tetramethyl-4-imidazolidinone (MC) was used as an antimicrobial coating for the nonwoven materials. MC (at 1 wt %) was dissolved in EtOH solution at room temperature, and then 300 cm^2 pieces of polypropylene nonwoven fabrics were soaked in the coating solution for 10 min. The fabrics were then padded through a laboratory wringer (Birch Brothers Southern, Waxhaw, NC) at low pressure settings. This procedure was followed by drying the fabrics at room temperature for 24 h. The control fabrics were untreated 22 and 50 g/m^2 polypropylene nonwovens. Ethanol solvent does not alter either MC or polypropylene.

Iodometric Titration. A modified iodometric/thiosulfate titration procedure was used to determine the active chlorine content on the MC-coated fabrics.[33] Cl$^+$% was calculated by the following equation:

$$Cl^+\% = \left(\frac{35.45 \times N \times V}{2 \times W}\right) \times 100$$

where Cl$^+$% is the weight percent of the oxidative chlorine, N and V are the normality (equiv/L) and volume (L) of the $Na_2S_2O_3$ (titrant), respectively, and W is the weight of the polypropylene fabric in grams.

Shelf-life Stability. Storage or shelf-life stability of the 22 g/m^2 fabrics were studied. Fabric samples were stored in a cabinet (dark environment) without exposure to fluorescent light and on the laboratory bench (under fluorescent light) at room temperature. The stability of the chlorine content over time was measured for 24 weeks. The stabilities of the MC-coated fabrics with a basis weight of 22 g/m^2 were determined at 22 °C by measuring the amount of remaining chlorine on the fabrics by using the standard iodometric/thiosulfate titration procedure.

Antimicrobial Efficacy Testing. Two types of tests were conducted in order to determine the biocidal efficacy of the face mask samples. *Staphylococcus aureus* (*S. aureus*, ATCC 6538) was used as a Gram-positive bacterium and *Escherichia coli* (*E. coli* O157:H7, ATCC 43895) was used as a Gram-negative bacterium in order to challenge the unchlorinated and chlorinated-coated fabrics.

In the first method, a "sandwich test" was used.[33] In this procedure, bacteria were suspended in 100 μM phosphate buffer (pH 7) to produce a suspension of known population (colony forming units, CFU). Then, an aliquot of 25 μL of this suspension was placed in the center of a 2.54 cm square swatch, and a second identical swatch was placed on top. Both swatches were covered by a sterile weight to ensure a good contact with the bacteria. After predetermined contact times, samples were quenched by 5.0 mL of sterile 0.02 N sodium

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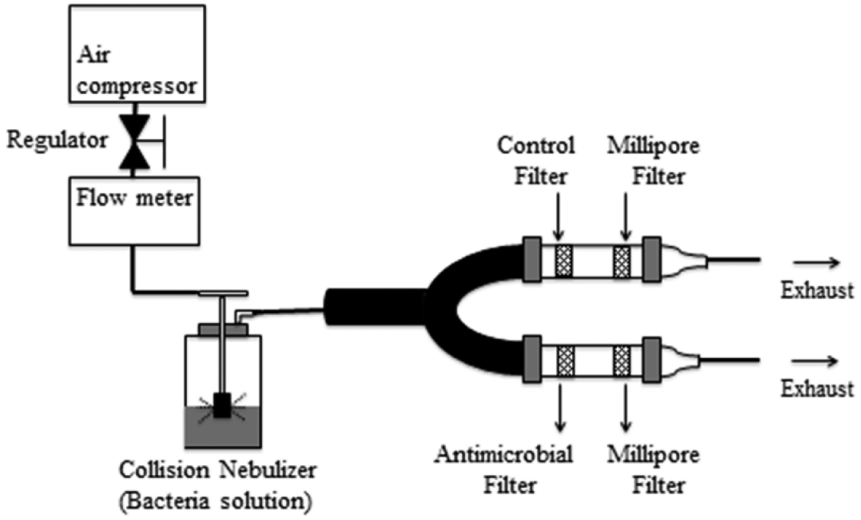

Figure 2. Schematic diagram of experimental setup for bioaerosol testing of the filters.

thiosulfate solution to neutralize the oxidative chlorine and thus terminate the disinfection action. Samples were vortexed for 2 min, and then serial dilutions were prepared using pH 7, 100 μM phosphate buffer and plated on trypticase soy agar plates. After the plates were incubated at 37 °C for 24 h, bacterial colonies were counted for the biocidal efficacy analysis. For each contact time, a single fabric swatch was vortexed in a quenching solution to wash the bacteria into a suspension that was immediately plated into duplicate serial dilutions followed by counting the viable bacteria. All experiments were performed at least twice (on different days) using different bacterial inocula.

The second procedure was based on ASTM Method F 2101.01 "Standard Test Methods for Evaluating the Bacterial Filtration Efficiency of Medical Face Mask Materials, Using a Biological Aerosol of *Staphylococcus aureus*", and a modified version of the method was applied. A bacteria suspension was prepared in 200 mL of 100 μM phosphate buffer (pH 7) to produce a suspension of known population (colony forming units, CFU). First, small samples of two test masks (3.175 cm diameter, 7.91 cm^2), one being coated with MC disinfectant and the other being a control, were clamped into the chamber under sterile conditions before challenging with aerosolized bacteria. *S. aureus* and *E. coli* O157:H7 bacteria, respectively, were aerosolized by using a one jet nebulizer through the chamber. A diagram of the experimental apparatus is shown in Figure 2.

Aerosolized bacteria were introduced into the U shaped aerosol chamber by using compressed laboratory air where the streaming air pressure was adjusted to 20 psi through a pressure regulator. Airflow was set to 259 mL/min by a flow meter and allowed to pass through the MC-coated and uncoated test fabrics for 3 h. Approximately 0.046 m^3 of bacteria were aerosolized from the nebulizer, but only a fraction of the bacteria contacted the test fabrics due to the torturous path between the nebulizer and the chambers containing the test fabrics. After 3 h of challenge, the aerosol flow was terminated, and the mask samples were retained in the test chamber for an additional 10 min.

Small porous (0.45 μm) sterilized Millipore filters were mounted behind the test fabrics. Any bioaerosols which penetrated through the mask samples were collected onto the Millipore filters in the chamber. After the additional 10 min residence in the chamber, the samples were aseptically removed and transferred into 5.0 mL of sterile 0.02 N sodium thiosulfate solution to neutralize any chlorine and thus terminate the disinfection action. Similar to the previous analysis process, the mask samples were vortexed for 2 min, and then 10-fold serial dilutions were prepared using pH 7, 100 μM phosphate buffer and plated on Trypticase soy agar plates. After incubating the plates at 37 °C for 24 h, bacterial colonies were counted for the biocidal efficacy analysis. All experiments were performed in duplicate at different times.

RESULTS AND DISCUSSION

Characterization of the Coatings. The structures of the compound MC and coated fabrics were confirmed by Fourier transform infrared (FTIR) and NMR characterization. ^{1}H NMR, ^{13}C NMR, and FTIR spectra are included in the Supporting Information. The analytical titration results for the coatings showing the presence of oxidative chlorine bonded to MC and the antimicrobial test results showing complete inactivation of the bacteria indicate that MC was indeed present in the coated fabric samples. However, it is to be emphasized that MC was not chemically bonded to the polypropylene fibers and did not affect their structures; rather MC was adsorbed on the fibers and could not be removed mechanically, but only by solubilization with water.

Shelf-life Stability of MC-Coated Polypropylene Fabrics. The results are summarized in Table 1. Fabrics that were stored in dark environmental conditions retained their initial chlorine loadings, i.e., the fabrics showed no significant chlorine loss during a 6 month time period. The variation in the chlorine loadings shown in Table 1 can be attributed to different initial sample loadings due to inconsistencies in the filter sample materials. However, when the fabrics were exposed to fluorescent light, a rapid chlorine loss was observed. Almost all of their initial chlorine loading was lost within a 2 week time period, and the remaining chlorine was lost after 3 weeks of exposure. Earlier work has reported that in order to provide antimicrobial activity, 0.04 wt % Cl^+ loading would be sufficient.[33] Fabrics can still show biocidal efficacy after 2

Table 1. Storage Stability of the MC-Coated Fabrics[a]

time (weeks)	dark storage[b]	fluorescent light[b]
initial	0.36	0.40
2	0.37	0.05
3	0.40	0
5	0.37	0
8	0.40	0
12	0.42	0
24	0.41	0

[a]The error in the measured Cl^+ loading was about ±0.01. [b]Chlorine loadings are reported in wt % Cl^+.

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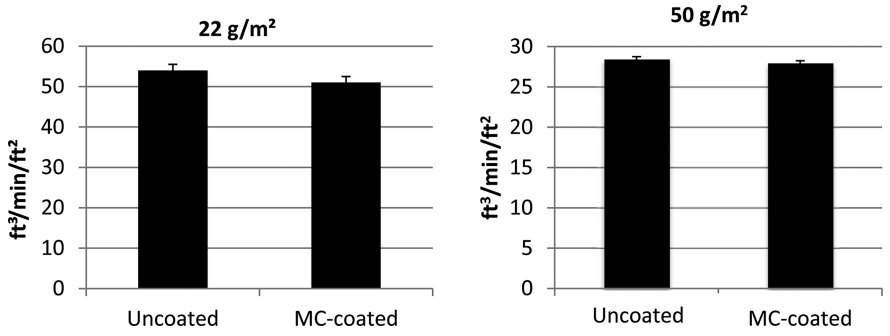

Figure 3. Air permeability of the 22 and 50 g/m^2 nonwoven fabrics.

weeks of fluorescent light exposure. The chlorine loss from the fabrics was associated with the N−Cl bond photodissociation. The MC-coated filter material should necessarily be stored in opaque packaging in a real application.

Air Permeability of the Fabrics. Figure 3 shows that the MC coating on the fabrics did not significantly influence the air permeability of the fabrics, as the air permeability of the MC-coated 50 and 22 g/m^2 fabrics remained essentially the same as for the uncoated fabrics. It was recorded that the average air permeability of the MC-coated higher weight basis fabrics (50 g/m^2) and the lower weight basis fabrics (22 g/m^2) were 28 ± 0.5 and 52.5 ± 1.5 ft^3/min/ft^2, respectively. This is due to the product development of the materials. Because 50 g/m^2 fabrics were designed to filter 95% of airborne particles, the pore sizes of the fabric were smaller than for the 22 g/m^2 fabric. In addition, the greater thickness (0.43 mm) of the 50 g/m^2 fabric could cause lower air flow permeability than for the thinner (0.16 mm) 22 g/m^2 fabric. The coated fabrics exhibited air permeability higher than most protective clothing materials currently in use and higher than for a previous antimicrobial polymer-coated polypropylene[31] and most protective clothing materials currently studied.[36]

Antimicrobial Efficacy by a Sandwich Test. Antimicrobial efficacy of the mask materials was analyzed by the sandwich contact test method. The antimicrobial efficacy of the coated (chlorinated) and uncoated (unchlorinated) swatches were evaluated by challenging both types of fabrics against *S. aureus* and *E. coli* O157:H7 where the bacteria inoculum population was 1.80 × 10^6 CFU and 1.27 × 10^6 CFU, respectively. In Table 2, antimicrobial results are summarized at different contact time intervals.

Both of the coated test fabrics, 50 and 22 g/m^2, showed significant bacterial reduction against *S. aureus* and *E. coli* O157:H7 bacteria. The uncoated (control) samples exhibited much lower reductions, even after 30 min of contact time. These reductions were due to adherence of live bacteria to the filter materials, not to inactivating bacteria. Both types of fabric showed complete 6 log inactivation against *E. coli* O157:H7 after 10 min of contact time. The fabrics exhibited a somewhat better inactivation rates against *S. aureus*.

Even though they all bear the same N-halamine compound and oxidative chlorine loadings, the inactivation rate was different between the low and high basis-weight of fabrics against *S. aureus*. Lighter weight fabrics had a slower inactivation rate than the heavier weight fabrics. The heavier fabrics showed 6.26 log reduction within 5 min of contact time; whereas, lighter fabrics provided only 4.13 log reduction. Because heavier fabrics (50 g/m^2) held a higher number of chlorine atoms then the lighter weight (22 g/m^2) fabrics due to the greater surface areas provided by the thickness of fabric, inactivation of the bacteria was much more rapid for the heavier fabrics. Although they possessed less concentration of chlorine atoms, the lighter weight fabrics were still very effective, as it required only 10 min to inactivate the *S. aureus* bacteria completely.

Table 2. Biocidal Efficacy Results of 1 wt % MC-Coated Polypropylene Nonwoven Face-Piece Material

	samples	contact time (min)	bacterial reduction (log) *S. aureus*[a]	bacterial reduction (log) *E. coli*[b]
22 g/m^2	control	30	1.64	0.047
	MC-coated Cl$^+$ % = 0.52	5	4.13	3.68
		10	6.26	6.10
		15	6.26	6.10
		30	6.26	6.10
50 g/m^2	control	30	1.69	0.023
	MC-coated Cl$^+$ % = 0.52	5	6.26	3.80
		10	6.26	6.10
		15	6.26	6.10
		30	6.26	6.10

[a]The inoculum for *S. aureus* bacteria was 1.80 × 10^6 CFU or 6.26 log per sample. [b]The inoculum for *E. coli* O157:H7 bacteria was 1.27 × 10^6 CFU or 6.10 log per sample.

Antimicrobial Efficacy by an Aerosol Test. The coated and uncoated (control) samples of both types of fabrics were tested also against *S. aureus* and *E. coli* O157:H7 by an aerosol test. The results of 50 and 22 g/m^2 polypropylene samples are shown against *E. coli* O157:H7 and *S. aureus* bioaerosols in Tables 3 and 4, respectively. It was found that both types of fabrics were remarkably effective against both types of aerosols. Untreated samples of both types of fabrics (50 and 22 g/m^2) were used as controls. For example, after 3 h of aerosol nebulization, the average *E. coli* O157:H7 bacteria loading onto 50 and 22 g/m^2 control specimens from two different sets of experiments were 2.15 × 10^3 CFU/sample and 1.60 × 10^3, respectively (Tables 3 and 4). The average viable *S. aureus* bacteria collected on the 50 and 22 g/m^2 control specimens were 6.08 × 10^4 CFU/sample and 1.92 × 10^5 CFU/sample, respectively (Tables 3 and 4). The experiments were performed on different days; therefore, different bacterial solutions were used in each experiment even though the CFU concentrations of bacteria were prepared to be the same (1 × 10^8 CFU/mL). The slight difference of bacterial loading on control samples for each experiment was as expected for these types of challenging experiments. The total number of collected *E. coli* O157:H7 aerosol CFU was consistently less than the total number of the

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Table 3. Biocidal Efficacies of 50 g/m^2 Fabrics against *E. coli* O157:H7 and *S. aureus* Bioaerosols

samples (50 g/m^2)	aerosol exposure time (h)	viable bacteria recovered (CFU/sample)			
		E. coli (exp 1)	*E. coli* (exp 2)	*S. aureus* (exp 3)	*S. aureus* (exp 4)
control	3	2.90×10^3	1.40×10^3	1.47×10^4	1.07×10^5
MC-coated Cl^+% = 0.47	3	0	0	0	0
filter[a]	3	0	0	0	0
filter[b]	3	0	0	0	0

[a]The Millipore sterile filter material on control side of the chamber. [b]The Millipore sterile filter material on MC-coated side of the chamber.

Table 4. Biocidal Efficacies of 22 g/m^2 Fabrics against *E. coli* O157:H7 and *S. aureus* Bioaerosols

samples (22 g/m^2)	aerosol exposure time (h)	viable bacteria recovered (CFU/sample)			
		E. coli (exp 5)	*E. coli* (exp 6)	*S. aureus* (exp 7)	*S. aureus* (exp 8)
control	3	1.87×10^3	1.33×10^3	1.00×10^4	3.73×10^4
MC-coated Cl^+% = 0.47	3	0	0	0	0
filter[a]	3	0	0	0	0
filter[b]	3	0	0	0	0

[a]The Millipore sterile filter material on control side of the chamber. [b]The Millipore sterile filter material on MC-coated side of the chamber.

collected *S. aureus* aerosol CFU. This could possibly be attributed to the effect of the bacterial shapes and the aerodynamic sizes. Willeke et al.[34] demonstrated that the penetration of the rod-shaped organisms (*Pseudomonas fluorescens*) through a surgical mask and a DM respirator was lower than that of the spherical organisms (*Streptococcus salivarius*), although in the current work, no organisms survived to be caught by the Millipore filters. This could be dependent on the shapes of *S. aureus* (spheres) versus *E. coli* (rods) in the nebulized air stream striking the walls of the tubing and adsorbing there. In any case, the MC-coated fabrics exhibited significant reduction against *E. coli* O157:H7 and *S. aureus* aerosols and inactivated the total concentrations of the aerosols collected on the fabrics.

When compared to current investigations on antimicrobial filter masks, the current results present greater antimicrobial activity.[20,21,36] For example, Jung et al.[20] showed a bacterial reduction after a 1200 min residence time against *Staphylococcus epidermidis*, and *E. coli*, where silver nanoparticles and carbon nanotubes were used as antimicrobial agents. After the lengthy residence time, the relative bacterial viability was determined as 32, 13, 5, and 0.9% on the control, CNT, Ag nanoparticle, and Ag/CNT modified filters, respectively, for *S. epidermidis* and 13, 2.1, 0.4, and 0.1% on the control, CNT, Ag nanoparticle, and Ag/CNT modified filters, respectively, for *E. coli*.[20] Yoon and co-workers[21] obtained complete inhibition of *E. coli* on silver-deposited activated carbon filters at a contact time of 60 min; the necessary contact time for a complete inhibition of *Bacillus subtilis* was a reasonable 10 min. Tiliket and co-workers[35] reported only filter efficiency of polyethylenimine (PEI) modified commercial nonwoven materials, but no inactivation data were provided. Zhu and co-workers have studied nanofibrous membranes coated with a novel N-halamine copolymer.[18] The efficacies of these membranes against wet *E. coli* and *S. aureus* were very good with 7 to 8 log reductions within 15 min contact time, further emphasizing the superior utility of N-halamine antimicrobials. However, air penetration of the filter materials was reduced considerably by the coating process in contrast to the current results for the MC-coated fabrics.

Moreover, a Millipore type filter material was mounted behind the test fabrics in order to collect bioaerosols that could pass through the control and coated fabrics. No viable bacteria were observed on the Millipore filter material, which indicates that both types of nonwoven fabrics were effective in capturing all of the aerosolized bacteria and were effective in inactivating the total aerosolized number of the bacteria when coated with MC. This suggests that N95 and surgical types of masks used in this research can prevent the penetration/bypass of the aerosol bacteria. Furthermore, in a real use scenario, MC would be applied to an internal melt-blown layer which would not contact the skin of the user. Hence there are no issues of biocompatibility or toxicity since MC is not volatile (mp of 157 °C) and does not emit any chlorine gas (dissociation constant lower than 10^{-11}). The filter masks would be necessarily disposable after a single use and could stored in sealed opaque packages to prevent premature contact with moisture or light, thus preventing loss of MC during long shelf-life storage.

CONCLUSIONS

Two types of polypropylene melt-blown nonwoven fabrics, having the basis-weights of 22 and 50 g/m^2, were successfully coated with 1-chloro-2,2,5,5-tetramethyl-4-imidazolidinone (MC). MC was applied onto nonwoven fabrics using a simple pad-dry technique. The effects of coating on biocidal activity and air permeability were investigated. Both types of coated fabrics revealed remarkable antimicrobial activities against *E. coli* O157:H7 and *S. aureus* bacteria. The MC coating on the fabrics did not significantly influence the air permeability of the fabrics. In addition, storage stability of the coatings was evaluated. The fabrics were stable to loss of oxidative chlorine when they were stored in a dark environment, whereas fluorescent light reduced the chlorine content of the fabrics. Surgical masks and other air filtration devices can be rendered antimicrobial by the application of the N-halamine MC in an inexpensive coating process. This represents a vast improvement over similar masks and devices that merely collect live pathogens, or very slowly inactivate them, and are thus still contaminated with active bacteria when they must be disposed of using human contact. In future work in these laboratories, protective clothing impregnated with MC will be evaluated for efficacy in inactivating virus particles given the current importance in prevention of *Ebola* transmission.

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■ ASSOCIATED CONTENT

Supporting Information

^{1}H and ^{13}C NMR spectra for compound MC and an FTIR spectrum for a 22 g/m^2 polypropylene filter material loaded with MC. This material is available free of charge via the Internet at http://pubs.acs.org.

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Notes

The authors declare no competing financial interest.

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