Engineering xxx (xxxx) xxx

Contents lists available at ScienceDirect

Engineering

journal homepage: www.elsevier.com/locate/eng

Research
Coronavirus Disease 2019—Article

Can Masks Be Reused After Hot Water Decontamination During the COVID-19 Pandemic?

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ARTICLE INFO

Article history:
Received 26 May 2020
Accepted 29 May 2020
Available online xxxx

Keywords:
Masks
Reusable
COVID-19
Decontamination
Green development concept

ABSTRACT

Masks have become one of the most indispensable pieces of personal protective equipment and are important strategic products during the coronavirus disease 2019 (COVID-19) pandemic. Due to the huge mask demand–supply gap all over the world, the development of user-friendly technologies and methods is urgently needed to effectively extend the service time of masks. In this article, we report a very simple approach for the decontamination of masks for multiple reuse during the COVID-19 pandemic. Used masks were soaked in hot water at a temperature greater than 56 °C for 30 min, based on a recommended method to kill COVID-19 virus by the National Health Commission of the People's Republic of China. The masks were then dried using an ordinary household hair dryer to recharge the masks with electrostatic charge to recover their filtration function (the so-called "hot water decontamination + charge regeneration" method). Three kinds of typical masks (disposable medical masks, surgical masks, and KN95-grade masks) were treated and tested. The filtration efficiencies of the regenerated masks were almost maintained and met the requirements of the respective standards. These findings should have important implications for the reuse of polypropylene masks during the COVID-19 pandemic. The performance evolution of masks during human wear was further studied, and a company (Zhejiang Runtu Co., Ltd.) applied this method to enable their workers to extend the use of masks. Mask use at the company was reduced from one mask per day per person to one mask every three days per person, and 122 500 masks were saved during the period from 20 February to 30 March 2020. Furthermore, a new method for detection of faulty masks based on the penetrant inspection of fluorescent nanoparticles was established, which may provide scientific guidance and technical methods for the future development of reusable masks, structural optimization, and the formulation of comprehensive performance evaluation standards.

1. Introduction

During the coronavirus disease 2019 (COVID-19) pandemic in 2020, masks have become one of the most indispensable pieces of personal protective equipment. On 20 January 2020, Prof. Nanshan Zhong, the head of the high-level expert group appointed by the National Health Commission of the People's Republic of China to fight the novel coronavirus, emphasized the importance of wearing masks in an interview with China Central Television [1]. On 22 January 2020, the spokesperson of the National Health Commission in the State Council Information Office of the People's Republic of China advocated the "mask civilization" and pointed out that "wearing masks is not only for the protection of ourselves, but also for the protection of others" [2]. However, according to the data publicly reported by the Ministry of Industry and Information Technology of the People's Republic of China, the production of masks in China was only 8 million per day on 23 January 2020 and reached 10 million per day by 2 February 2020. Given China's population of over 1.4 billion people, the huge mask demand–supply gap is obvious. According to *Technical guidance on the selection and use of masks for different population to prevent novel coronavirus*, which was released by the National Health Commission of the

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https://doi.org/10.1016/j.eng.2020.05.016
2095-8099/

Please cite this article as: D. Wang, B. C. Sun, J. X. Wang et al., Can Masks Be Reused After Hot Water Decontamination During the COVID-19 Pandemic?, Engineering, https://doi.org/10.1016/j.eng.2020.05.016

People's Republic of China on 4 February 2020, people in supermarkets, shopping malls, airports, subways, indoor offices, and other low-risk places are recommended to wear disposable medical masks or surgical masks to prevent the spread of the COVID-19 virus [3]. As a result, medical masks, which were originally designed for use in clinics and hospitals, are now widely used and appear in stations, airports, markets, parks, and other public places. The technical guideline also indicated that during the COVID-19 pandemic, the use of masks may be appropriately extended (including the duration of single use and times of repeated use) if it is safe to do so. In particular, people in low-risk places are recommended to reuse masks. However, the existing national standards and local standards for masks mainly focus on the performance of disposable masks, and there are no specific requirements or instructions on mask performance for multiple uses, including the duration of a single use, disinfection methods, and the number of times a mask can safely be reused. How can masks be efficiently sanitized for multiple uses during the COVID-19 pandemic? Are masks damaged during decontamination treatment? How many times can masks be decontaminated by appropriate methods? In fact, there is no scientific theory or experimental data support to answer these questions. During the mask shortage, most people—including front-line medical staff—have been spontaneously reusing masks several times, which eases the tension between supply and demand to a certain extent; however, this practice might also increase these people's risk of exposure. Therefore, user-friendly technologies and methods are urgently needed to effectively extend the service time of masks.

Masks, including disposable medical masks, surgical masks, medical protective masks, and dust masks, are usually made of non-woven polypropylene fabric with electrostatic properties that enhance particle capture. The electrostatic charge keeps airborne particles out by drawing them onto the fiber surfaces, much like iron filings are drawn onto a magnet. The spaces between the fibers of the mask at the microscale are much larger than the sizes of bacterial viruses and respiratory aerosols/droplets, so masks are not able to block particles at the nanoscale by means of mechanical filtration. Therefore, the electrostatic charge on the fibers plays an important role in intercepting virus particles with diameters of 100 nm and aerosols/droplets containing bacterial viruses. In the process of using the mask, elimination of the electrostatic charge layer occurs along with the deposition of bacteria viruses and haze (water vapor) onto the electrostatic layers, which causes a decline in filtration efficiency and even invalidation of the protective performance of the mask. Therefore, during the COVID-19 pandemic, if people are driven by necessity to extend the use of masks that were originally designed and marketed as disposable masks, there are two points to consider: first, user-friendly decontamination to kill possible COVID-19 viruses on the used masks; and, second, efficiently controlled charge regeneration of masks to maintain mask performance for reuse. On 14 February 2020, the ScienceNet website reported a preliminary "regeneration treatment" approach toward the reuse of disposable masks developed by our group at Beijing University of Chemical Technology [4]. Advice was given to soak used medical masks in hot water at a temperature greater than 56 °C (typically 60–80 °C) for 30 min for decontamination. Ordinary household appliances such as a hair dryer, electric fan, or electronic igniter would then be used to dry the masks and recharge them with electrostatic charge. Successful regeneration of a mask could be confirmed by sprinkling the mask with small scraps of paper at home, without the need for special professional instruments [4]. According to official guidance from *Prevention and control program of COVID-19 (4th edition)* released by the National Health Commission of the People's Republic of China on 6 February 2020 [5], this temperature (> 56 °C) and time (30 min) are efficient for killing the COVID-19 virus. The charge-regeneration procedure aims to infuse the filter with electrostatic charge, which is the key contributor to a mask's high level of filtration.

In this article, we summarize our experimental results and evaluations on three kinds of typical masks (disposable medical masks, surgical masks, KN95-grade masks) treated by the so-called "hot water decontamination + charge regeneration" approach. The evolution of static electricity on the masks is revealed. The microstructures of the masks were studied by scanning electron microscope (SEM) and the waterproof properties were assessed by the hydrostatic pressure method. The filterability of the masks was tested according to respective national standards and local standards. The performance of the KN95-grade masks in 121 °C steam for 30 min, which is a well-accepted approach for killing almost all pathogens, was also investigated. Furthermore, a method based on fluorescent nanoparticle penetrant inspection was proposed for the detection of inner defects in used masks, in order to provide necessary data for the development of reusable masks, structural optimization, and evaluation standards.

2. Materials and methods

2.1. Samples

Three types of disposable masks were tested: disposable medical masks (CHTC Jiahua Non-woven Co., Ltd., China), disposable surgical masks (from three locations: ESound Medical Device Co., Ltd., Anbang Medical Supplies Co., Ltd., and Yubei Medical Supplies Co., Ltd., China), and KN95-grade masks (the 3M 9502 and KF94 masks from the Republic of Korea). These masks are referred to herein as "JH," "YX," "AB," "YB," "3M," and "KF," respectively.

2.2. Hot water decontamination and charge regeneration

Three kinds of containers, including a household aluminum basin, a polypropylene plastic lunch box, and a stainless steel thermos cup, were used in the experiments. In a typical procedure, boiling water was directly poured into the container at room temperature. The volume of water exceeded 80% of the total capacity of the container and the temperature was measured by a thermometer. The mask was immersed in the water by placing a heavier object on top of it, such as a spoon. The container was then closed and the mask was left to soak in the hot water for 30 min. After that, the container was opened and the mask was removed from the hot water. The liquid on the mask was slightly shaken off and the mask was placed on the surface of dry insulating material, such as wooden, plastic tables, and bed sheets. The mask was then dried with a standard hair dryer for 10 min.

2.3. Static electricity test

A hand-held electrostatic field meter (FMX-004; Simco, Japan) was used to test the electrostatic charge of mask. The mask to be tested was hung on an insulation component at least 5 m away from other instruments with static electricity in order to avoid interference from other static electricity fields. Before measurement, the researcher washed his or her hands with water to remove static electricity from the hands. The probe was gradually moved closer to the measurement position on the mask until the two laser dots from the electrostatic field meter coincided. The value of the instrument readings was recorded.

2.4. Waterproof test

Waterproof testing of the masks was performed by a Buchner funnel procedure. To summarize, the mask was placed at the bot-

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tom of the bowl, with the outer surface of the mask facing upward. A hose pipe was used to attach the filter flask sidearm onto the vacuum aspirator. A vacuum aspirator operating at 30 L·min^{-1} was used for the suction of liquids, through the filter paper. A total of 100 mL water was then poured onto the surface of mask within 20 s from a height of 20 cm. The pumping filtration was maintained for 3 min and the flask was watched to see if water dropped down. Then the water was removed from the Buchner funnel, and the vacuum suction system was turned off. The inner surface of the mask was then observed to determine the wettability/waterproofness of the mask.

2.5. Filterability test

The filtration efficiency of the samples for sodium chloride (NaCl) particles was measured by using TSI 8130 equipment (TSI Incorporated, USA). The particle size distribution of the NaCl aerosol for the specified test conditions was the median diameter of the number of particles at (0.075 ± 0.020) μm. The geometric standard deviation did not exceed 1.86 and the concentration did not exceed 200 mg·m^{-3}. The detection system had a device to neutralize the charged particles. To test the KN95-grade masks, the gas flow rate was stabilized to (85 ± 4) L·min^{-1}, while to test the disposable medical masks and surgical masks, the gas flow rate was stabilized to (30 ± 2) L·min^{-1}, and the cross-sectional area of the air flow was 100 cm^2.

3. Results and discussion

3.1. Decontamination of masks

It has been well accepted that the COVID-19 virus can be killed after being maintained at over 56 °C for 30 min [5]. Due to thermal activation, the envelope protein of the virus will denature and the virus will lose its infectious ability. Therefore, high-temperature treatment is an effective way to kill the virus. In our work, we proposed the hot water method for mask decontamination; that is, killing the potential COVID-19 virus on a used mask by keeping the mask in hot water at greater than 56 °C for 30 min [5]. Fig. 1(a) shows the three types of containers used in our experiments: a household aluminum basin, a polypropylene plastic lunch box, and a stainless steel thermos cup. When boiling water was first poured into the container at a room temperature of 20 °C, the temperature of the water was measured at around 90 °C, and decreased as time passed. After 30 min, the temperatures of the water in the covered aluminum basin and in the polypropylene plastic lunch box were both around 60 °C, and the temperature of the water in the stainless steel thermos cup was 85 °C (Fig. 1(b)). Thus, the hot water approach for mask decontamination is easy to achieve at home. Compared with other proposed decontamination methods for masks, such as organic solvent, ultraviolet (UV) radiation, and hydrogen peroxide steam, hot water decontamination is more suitable for people to perform at home without the use of additional solvents or high-tech equipment. In addition, this approach has the advantage of cleaning the mask to some degree. Fig. 1(c) shows a typical used mask that has been worn for 4 h. Although the used mask looks as good as new, some fluorescent spots were clearly observed under a 365 nm UV lamp. The fluorescence signal was generated by wastes from the oral cavity and respiratory tract of the user. These wastes were adsorbed on the masks, making the masks smell bad. After decontamination of the used mask in hot water, followed by drying treatment, no fluorescent spots were observed on the masks under the UV lamp (Fig. 1(d)) and there was no bad smell from the masks.

3.2. Variation of electrostatic quantity

Typical masks are composed of three layers of non-woven fabric (Fig. 2(a)). The outer layer is a waterproof non-woven fabric that is used to isolate the liquid sprayed by others, and the inner layer is a common non-woven fabric that absorbs the moisture released by the wearer. The filter layer in the middle, which is composed of a polypropylene melt-blown non-woven fabric treated with electret, serves as a barrier against germs. In typical masks, the melt-blown filter layer is 100–1000 μm thick and is composed of polypropylene microfibers with diameters in the range of 1–10 μm (Figs. 2(b) and (c)). The filtering mechanism of a typical mask involves Brownian diffusion, entrapment, inertial collision, gravity sedimentation, and electrostatic adsorption. Among these factors, electrostatic adsorption is critical for masks to capture nanosized particles in order to achieve high filterability while maintaining low gas resistance. During mask decontamination in hot water, the static electricity disappears. To reuse a mask, the microfibers of the melt-blown filter layers must be recharged with static electricity to capture nanoparticles. After naturally air-drying masks for 10 h in our experiment, the static electricity of the surgical masks was recovered to 60% of the level of new masks (Fig. 2(d)), due to

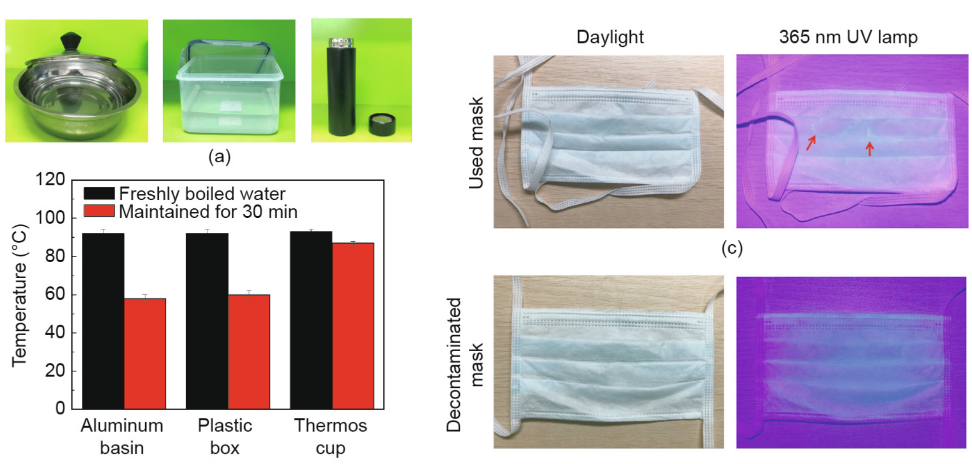

Fig. 1. (a) Three types of containers used in our experiments: a household aluminum basin, a polypropylene plastic lunch box, and a stainless steel thermos cup; (b) the temperature of freshly boiled water when first poured into the containers and then after 30 min; (c) photographs of a typical used mask under daylight and under 365 nm UV lamp excitation, as well as (d) the same mask after decontamination in hot water.

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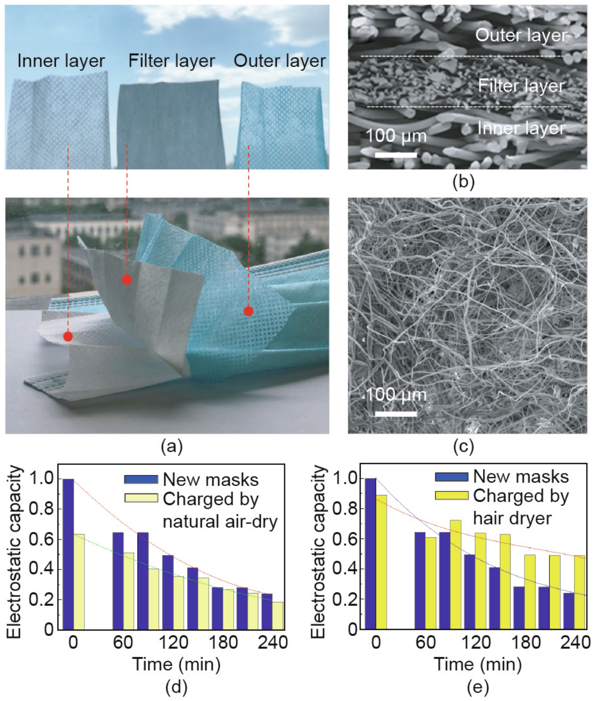

Fig. 2. (a) Photographs of the triple-layer structure of a typical surgical mask; (b) an SEM cross-section image revealing the microstructures of the three layers of a typical surgical mask; (c) an SEM image of the melt-blown fibers of the filter layer; (d) the electrostatic capacity of the filter layers of new masks and of recharged masks that have been naturally air-dried for 10 h; (e) the electrostatic capacity of the filter layers of new masks and of recharged masks that have been dried using a standard hair dryer for 10 min.

micro-friction of the microfibers caused by the air flow of the drying process. However, when a more effective method was used—that is, drying the mask with a standard hair dryer for 10 min—the static electricity of the surgical mask was recovered to 90% of the level of a new mask (Fig. 2(e)). These results indicate that the electrostatic charge attenuation velocity of a regenerated mask is similar as that of a new mask. Therefore, it is feasible and effective to recharge a mask with static electricity. Compared with natural air-dry processing, the use of a standard hair dryer removes the moisture from a wet mask more quickly and recharges the mask with static electricity more efficiently. This method is particularly suitable for rapid charge regeneration of masks in humid regions or during humid weather. In addition, allowing a mask to air-dry naturally over a long period of time allows the potential growth of a large amount of bacteria and microorganisms. In contrast, rapidly regenerating the charge after a mask has been decontaminated in hot water prevents the growth of bacteria inside the mask.

3.3. Waterproof property and microstructure analysis

As mentioned above, the outer layer of a mask is usually made of a waterproof non-woven fabric to isolate the liquid sprayed by others. Therefore, a mask's waterproof property is a key factor for ensuring the mask's performance in blocking the microorganisms in liquid droplets. Using a hydrostatic testing method (Fig. 3(a)), we demonstrated that the regenerated masks presented good water resistance. Even after masks had been repeatedly treated for 10 cycles of decontamination (soaking in hot water for 30 min) and charge regeneration (drying with a hair dryer for 10 min), they still maintained a good waterproof property; that is, no water seepage was observed in the inner layers of the masks (Fig. 3(b)). These results indicate that decontamination and regeneration processing over 10 cycles did not damage the structure of the polypropylene fibers. As seen in the SEM images, the microstructures of the regenerated masks were similar to those of new masks, and no significant fiber breakage or fracturing was observed in either the outer layers (Fig. 3(c)) or the filter layers (Fig. 3(d)).

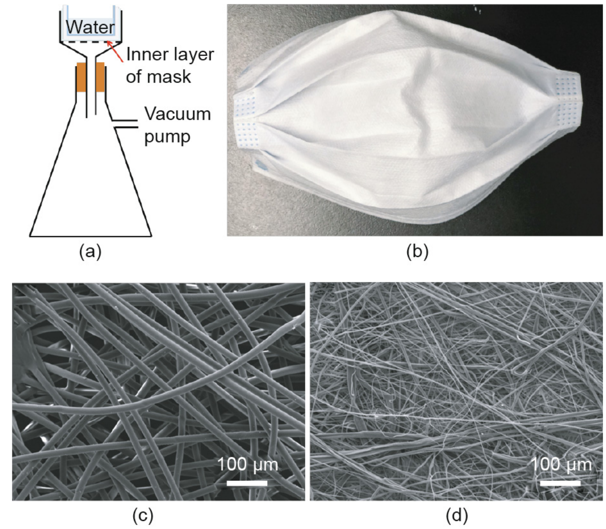

Fig. 3. (a) Schematic illustration for testing the waterproof property of masks; (b) photographs of the inner layer of the mask after testing; (c) SEM image of the outer layer of the mask; (d) SEM image of the filter layer of the mask.

3.4. Effects of decontamination on mask filterability

As typical personal protective equipment, masks are used to block microorganisms, droplets, pollen, and other particles. Thus, filterability is one of the most important indexes of a mask. In our experiments, the filterability of three typical mask types (disposable medical masks, surgical masks, KN95-grade masks,) was tested after hot water decontamination and charge-regeneration treatments, following the rules of the respective national standards or industrial standards in China. To summarize, the regenerated masks were treated by soaking in hot water at 56 °C for 30 min and were then dried using a standard hair dryer for 10 min. A bacterial filtration efficiency (BFE) test determines the filtration efficiency by comparing the bacterial control counts with the test article effluent counts, and is a key performance indicator for both disposable medical masks and surgical masks. According to the standards for a single-use medical face mask (YY/T 0969–2013) and a surgical mask (YY 0469–2011), the BFE of these masks should be no less than 95%. Fig. 4 shows the BFE values of a regenerated disposable medical mask (JH) and a regenerated surgical mask (YB) in our experiments, which are higher than 95% (Fig. 4(a)). A particle filtration efficiency (PFE) test evaluates the nonviable particle retention or filtration efficiency of filter media and other filtration devices at sub-micron levels. The standards for single-use medical face masks (YY/T 0969–2013) have no requirement for PFE, whereas the standards for surgical masks (YY 0469–2011) state that the PFE should be no less than 30% under specific conditions. In our experiments, we found that most of the regenerated surgical masks had a PFE much higher than 30%, with an average value of 92.3%. For KN95-grade masks, the PFE should be no less than 95% under specific conditions, according to the Chinese national standard GB 2626–2019. In our experiment, the KN95-grade masks (3M and KF) retained a PFE greater than 95% (Fig. 4(b)). In order to investigate the effects of the regeneration treatment on the properties of the masks, we prepared samples of five different brands of masks (JH, AB, YX, 3M,

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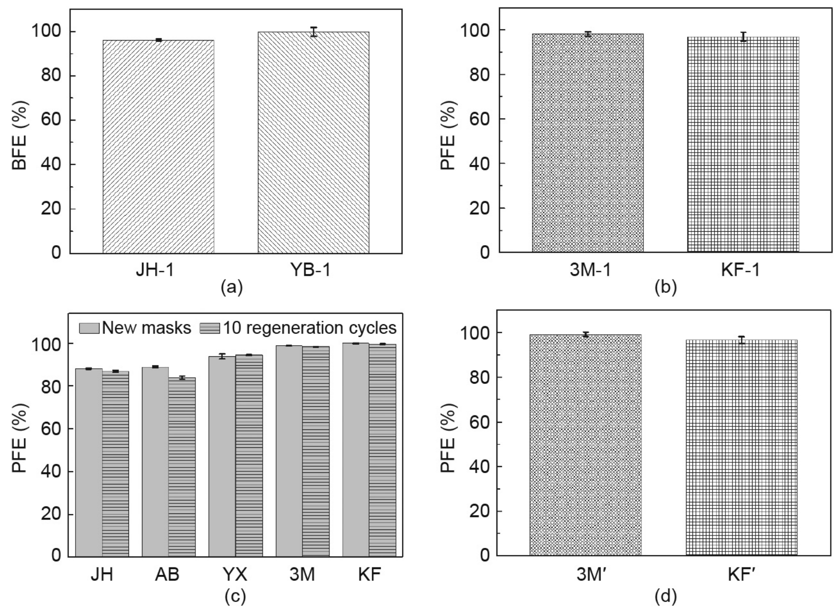

Fig. 4. (a) BFE results of a regenerated disposable medical mask (JH) and a regenerated surgical mask (YB). (b) PFE results of regenerated KN95-grade masks. (c) PFE results of new and regenerated masks after 10 regeneration cycles. The PFE of new and regenerated disposable medical masks (JH) and surgical masks (AB and YX) was tested according to the Chinese industrial standard YY 0469–2011, using a gas flow rate of 30 L·min^{-1}. The PFE of new and regenerated KN95-grade masks (3M and KF) was tested according to the Chinese national standard GB 2626–2019, using a gas flow rate of 85 L·min^{-1}. (d) The PFE of KN95-grade masks after decontamination with pressurized steam at 121 °C for 30 min, followed by charge regeneration.

and KF) that were treated by hot water decontamination and charge-regeneration processing for 10 cycles. As shown in Fig. 4(c), regeneration processing over 10 cycles had little effect on the filtration properties. Furthermore, we extended our investigations to decontamination treatment at a higher temperature. The KN95-grade masks (3M and KF) were placed in an autoclave, covered with a clean piece of cloth to avoid damage from heavy turbulence. Steam sterilization is the most widely available and dependable method for disinfection and sterilization in healthcare facilities, and most hospitals and many clinics already have the necessary materials on hand to sterilize surgical equipment. In our experiments, the masks were treated by pressurized steam at 121 °C for 30 min. The average PFE of the 3M 1860 masks after steam sterilization was measured to be 99.2% and that of the KF94 masks was 96.6% (Fig. 4(d)). According to the experimental results, the regenerated masks was still at a relatively high level; therefore, the regenerated masks should have a significant effect on blocking microorganisms, droplets, pollen, and other particles.

3.5. Effects of actual service processing

In order to study the influence of actual service processing on masks, we examined mask samples that had been worn for 8 h by participants. For surgical masks, the effects of wearing varied among individuals and for the same individuals at different times. After being worn for 8 h, followed by hot water decontamination and charge regeneration, the PFE values of the surgical masks decreased by 0.5%–12% in our experiments, based on the testing of 15 samples. However, all of the tested KN95-grade masks (10 samples) that had been worn for 8 h, followed by hot water decontamination and charge regeneration, were able to retain filtration efficiencies greater than 95%. It was observed that the waterproof property of masks that were worn might change, as a result of the adsorption of dirt and oil from the participants' skin. Fig. 5(a) shows droplets on the surface of the outer layer of a typical disposable medical mask under daylight and under a 365 nm UV lamp, respectively. Under UV excitation, the droplets of water lacked brightness but the fluorescent nanodispersion droplets exhibited a bright blue emission due to the fluorescence of the carbon nanodots. After removing the droplets, no significant marks of the fluorescent nanoparticles were observed (Fig. 5(b)), indicating the excellent resistance to wetting of the outer layer of the mask. However, if the wettability of the masks was enhanced by potential interfacial reactions between dirt/oil and the fibers, a spontaneous infiltration process could be promoted. In this work, we developed a fluorescent liquid penetrant test based on fluorescent nanodispersion for investigating masks. To summarize, water-dispersible carbon nanodots [6] were sprayed onto the surface of the outer layer of the mask, and the liquid drops were then allowed to remain for 30 min while the penetrant was sinking into the mask. After that, the excess liquid on the surface of the outer layer of the mask was removed, and the inner layer of the mask was inspected under the irradiation of a hand-held UV lamp with emission at 365 nm. As shown in Fig. 5(c), no significant fluorescence signal of the nanodots was observed when testing new masks. However, the fluorescent nanoparticles penetrated into the surface defects of a mask that was damaged by oil, with the fluorescence signal mainly being concentrated in the "damaged area," where the hydrophobicity of the fibers changed. These findings may aid in the development of new materials and design strategies for reusable masks.

3.6. Practical application

A Chinese company named Zhejiang Runtu Co., Ltd., which is a large-scale stock enterprise with over 4000 staff members engaged in producing and selling disperse dyes, reactive dyes, chemical intermediates, and so forth, faced a shortage of masks in mid-February 2020, when the workers resumed work. To carry out scientific and orderly prevention and control work in accordance with the law, the workers needed to wear masks during the COVID-19 pandemic. However, it was difficult to obtain enough mask supplies in China from February to March 2020. Scientific and technical engineers at Runtu learned about our technology, which had been reported by ScienceNet [4], and independently verified the engineering feasibility of the hot water decontamination and

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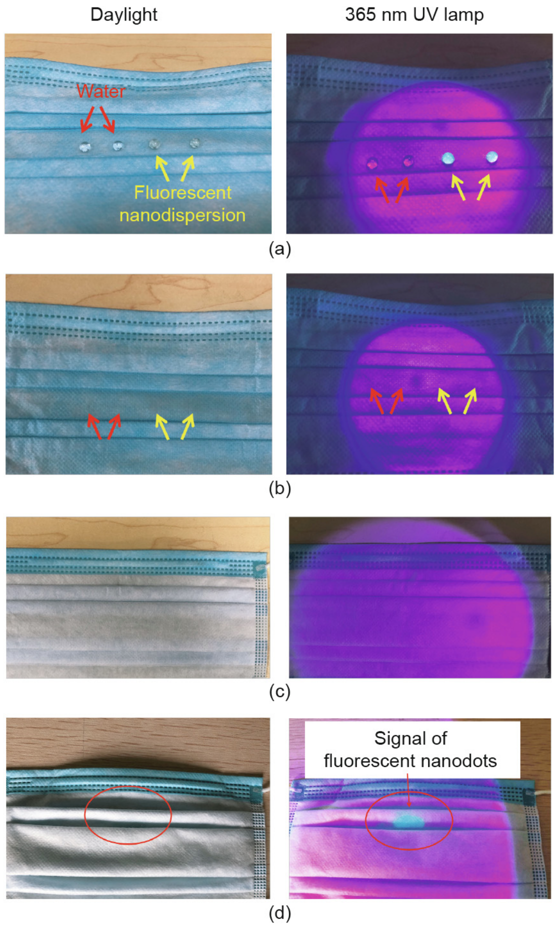

Fig. 5. Photographs of the outer layer of (a) a typical disposable medical mask with liquid droplets of water and fluorescent nanodispersion on the surface and (b) the same mask after removing the droplets. The inner layer of (c) a new mask and (d) a mask with a patch of oil after fluorescent liquid penetrant testing. The photographs in the left column were taken under daylight, while the photographs in the right column were taken under 365 nm UV light.

charge-regeneration method. The company then required their workers to apply the hot water decontamination and charge-regeneration method in order to safely and effectively reuse their masks. Between 20 February and 30 March 2020, mask usage at Runtu was reduced from one mask per day per person to one mask every three days per person, and 122 500 masks were saved by this company during the COVID-19 pandemic in China [7,8].

4. Conclusions

Masks have been recommended as a powerful tool to tackle the COVID-19 pandemic. In many countries around the world, people are not allowed into public places or on public transportation without wearing masks [9]. Growing evidence is demonstrating the benefits of wearing masks in preventing the transmission of human coronaviruses and influenza viruses from symptomatic individuals [10]. However, the limited productivity and scarce resources cannot meet the ever-increasing demand for masks. Meanwhile, pollution caused by waste masks is having an adverse effect on the economic development of society and on the ecological environment. Therefore, the development of user-friendly methods to effectively extend the service time of masks is urgently needed. Our group proposed a specifically designed method for household use to extend the use of disposable masks in mid-February 2020. In this article, we summarize our experimental results and evaluations on three typical kinds of mask (disposable medical masks, surgical masks, and KN95-grade masks) treated by the so-called "hot water decontamination + charge regeneration" approach. We provide solid evidence that the essential performance of the masks was maintained after decontamination for up to 10 cycles. It should be noted that several other technical solutions for N95 respirators have been reported very recently. For example, researchers at the University of Nebraska Medical Center built towers of UV bulbs to kill viruses on masks, while Bioquell Inc. manufactured hydrogen peroxide vapor generators for the decontamination of N95 masks for multiple use [11]. Scientists at 4C Air, Inc. and at Stanford University have reported that heat ($\leq$ 85 °C) under various levels of humidity ($\leq$ 100% relative humidity) is a promising, nondestructive method for the preservation of the filtration properties in N95-grade respirators, since they have found that UV light can potentially impact the material strength and subsequent sealing of masks [12].

Compared with approaches that use "high-tech" equipment such as UV radiation towers, hydrogen peroxide vapor generators, or constant-temperature cabinets, our work provides a simpler and more convenient method for the decontamination of masks during the COVID-19 pandemic. By soaking the masks in hot water at greater than 56 °C for 30 min, viruses are killed and the dirt on the surface of the masks is removed. After the mask is dried with a standard hair dryer for 10 min, the static electricity of the surgical mask can be recovered to 90% of the level of a new mask. According to tests on three typical kinds of masks (disposable medical masks, surgical masks, and KN95-grade masks), all of the regenerated masks retained a similar waterproof property, microstructure, and filterability in comparison with the respective new masks. For the KN95-grade masks with good quality, we found that the masks retained a PFE greater than 95% after being treated in pressurized steam at 121 °C for 30 min. These results demonstrate that the regenerated masks should have a significant effect in blocking microorganisms, droplets, pollen, and other particles. We also studied the influence of actual service processing on masks. For surgical masks, the effects of wearing vary among individuals and for the same individual at different times. After being worn for 8 h, followed by hot water decontamination and charge regeneration, the PFE values of surgical masks decreased by 0.5%–12% in our experiments on 15 samples. However, all tested samples of KN95-grade masks that had been worn for 8 h, followed by pressurized steam at 121 °C for 30 min and charge regeneration, were able to retain filtration efficiencies greater than 95%. A fluorescent liquid penetrant test based on fluorescent nanodispersion for investigating masks was carried out, and revealed that the adsorption of dirt and oil from participants' skin was partly responsible for changes in the wettability and filterability of polypropylene masks. Many researchers have made great efforts regarding the reuse of masks, and have conducted active and beneficial exploration. Some industry associations have issued related standards to ensure the quality and life of masks for multiple reuses, including the standards for reusable civil masks (T/BJFX 0001–2020) and for reusable daily protective masks (T/CSTM 00387–2020) that have been released by industry associations in China. Many productions of reusable masks are coming onto the market [13]. We hope that this short communication article can contribute to alleviating the panic over mask shortage and to promoting new methods for the detection of mask damage zones and the optimal design of reusable masks.

Acknowledgements

We are grateful for financial support from the National Key Research and Development Program of China (2020YFC0844800).

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Compliance with ethics guidelines

Dan Wang, Bao-Chang Sun, Jie-Xin Wang, Yun-Yun Zhou, Zhuo-Wei Chen, Yan Fang, Wei-Hua Yue, Si-Min Liu, Ke-Yang Liu, Xiao-Fei Zeng, Guang-Wen Chu, and Jian-Feng Chen declare that they have no conflict of interest or financial conflicts to disclose.

References

[1] [How is the COVID-19 going?] [video]. Beijing: China Central Television; 2020 Jan 20 [cited 2020 May 1]. Available from: http://tv.cctv.com/2020/01/20/VIDECRZF7PWXb80z86QyB0db200120.shtml. Chinese.

[2] Qu T, Wang BY. [The National Health Commission of the People's Republic of China suggested wearing a mask to promote "mask civilization"] [Internet]. Beijing: XinhuaNet; 2020 Jan 22 [cited 2020 May 1]. Available from: http://www.xinhuanet.com/2020-01/22/c_1125493839.htm. Chinese.

[3] [Joint Prevention and Control Mechanism of the State Council: technical guidance on the selection and use of masks for different population to prevent novel coronavirus] [Internet]. Beijing: Joint Prevention and Control Mechanism of the State Council in Response to the Novel Coronavirus Pneumonia; 2020 Feb 4 [cited 2020 May 1]. Available from: http://www.gov.cn/xinwen/2020-02/05/content_5474774.htm. Chinese.

[4] Cheng W. [Can't buy mask? It can be reused after regeneration treatment!] [Internet]. Beijing: ScienceNet; 2020 Feb 14 [cited 2020 May 1]. Available from: http://news.sciencenet.cn/htmlnews/2020/2/435754.shtm. Chinese.

[5] National Health Commission of the People's Republic of China. [Prevention and control program of COVID-19 (4th edition)]. Beijing: General Office of National Health Commission of the People's Republic of China; 2020 Feb 6 [cited 2020 May 1]. Available from: http://www.nhc.gov.cn/jkj/s3577/202002/573340613ab243b3a7f61df260551dd4/files/c791e5a7ea5149f680fdcb34dac0f54e.pdf. Chinese.

[6] Wang D, Wang Z, Zhan Q, Pu Y, Wang JX, Foster NR, et al. Facile and scalable preparation of fluorescent carbon dots for multifunctional applications. Engineering 2017;3(3):402–8.

[7] Cheng W. [Technology of reuse of masks helps to fight against virus] [Internet]. Beijing: ScienceNet; 2020 Apr 28 [cited 2020 May 1]. Available from: http://news.sciencenet.cn/htmlnews/2020/4/439043.shtm. Chinese.

[8] Liu Y. Charge regeneration to make full use of each mask [Internet]. Beijing: Science and Technology Daily; 2020 Apr 29 [cited 2020 May 1]. Available from: http://digitalpaper.stdaily.com/http_www.kjrb.com/kjrb/html/2020-04/29/content_444079.htm. Chinese.

[9] Feng S, Shen C, Xia N, Song W, Fan M, Cowling BJ. Rational use of face masks in the COVID-19 pandemic. Lancet Respir Med 2020;8(5):434–6.

[10] Leung NHL, Chu DKW, Shiu EYC, Chan KH, McDevitt JJ, Hau BJP, et al. Respiratory virus shedding in exhaled breath and efficacy of face masks. Nat Med 2020;26:676–80.

[11] Mackenzie D. Reuse of N95 Masks. Engineering 2020;6(6):593 6.

[12] Liao L, Xiao W, Zhao M, Yu X, Wang H, Wang Q, et al. Can N95 respirators be reused after disinfection? How many times? ACS Nano 2020;14(5):6348–56.

[13] Zhang Z, Xing Y. New reusable face masks in production [Internet]. Beijing: China Daily; 2020 Mar 2 [cited 2020 May 1]. Available from: https://www.chinadailyhk.com/article/122864.

Please cite this article as: D. Wang, B. C. Sun, J. X. Wang et al., Can Masks Be Reused After Hot Water Decontamination During the COVID-19 Pandemic?, Engineering, https://doi.org/10.1016/j.eng.2020.05.016