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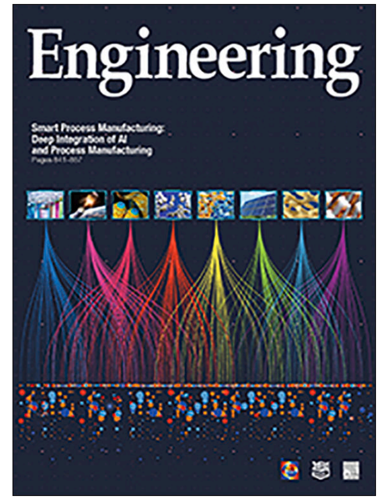

News & Highlights

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Dana Mackenzie

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Reuse of N95 Masks

Dana Mackenzie

Senior Technology Writer
dave.egerter@gmail.com

As the COVID-19 pandemic enters its second month (April 2020) in the United States, one of the simplest pieces of medical equipment is in desperately short supply: medical-grade protective facemasks, typically engineered and specified for a single use only. Now, to meet the critical and quickly intensifying need, Chinese and American engineers are devising new procedures for decontaminating and reusing masks that hospitals already have on hand (Fig. 1) [1]. Although some of these procedures require specialized equipment, others are simple enough to use at home (Fig. 2) [2,3].

Fig. 1. N95 masks, like the “CLEAN” ones shown here, are being reused at Duke University Hospitals (Durham, North Carolina) after decontamination using a Bioquell (Horsham, Pennsylvania) Z-2 device (see Fig. 2) that uses hydrogen peroxide vapor for sterilization [1]. Credit: Duke University, with permission.

Fig. 2. The "regeneration treatment" decontamination process for mask reuse developed by Professor Jian-Feng Chen and colleagues at Beijing University of Chemical Technology is recommended only for non-medical, household use [2,3], per the instructions provided in this graphic. Credit: Courtesy of J-F Chen.

How do you kill a virus? It is not very hard, as long as the virus is not in a human body. "The simplest way is to take a mask and let it sit out for two weeks," said Michael Mina, an assistant professor of epidemiology at Harvard University's T.H. Chan School of Public Health. "We know the virus tends to die out after ten days or so." However, such a slow solution is not especially practical.

Five fast ways to kill a virus are to irradiate it, fumigate it, heat it in hot water, steam it, or bake it. Each of these approaches seems to be effective, but that is not the only criterion for a successful decontamination. It is also important for masks to come out of the decontamination process as good as new. According to a technical bulletin from 3M (Maplewood, MN), the largest manufacturer of N95 masks in the United States, there are four criteria a good decontamination method should satisfy: it should ① be effective against the target organism, such as the SARS-CoV-2 virus that causes COVID-19; ② not damage the respirator's filtration; ③ not affect the respirator's fit; and ④ be safe for the person wearing it [4].

Some obvious methods fail these tests. Microwaving, for example, can partially melt the masks [5]. Alcohol and bleach destroy the static charge within the mask, which is vital to its proper function [5,6]. The active layer of an N95 mask is 90% empty space, so the fibers need help to trap 95% of the particles that pass through—they get that help from static electricity [6,7].

1. Ultraviolet Radiation and Fumigation

The first of the five methods mentioned above, ultraviolet radiation (UV), is now being employed at the University of Nebraska Medical Center in Lincoln, Nebraska [8,9]. Their procedure places two towers, each containing eight ultraviolet C (UVC) bulbs, in a room with walls coated with reflective paint (Fig. 3) [9]. The masks are hung from clotheslines, and the room has a capacity of 90 masks. Testing shows that 15 min of UVC radiation is enough to kill the virus [9].

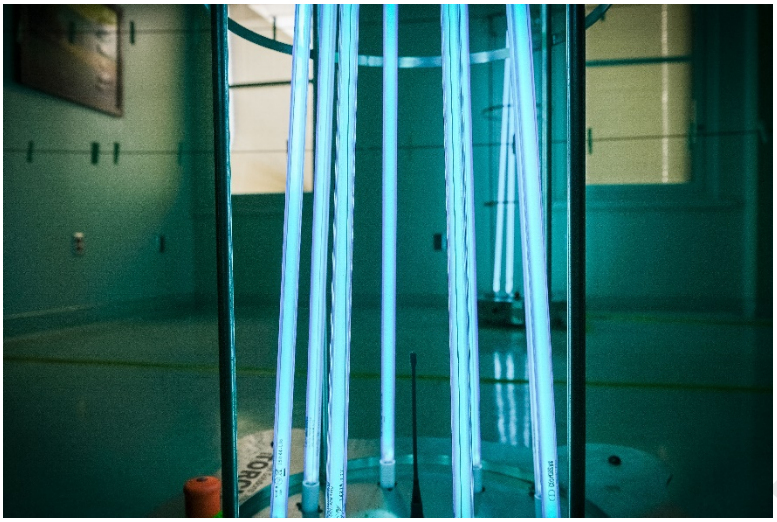

Fig. 3. The University of Nebraska Medical Center uses UV radiation to sterilize N95 masks for reuse by medical personnel [9]. Used masks are hung on clotheslines between two towers that each shine eight UVC bulbs; a 15 min exposure suffices for sterilization, and 90 masks may be treated at one time. Credit: University of Nebraska, with permission.

A second alternative is fumigation. Duke University Hospitals (Durham, North Carolina) are now using—and testing—systems manufactured by Bioquell, Inc. (Horsham, Pennsylvania), which exposes the masks to vaporized hydrogen peroxide [1]. Depending on the machine used, the amount of hydrogen peroxide gradually builds up to 300–750 ppm (1 ppm = 1×10^{-6}) and is held there for 20 min. The most time-consuming part of the procedure is de-gassing; it usually takes 4 h before the decontamination room is safe to enter. But the masks are safe to wear after that, because the hydrogen peroxide decomposes into oxygen and water. Using the Bioquell Z-2 hydrogen peroxide vapor generator (Fig. 4), the Duke staff can disinfect 1250 masks per cycle, and 2500 per 12 h shift [1].

Fig. 4. Using a Bioquell (Horsham, Pennsylvania) hydrogen peroxide vapor generator, Duke University Hospitals staff can disinfect, for reuse, 1250 masks per cycle, and 2500 per 12 h shift [1]. A larger version of the set up manufactured and operated by Battelle (Columbus, Ohio) can process 80 000 used masks per day, enough to supply multiple hospitals and even hospital systems [10]. Credit: Duke University, with permission.

But both the UV and hydrogen peroxide methods require equipment that not all hospitals have on hand. "I worry that places around the globe will not have enough masks, and reuse will be incredibly important," said Mina. "I would encourage my colleagues to think about solutions that will work for hospitals without high-tech resources."

2. Hot Water Heating and Steaming

For settings without such resources, three potential solutions are heating in hot water, steaming, and baking. By mid-February 2020, a Beijing University of Chemical Technology team led by Jian-Feng Chen, professor and director of the state key laboratory of organic–inorganic composites, had developed a "regeneration treatment" for reusing disposable masks [2,3]. Designed specifically for household use, the method involves two steps (Fig. 2). The first step calls for steeping used masks in hot water at a temperature > 56 °C (typically 60–80 °C) for 30 min. The temperature and timing are based on guidance from the National Health Commission of the People's Republic of China for killing the COVID-19 coronavirus [2]. In the second step, essential to restoring the electrostatic charge critical to their filtering function, the masks are dried with a standard—but non-static—hair dryer for 10 min. Successful regeneration is confirmed by sprinkling the mask with small scraps of paper—if the paper sticks, the electrostatic charge has been restored.

Using this method, the group found that mask performance is maintained for filtering efficiency and resistance to airflow after one decontamination and, with surgical masks, after ten cycles of decontamination (Table 1) [2]. The group notes, however, that this method is recommended only for individuals at low risk for infection and without access to new masks, and not for healthcare professionals [2,3].

Table 1.

Filterability for 0.1 μm particles in new and used (8 h) masks after regeneration treatment [2], tested per China National Standard GB 2626-2006.

Mask type	Status	Sample size	Filterability for 0.1 μm particles, mean (range), %	Example photographs
KF94 (Air Puri)	New	3	98.6 (97.4–99.9)	
	Regenerated, 1 cycle	3	98.1 (97.7–98.5)	
Disposable medical (Hubei Lexin)	New	5	46.5 (45.8–46.8)	
	Regenerated, 1 cycle	5	46.0 (44.3–47.2)	
Disposable surgical (Henan Yubei)	New	5	76.9 (73.9–78.5)	
	Regenerated, 1 cycle	5	75.5 (74.9–77.0)	
	Regenerated, 10 cycles	5	76.2 (73.7–77.9)	

In March 2020, the Chen group extended their mask reuse investigations to the clinical setting by using an autoclave, which most hospitals and many clinics already commonly have on hand to sterilize surgical equipment. "It is well accepted that 30 min of pressurized steam at 121 °C kills almost all pathogens," Chen said. Chen also noted that steam sterilization is recognized by the US Centers for Disease Control and Prevention as the most widely available and dependable method for disinfection and sterilization in healthcare facilities [11].

The group's initial experiments with autoclave sterilization followed by "charging" suggest that used masks retain their filtering effectiveness after decontamination. "We tested regenerated N95 masks previously used for 8 h by volunteers in our university and the average filterability for 0.1 μm particles was maintained at over 99%," said Dan Wang, a scientist in Chen's group. Chen, Wang, and colleagues are currently working to optimize the technological parameters of their autoclave-based method, with testing—including a qualitative one for fit—to determine how the process may affect other functional and performance requirements for N95 masks. "The testing of masks actually used by healthcare personnel is important to demonstrate the method's effectiveness and suitability for widespread use," Chen said.

3. Baking and Comparisons

Finally, a group at Stanford University and 4C Air, Inc. (Sunnyvale, CA), led by Stanford professor of materials science and engineering Yi Cui, has experimented with baking [6,7]. Their current standard is to bake the masks at 75 °C for 30 min. "Some people have suggested that higher humidity helps kill the virus even faster," Cui said, so they are also experimenting with different levels of humidity as well as different temperatures. Temperatures of 85 °C or 100 °C also seem to work well, but "125 °C is too high," Cui said. At that temperature the performance of the polypropylene starts to degrade.

One remaining uncertainty about baking is its effectiveness at killing the virus. Previous research was conducted on viruses "in liquid buffer or culture medium," said Jing Jin, a scientist at Vitalant Research Institute in San Francisco who collaborates with Cui. To make sure that baking will actually kill virus in the clinic, Jin is currently studying the effect of dry heat on viruses on polypropylene cloth. Although she does not expect her final results until mid-April, she said, "I am very confident that 75 °C for 30 min is enough."

Assuming that all the methods are equally effective at killing viruses, the choice comes down to other considerations. So, Cui and his collaborators (including the Nobel Prize-winning physicist and Stanford professor of physics and molecular biology Steven Chu, who co-founded 4C Air with Cui) compared the effect of irradiation, steaming, and baking on mask performance.

When exposed to UV light, the masks retained their performance (filtering efficiency and pressure drop) over ten cycles of decontamination, but "degraded quite a bit" after 20 cycles, Cui said. "We are cautious on UV, also, because the penetration depth might be limited. The mask has a three-dimensional structure, so something could be trapped deep inside, and you would have to use a very high dose to disinfect that."

For steam heating, Cui used 10 min cycles with steam from a boiling beaker as compared to the 30 min cycles of autoclaving used by Chen's group. Cui said they saw no reduction in performance after three 10 min cycles, but after ten 10 min cycles the filtration rate was down to 80%. In effect, it was no longer a N95 mask.

As noted above, the Beijing team is still assessing the effectiveness of autoclaving after multiple treatments. If there is a discrepancy between the Cui group's results and those of the Chen group, it might be attributable to the fact that Cui's group did not "charge" the mask with a hair dryer between cycles and/or differences in the steaming process between the two groups. So, at present, it appears that the Chen group's autoclaving method will work at least once, but its effectiveness for decontaminating a mask multiple times remains to be confirmed.

Dry heat performed best in the Cui group's tests. It was the only one of the three methods for which the mask retained its filtering efficiency, its pressure difference, and its fit even after 20 cycles. Cui's group did not test hydrogen peroxide fumigation, but the Duke University Hospitals investigators plan to decontaminate and reuse their N95 masks up to 30 cycles [1], with the limiting factor being degradation of the elastic straps (after 30 cycles, the masks might no longer fit properly).

4. Supply and Demand

On an emergency basis, the US Food and Drug Administration on 29 March approved a much larger version of Duke's Bioquell device, which was itself approved in 2016. Manufactured and operated by Battelle (Columbus, Ohio), the larger version (basically a modified shipping container fitted with racks to hold the masks and a hydrogen peroxide vaporizer) may be used for up to 20 cycles of mask decontamination and reuse [10]. Already deployed in Massachusetts, Ohio, and New York, the Battelle systems can clean 80 000 masks per day, enough to supply multiple hospitals and even hospital systems [12].

As of 27 March, however, 3M continued to insist, that "no disinfection method has met all four" of the criteria mentioned above, when repeated five to ten times [4]. In an early April update [13], the manufacturer states that while hydrogen peroxide and other decontamination methods are still being evaluated, baking, steaming, or autoclaving are not recommended “due to significant filter degradation.”

In any case, the urgent need to address rapidly depleting mask supplies is clear. At the beginning of March 2020, the US Strategic National Stockpile contained about 42 million masks, barely 1% of the projected annual need in a pandemic [14]. If the projected 3.5 billion masks were indeed needed, this “stockpile” would be depleted in half a week.

On the supply side, 3M previously made 500 million masks per year worldwide. The company has already doubled its production rate since the coronavirus epidemic began [15]. And on 31 March, 3M committed to doubling their worldwide output yet again and producing 600 million masks annually in the United States [16]. Even so, comparing this source of supply (600 million) to the potential need (3.5 billion) there is a clear gap. It is highly likely that masks will need to be reused, and multiple times. The United States is getting some help in closing the gap. On 2 April, the city of Boston received a well-publicized shipment of 1.2 million masks from China, with more reportedly on the way [17].

But even that generous gift is small compared to the number of masks that could be potentially be made available through decontamination and reuse. And that strategy is benefiting from the research of both American and Chinese scientists.

References

[1] Schwartz A, Stiegel M, Greeson N, Vogel A, Thomann W, Brown M, et al. Decontamination and reuse of N95 respirators with hydrogen peroxide vapor to address worldwide personal protective equipment shortages during the SARS-CoV-2 (COVID-19) pandemic. Appl Biosaf 2020; in press.

[2] Cheng W. [Can't buy mask? It can be reused after regeneration treatment!][Internet]. Beijing: ScienceNet; 2020 Feb 14 [cited 2020 Apr 6]. Available from: http://news.sciencenet.cn/htmlnews/2020/2/435754.shtm. Chinese.

[3] Zhang Z, Xing Y. New reusable face masks in production [Internet]. Hong Kong: China Daily; 2020 Mar 2 [cited 2020 Apr 6]. Available from: https://www.chinadailyhk.com/article/122864.

[4] 3M. Disinfection of filtering facepiece respirators [Internet]. Technical Bulletin; 2020 Mar [cited 2020 Apr 3]. Available from: https://multimedia.3m.com/mws/media/1816576O/disinfection-of-disposable-respirators-technical-bulletin.pdf.

[5] Viscusi DJ, Bergman MS, Eimer BC, Shaffer RE. Evaluation of five decontamination methods for filtering facepiece respirators. Ann Occup Hyg 2009;53(8):815–27.

[6] Liao L, Wang X, Yu X, Wang H, Zhao M, Wang Q, et al. Can N95 facial masks be used after disinfection? And for how many times? [Internet]. Stanford: Learnly Anesthesia/Stanford AIM Lab COVID-19 Evidence Service; [cited 2020 Apr 2]. Available from: http://stanfordmedicine.app.box.com/v/covid19-PPE-1-2.

[7] Price A, Chu LF. Addressing COVID-19 face mask shortages (v 1.3), March 2020. [Internet]. Stanford: Learnly Anesthesia/Stanford AIM Lab COVID-19 Evidence Service; [cited 2020 Apr 2]. Available from: http://stanfordmedicine.app.box.com/v/covid19-PPE-1-2.

[8] Kolata G. As Coronavirus looms, mask shortage gives rise to promising approach [Internet]. New York: New York Times; 2020 Mar 20 [cited 2020 Apr 4]. Available from: https://www.nytimes.com/2020/03/20/health/coronavirus-masks-reuse.html.

[9] Lowe JL, Paladino KD, Farke JD, Boulter K, Cawcutt K, Emodi M, et al. N95 filtering facepiece respirator ultraviolet germicidal irradiation (UVGI) process for decontamination and reuse [Internet]. Lincoln: University of Nebraska; [cited 2020 Apr 4]. Available from: https://www.nebraskamed.com/sites/default/files/documents/covid-19/n-95-decon-process.pdf.

[10] Battelle CCDS Critical Care Decontamination System™ being deployed to meet urgent need for personal protective equipment for nation's healthcare workforce [Internet]. Columbus: Battelle Press Office; 2020 Mar 28 [cited 2020 Apr 4]. Available from: https://www.battelle.org/newsroom/press-releases/press-releases-detail/battelle-ccds-critical-care-decontamination-system-being-deployed-to-meet-urgent-need-for-personal-protective-equipment-for-nation-s-healthcare-workforce.

[11] Guideline for disinfection and sterilization in healthcare facilities (2008) [Internet]. Atlanta: Centers for Disease Control and Prevention; 2016 Sep 18 [cited 2020 Apr 6]. Available from: https://www.cdc.gov/infectioncontrol/guidelines/disinfection/sterilization/steam.html.

[12] Ostriker R. Boston hospitals getting 'game-changer' machine that sterilizes 80 000 protective masks a day [Internet]. Boston: Boston Globe; 2020 Apr 2 [cited 2020 Apr 4]. Available from: https://www.bostonglobe.com/2020/04/02/metro/boston-hospitals-getting-game-changer-machine-that-sterilizes-80000-protective-masks-day.

[13] 3M. Decontamination methods for 3M N95 respirators [Internet]. Technical Bulletin; 2020 Apr [cited 2020 Apr 4]. Available from https://multimedia.3m.com/mws/media/1824869O/decontamination-methods-for-3m-n95-respirators-technical-bulletin.pdf.

[14] Lovelace Jr B. HHS clarifies US has about 1% of facemasks needed for 'full-blown' coronavirus pandemic [Internet]. New York: CNBC; 2020 Mar 4 [cited 2020 Apr 4]. Available from: https://www.cnbc.com/2020/03/04/hhs-clarifies-us-has-about-1percent-of-face-masks-needed-for-full-blown-pandemic.html.

[15] Gruley B, Clough R. How 3M plans to make more than a billion masks by end of year [Internet]. New York: Bloomberg Businessweek; 2020 Mar 25 [cited 2020 Apr 4]. Available from: https://www.bloomberg.com/news/features/2020-03-25/3m-doubled-production-of-n95-face-masks-to-fight-coronavirus.

[16] 3M. Putting healthcare workers first during the coronavirus outbreak [Internet]. Maplewood: 3M News Center; 2020 Apr 1 [cited 2020 Apr 4]. Available from: https://news.3m.com/blog/3m-stories/3m-responds-2019-novel-coronavirus.

[17] Hightower K. New England Patriot's plane delivers 1.2 million N95 masks from China to Massachusetts [Internet]. New York: Time; 2020 Apr 2 [cited 2020 Apr 4]. Available from: https://time.com/5814865/new-england-patriots-plane-masks/.