Ozone Sterilization of N95 Masks

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Abstract:

The rapid spread of the COVID-19 worldwide pandemic at the beginning of 2020 has significantly affect-ed the global economy with severe human and economic losses. Despite the shortage of personal protective equipment, the facemask serves as a fundamental means to protect health care professionals' and re-strict the spread of the coronavirus. However, due to the limited stock of facemasks, many sterilization methods were developed to eliminate the infection and established strategies for fast and repeated reuse without affecting the filtration efficiency. The current study extrapolates the effective utilization of the ozonic sterilization of the N95 mask. First, we demonstrated the potential of ozone as a disinfectant that successfully destructs the organic food colour compounds deposited on the N95 mask; In the quantitative part of this research, the N95 facemask pieces were soaked in diphenylamine solution and later oxidized with ozone under the different intervals of time. Finally, the different standards of diphenylamine and methanol solution were calibrated under the spectrometric analysis to quantify the amount of the oxidized product present in the methanol solvent. The results show that ozone disinfectant has a significant potential to sterilize the mask, recover the cost-effective reuse, and can generate a comparable result equivalent to the other high-cost techniques. Furthermore, it was observed that the sample's ozone expo-sure time and accurate calibration are vital to influence the organic species' oxidization and accurately quantify the oxidized amount.

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Ozone Sterilization of N95 Masks

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ABSTRACT

The rapid spread of the COVID-19 worldwide pandemic at the beginning of 2020 has significantly affected the global economy with severe human and economic losses. Despite the shortage of personal protective equipment, the facemask serves as a fundamental means to protect health care professionals' and restrict the spread of the coronavirus. However, due to the limited stock of facemasks, many sterilization methods were developed to eliminate the infection and established strategies for fast and repeated reuse without affecting the filtration efficiency. The current study extrapolates the effective utilization of the ozonic sterilization of the N95 mask. First, we demonstrated the potential of ozone as a disinfectant that successfully destructs the organic food colour compounds deposited on the N95 mask; In the quantitative part of this research, the N95 facemask pieces were soaked in diphenylamine solution and later oxidized with ozone under the different intervals of time. Finally, the different standards of diphenylamine and methanol solution were calibrated under the spectrometric analysis to quantify the amount of the oxidized product present in the methanol solvent. The results show that ozone disinfectant has a significant potential to sterilize the mask, recover the cost-effective reuse, and can generate a comparable result equivalent to the other high-cost techniques. Furthermore, it was observed that the sample's ozone exposure time and accurate calibration are vital to influence the organic species' oxidization and accurately quantify the oxidized amount.

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INTRODUCTION

During the COVID-19 crises, the spread of the COVID-19 in large cities caused the shortage of personal protective equipment (P.P.E.) and widely highlighted the capacity to reuse the P.P.E. worldwide. Despite the challenges, the health care professionals continued to use fundamental respiratory tools such as N95 masks, which filter the 95 % particulate matter at or above the 0.3-micron size [1,2]. Recently, the Italian institute of health has published a report that broadly recommends and emphasize the sanification process for non-healthcare environments to disinfect the surfaces and maintain the hygienic quality in the indoor environments [3]. Therefore, to cope with the shortage and at the same to meet filtration standards, the government, hospitals, and the companies emphasized and doubled their efforts to look for better disinfect solutions for certified masks, including several other personal protective equipment [4,5]. As a result, a great deal of effort and many strategies have been proposed for the quick and safe reuse of the N95 masks. Several disinfection technologies have already been utilized in large hospitals, especially the initial progress with highly concentrated hydrogen peroxides. However, the cost-effective disinfection technologies to cope with the shortage and at the same time disinfect the PPEs with ultra-high filtration is a big challenge [6,7].

Many sterilization methods, such as U.V. irradiation, and steam treatment, also have been used. Nevertheless, light (intensity-wavelength) standardization and mask degradation are significant challenges in U.V. irradiation. However, ozone disinfection is one of the widely accepted methods reported in the literature [8–10]. Besides, its recognition as an effective disinfectant has been widely accepted by numerous international organizations such as the European food and drug administration, the centre for disease control and prevention, the European chemical agency, and the international ozone associations [11]. It is an allotropic form (O3) of oxygen produced from the air using air plasma or U.V. irradiation [2]. The natural presence of ozone in the atmosphere is approximately 0.04 ppm (I ppm = 2mg/m^3), and nearly 90% of the ozone is located in the stratospheric zone. It has roughly ten times higher solubility (49 ml per 100 ml at 0 ^{0}C) in the water compared to oxygen; this makes them immediately react with any biological substance in the biological fluids; in addition, it has a higher density (2.14 kg/m^3) than air, concentrating it close to the environment and indoor stations. It has high reactivity and the potential to oxidize the organic compounds [8,11–13]. Moreover, it has been used successfully in waste water treatments [14,15], and effectivity deactivated the bacteria [13] and some members of the corona family [4,16,17]; Being a gaseous sterilizations agent, it can assess and disinfect the materials that are difficult to access because of tiny pores [2].

Therefore, this study aims to investigate the potential role of ozone as a disinfectant for N95 masks in indoor environments. Also, the crucial role of ozone in damaging the organic substances in the food colour is highlighted—the reason to choose particular food colours is due to their availability, safety, and ease of use. In addition, for the quantitative analysis, the masks samples were oxidized with diphenylamine and later, the oxidized amount was measured using the calibration method under the spectroscopy characterization. Finally, we demonstrate that this approach is straightforward, cost-effective, and can be extended for further broad-scale research.

METHODS

In the first qualitative set of the experiment, a particular class of quartz reactor as shown in Figure 1, the ozone generator containing oxygen and inert (Ar) cylinders as shown in Figure 2 and different organic food colours (red, green, purple, blue, and black) were used as received without any further treatment. The organic foods relevant to our studies were used without further treatment and endured multiple cycles of ozone exposure.

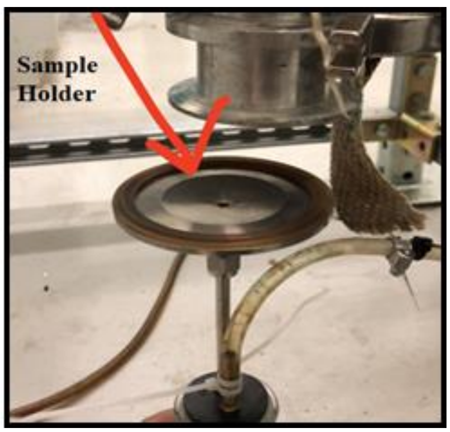

Figure 1: Specimen holder in the quartz reactor.

Initially, the N95 masks were cut into small pieces and later soaked into organic food colour. Before injection of the ozone into the reactor, the reactor was tightly sealed, and it was assured that there was no gas leakage by supplying the Ar gas. Next, the ozone gas was injected from the ozone generator into the reactor for 15 seconds before the sample was collected for analysis. The same procedure was repeated for all the other organic colours (purple, black, yellow, and green).

In the quantitative set of experiments, the N95 mask was cut into ten small pieces and soaked in different colourless 4000 ppm diphenylamine ($(C_6H_5)_2NH$) solutions under the different intervals from 1 to 2 hours, as shown in Table 1.

Later, the soaked samples were individually introduced into the quartz reactor, and the ozone gas was injected into the reactor with the O_2 flow rate of 500mL/min until the samples were fully oxidized and returned yellow. Next, the oxidized sample from the reactor was placed under the known amount (15 ml) of methanol until the sample was restored (white) as shown in Figure 3.

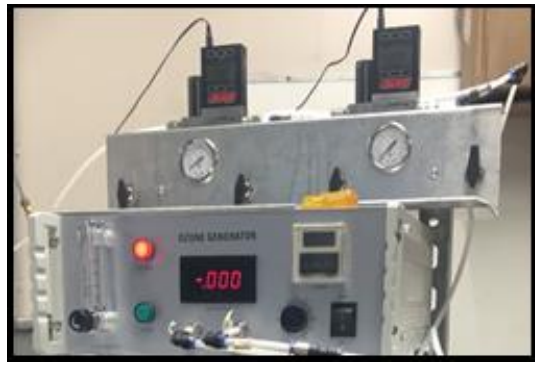

Figure 2. Ozone generator

Table 1: Details of the preparation tests (1 to 9)

Test number	Volume of stock solution (ml)	Number of masks pieces	Ozone exposure time (seconds)	Methanol volume (ml)
1	3	2	120	15
2	2	1	80	15
3	2	1	40	15
4	2	1	20	15
5	2	1	10	15
6	2	1	5	15
7	2	1	3	15
8	2	1	2	15
9	2	1	1	15

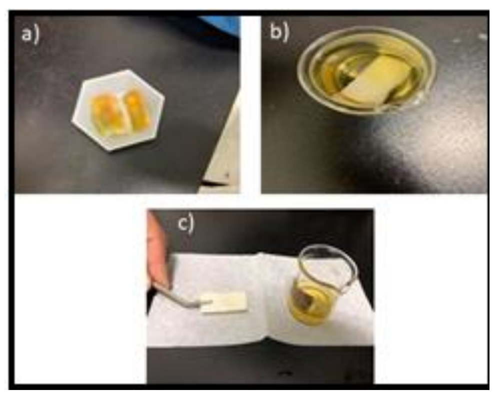

Figure 3. (a) two pieces of oxidized mask initially soaked in 3mL of a 4000 ppm diphenylamine solution (b) oxidized mask soaked in 15 ml of methanol (c) discolouration of the mask after soaking in methanol solution.

Finally, to quantify the amount of oxidized compounds in the methanol, the different known quantities of the standard solution of the methanol and diphenylamine were calibrated, as sown in Figure 4, and the oxidized amount in the methanol sample was quantified using spectrometry characterization. A similar procedure was repeated for all the ten samples reported in Table 1.

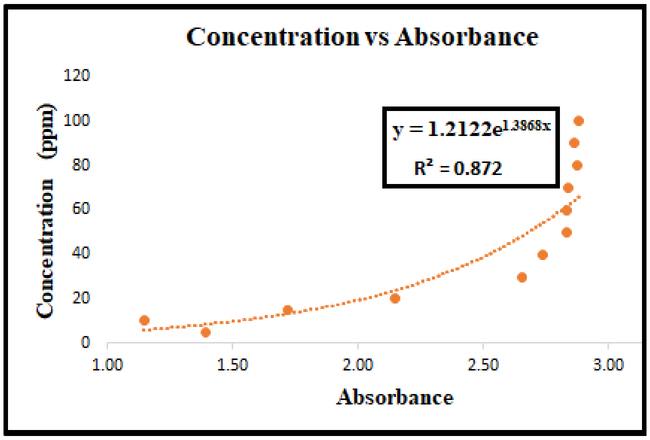

Figure 4. Standard concentration curve as a function of absorbance

RESULT

Figure 5 shows the images of the samples before and after the oxidation with ozone for 20 seconds. Changes in the colour sample after the oxidation validates the successful sterilization of the organic contaminants in the mask samples. It is essential to mention that there was no fabric degradation and elastics loss in the mask strap as shown under the blue arrow in figure 6, except some decline in rigidity and enhancement in the elasticity was observed in the nose wire.

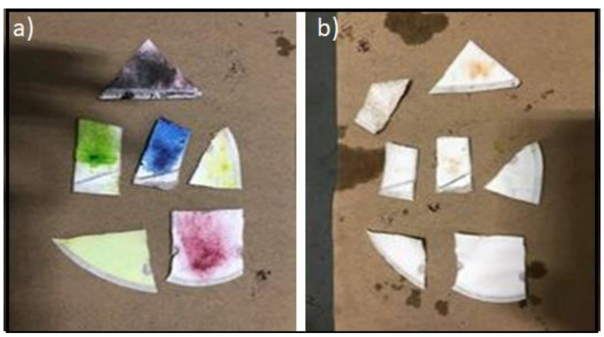

Figure 5. (a) Mask colours before the oxidation and (b) after oxidation (20 seconds)

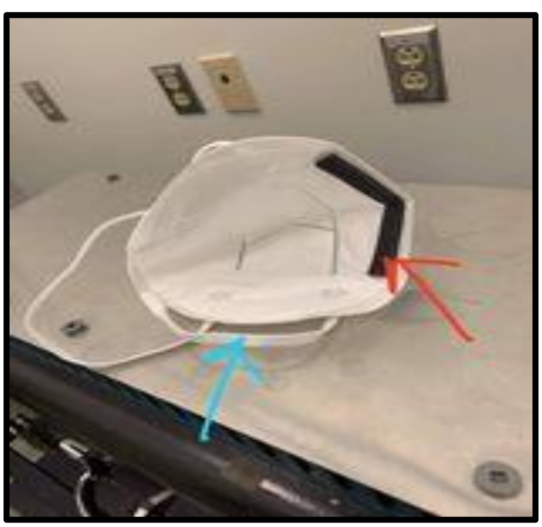

Figure 6. Mechanical test of the mask after the oxidation

Test number	After oxidation	After washing with methanol
1		
2		
3		
4		
5		
6		
7		
8		
9		

Figure 7. Colours of the masks samples under the oxidized diphenylamine and after the immersion in pure methanol.

Similarly, Figure 7 represents all the nine oxidized mask samples initially soaked in the diphenylamine and later in the methanol solvent. Variation of colour in all the samples indicates that all the oxidized diphenylamine has been absorbed by methanol solvent efficiently. Besides, the yellow colour of the methanol solvent is another indication that methanol solvent has fully absorbed the diphenylamine. Moreover, it is essential to mention that only three samples out of these nine samples were exposed to ozone gas in the quartz reactor under a different period, such as 1, 5 and 10 seconds, to observe the time effect on the quantity of oxidized amount in the methanol solvent. The results show that by increasing the oxidation time from 1 to 5 seconds, the oxidized amount (diphenylamine) was increased from 46.64 ppm to 55.7 ppm. However, with further increases in oxidation time, such as 10 seconds, the oxidized amount declined to 51.33 ppm. Hence it was observed that the optimum combination of sample exposure time under the ozone and the accuracy of the standard method to calibrate the concentration of methanol and diphenylamine are vital to identify the oxidized amount accurately.

CONCLUSION

We have demonstrated the potential of ozone sterilization, intending to reuse the N95 mask at a lower price and counter the shortage of the facemask across the globe. The quantitative analyses have confirmed the ozone's effective utilization as an oxidant to damage organic components present in the food colours. When ozone gas was passed from the sample, the flow configuration in the quartz reactor demonstrated excellent performance to sterilize the colour samples. However, careful handling of the reactor, such as to protect the ozone leakage, is vital to protect the health and environmental damage. In the second part, a colourless organic compound, diphenylamine, was successfully oxidized with ozone gas. An amine bonded with two phenyl groups completely turned yellow once oxidizes with ozone gas. A spectrometric characterization with the aid of a standard calibration method based on lower concentration (from 10 to 100 ppm) was used to quantify the oxidized amount in the methanol solvent accurately. It was observed that the standard method's accurate concentration and sample oxidation time are vital to analyze and quantify the oxidized amount correctly.

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