EFFECT OF DECONTAMINATION METHODS ON THE FILTER PARTICLE PENETRATION, BREATHING RESISTANCE AND MORPHOLOGY OF FILTERING FACEPIECE RESPIRATORS

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Abstract. Filtering Facepiece Respirators (FFR) have been used by healthcare workers in their working activities. However due to scale of breakout, FFR are becoming short and insufficient to cope with demand, thus the potential decontamination methods need to be identified. The present study is aimed to evaluate the performance of three different models of FFR when exposed to three decontamination methods; vaporized hydrogen peroxide (VHP), bleach and autoclave. Filter particle penetration and breathing resistance penetration and relationship to the FFRs microstructure was performed. Scanning Electron Microscope (SEM) was used to observe the morphology property of the FFR. Comparison with the control samples indicated that Model 1 exhibited the lowest average filter penetration than those Models 2 and 3. After bleach decontamination of the FFR, high deviation of particle penetration and breathing resistance penetration data from the control was observed. This is due to the FFR structure degradation. Based on the study, it is found that all models showed acceptable filter particle penetration and breathing resistance even after most aggressive testing conditions used for the three decontamination methods.

Keyword: Filtering face respirators, decontamination, filter, penetration, resistance

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Introduction

COVID-19 has been a catastrophic event for humans as it has infected millions of humans. Due to this, healthcare workers and general public are advised to use filtering facepiece respirators (FFR) for daily activities [1]. FFR are meant to reduce inhalation exposure to certain contaminants. They are face-mounted personal defenders that shield the nose and mouth from airborne particles such as dust, infectious agents, gases, or vapors [2-3]. FFR aid in air purification, lowering the danger of contamination of the wearer in a polluted environment. In most industries, these respirators are employed to lessen exposure to wood dust, animal dander, and pollen. More recently, health care facilities have been using N-95 filtering facepiece respirators as part of their COVID-19 control program. In this issue, hospitals used them for protection from infectious aerosolized droplets released from sick patients.

However, due to scale of breakout, FFR are becoming short and insufficient to cope with the demand [4]. Centers for Disease Control and Prevention (CDC) guidance suggested that once an FFR are worn in the presence of an infected patient, it should be considered possibly contaminated, regarded as infectious wasted [5]. N95 makes up most products currently certified by NIOSH and are most generally utilized in a healthcare setting [6]. However, during this pandemic, KN95 has been used widely compared to that of N95 especially in high-risk area because of cost. In countries where supply is scarce and limited, decontamination is best offer available as FFR can be worn for a longer period and lower number of uses of new FFR. Using decontaminated FFR, it helps to cope with the sudden demand for FFR around the world. Decontamination of N95 FFR is a crisis capacity strategy permitted when there are known shortages of FFR.

Decontamination is a process whereby the neutralization or removal of dangerous substances, radioactivity, or germs from an area, object, or person which is fundamentally to decrease amount of pathogens on used FFR before reusing them [7]. FFR are deemed one-time use products, as there are presently no manufacturer-allowed methods for FFR decontamination before reuse [8]. This is due to only FFR manufacturer can provide guidance on how to decontaminate their specific products [9]. However, in absence of manufacturer's ability to recommend, third parties, like decontamination companies, safety organizations as well as research laboratories may also guide on how to decontaminate respirators without impacting structure and performance.

An efficient FFR decontamination method should decrease pathogen burden, not damage the fit or filtration performance of the respirator and it should display no residual chemical hazard. NIOSH discovered that as of April 2020, ultraviolet germicidal irradiation, vaporous hydrogen peroxide (VHP), and moist heat have shown the most promising method as possible to decontaminate respirators [10]. Chemical and non-chemical treatments are two classes of decontamination. Chemical decontamination utilizes chemical substances to inactivate and kill infectious bacteria. Example of chemical substances are sodium hydroxide, vaporized hydrogen peroxide and hydrochloric acid. As for non-chemical methods, non-chemical substance is used to achieve similar purpose which includes autoclaves, dry heat, moist heat, microwave, and ultraviolet radiation.

Based on recent studies [11, 12], there are many potential decontamination methods with different possible adverse effect and different performance. However limited study has been carried out to compare the performance of chemical methods (VPH and bleach) and non-chemical method which is autoclave. Furthermore, the outcomes from previous works majority focused on determining the effective decontamination processes by using chemical and non-chemical treatments. Potentials of used FFR to damage fit, physical appearance, lowered filtration efficiency, and lowered breathability are covered in their studies. In this study the authors aimed to evaluate performance of FFR by determining the effect of VPH, bleach and autoclave decontamination treatments to the FFR electret filter media microstructure based on the particle penetration and breathing resistance measurement.

Materials and Methods

Respirator Selection. In this study, three types of FFR are used; FFR Model 1 and Model 2 are N95 type FFR and Model 3 is KN95 type FFR as shown in Figures 1 (a) - (c), respectively. Table 1 shows description of the Model 1 to 3 used in the study. All FFRs consist of 3 layers with thicknesses ranging from 1.11 to 2.90 mm.

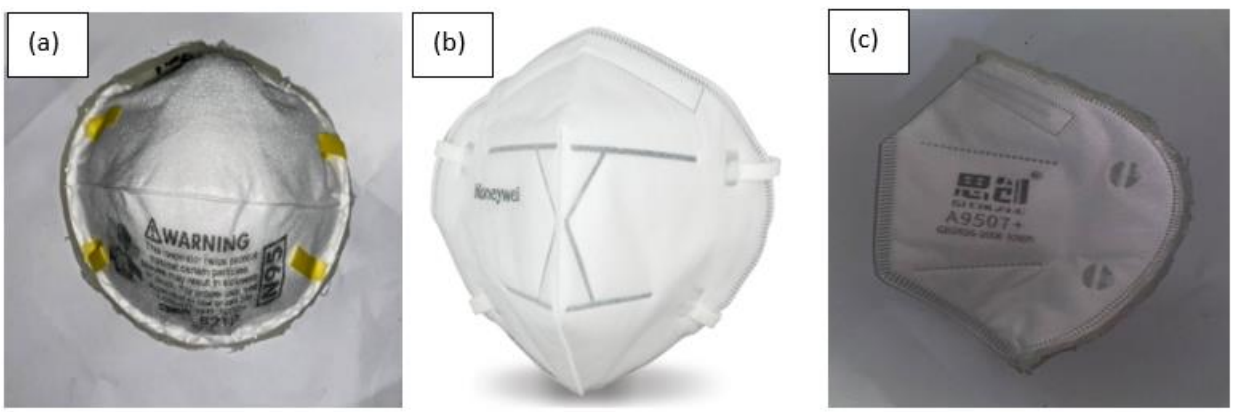


Figure 1. (a)-(b) N95 Model and (c) KN95 Model

Table 1. Description of the FFRs Models 1 - 3

Model	Manufacturer	Thickness (mm)	Layers	Filter	Shape
1	Singapore	2.90	3	Melt blown	Fold valve less
2	China	2.47	3	Melt blown	Fold valve less
3	China	1.11	3	Melt blown	Fold valve less

Decontamination Method Selection. Three decontamination methods were used in the study; chemical methods (VPH and bleach) and non-chemical method (autoclave). Table 2 summarizes the experimental conditions and parameters for the three decontamination methods. All laboratory experiments were conducted under standard laboratory conditions (22 ± 2 °C and relative humidity of 50 ± 10%) on triplicate sets of FFRs. The test conditions (less aggressive and most aggressive) of the three decontamination methods were recommended based on previous study reported by Viscussi et al. [8]. The conditions were reported as effective conditions for the three decontamination methods.

Table 2. Conditions of the three decontamination methods used in the study

Decontamination Methods	1st Test Condition Less aggressive	2nd Test Condition Most aggressive
VHP	1 cycle	5 cycles
Bleach	0.5%	5.25%
Autoclave	15 mins	30 mins

Control or 'as-received' sample refers to the untreated out-of-the-box FFR for the three FFR models used in the analysis. For VHP, all samples were put into the Plasmapp Sterlink Low Temperature Plasma Sterilizer for 2 stage cycle (1 cycle and 5 cycles). The respirators were air-dried 72 hours before testing. For bleach method, samples were dunk in bleach mixture at 2 different concentrations (0.5% and 5.25%). The bleach solution was made by mixing Fisher 5.25% sodium hypochlorite (NaOCl) with 0.20% sodium hydroxide (NaOH) for second concentration. The FFR were then left dried overnight with the help of standing fan. On the other hand, for the autoclave method, all samples were sealed in a standard paper autoclave bag and treated for autoclave decontamination at 121°C (15 psi) under 2 different conditions (30 and 15 minutes) using Market Forge Automatic Sterilmatic steam pressure sterilizer (Everett, MA). The FFR were then left dried for 72 hours prior to test.

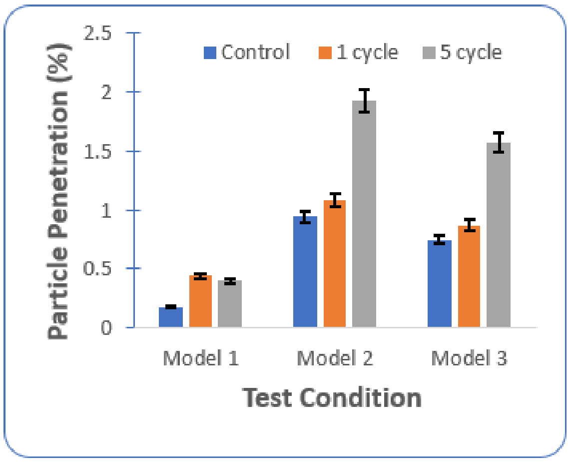
Characterization. TSI Model 8130 Automated Filter Tester (AFT) (TSI, Inc., St. Paul, MN) was used to measure filter aerosol penetration and airflow resistance. A total of 12 samples (3 samples of each test condition and 3 control samples) tested for the filter penetration performance and filter airflow resistance tests. This test was to evaluate how decontamination affect filtration efficiency and to check reusability of FFR after being decontaminated. For microscopic analysis of FFR, samples were analyzed using tabletop scanning electron microscope (SEM), Hitachi TM3000.

Results and Discussion

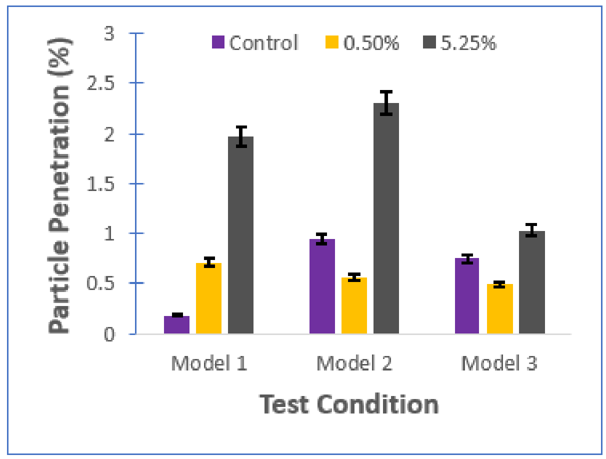
Table 3 summarizes the average filter particle penetration results of three types of FFR after VHP, bleach and autoclave decontamination methods. For comparison purpose, normalized values for three decontamination methods for all types of FFR were shown in second row of each FFR. Figure 2 shows average filter particle penetration results of three types of FFR using VHP, bleach and autoclave methods. Normalized values were defined as a ratio of selected FFR penetration performance per selected FFR control sample. All normalized values for control samples for each type of FFR continually started from one. The lower the amount of penetration performance value, the better the penetration performance of the FFR. All three types of FFR, before exposed to decontamination procedure showed particle penetration of less than 6 % which complying to the Malaysian Standard (MS 2323:2010) [13].

Table 3. Average filter particle penetration results (%) of three types of FFR models using VHP, bleach and autoclave methods (Second row of each FFR is the normalized value)

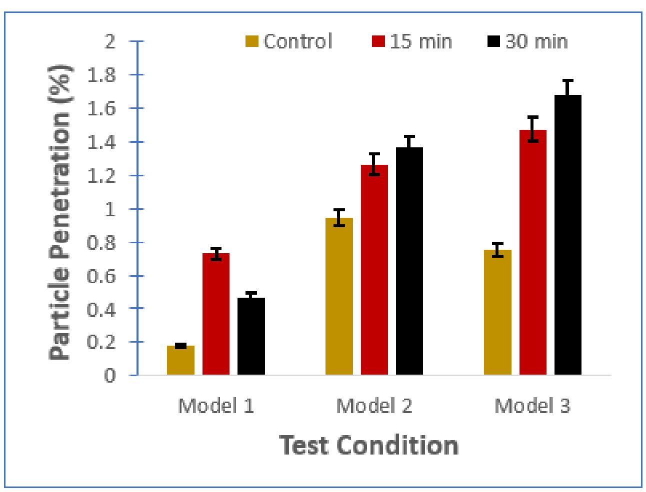
Type of FFR	Control	VHP		Bleach		Autoclave	
		1 Cycle	5 Cycle	0.5%	5.25%	15 min	30 min
N95	0.18	0.44	0.40	0.71	1.97	0.73	0.47
Model 1	1	2.44	2.22	3.94	10.94	4.05	2.61
N95	0.94	1.08	1.92	0.56	2.31	1.26	1.36
Model 2	1	1.15	2.04	0.59	2.46	1.34	1.45
KN95	0.75	0.87	1.57	0.49	1.03	1.47	1.68
Model 3	1	1.16	2.09	0.65	1.37	1.96	2.24



(a) VHP



(b) Bleach



(c) Autoclave

Figure 2. Average filter particle penetration of FFRs Models 1, 2 and 3 using (a) VHP, (b) bleach and (c) autoclave decontamination methods (acceptable particle penetration is 6%)

Comparison among the FFR showed that Model 1 exhibited the biggest deviation in filter penetration results for the three decontamination methods. Based on the data for three methods, it is found that FFR Model 2 and Model 3 showed lower normalized penetration values. This indicated FFR Models 2 and 3 exhibited less deviation from the control FFR [14]. However, based on Figure 2, these two models showed higher percentage of particles penetration compared to that of Model 1. As expected, increase in treatment time or cycle results in increasing average percentage of particle penetration due to the electret filter media structure degradation of the FFR. Morphologies in Figure 3 (b and c) shows the example of filter structure degradation with increasing number of autoclave treatment time for Model 1. Comparison on the morphologies showed that the gap between fibres were increased with longer treatment time. Control sample shows more homogeneous fibre, however the morphology changed after decontamination. Referring to Figure 3(c), it is apparent that some of the fibres sticked together and produced bigger fibres diameter, and results in slightly bigger porosity if compared to control morphology. As seen in Table 2, normalized value of FFR Model 1 penetration performance increased significantly at 5.25% concentration. As compared to the control sample, FFR after bleach method showed changes in the structure (refer to Figure 3(d)), which causes penetrability of FFR to increase.

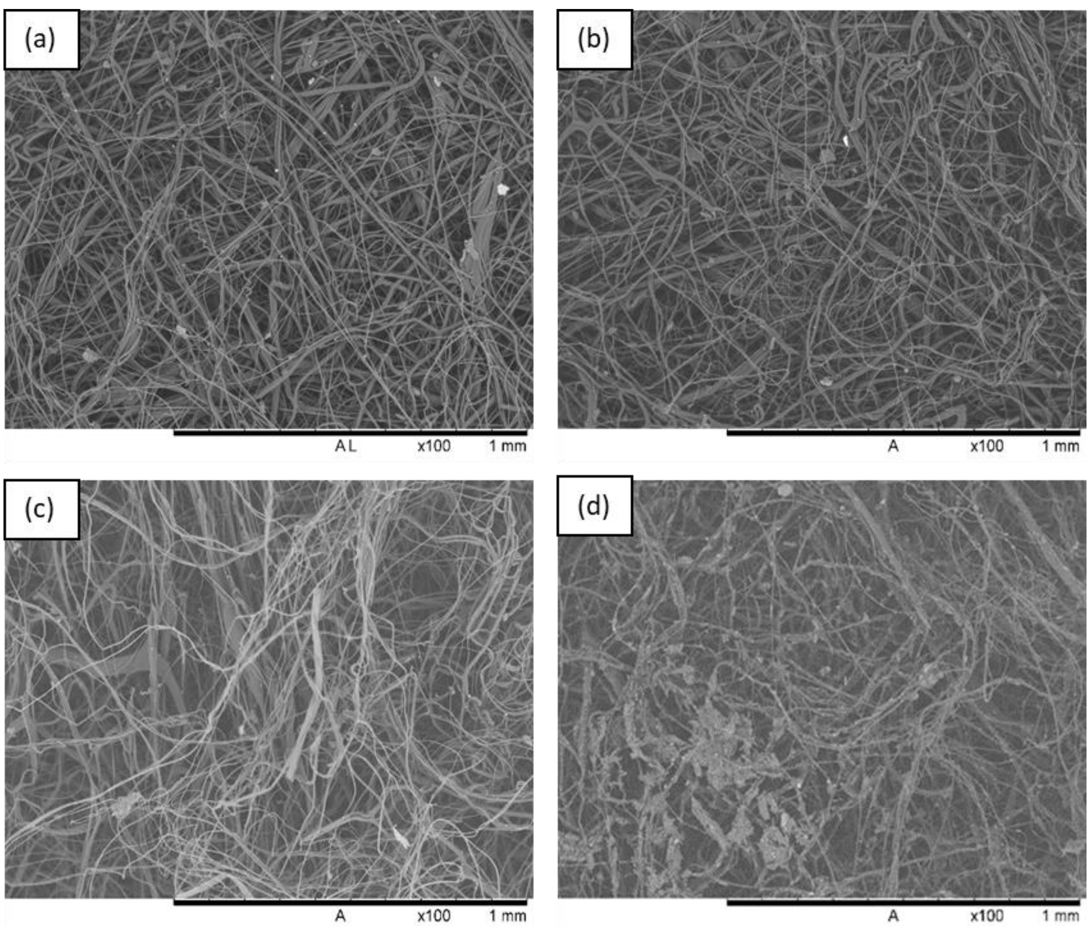
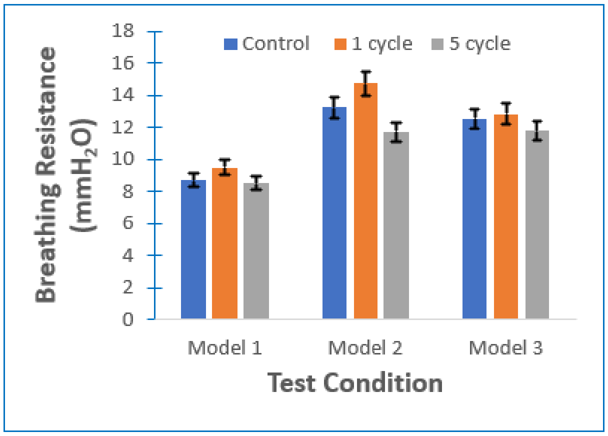


Figure 3. SEM images of (a) control sample, autoclave decontamination at (b) 15 minutes and (c) 30 minutes for FFRs Model 1. Figure (d) is the morphology of FFRs Model 1 after bleach decontamination at 5.25% concentration

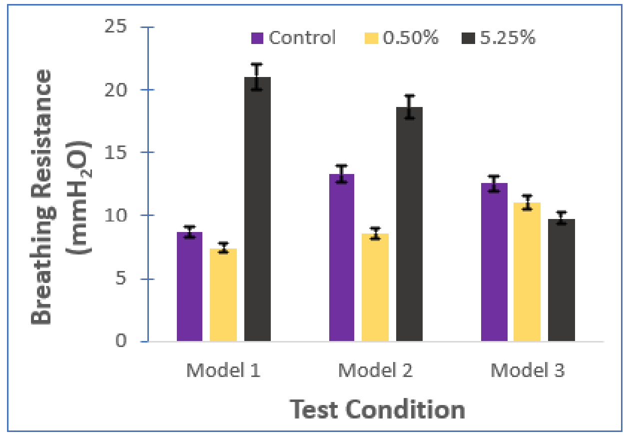
Table 4 shows the average breathing resistance results and Figure 4 (a-c) shows normalized data for all the decontamination methods for Models 1-3. Low normalized average breathing resistance value is desirable and indicates the performance is comparable with control sample. Based on the data in Table 4, it is found that insignificant changes were observed for the breathing resistance values using the three decontamination methods and three different types of FFR. All models showed breathing resistance less than acceptable limit based on Malaysian Standard; MS 2323:2010 (24.4 mmH_2O) even after most aggresive condition for all decontamination methods. The highest breathing resistance (21.2 mmH_2O) is shown by Model 1 after bleach decontamination at 5.25% concentration. The results can be explained by referring to the morphology changes after decontamination (Figure 3(d)). Based on the normalized data of filter particle penetration and breathing resistance for the three decontamination methods, it is found that bleach method showed high deviation from the control FFR due to the FFR electret filter media structure degradation.

Table 4: Average breathing resistance results (mmH_2O) of three types of FFR models using VHP, bleach and autoclave methods (Note: Second row of each FFR is the normalized value)

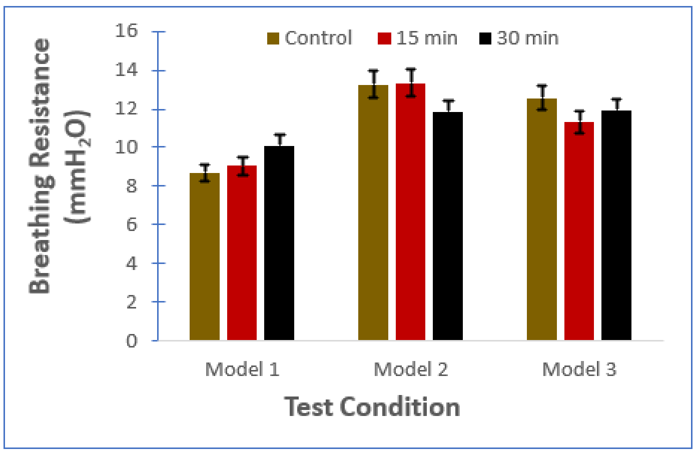
Type of FFR	Control	VHP		Bleach		Autoclave	
		1 Cycle	5 Cycle	0.5%	5.25%	15 min	30 min
N95	8.71	9.50	8.51	7.41	21.02	9.04	10.11
Model 1	1	1.09	0.97	0.85	2.41	1.03	1.16
N95	13.27	14.75	11.72	8.61	18.64	13.34	11.86
Model 2	1	1.11	0.88	0.65	1.40	1.01	0.89
KN95	12.56	12.85	11.78	11.08	9.78	11.33	11.93
Model 3	1	1.02	0.94	0.88	0.78	0.90	0.94



(a) VHP



(b) Bleach



(c) Autoclave

Figure 4. Normalized data of breathing resistance of FFR Models 1, 2 and 3 using VPH, bleach and autoclave decontamination methods (acceptable limit of breathing resistance is 24.4 mmH_2O)

Conclusion

Based on the results of chemical and non-chemical decontamination methods used for three types of FFR, the following conclusions were made:

1. Comparison with the control samples showed Model 1 exhibited the lowest average filter penetration than those Models 2 and 3.
2. Based on the normalized data of filter particle penetration and breathing resistance, bleach method showed high deviation from the control due to the FFR structure degradation.

3. All models performed within acceptable limit for filter particle penetration and breathing resistance, even after most aggressive testing condition used in the three decontamination methods.

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Author Contributions

All authors contributed toward data analysis, drafting and critically revising the paper and agree to be accountable for all aspects of the work.

Disclosure of Conflict of Interest

The authors have no disclosures to declare.

Compliance with Ethical Standards

The work is compliant with ethical standards.

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