EVALUATION OF FILTERING FACEPIECE RESPIRATORS USING CHEMICAL/NO-CHEMICAL DECONTAMINATION METHODS

by

MUHAMAD HAFIZUDDIN BIN AHMAD SHOBANI

Thesis submitted in fulfilment of the
requirements for the degree of
Bachelor of Engineering (Honours) (Aerospace Engineering)

July 2021

ENDORSEMENT

I, Muhamad Hafizuddin Bin Ahmad Shobani hereby declare that all corrections and comments made by the supervisor and examiner have been taken consideration and rectified accordingly.

(Signature of Student)

Date: 16/7/2021

(Signature of Supervisor)

Name: Ir. Dr. Hussin Mamat
Date: 16/7/2021

(Signature of Examiner)

Name: Dr. Pooya Lahijani Amiri
Date: 26/7/2021

DECLARATION

This thesis is the result of my own investigation, except where otherwise stated and has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any other degree.

(Signature of Student)

Date: 16/7/2021

ACKNOWLEDGEMENTS

First and foremost, I would like to express my deepest and sincere gratitude to my supervisor, Ir. Dr. Hussin Mamat, lecturer at School of Aerospace Engineering at Universiti Sains Malaysia, for his guidance, patience, and full support throughout the completion of this study possible.

I would like to acknowledge the support from School of Aerospace Engineering, Universiti Sains Malaysia for providing the necessary facilities which had been directly used for the simulations that presented in this study. I would like to express my appreciation to CATIA Lab technical staffs for resolving technical problems and issues that I had encountered during the research.

I would also like to thank each of my course mates and friends who have been giving me suggestions, advice, and supports in assisting me to complete this study.

Last but not least, I would like to express my gratitude to my family especially my parents, who have always provided me with unfailing support and continuous encouragement throughout my years of study.

Thank you.

EVALUATION OF FILTERING FACEPIECE RESPIRATORS USING CHEMICAL/NO-CHEMICAL DECONTAMINATION METHODS

ABSTRACT

COVID-19 has been a catastrophic event for humans as it has infected millions of humans. Due to this, healthcare workers and general public has highly advised the use of Filtering Facepiece Protectors (FFRs) for daily activities. However due to scale of breakout, FFRs are becoming short and insufficient to cope with demand. This experiment aims to evaluate performance of FFRs by characterization of penetration and filter resistance and to determine the effect of decontamination performance to FFRs macrostructure and microstructure. A total of 36 labelled FFRs N95 and KN95 were exposed to four decontamination methods like bleach, vaporized hydrogen peroxide, autoclave, and moisture heat with two N95 and two KN95 FFR as control samples. A filtration performance and airflow resistance test were performed on each of decontaminated FFR. Then, FFR were observed for physical change and significant degradation on its appearance. Next, FFR were taken for microstructure test which was done under Scanning Electron Microscope (SEM) to observe its morphology property. Based on the normalised data of filter penetration and airflow resistance, VHP was the best decontamination method as decontaminated FFR show good performance with least deviation data. As for macrostructure test, Moisture Heat was the only decontamination method which showed no degradation on FFR. As for microstructure test, Bleach decontaminated FFR illustrated the highest fiber breakage and shrinkage occurred on its fiber structure.

PENILAIAN TERHADAP DEKONTAMINASI PELITUP MUKA SECARA KIMIA/TANPA KIMIA

ABSTRAKS

COVID-19 telah menjadi bencana bagi manusia kerana telah menjangkiti berjuta-juta manusia. Oleh kerana itu, pekerja kesihatan dan masyarakat umum sangat menasihati penggunaan Pelitup Muka (*Filtering Facepiece Protectors)* untuk aktiviti harian. Namun kerana skala besar jangkitan, FFR semakin berkurang dan tidak mencukupi untuk menampung permintaan. Eksperimen ini bertujuan untuk menilai prestasi FFR dengan mencirikan ketahanan penembusan dan rintangan aliran udara dan untuk menentukan kesan prestasi dekontaminasi terhadap struktur makro dan struktur mikro FFR. Sebanyak 36 FFR berlabel N95 dan KN95 didedahkan kepada empat kaedah dekontaminasi seperti peluntur, hidrogen peroksida yang diuapkan, autoklaf dan kepanasan lembap dengan dua N95 dan dua KN95 FFR sebagai sampel kawalan. Ujian ketahanan penembusan dan rintangan aliran udara dilakukan pada setiap FFR yang telah tercemar. Kemudian, FFR diperhatikan pada perubahan fizikal dan perbezaan ketara pada penampilannya. Seterusnya, FFR diambil untuk ujian struktur mikro yang dilakukan di bawah *Scanning Electron Microscope* (SEM) untuk menyelidiki sifat morfologinya. Berdasarkan data normal ketahanan penembusan dan rintangan aliran udara, VHP adalah kaedah dekontaminasi terbaik kerana FFR yang tercemar menunjukkan prestasi yang baik dengan sisihan data yang paling sedikit. Bagi ujian struktur makro, kepanasan lembap adalah satu-satunya kaedah dekontaminasi yang tidak menunjukkan kerosakan pada FFR. Bagi ujian struktur mikro, FFR yang telah dekontaminasi peluntur menggambarkan kerosakan dan kecatatan gentian terbanyak berlaku pada struktur gentiannya.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

FFR	Filtering Facepiece Respirator
VHP	Vaporized Hydrogen Peroxide
CDC	Present Centers for Disease Control and Prevention
NIOSH	National Institute of Occupational Safety and Health
SEM	Scanning Electron Microscope
EtO	Ethylene Oxide
UVGI	Ultraviolet Germicidal Irradiation
L/min	Liter per min

CHAPTER 1
INTRODUCTION

1.1 Background

COVID-19 has been a catastrophic event for humans as it has infected millions of humans. Due to this, healthcare workers and general public has highly advised the use of Filtering Facepiece Respirator (FFR) for daily activities (Picard et al., 2020). However, due to scale of breakout, FFR are becoming short and insufficient to cope with demand (Wu et al., 2020). Present Centers for Disease Control and Prevention (CDC) guidance suggests that once an FFR is worn in the presence of an infected patient, it should be considered possibly contaminated, regarded as infectious wasted (Rubio-Romero et al., 2020).

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 (Hunt, 2019). The purpose of it is to limit self-contamination. Decontamination and frequent reuse of FFR should solely be implemented where FFR shortages occurred. Decontamination can only be done on FFR without exhalation valves.

For the moment, FFR are deemed one-time use products, as there are presently no manufacturer-allowed methods for FFR decontamination before reuse (Allison et al., 2020). This due to only FFR manufacturer can provide guidance on how to decontaminate their specific products (Garcia-Haro et al., 2021). 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 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 (Sarkis-Onofre et al., 2021).

Decontamination is potential to damage fit, lowered filtration efficiency, and lowered breathability of used FFR as a result of adjustments to the filtering material, straps, nose bridge material, or strap attachments of the FFR. Decontamination may also produce chemical inhalation hazards and should be assessed for off gassing.

NIOSH-certified N95 FFR are intended to filter 95% of particles when properly equipped to the face (Dugdale & Walensky, 2020). This implies that an N95 that is improperly fitted to the face will be expected give the wearer less protection. N95 FFR are intended to be one-time-use devices but may be used several times under crisis capacity strategies. N95 FFR performance will decline as the number of hours and number of dress in and removing increase (Grinshpun et al., 2020).

The number of times that an FFR can be reused will highly be limited by its fit because the tethering straps can become weaker or loose after each put on. Every time an N95 FFR is put on or removed, the integrity of the straps may be impacted. Repeated put on and removing will result in the straps no longer being able to produce sufficient force to establish a tight seal with

the face. The following poor seal will let unfiltered air to go through the N95 FFR and into breathing zone.

CDC suggests limiting the number of put on for an N95 FFR to no further than five per device (Fisher & Shaffer, 2014). It may be achievable to put on some models of FFR more than five times. Single study stated that fit performance reduced over numerous, consecutive put on and fit differed among the different models of FFR analyzed. If manufacturer guidance on how many times a particular FFR can be donned is not accessible, the CDC suggests restricting the number of uses to no more than five per device based on available data on changes in FFR fit from a limited number of FFR models over multiple put on.

Decontamination of an N95 FFR inactivates viruses and bacteria on the device but does not reinstate the N95 FFR to "brand new" performance. Decontamination studies have assessed the effect of the decontamination process on the fit and filtration performance of N95 FFR; however, these studies did not consider the likelihood that N95 FFR worn by healthcare personnel are likely donned and doffed multiple times before undergoing decontamination. N95 FFR performance will decrease as the number of hours and number of donning and doffing increase. Repeated decontamination and handling of FFR can damage the fit and filtration performance of N95 FFR. Fit performance during limited reuse, including decontaminated FFR, should be monitored by the respiratory protection program manager or appropriate safety personnel. Information about how to assess N95 FFR fit during limited reuse can be found below.

1.2 Importance of using decontamination.

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 filtering facepiece respirators (FFR) is a crisis capacity strategy permitted when there are known shortages of FFR.

1.3 Problem Statement and Research Objectives

The increase uses of FFR across the globe has effectively reduce contagion. Almost all countries in world are implementing a must-wear mask regulation urging their citizen to wear a FFR in public or in crowded places. However, as the number of FFR increase to billion, manufacturers is unable to cope with the demand which makes FFR are not sufficient for everyone and lead few countries to not having enough FFR which causes crisis capacity.

Next, FFR are required to be worn on daily basis especially in crowds and can be fined up to RM10,000 for not wearing it (Syahrul, n.d.)(Pesuruhjaya Penyemakan Undang-undang, 2017). Hence, cost of mask for daily uses is greatly considered as a reason to use a used mask and an approved FFR can be very expensive. For an example, a Niosh-approved FFR can cost up until RM100 for a piece which is expensive to most of public.

So, to pursue that research, an experiment regarding the reclaimed mask effectiveness was carried out at NIOSH Bangi to evaluate the performance of FFR characterization of the aerosol penetration and filter resistance of American version N95 and Chinese version KN95 type. The microstructure of the filtering system and mask macrostructure were carried out at the

Engineering Campus, Universiti Sains Malaysia. The evaluation will be done after the FFR have gone through the specific decontamination procedures.

There are two objectives to achieve in this project:

- To evaluate performance of FFR by characterization of penetration and filter resistance
- To determine the effect of decontamination treatment to FFR macrostructure and microstructure.

1.4 Scope of study

This study aims to understand the influence of specific decontamination methods towards contaminated FFR. Throughout the study, N95 and KN95 FFR is used for comparison test and four types of decontamination methods which includes Vaporized Hydrogen Peroxide and Bleach as chemical decontamination methods and Autoclave and Moisture Heat as non-chemical methods.

1.5 Research Outline

This thesis comprises several chapters which includes.

Chapter one states the introduction for the project giving a short explanation of the background and theory of the research. This includes the purpose, objectives, and research methodology. Next, it also includes the outline of this thesis.

Chapter two states the literature review of the study which is a comprehensive summary of previous research on Decontamination of Filtering Facepiece Respirators specifically on effect of decontamination on its structure.

Chapter three states the methodology for the experiment which is detailed steps on the process of the experiment such as the preparation of FFR and equipments, evaluation methods in term of penetration ability and structure. In this section, it also shows on how TSI-8130, operates to measure filter aerosol. Furthermore, evaluation is also done under Scanning Electron Microscope (SEM) for microstructure test.

Chapter four states the result and discussion. In this chapter, data acquired are discussed and pointed out if there are unusual findings. It also is to compare all data at different method of decontamination, chemical and non-chemical.

Chapter five states the conclusion for this study. This is to summarize and reflect on the research. In this chapter the outcome of the thesis is stated which is whether the decontamination method used are able to kill the germs without degrading the performance. Recommendation for future work on decontamination of FFR are also included in this section.

CHAPTER 2
LITERATURE REVIEW

The COVID-19 pandemic is putting globe at its worst. To counter with this problem, the key health measures being implemented in the workplace and at home involve the establishment of safety procedures, including physical distance measures, hygiene and the use of personal protective equipment such as mask (Rubio-Romero et al., 2020). FFR are component of non-pharmaceutical involvements offering breathing defense mechanism to the nasal organs by reducing absorption of pathogen (Vainshelboim, 2021). However, World Health Organization has not yet recommended for broad population mainly due to cost of manufacturing and shortage of supply. Due to the current shortage of masks, it is the best to keep mask usage at minimum.

In Malaysia only, almost 12 billion masks will be required for 32.69 million Malaysian (Mahidin, 2020) annually if 1 person uses 1 mask per day. This is far beyond the current capacity of Malaysia face mask manufacturing. Therefore, a series of research articles about decontamination are introduced by National Institute of Occupational Safety and Health (NIOSH) which is one is effect of five decontamination methods (Lin et al., 2017). There are few data released on the effects of decontamination on FFR performance. A laboratory filtration performance was measured by (Viscusi et al., 2007) on N95 model and P100 model FFR which are left exposed to 20 different biological decontamination process. The result came out, after decontamination using bleach, ethylene oxide (EtO), microwave over irradiation, ultraviolet germicidal irradiation (UVGI) as well as hydrogen peroxide was to have filter aerosol penetration values kept on less than NIOSH certification criteria. Apart from that, decontamination using, using autoclave, 160°C dry heat, 70% isopropyl alcohol, and soap and

water (20-min soak) resulted significant degradation to filtration efficiency (Viscusi et al., 2007).

2.1 Filtering facepiece respirator

Filtering facepiece respirators 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 (C. Bailar III et al., n.d.; Leung et al., 2020). It aids in air purification, lowering the danger of contamination of the wearer in a polluted environment. In the most industry, these respirators are employed to lessen exposure to harms such as 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 use them for protection from infectious aerosolized droplets released from sick patients.

As for now, 42 CFR part 84 regulation offer for nine categories of particulate filters for use with negative pressure air-purifying respirators, with three subcategories of resistance to filter efficiency degradation (series N, R, and P) which have three levels of filter efficiency associated with them (95%, 99%, and ≥99.97%). All these new respirators will follow the performance criteria mentioned by CDC for respiratory devices operated in health-care settings for protection against Mycobacterium tuberculosis (Mtb), the infectious foreign body that triggers tuberculosis (TB). The P-series is oil resistant and has a service life defined by the manufacturer, the R-series is resistant to oils but has a one shift use limitation and the N-series is not resistant to oils. N95 makes up most products currently certified by NIOSH and are most generally utilized in a healthcare setting (Fennelly, 1997). However, during this pandemic, KN95 has been used widely as N95 especially in high-risk area because of cost.

2.1.1 N95

An N95 filtering facepiece respirator, usually abbreviated N95 respirator is a particulate-filtering facepiece respirator that fits the U.S. National Institute for Occupational Safety and Health (NIOSH) N95 classification of air filtration, in the sense that it filters at least 95% of airborne particles as shown in Figure 2-1 (Chan, 2021). These non-oil resistant FFR masks, commonly known as electrets filters, are a form of FFR mask. The term N95 refers to the fact that these masks can filter at least 95% of particles with a diameter of 0.3 m (C. Bailar III et al., n.d.). According to A. Balazy, N95 respirators may not always provide adequate protection against penetrating aerosol particles smaller than 300 nm. As a result, the level of protection provided by some N95 respirator masks might fall below 95%, especially at high inhalation flow rates (Bałazy et al., 2006). It's worth noting that the performance of N95 respirators from different manufacturers varies depending on the size of the penetrating particles (Qian et al., 1998).

Figure 2-1: NIOSH N95 FFR

There are also several varieties of N95 respirators, such as surgical N95 respirators, which are more efficient than ordinary N95 respirators. From the inside to the outside, the N95 respirator is made up of four layers: an inner layer, a support layer, a filter layer, and a layer mask filter layer. In addition, to facilitate breathing, a ventilator fan is placed in the outer layer of N95.

2.1.2 KN95

KN95 masks are a type of filtering facepiece respirator that are frequently made in China and similar to N95 masks frequently used in the United States. N95 masks have marginally stricter requirements for pressure drop while inhaling. That implies N95 also have somewhat stricter requirements for pressure drop while exhaling, which should assist with breathability they are necessary to be slightly more breathable than KN95 masks. Figure 2.2 shows the KN95 FFR (Chan, 2021).

Figure 2-2: KN95 FFR

2.1.3 P100

P100 is a type of FFR which can effectively resist to oil and can filter up to 99.97% of aerosol particles. The findings of comparing the permeability values of these two types of masks before and after exercise revealed that there was no significant difference in the permeability values before and after exercise. Despite the fact that P100's post-exercise results were more convenient, FFR N95 failed the post-exercise criteria. Additionally, there is a risk of reshaping the mask due to the possible impacts on the face seal, breathing restriction, and moisture retention during exercise and hard activity. Under comparison to the N95, rigid FFRs like P100 could maintain their form in humid and hot temperatures (Kim et al., 2016). Several investigations have shown that the mean penetration for N95 and P100 is 2 and 0.03 percent, respectively, when using a high volumetric flow (Gardner et al., 2013). Figure 2-3 shows P100 FFR.

Figure 2-3: P100 FFR

2.1.4 Full Face Respirator

A full-face respirator mask is made of rigid plastic with a transparent viewing portion and a central port section beneath the viewing portion. These masks are used to treat breathing issues and sleep disorders (such as apnea) by delivering or assisting patient respiration with a breathable air spray. The part that comes into touch with the face is made of a soft, flexible elastomeric material that covers the various contours of the face well. Straps are used to keep the mask on the wearer's head. The straps are meant to hold the mask in place against the wearer's face with enough force to form a gas-tight seal. However, when the wearer is in a sleeping mood, this configuration of the masks may cause a problem. The mask will become dislodged in this situation, and the seal between the mask and the wearer's face will be broken. In the case of respiratory issues such as apnea, this leakage will reduce the pressure required for treatment, lowering the therapy's effectiveness (Ungar et al., 2010). Figure 2-4 displays full face respirator (*3M™ Ultimate FX Full Facepiece Reusable Respirator FF-402 Medium 4 EA/Case | 3M United States*, n.d.).

Figure 2-4: Full face respirator

2.1.5 Standard of FFR

Table 1 (Talhelm, 2021) summarizes standard of worldwide FFR, As displayed in Table 1, filter performance of all type of FFR must be at least 94% filtration performance to become efficient FFR. As flow rate, N9 5, DS and KN95 allow 85 L/min for NaCL to flow through as it indicates higher permeability of air flow. Almost all FFR has less than 8% leakage to avoid toxic substances leaked and put wearer in risk.

Table 2.1: Standard of FFR

Certification/ Class (Standard)	N95 (NIOSH-42CFR84)	FFP2 (EN149-2001)	KN95 (GB2626-2006)	P2 (AS/NZ1716:2012)	Korea 1st Class (KMOEL-2017-64)	DS (Japan JMHLW-Notification 214,2018)
Filter performance (must be ≥ X% efficient)	≥ 95%	≥94%	≥95%	≥94%	≥94%	≥95%
Test agent	NaCI	NaCI and paraffin oil	NaCl	NaCl	NaCI and paraffin oil	NaCI
Flow rate	85 L/min	95 L/min	85 L/min	95 L/min	95 L/min	85 L/min
Total inward leakage (TIL)*- tested on human subjects each performing exercises	N/A	≤8% leakage (arithmetic mean)	≤8% leakage (arithmetic mean)	8% leakage (individual and arithmetic mean)	≤8% leakage (arithmetic mean)	Inward Leakage measured and included in User Instructions
Inhalation resistance - max pressure drop	≤ 343 Pa	≤ 70 Pa (at 30 L/min) ≤ 240 Pa (at 95 L/min) ≤ 500 Pa (clogging)	≤ 350 Pa	≤ 70 Pa (at 30 L/min) ≤240 Pa (at 95 L/min)	≤ 70 Pa (at 30 L/min) ≤ 240 Pa (at 95 L/min)	≤ 70Pa (w/valve) ≤ 50 Pa (no valve)

Table 2.1 continued

Flow rate	85 L/min	Varied — see above	85 L/min	Varied — see above	Varied above	40 L/min
Exhalation resistance max drop	≤ 245 Pa	≤ 300 Pa	≤ 250 Pa	≤ 120 Pa	≤ 300 Pa	≤ 70Pa (w/valve) ≤ 50 Pa (no valve)
Flow rate	85 L/min	160 L/min	85 L/min	85 L/min	160 L/min	40 L/min
Exhalation valve leakage	Leak rate ≤ 30 mL/min	N/A	Depressurization to 0 Pa ≥ 20 sec	Leak rate ≤ 30 mL/min	visual inspection after 300 L/min for 30 sec	Depressurization to 0 Pa ≥ 15 sec
Force applied	245 Pa	N/A	-1180 Pa	-250 Pa	N/A	-1470 Pa
C02 clearance requirement	N/A	≤ 1%	≤ 1%	≤ 1%	≤ 1%	≤ 1%

2.2 Mechanism of filtration

Due to trapping of the aerosol occurs in the sub-micron size regime by various mechanisms such as gravity sedimentation, inertial impaction, interception, diffusion, and electrostatic attraction, penetration has an unprecedented reliance on the particle scale (Konda et al., 2020). The potential of these mechanisms being activated is investigated in the following section by examining particle sizes. The type of active ingredient, which includes physical and chemical features such as molecular weight, particle size, and so on, has a strong influence on kinetics and related mechanisms.

2.1.1. Gravity Sedimentation

For aerosol with size in the range of 1 micrometer to 10 micrometer, gravity sedimentation is play a huge role because ballistic energy and gravity that has initial effect on the huge exhaled droplets (Konda et al., 2020). Therefore, aerosol with smallest size has the highest penetrating

ability. Inertia and gravity are likely to be the leading mechanisms for the size of particles (0.5>m), according to (McCullough et al., 1997), and it has been projected that the aerosol with the smallest size, a polystyrene latex spherical (0.5 m), has the most penetrating capability.

2.1.2. Inertial Impaction

Inertial impact happens when inertia of the particles becomes too big that produces changes in the direction of the particle movement in the airflow. Particles with larger sizes, face velocities, and densities have more inertia, allowing them to be collected more easily. Because of their inertia, these particles are unable to flow around the respirator fibres (Hinds, 2012). Furthermore, rather of passing through the material filter, larger particles stray from the air streamlines, collide with the fibers, and attach to them. This technique can successfully remove particles with a diameter of 1 m or bigger (Janssen, 2003). However, it does not play a substantial role in nanoparticle capture mechanisms (Brown, 1993; Hinds, 2012; K. W. Lee & Liu, 1980). For particles smaller than 0.2 m, diffusion is the primary aggregation mechanism, while particles larger than 0.2 m are dominated by detection and inertial impaction.

2.1.3. Diffusion

Based on the random Brownian motion of particles bouncing into the filter media, it is the most effective mechanism for capturing particles with sizes less than 0.2 μm (Janssen, 2003). Indeed, in a streamline that does not intercept, anomalous particle motion increases the likelihood of particle-fiber collision (Hinds, 2012). Diffusion of extremely small things, such as ultrafine articles and nanoparticles, becomes more significant than interception as a result. The rate of diffusion becomes more visible as particle size or facial velocity decreases. With

lower speeds, the particle residence period is increased by means of filter media; hence the probability of collision between particle and filter media is increased significantly (Qian et al., 1998). Different investigations represented that when the bulk of the outflow entered the matrix of the mask, its velocity decreased immediately because of diffusion into the mask. There is a general model of the Fick's first law, which corresponds to mass diffusion across a unit area in a unit of time, and the Fick's second law, which represents the change in concentration with time in the defined region, for the mechanism of mass transport.

2.1.4. Interception

Interception defines as a particle follows the main streamline to permit contact between particle and filter media within one particle width of the surface of fiber (Hinds, 2012). Interception is not plainly determined by particle velocity, but it is more noticeable as particle size decreases. There is a critical distinction between interception and inertial impaction that there is no divergence from the central streamline for an interception, where the filter substance intercepts the particle (Mahdavi, 2013). It is worth noting that Brownian motion has a big influence on tiny particles. For particles smaller than 0.2 m, diffusion is the primary aggregation mechanism, while particles larger than 0.2 m are controlled by detection and inertial impaction (K. W. Lee & Liu, 1980). It has been claimed that by reducing aerosol size in the range of 100 nm to 1 m, Brownian motion diffusion and mechanical particle interception by filter fibers are the dominant mechanisms (Konda et al., 2020).

2.3 Methods of decontamination

Firstly, decontamination refers to the reduction or removal of chemical agents. Decontamination methods can be either physically eliminate contaminants, deactivate

contaminants by chemical detoxification or disinfection/sterilization, or delete contaminants by a mixture of both no-chemical and chemical methods.

Based on recent studies, there are many potential decontamination methods with different possible adverse effect and different performance. Decontamination methods are prioritized based on their potential for significantly reducing the number of infectious virus particles on FFR, are always accessible in emergency situation or high-risk area such as hospital setting and must be done within the shortest timeframe.

Chemical and non-chemical treatments are considered for this study as two classes of decontamination. Chemical decontamination, will be explained below, utilize 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, utilized non-chemical substance to achieve similar purpose and includes dry heat, moist heat, microwave, and ultraviolet radiation. Below are disinfectants that are effective against SARS, virus, and pandemic influenza and most of agents from below-listed classes are generally found in home or healthcare facility, cheap and successful way against influenza (Dvorak, 2005):

1) Alcohols (ethanol, isopropyl alcohol (IPA), etc.)

2) Halogens (Clorox bleach, Betadyne®, etc.)

3) Aldehydes (formaldehyde, glutaraldehyde, etc.)

4) Phenolic compounds (Lysol, etc.)

5) Biguanides (chlorhexidine, etc.)

6) Oxidants (hydrogen peroxide, ozone, etc.)

7) Acids, non-irritating (acetic acid, citric acid, peroxyacetic acid, etc.)

8) Quaternary ammonium compounds (Zephiran, Roccal, etc.)

9) Alkalis (sodium hydroxide, ammonium hydroxide, sodium carbonate, etc.)

2.3.1 Chemical Method

Decontamination may be done by removal of these agents by physical means or by chemical neutralization or detoxification.

2.3.1.1 Hydrogen Peroxide, Sodium Hypochlorite Solution and Ethanol

Six FFR were studied (Viscusi et al., 2007)for filtration performance (three-cycle, 30-minute submersion for both 6% hydrogen peroxide and 0.6% sodium hypochlorite solution) noticed small difference in filtration performance compared with controls. One of FFR for sodium hypochlorite solution has a degraded nose pad which dissolved 50%. Prior to air-drying, sodium hypochlorite solution odor was stated to remain on the FFR. For the liquid hydrogen peroxide treatments, staples were tarnished to varying degrees. Sodium hypochlorite solution treatment has the downside of the possibility for producing exposure to sodium chlorate salts remaining on FFR following air-drying. This due to chlorates are toxic in high concentrations (Lubbers et al., 1984; World Health Organization, 2005).

2.3.1.2 Bleach

Bleach is the name every chemical product which is utilized domestically and industrially to eliminate color from a fabric or fiber or to wash or to get rid of stains in a process called

bleaching. It often implies, specifically, to a dilute solution of sodium hypochlorite, as well called "liquid bleach".

Numerous bleaches have extensive spectrum bactericidal properties, getting them beneficial for disinfecting and sterilizing and are used in swimming pool sanitation to reduce bacteria, viruses, and algae and in many places where sterile conditions are needed. They are also used in many industrial activities, especially in the bleaching of wood pulp. Bleaches also have other small uses as removing mildew, killing weeds, and extending the longevity of cut flowers.

Bleaches act by responding with many colored organic compounds, such as natural pigments, and transforming them into colorless ones. While most bleaches are oxidizing agents, some are reducing agents.

2.3.1.3 Vaporized Hydrogen Peroxide (VHP)

Vaporized hydrogen peroxide (VHP), on the other hand described to as hydrogen peroxide vapor (HPV), is used to disinfect medical devices and for atmospheric disinfection of clinical areas (Ray et al., 2010). Numerous technologies are employed to transform liquid hydrogen peroxide (in the range of 30–35% concentration) into vapor (Lerouge, 2012). Vaporization units can also be integrated into enclosures implemented for pharmaceutical manufacturing and clean-room applications. Stand-alone units are accessible to sterilize reusable metal and nonmetal devices used in hospital and are compatible with a wide spectrum of medical instruments and materials.

2.3.2 Non-Chemical Method

Decontamination may be done by removal of these method by physical means but not by chemical neutralization or detoxification. For instance, using heat.

2.3.2.1 Dry heat

One of the earliest forms of sterilization practiced is dry heat sterilization of an article. It operates hot air that is either free from water vapor or has very little of it, where this moisture plays a negligible or no role in the process of sterilization. Sterilizing by dry heat is achieved by conduction. Outside surface absorbed the heat of the object, then goes towards the center of the object, layer by layer. The entire object will finally achieve the temperature necessary for sterilization to take place.

Most of the damage comes from dry heat is by oxidizing molecules. The essential cell constituents are damaged, and the organism perishes. The temperature is preserved for nearly an hour to kill the hardest of the resistant spores. A surfactant or a mix of surfactants is a called a detergent with cleansing properties in dilute solutions. Next, these substances are normally alkylbenzene sulfonates, a family of compounds that are related to soap yet are more soluble in hard water, due to the polar sulfonate is less likely than the polar carboxylate to attach to calcium and other ions located in hard water.

2.3.2.2 Moist Heat

One of the oldest means of sterilizing was heating an object. Moist heat sterilization procedures use heated air that is highly laden with water vapor to sterilize, with water vapor playing the most critical part in the process. Boiling a sample for 30 minutes or longer kills nearly all vegetative cells present, but not spores, which can germinate and begin growth shortly afterward. As a result, boiling is not a sufficient procedure for sterilizing (Ananthanarayan & Paniker, 2005).

2.4 Summary findings on decontaminations

Tables 2.2 display the summary of the decontamination studies. Related to the study design of included reports, articles were letters to the editors and were in vitro studies. Schwartz et al. (2020) explained the process executed at Duke University (US) and exhibited that vaporized hydrogen peroxide is an effective decontamination method that does not cause physical or performance degradation of the masks. Xiang et al. 2020 described that dry heat at 60 ◦ C and 70 ◦ C for 1 h can ensure the decontamination of surgical face masks and N95 respirator while maintaining their filtering efficiency and shape for up to at least three rounds of dry heat. The results demonstrated that the size range of the droplets was 0.5 15 μ and that most of the droplet articles were between 0.74 and 3.5 μ in diameter. Vo et al. (2020) explained that treatment with sodium hypochlorite (bleach) was an efficient chemical decontamination method for MS2 virus loaded onto FFR as it will result in no detectable MS2 virus if treated with higher sodium hypochlorite doses. Ma et al (2020) described that study shows that if a mask will be reused, it should be doffed without touching its surface, and the doffed mask should be put immediately into a plastic bag or stainless-steel box for steam and preventing contamination of the surface of other items. Table 2.2 shows the summary of findings.

Table 2.2: Summary of finding on decontaminations.

Author	Method	Finding
Xiang et al. 2020	Dry heat at 60 C and 70 C for 1 h	"Dry heat at 60 ◦ C and 70 ◦ C for 1 h can ensure the decontamination of surgical face masks and N95 respirator while maintaining their filtering efficiency and shape for up to at least three rounds of dry heat".
Vo et al. 2020	Sodium hypochlorite and UV irradiation	The results demonstrated that the size range of the droplets was 0.5 15 µ and that most of the droplet articles were between 0.74 and 3.5 µ in diameter. Treatment with sodium hypochlorite (bleach) was an efficient chemical decontamination method for MS2 virus loaded onto FFR. Treatment with low sodium hypochlorite doses (2.75 5.50 mg/liter) resulted in approximately 3 to 4 log reductions in the levels of MS2 coliphage, while treatment with higher sodium hypochlorite doses (8.25 mg/liter) resulted in no detectable MS2 virus.
Schwartz et al. 2020.	Hydrogen peroxide vapor	Using hydrogen peroxide vapor is a proven method of decontamination. Authors believe that decontamination of N95 respirators with hydrogen peroxide vapor is one such solution that affords us better ability to protect our health care workers as we continue to tackle this monumental issue.
Ma et al. 2020	Steam on boiling water	The study observes that if a mask will be reused, it should be doffed without touching its surface, and the doffed mask should be put directly into a plastic bag or stainless-steel box for steam and avoiding contamination of the surface of other

	items. They also presume that the masks can be used for up to seven or ten days, if they keep clean and fitted, and have not been damaged by other factors.

CHAPTER 3
METHODOLOGY

3.1 Overview

In this chapter, the techniques to perform the research work on decontamination on filtering facepiece respirator are stated. This chapter also includes the FFR selection, preparation of decontamination process, procedures on setting up experiment and all the mathematical equation to calculate all penetration and resistance of facemask.

3.2 Filtering facepiece respirator selection

For this study, as described in the following paragraph, a selection strategy is used to select a few respirator types for this testing. A criterion that might affect the change in filtration performance resulted by the decontamination is the filter efficiency degradation. Generally, studies have displayed that many organic solvents, when applied in liquid form, results an impact on filtration performance of FFR containing electret filter media (Kanaoka et al., 1984; Martin and Moyer, 2000; Janssen et al., 2003; Jasper et al., 2005; Jasper et al., 2006). Most of N95 and KN95 uses only electret filter media.

In this study, two types of FFR are used, the N95 and KN95 as shown in Figure 3-1 and Figure 3-2 respectively. A single type of FFR model is chosen from same manufacturer. Both types used in this study contained electric filter media, are purchased at the same time prior to testing.