AN INVESTIGATION OF PPE DEGRADATION UPON DISINFECTION WITH HYDROGEN PEROXIDE

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ABSTRACT

The PPE or personal protective equipment is the protective equipment used to minimize the exposure to disease and reduce the chance of infection, including surgical masks, gloves, and protection suits. Nowadays, the COVID-19 pandemic has once caused the shortage of PPEs because the healthcare staffs need the PPE for protecting them from the infected patients, as well as the other people who want to protect themselves. Therefore, several methods have been suggested to disinfect and reuse the PPEs. For our project, we focus on using hydrogen peroxide for disinfection of the PPE in order to characterize the PPE properties after being disinfected with H_2O_2. The H_2O_2 disinfection device was assembled, using 3% of H_2O_2 solution spray to disinfect the surgical masks. The properties of masks with and without H_2O_2 disinfection were evaluated by contact angle measurement and FTIR spectroscopy for comparison. Based on the results, the mask properties in terms of water contact angle after H_2O_2 disinfection were not significantly different from the original samples, whereas slight changes in the chemical structure were observed when using H_2O_2 spray for disinfection for 5 minutes and longer. Therefore, we can conclude that the H_2O_2 disinfection at 3% concentration may be able to affect the mask properties in some aspect, although not affecting their contact angle that is related to their hydrophobicity. However, it would require further experiment in future to investigate the protective performance of the surgical masks disinfected by H_2O_2.

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Symbols/Abbreviations	Terms
=C-H	Alkenes, the vinylic hydrogen stretches
ATR-FTIR	Attenuated total reflection Fourier transform infrared spectroscopy
BFE	Bacterial filtration efficiency
C=C	Alkenes compounds
C=O	Carbonyl compounds
C-C	Carbon to Carbon Bonds
C-H	Carbon to Hydrogen bonds
CH2	Methylene
CH3	Methyl groups
CH_3CHO	Acetaldehyde
CH_3CO_2H or CH_3COOH	Acetic acid
CH_3CO_3H	Peracetic acid
Cl_2	Chlorine
COPD	Chronic obstructive pulmonary disease
COVID-19	Coronavirus disease of 2019
CT	Computed tomography
EUAs	Emergency Use Authorizations
FTIR	Fourier transform Infrared Spectroscopy
GLT	Glutaraldehyde
H_2	Hydrogen monohydride
H_2O_2	Hydrogen peroxide
HAI	Hospital-acquired infection
HIV / AIDS	Human immunodeficiency virus / Acquired immunodeficiency syndrome
HOCl	Hypochlorous acid
HSD	Tukey's Honestly Significant Different
ICU	Intensive care unit
LSD	Least -Significant Different

NaCl	Sodium chloride
NaClO	Sodium hypochlorite
NaOH	Sodium hydroxide
NCl_3	Nitrogen trichloride
NH	Ammonia
NH_2Cl	Monochloramine
NH_3	Ammonia
$NHCl_2$	Dichloramine
$NHCl_2$	Dichloramine
OH	Hydroxide
PAA	Peracetic acid or peroxyacetic acid
PFE	Submicron particle filtration efficiency
PP	Polypropylene
PPE	Personal protection equipment
RT-PCR	Reverse transcription polymerase chain reaction
SARS-CoV-2	Severe acute respiratory syndrome coronavirus 2
SPSS	Statistical Package for Social Sciences
US FDA	United States Food and Drug Administration
UV	Ultraviolet
WHO	World health organization

CHAPTER 1

INTRODUCTION

1.1 Statement of the problems

For centuries, infectious diseases have been fatal for the world population. According to the report [1], the following list shows the top-ten highly fatal infectious diseases which are responsible for around 17 million deaths in 1995. Several of these were still being fatal in 2018, as shown in Table 1.

1. Lower respiratory illnesses, such as pneumonia (4.4 million)
2. Diarrheal diseases, including cholera, typhoid and dysentery (3.1 million, most of them are infants)
3. Tuberculosis (3.1 million, mostly adults)
4. Malaria (2.1 million people, and one million is children)
5. Hepatitis B infections (1.1 million)
6. HIV / AIDS (1 million)
7. Measles (1 million of children)
8. Neonatal tetanus (460,000 children)
9. Whooping cough (pertussis) (355,000 infants)
10. Intestinal worm diseases (At least 135,000)

Disinfection in several methods, such as hot air, UV irradiation, and chemicals are extensively used for disinfecting the contaminated surface and equipment to prevent the disease transmission, especially in the hospital where the infected patients are treated. The recent example of the serious outbreak is COVID-19 pandemic [2]. It has been suggested by the world health organization (WHO) that hand washing, surgical mask wearing, and social distancing are among the procedures for reducing the transmission of this disease.

Table 1. The top-ten cause of death reported by WHO in 2018 [3].

The Top Ten Leading Causes of Death			
Rank	Worldwide	Low Income Countries	High Income Countries
1	Heart disease	Lower respiratory infections	Heart disease
2	Stroke	Diarrheal diseases	Stroke
3	Chronic obstructive pulmonary disease (COPD)	Heart disease	Alzheimer's disease
4	Lower respiratory Infections	HIV/AIDS	Lung cancers
5	Alzheimer's disease	Stroke	COPD
6	Lung cancers	Malaria	Lower respiratory infections
7	Diabetes	Tuberculosis	Colon cancers
8	Road injury	Preterm birth complications	Diabetes
9	Diarrheal diseases	Birth asphyxia and trauma	Kidney diseases
10	Tuberculosis	Road injury	Breast cancer

From the COVID-19 pandemic [2], healthcare staff are the front lines in treating COVID-19 patients in the hospital settings. Face masks and personal protection equipment, or PPE, are widely demanded for these staff to protect themselves from infection, as well as for the other people. Hence, the PPE shortage has once become a serious issue in the highly infected area. At the same time, a method of PPE disinfection and reuse was thought to be one of the key solutions to this problem. Among the standard disinfection methods, hydrogen peroxide (H_2O_2) is widely used for medical and dental applications as it does not leave a residue and is environmentally friendly. H_2O_2 has research results for its medical and chemical safety, if used properly. It is a strong oxidizing agent, especially at high concentrations, and has a limited lifetime. Hence, it is not used to disinfect common infections [4]. However, H_2O_2 disinfection is more commonly used in conditions that require high-reliability sterilization processes, such as in the operating room and on the medical equipment surface. Some research has even shown that H_2O_2 sterilization could clean N95 masks for reuse, while maintaining the performance of the mask and its components [5]. Moreover, the United

States Food and Drug Administration (US FDA) also has approved H_2O_2 for disinfecting and cleaning the N95 masks for reuse in a state of shortage. Therefore, this material can be sterile vaporized and highly safe.

For this reason, the objectives of this research was to investigate whether H_2O_2 disinfection could affect the properties of surgical masks or not, starting from the design and manufacturing of the H_2O_2 disinfection device towards the characterization of the masks properties.

1.2 Objectives

To assemble the H_2O_2 disinfection device that can be used for surgical mask degradation studies.

To characterize the changes in the surgical mask properties after H_2O_2 disinfection

1.3 Scope of study

In this study, H_2O_2 disinfection will be carried out using the custom in-house made device. The disinfection parameters will be optimized based on the effective area and wetting of the masks. Mask properties are characterized using the contact angle analysis and Fourier transform infrared spectroscopy (FTIR).

1.4 Report outline

There are 5 chapters in this report.

Chapter 1 Introduction: this chapter contains a statement of problems, objective, and the scope of this study

Chapter 2 Theory and Related literature: this chapter contains an explanation of clinical problems, types of infectious diseases, disinfection strategies, and mechanism of H_2O_2 disinfection.

Chapter 3 Research methodology: this chapter contains the experimental procedures carried out in this study.

Chapter 4 Results: this chapter contains the result of H_2O_2 disinfection parameter optimization, contact angle measurement, and the FTIR analysis.

Chapter 5 Conclusions, discussion and suggestions: this chapter contains a summary of results and problems in this research and suggestions for applying in future work.

CHAPTER 2
RELATED THEORIES AND LITERATURE REVIEWS

2.1 Clinical problems of infectious diseases

Infectious diseases are caused by the contamination of pathogenic microorganisms, such as bacteria, viruses, parasites, and fungi. Some infectious diseases are transmissible across the people and/or animals via inhalation, ingestion or direct contact. Various symptoms are found from the infectious diseases depending on their types, of which fatigue and fever are common. The transmission of the infectious diseases could be prevented be frequent hand washing, social distancing, as well as vaccination [4, 6, 7]

Infectious Diseases in humans

Usually, there is the presence of non-pathogenic pathogens already in many organs, such as the skin, upper respiratory tract, mouth, small intestine, large intestine, and vagina. Non-pathogenic in the human body has many benefits, such as E. coli that synthesizes vitamin K in the intestine. Despite being able to enhance the immunity of healthy people, non-pathogenic microorganisms may also cause problems in some people with weak immunity, known as Opportunistic infection [6].

Classification of Infectious agents

The following information are summarized from [7].

1. Bacteria

They are simple single-celled organisms, i.e. prokaryotic cells with no membrane around the nucleus. Bacterial infection could directly affect the host's cells and damage the tissues. Moreover, toxins produced from bacteria are also harmful. Most bacteria enter the host's body through wounds, ingestion, and inhalation.

2. Viruses

Viruses are much smaller than cells. Apparently, viruses are like capsules containing genetic material. These tiny particles are about 20 to 400 nanometers in diameter and have the ability to mutate and evolve itself. During the infection, viruses pass their genetic material into the host's cells or penetrate directly into the cell, which alter the cellular activities and lead to the disease.

3. Fungi

These are multicellular organisms with various sizes and shapes. Fungi rely on the secretion of enzymes to decompose and assimilate organic material in the surrounding area. Their spores can diffuse into the air for reproduction. Most infections occur through direct contact with spores or inhalation of fungi. As a result, the infection usually occurs on the skin and in the respiratory system.

4. Parasites

Parasite worms are the multicellular organisms and are visible to the naked eyes. They can invade the host's body from a variety of paths throughout their lifecycle, either during their life as an egg, an embryo, or an adult. Some parasites can penetrate directly through the skin and enter the host's body. Generally, the helminth invades the host's cells through the lymphatic or circulatory systems to enter vital organs in the infected person's body, such as the heart and lungs, or invades the digestive tract to develop into an adult within the small intestine to absorb nutrients.

5. Protozoa

They are single-celled organisms with living properties like multicellular animals. They live independently and cohabit with other living things. In the life cycle of protozoa, they can reproduce many times, and there are many methods for their reproduction. Protozoa can invade the host's body through the digestive tract, circulatory system and other parts of the body with a mechanism of action similar to a virus.

2.2 Infectious diseases prevention

According to [8], there are three major strategies to reduce the transmission of infectious diseases. The first strategy is disease site prevention. This strategy includes the disinfection and quarantine of all the potentially contaminated sources, such as waste water sources. The second strategy is the transmission medium prevention, which includes the purification and filtration of the air. The third strategy is to protect the people from committing the infectious agents, which are the use of protective equipment, vaccines, or the medication. However, as mentioned in the introduction, this study focuses on the use of H_2O_2 disinfection. Hence, the following section further describes the disinfection strategies and their working mechanisms.

2.3 Coronavirus disease 2019 (COVID-19).

According to a literature review of Coronavirus disease 2019 [9], the coronavirus is a contagious infection caused by the severe acute respiratory syndrome coronavirus 2 called (SARS-CoV-2). The first outbreak of Coronavirus disease occurred in Wuhan city, China in December 2019. The Coronavirus disease has spread worldwide since January 2020 and the World Health Organization declared the COVID-19 pandemic as a public health emergency in international concern [10]. The following sections will describe the sign and symptoms of COVID-19.

The signs and symptoms of COVID-19.

Symptoms of COVID-19 are ranging from mild to severe symptoms. The common symptoms include fever, headache, loss of smell and taste, muscle pain, and breathing difficulties, and the severe symptoms such as decreased white blood cells, kidney failure, persistent chest pain, and organs failure [11]. The example of COVID-19 symptoms are shown in figure 1.

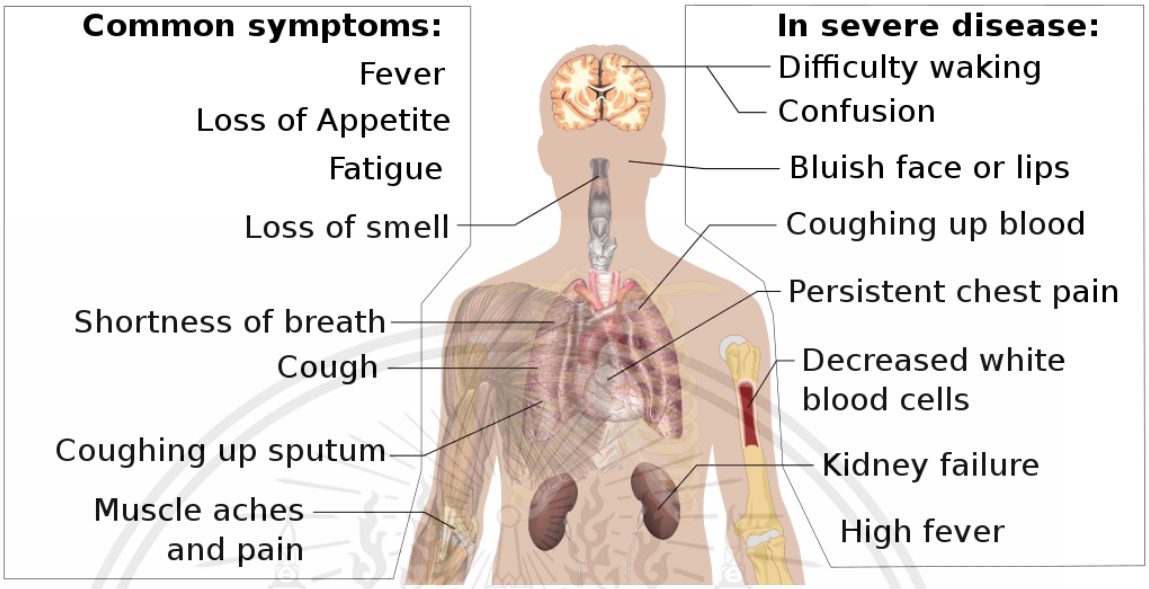

Figure 1. Symptoms of COVID-19 [11].

Moreover, most infected people will develop mild symptoms to moderate symptoms within two to seven days after exposure, and then suffer severe symptoms within 12 days respectively and the period from infection to symptoms of COVID-19 is 14 days [11]. However, some infected people continue to have a long-term effect of the disease for months after recovery and the effects may cause the organs to fail.

Causes of COVID-19.

COVID-19 is caused by the SARS-CoV-2 virus strain. Nowadays, there are three variants of SARS-CoV-2 which spread in global populations including the UK variant, South Africa variant, and Brazil variant [9]. The next section will explain how the COVID-19 is spread widely.

In terms of the transmission of COVID-19, the virus is transmitted through the respiratory tract as a respiratory droplet when an infected person coughs, speaks, sneezes including breaths. The closer people who are close interact with the infected people may get a respiratory droplet from an infected person into the mouth, nose, or eyes [12]. During the transmission of human to human, 1000 infectious SARS-CoV-2

virions are transmitted to a new infection. However, the virus is able to spread indoors particularly in less ventilated or crowded places that it often spreads as a disease cluster such as nightclubs, gyms, restaurants and offices [12]. Likewise, there are super-spreading events, where crowds are infected by one person before their symptoms appear in two days.

WHO has published the standard methods of testing for diagnosing the presence of SARS-CoV-2 which is the reverse transcription polymerase chain reaction (RT-PCR) or nucleic acid test of infected secretions that is typically used a nasopharyngeal swab for respiratory samples and chest CT scans also use to diagnose the COVID-19 in individuals [13].

According to the COVID-19 pandemic prevention [14], the COVID-19 virus primarily spreads through respiratory droplets from infected people as mentioned in the causes of COVID-19. There are five important ways to protect yourself and others during the COVID-19 pandemic in the following sections.

Firstly, wash your hands often with soap and water for at least 20 seconds or follow a handwashing procedure after going out to the public place, the bathroom, after sneezing, coughing, before and after eating and touching public things. If washing with soap and water is not available, use hands sanitizer with at least 75% of alcohol and rub your hands together until your hands feel dry [14].

Secondly, social distancing that is infection control to slow the spreading of the diseases such as travel restrictions, closing some workplace or communities place and self-quarantines after having been to high-risk areas for 14 days from the last time of exposure. Individual social distancing is also important in infection control such as staying at home, avoiding crowded peoples, no-contacting greetings and using physical distance with others [14].

Thirdly, wear a face mask in public places to decrease risk of COVID-19 transmission through respiratory tracts and reduce the chances of infection. Wearing respirators and

personal protective equipment are also strongly recommended by the WHO to healthcare staff who are taking care of infected patients or working in the hospital [15]. Moreover, if wearing a mask is not available, the WHO recommends using a tissue or inside the elbow to cover all the mouth and nose when sneezing or coughing and need to use hand sanitizer or washing your hands after any sneeze or cough [15].

Fourthly, surface cleaning including personal belongings, keyboards, furniture and public things because the virus can survive on surfaces for hours to several days at room temperature or even under ideal conditions especially in some surfaces such as fabric, non-porous surface and the dirty surface [14]. So, the virus can cause the body infection through a person possibly touching the dirty surfaces which may have survived coronavirus on surfaces. However, coronaviruses very quickly die when exposed to the UV light in sunlight or higher temperature [12]. Moreover, The WHO also recommends cleaning surfaces with detergent or disinfectant to reduce the risk of COVID-19 transmission [15].

Fifthly, preparation in case of someone in your household gets sick by stocking on supplies such as simple medicines, medical masks and disinfectants and preparing an isolated room with well-ventilated for someone who gets sick, keep physical distance from others, wear a medical mask all the time when contacting with sick person, using separate eating utensils and bedding from the sick person and frequently disinfect touched surfaces [12]. Moreover, the WHO recommends taking care of the sick person by monitoring the health of the sick person regularly. If there are danger signs such as difficulty breathing, chest pain, and loss of mobility that lead to a serious illness, call the healthcare staff immediately to pick up and further treatment in hospital [15].

Treatment of COVID-19

According to the COVID-19 treatment guidelines [16], there are two main processes to handle the pathogenesis of COVID-19. First stage, the disease primarily occurs by replication of SARS-CoV-2 and, second stages, the disease appears to be caused by an inflammatory response or a dysregulated immune to SARS-CoV-2 that leads to organ decompensation. So, the antiviral therapies were introduced to have the effective effect in the first stage of the disease. Likewise, immunosuppressive or anti-

inflammatory therapies are introduced to treat in the second stages of the disease. The following sections will explain the pharmacologic management of COVID-19 patients based on disease severity.

The disease severities can divide into three stages with pharmacologic recommendations including

First stage – Outpatients with mild to moderate COVID-19 infection, the patients who are not at high risk for disease spreading. The COVID-19 treatment guidelines [16] recommends to provide supportive care and symptomatic observation with self-isolation for reducing the risk of COVID-19 transmission to others. On the other hand, the patients who are at high risk for disease spreading,

The COVID-19 treatment guidelines [16] recommend the use of anti-SARS-CoV-2 antibody-therapies during the early stages of infection. The anti-SARS-CoV-2 monoclonal antibodies are available from Emergency Use Authorizations (EUAs) approved by the Food and Drug Administration (FDA) for the treatment of COVID-19.

Second stages – Hospitalized patients, The COVID-19 treatment guidelines [16] recommends the remdesivir is an antiviral agent which is approved by FDA for treatment of COVID-19 for use in the hospitalized patients who require supplemental oxygen. However, the remdesivir is recommended for use as appropriate but not in routine. Moreover, there is another therapy for treatment of COVID-19 which are approved by FDA [17], dexamethasone plus remdesivir which strongly recommend to improve survival in hospitalized patients who require increasing amounts of supplemental oxygen.

Third stages – Hospitalized patient and require noninvasive or invasive ventilation, The COVID-19 treatment guidelines [16] recommends to use dexamethasone plus remdesivir with adding tocilizumab which is a recombinant humanized antibody to improve survival of severe patients who rapidly respiratory decompensation or patients who are admission in the ICU for 24 hours.

In addition, according to the information provided by World Health Organization

(WHO) [18], COVID-19 vaccines are critical against COVID-19 pandemic and they not only reduce the chance of infection, but they also relieve disease severity and serious complications in case of infected patients. The vaccines work with developing the body's immunity and then induce the body to produce immunity against COVID-19. Moreover, the COVID-19 vaccines are recommended to primarily offer to the health care personnel in government and private hospitals, older people who are over 60 ages, frontline immigration officers and patients with severe diseases such as cardiovascular disease and diabetes [18]. Recently, there are five COVID-19 vaccines for emergency use that are approved by WHO [19] including Pfizer/BioNTech, Astrazeneca-SK Bio, Serum Institute of India, Janssen (Johnson & Johnson) and Moderna vaccines for emergency use.

2.4 Disinfection strategies

According to the guideline for disinfection and sterilization in healthcare facilities [20], disinfectants are often used as the solution for the safety and the cleaning of the anaerobic skin of living organisms and the contaminated surface of the household equipment or the medical devices. They contain antimicrobial agents that could kill or inhibit the pathogens. There are several commonly used antimicrobial agents suggested in the literature [21].

Halogen releasing agent group

The chemicals in this group are chlorine and iodine. Both are considered to be oxidizing agents, but chlorine is stronger than iodine. Chlorine used for disinfection contains elements of salts and other compounds. Chlorine is a gas, lemon-green color, and pungent in the atmospheric environment will transform into liquid and amber color with increasing temperature and pressure. When mixing with water, chlorine is highly oxidizing and corrosive. Chlorine can be produced from electrolysis of NaCl aqueous solution, resulting in chlorine and hydrogen gases formation alongside NaOH, as shown in equation 1.

$$2\ NaCl^{-I}\ (aq) + 2\ H^{I}_{2}O\ (l) \rightarrow 2\ NaOH^{I}\ (aq) + Cl^{0}_{2}\ (g) + H^{0}_{2}\ (g)$$

Equation 1. The formation of chlorine gas via electrolysis of NaCl aqueous solution [21].

The most popular chlorine disinfectant is sodium hypochlorite (NaClO) , which is a lemon-green colored solution commonly known as bleach. It usually has 7-15% chlorine concentration, which is widely used in water supply systems and waste water treatment. However, it should be noted that NaOH is unstable and easily decomposes. Therefore, it should be kept at below 30°C and away from light [21]. The mechanism of NaClO in disinfection of bacteria, fungi and viruses involve the reactions that destroy their enzyme and cell wall [21]. Most chlorine reactions are activated by ammonia, as shown in equation 2.

$$HOCl^{I} + N^{I}HCl_{2}^{-I} \rightarrow N^{III}Cl_{3}^{-I} + H_{2}O$$
$$0\ IOCl + 0\ NH_{2}Cl \rightarrow 0\ NHCl_{2} + 0\ H_{2}O$$
$$HOCl^{I} + N^{-III}H_{3} \rightarrow N^{-I}H_{2}Cl^{-I} + H_{2}O$$

Equation 2. Ammonia-activated reactions of NaCl [21].

Iodine has been used for over 100 years for treating the wounds. The iodine solution is brown in color and slightly water soluble, and thus the color stains could be a problem. In terms of the mechanism, the iodide ion binds to the bacterial cell wall and produces a protein complex that affects the protoplasm, oxidizes protein, and interferes with cellular metabolism. These mechanisms could kill 99% of the bacteria within 30 seconds to 1 minute, and as short as 15 minutes in destroying the fungal spores. There are many products of iodine solution today. For example, iodine tincture contains a mixture of 2% iodine with 2.4% potassium iodide (KI) dissolved in 50% ethanol. On the other hand, the strong iodine tincture solution consists of 7% iodine and 5% KI in 85% Ethanol, which is irritating to the skin [21].

Iodophor is a substance made by the combination of iodine and other substances such as detergents, wetting agents, and solubilizers that contain iodine up to 30% by

weight. The iodophor gradually releases iodine to disinfect bacteria, fungus, and virus, but it is not sporicidal. Iodophor works optimally at low pH, and thus it is used alongside phosphoric acid as an acid stabilizer for effective activation [21].

Alcohols

Alcohols are the intermediate level disinfectant. The most alcohols that are generally used as disinfectants in healthcare are ethyl alcohol. The antimicrobial action of alcohol is denaturation of proteins that leads to the inactivation of bacteria. The antimicrobial effect is effective when the ethyl alcohol concentration is around 70% and 50% for isopropanol. Alcohols react with the microorganisms which are covered by lipids because they dissolve lipids and cause protein denaturation. Alcohol is the effective disinfectant with high-safety, inexpensive, colorless, odorless, less corrosive, and nonresidue. However, alcohol might cause dry skin if redundantly used and should be kept away from direct sunlight and heating because alcohol is flammable. It should also be noted that the effectiveness of alcohol could drop sharply when diluted [21].

Aldehydes

The common chemicals of aldehydes used are formaldehyde and glutaraldehyde. These chemicals are effective in killing bacteria, fungus, virus, and spore [21].

Formaldehyde

Formaldehyde is classified as a monoaldehyde that is the volatile solution. It is called formalin when used in the form of liquid solution with 37% formaldehyde mixed with methanol. Formaldehyde is used as a disinfectant in both liquid and gaseous states. Normally, formaldehyde is bactericidal, sporicidal, and virucidal, but its reactivity is slower than glutaraldehyde. Formaldehyde reacts with the protein and DNA that cause condensation of primary amide and amino groups and also cross-link between protein and DNA. These mechanisms are negatively affecting the DNA synthesis of

microorganisms. Formaldehyde is used in healthcare applications, such as vaccine preparation and disinfection of the medical devices and equipment [21].

Glutaraldehyde (GLT)

Glutaraldehyde is accepted as a high-level disinfectant which is a saturated dialdehyde. Generally, the aqueous solutions of glutaraldehyde are acidic which are not sporicidal, but when the pH reaches 7.5-8.5, the solutions become sporicidal. Glutaraldehyde is highly effective in disinfection, which is sometimes called cold sterilization, and commonly used for disinfecting the medical equipment that cannot be autoclave, such as spirometry tubing, anesthesia, endoscopes, dialyzer, and respiratory equipment. Moreover, glutaraldehyde can also be used to destroy the bacteria, pseudomonas, fungus, and virus, including HIV and hepatitis B virus. This solution is non corrosive to metal and lensed instruments, rubbers, or plastics, but should not be used for cleaning the sensitive surface because it is very toxic and high cost [21].

Hydrogen peroxide (H_2O_2)

Hydrogen peroxide is a clear disinfectant which has the concentration varies from 3- 90%. It is germicidal, against both gram-positive and gram-negative types, virucidal, killing yeast, and sporicidal. It is an oxidant which is strongly oxidizing the catalase enzyme and also producing the hydroxyl free radicals, which negatively affect the components of cells, including lipids, protein, and DNA. However, it is noted that the microorganisms which produce high catalase content would be more resistant to H_2O_2. The hydrogen peroxide works by producing the hydroxyl free radicals which attack the components of cells including membrane lipids, protein, DNA and other essential cell components. On the other hand, the catalase enzyme is also produced from the typical cellular activities which are able to protect the cells from H_2O_2 by converting it into water and oxygen. Hence, using the suitable concentration of H_2O_2 is important. The hydrogen peroxide is available commercially and used as an effective disinfectant on the surfaces, such as soft contact lenses, fabrics, ventilators, and endoscopes [21].

Peracetic acid

Peracetic acid or peroxyacetic acid (PAA) is produced from the reaction between acetic acid and hydrogen peroxide, resulting in the clear aqueous compound. It works by disturbing the permeability of plasma membrane and inhibiting the essential enzymes of microorganisms, such as bacteria, bacilli, protozoa, and fungi. Peracetic acid is used for disinfecting the surgical devices at the concentration of 35% at room temperature [21]. The peracetic acid is produced by autoxidation of acetaldehyde, as shown in equation 3, which could further react with H_2O_2 and form acetic acid and water, as shown in equation 4.

$$O_2 + CH_3CHO \rightarrow CH_3CO_3H$$

Equation 3. Chemical equation of Peracetic acid [21].

$$H_2O_2 + CH_3CO_2H \rightarrow CH_3COOOH + H_2O$$

Equation 4. Chemical equation of acetic acid reacted with hydrogen peroxide [21].

Phenolic compounds

Phenolic compounds generated from carbolic acid that is usually used in agriculture and industry. In industry, phenolic compounds are used as an intermediate for plastic and resin production, whereas it is used for pesticide, antifungal, and anti-infectious drugs production in agriculture. Phenolic compounds are effective against gram-positive bacteria and some gram-negative bacteria. Phenolic disinfectant has a long-lasting effect, so it works well with wall surface disinfection and devices that are not exposed to the virus. Phenolic disinfectant is not used in the newborn baby room, operation room, and also not used with anesthesia equipment, ventilator and equipment for use with babies as it is toxic to the liver, kidney, and central nervous system [21].

2.5 The disinfection mechanism of hydrogen peroxide

Hydrogen peroxide, or H_2O_2, is a peroxide compound that consists of two oxygen atoms linked together by a single bond, as shown in figure 2. It is a clear liquid

and slightly more viscous than water, which can decompose into oxygen and water, as shown in equation 5. When diluted, H_2O_2 becomes unstable and tends to decompose [22]. Hydrogen peroxide is used as a sanitizer that inhibits the growth of microorganisms and bacteria.

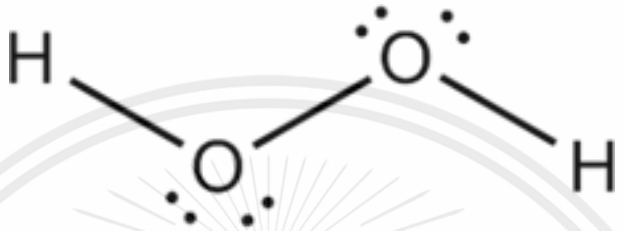

Figure 2. Chemical structure of hydrogen peroxide [22].

$$2\ H_2O_2\ (aq) \rightarrow 2\ H_2O(l) + O_2(g)$$
$$\downarrow$$
$$\bullet OH \rightarrow \text{affecting bacterial cell membranes.}$$
$$\text{(Hydroxyl radical)}$$

Equation 5. A reaction to free radicals affecting bacterial cell membranes [23].

H_2O_2 works by producing hydroxyl free radicals which are strongly active against the bacterial cell, as shown in figure 6. It oxidizes the sulfhydryl (-HS) group of bacteria on their cell membrane, causing the protein degradation in the cell [24].

2.6 Technology and industry

As mentioned, H_2O_2 is widely used in industrial applications to kill bacteria and microorganisms, such as disinfecting the cleanroom, animal room, and hospital emergency room. In the past, formaldehyde was used to kill germs, but there was a problem with bad smell, eye irritation, and nostrils, and also it took 1-2 days [25]. Therefore, H_2O_2 vapor sterilization is now used as an aggressive sterilization that can kill bacteria, viruses, and fungi, as well as spores effectively. It will degrade into water and oxygen, which will leave no residue in the environment, thus no irritation problems

and no cancer risk [26]. This method is now used in pharmaceutical production rooms, aseptic laboratories, ICU rooms, and operating rooms. According to the case study from the Faculty of Public Health, Mahidol University [27], the efficacy of H_2O_2 vapor for sterilizing the airborne microorganisms in an operating room was studied. The objective of this research was to study the difference in bacterial and fungal numbers before and after H_2O_2 vapor sterilization in an orthopedic operating room. The reported results showed the reduced number of bacteria and fungi following the H_2O_2 vapor sterilization in comparison with the initial condition, which proves the efficacy of this sterilization method.

However, using H_2O_2 requires measures to control its concentrations not to exceed 75 mg/m^3 (75 ppm) to prevent the health hazards. The concentration of hydrogen peroxide content should be controlled below 1 mg/m^3 (1 ppm) according to the American Industrial Hygiene Association, 1957 or National Institute for Occupational Safety and Health, 1996 [28].

2.7 Efficiency of hydrogen peroxide in disinfection.

The disinfection of the medical devices and workstations in the hospital-acquired infection (HAI) require the use of effective disinfectant to reduce a possible contamination especially in the operation room in the hospital that needs the highest hygiene requirement because the surgical instruments such as the implant devices which directly contact with patient fluids. So, it is necessary to use an effective disinfectant that not only disinfects the microorganism rapidly but also is not dangerous to the patient's health and medical devices [29].

According to the evaluation of the efficacy of a hydrogen peroxide disinfectant literature [30], the hydrogen peroxide is one of the high-level disinfectants widely used for eliminating infection of equipment for hospital purposes, industrial and household. The efficiency of a hydrogen peroxide disinfectant was evaluated by the agar plate technique with determining the percentage of inhibition of hydrogen peroxide at

different concentrations (0.02%-2%) and different contact times 5, 10 and 15 min against microorganisms includes Pseudomonas aeruginosa, Staphylococcus aureus, Salmonella choleraesuis, and Bacillus subtilis [30]. The efficacy of this disinfectant was evaluated by plate counting with the average of the microorganism's replication over contact time and the different concentrations of disinfectant to verify the percentage of inhibition of microorganisms before and after disinfected by hydrogen peroxide [31].

As the results from this literature [30], the hydrogen peroxide concentrations are recommended at 0.08%-2% because they presented high percentage of inhibition even in the shortest time, while concentrations between 0.02%-0.04% are not recommended to use because they presented low percentage of inhibition in exposure time 5-10 mins. Based on the discussion and conclusion from this literature [30], the high-level disinfectant as a hydrogen peroxide is 100% effective for reduction of the microorganism population when using 2% of concentration in the shortest time of exposure because it exerts a total inhibition of microorganism growth in 5 min exposure to hydrogen peroxide. However, lower concentrations are not guaranteed in destruction of the microorganisms.

Besides, the evaluation of hydrogen peroxide vapor for inactivation of pathogen [32], also used the same evaluation method as this literature but they used a higher concentration of hydrogen peroxide more than 3% to treat Bacillus subtilis spores and results were reported that hydrogen peroxide get approximately 95% killing or inactivated the spore's growth that monitored by the high fluorescence of Terbium-DPA to define amount of a colony on a treated spore nutrient plate with comparing the untreated spore on a nutrient plate and the germination of spores populations killed >95% by hydrogen peroxide but only 5-10% of treated spores are slowly germinated [32]. The results also reported that oxidizing agent of hydrogen peroxide caused significant damage to the spore germination proteins in oxidative reaction [32]. Therefore, using hydrogen peroxide concentration more than 3% is able to kill the spores in populations by oxidizing agent and slowly inactivate spore germination as well [32].

Moreover, H_2O_2 sterilization is also one of the disinfection methods suggested to reuse the PPEs, including surgical masks, during the shortage. Surgical masks are worn to protect the users from airborne disease transmission. According to the American society of testing and materials (ASTM), the effective surgical masks should pass 5 standard tests as follows [33].

Fluid resistance: The medical mask needs to resist the simulated blood absorbing under the pressure 160 mmHg. The more fluid resistant, the more protective. A medical mask has 3 layers, of which the outer layer of a medical mask is designed to protect any cough and sneeze droplets with hydrophobic components. This is to prevent the inhalation of infected droplets from others [34]. The easy way to test the effectiveness of a medical mask is dropping water on the outer layer of the medical mask. If a medical mask is effective, it would prevent the water from entering into the inner layer, which indicates that a medical mask effectively shields the user from inhaling the water droplets.

Bacterial filtration efficiency (BFE): The BFE testing used for testing the filter material, such as medical mask and filter sheet. The BFE tested by bacterial vaporized through the filter and counts the number of bacterial that can pass out and compare with the control filter [33]. The acceptable percentage of BFE is 95%-99.9% for 3-micron bacteria.

Submicron particle filtration efficiency (PFE): The PFE testing used for testing the filtration of small particles that are less than a micron. The PFE test was done by using a particle counter and polystyrene microspheres [33]. The acceptable percentage of PEE is 95%-99.9% for 0.1-micron particles.

Delta P, differential pressure: The delta P test indicates the differential pressure across the masks, which is related to the breathability and filtration. The acceptable delta P is 4.0-5.0 mm H_2O/cm^2. It is noted that the more differential pressure, the more filtering, but may also be difficult to breathe [33].

Flame spread: The flame spread test indicates how fast the mask burns. There are 3 classes for flame spread from 1 to 3. The best level is class 1, in which the mask burns slowly [33].

Out of five tests, this study aims to use the fluid resistance test as a primary characterization of the samples following the H_2O_2 disinfection due to the practicality of the experiment, which can be done by measuring the water contact angle. The results from this test will be further analyzed alongside the characterization of the material properties to meet the mentioned objectives of this study. The following section describes the details of the testing methods used in this study.

2.8 Evaluation of mask performance after sterilized by hydrogen peroxide: Fluid resistance

Fluid resistance of the mask is of importance for preventing the airborne diseases, such as COVID-19 that is currently spreading throughout the world. The use of masks with stable fluid resistance would effectively reduce the risk of infection [35]. The evaluation of mask performance in terms of fluid resistance could be done in various testing methods such as liquid penetration resistance tester or synthetic blood penetration. However, we would like to use the testing method which can produce an easy way and provide effective results. Hence, we have decided to implement the contact angle measurement technique using a mobile device, as suggested by Durham university [36]**.**

2.9 Contact angle measurement

The contact angle is the angle between liquid–vapor interface that meets a solid surface. This contact angle tells the tendency for the liquid droplets to disperse on the smooth surface of the solid. The contact angle is inversely proportional to the dispersion capacity of the liquid, as shown in figure 7.

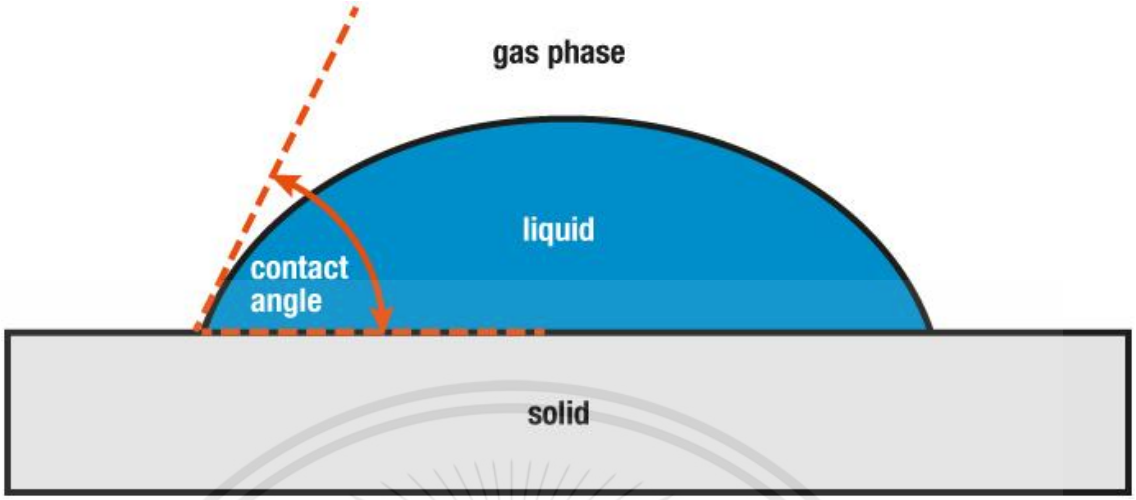

Figure 3. The explanation contact angle [37].

The contact angle of less than 90° generally means the liquid tend to spread over a wide area, whereas those greater than 90° represent poor wettability. A well-dispersed surface with an angle between 0° and 90° is called hydrophilic, and a poorly-dispersed surface with an angle between 90° and 180° is called hydrophobic. Moreover, superhydrophobic provides a contact angle of more than 150° and the angle clearly approaches the value of 180 °, resulting in very little contact between liquids and solids. This case is referred to as the "Lotus effect" or the "lotus leaf phenomenon [25,27]. The explanation of contact angle is shown in figure 4.

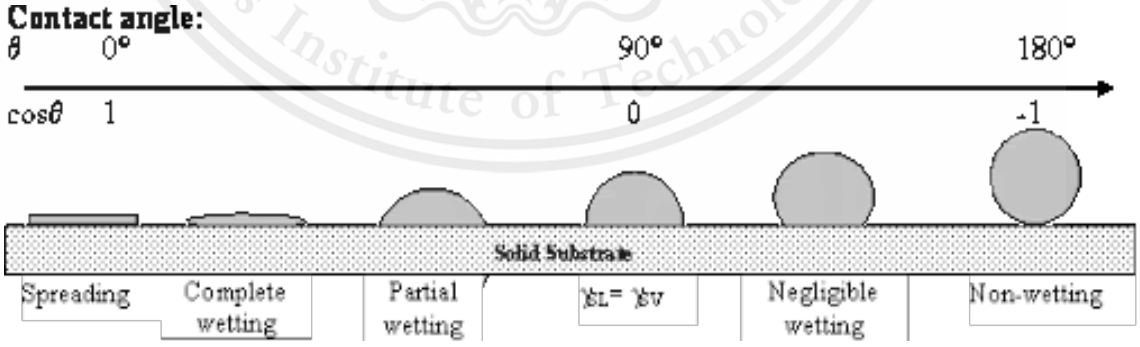

Figure 4. The meaning of contact angle. Contact angles between 0° to 90° are hydrophilic. Contact angles between 90° to 180° are hydrophobic. Contact angle of more than 150 ° is superhydrophobic [38].

In order to support our contact angles measurement results, this study uses the one-way ANOVA in SPSS statistics software for analysis of the variance of average measured contact angles. The following section will describe the details of this analysis.

2.10 Analysis of variance in ANOVA: One-way ANOVA in SPSS Statistics software.

SPSS program (Statistical Package for the Social Sciences) is a widely used statistical package with the ability to analyze data using statistical techniques and ability to manipulate data and results in the form of graphs and tables [39]. This study used the statistical techniques in this program to analyze the data by using analysis of variance in ANOVA technique. The next section will describe the analysis of variance in ANOVA.

Analysis of variance in ANOVA is used to analyze whether there are statistically significant differences between means of more than two independent groups (k groups). Analysis of variance in ANOVA has two ways for analysis, including one-way ANOVA and two-way ANOVA [39]. This study will mention only the theory of one-way ANOVA. The one-way ANOVA is the analysis of variance of data by a single factor which can have different conditions. Thus, it is an analysis of significant differences between the comparing mean of the data from different experimental conditions of the single factor [39].

According to the literature [40], analysis of variance in one-way ANOVA can be described in three parts as following sections. Firstly, the principle of one-way ANOVA analysis is dividing the variance of total data according to the cause of data differences that are the variance within the group and the variance between groups. So, the condition of variance is the total of variances = the variance within the group + the variance between groups.

Secondly, one-way ANOVA analysis requires important assumptions including a normal distribution in population in k groups, homogeneity of variances and the random

samples from each population are independent or independent observations. So, the data for variance analysis needs to pass these assumptions before using one-way ANOVA [40].

Thirdly, the hypothesis of one-way ANOVA analysis is divided into two hypotheses include the means are not significantly different if the probability values (p values) or significant values (Sig.) are more than the statistical significance is commonly set to 0.05 that means the probability of observing difference in the data by chance is 5%. On the other hand, the means are significantly different if the probability values (p values) or significant values (Sig.) are less than the statistical significance [40].

As the results of the hypothesis of one-way ANOVA that can explain the significant differences of means but not precisely indicate which mean differs from other means. Therefore, the post hoc test by multiple comparison is an alternative method that interprets the results of significant differences of means precisely in pairs. The common methods such as Least -Significant Different (LSD), Tukey's Honestly Significant Different (HSD) and The Sheffe's Post hoc Comparison (Sheffe') [39].

2.10 Evaluation of mask properties after sterilized by hydrogen peroxide: ATR-FTIR

Another important mask property is the structural stability. Therefore, we decided to evaluate the stability of mask compositions by ATR-FITR technique which is an analytical technique for observing chemical structure. This technique is used in this study because it is one of the most effective techniques to analyze and identify the chemical bonding of the organic materials. It is thought that the mask that could withstand H_2O_2 disinfection should not change its chemical structure and thus it should provide similar FTIR spectra before and after H_2O_2 disinfection.

2.11 The principle of ATR-FTIR analytical technique.

According to the literature [41], ATR-FTIR stands for attenuated total reflection Fourier transform infrared spectroscopy. It is an analytical technique to examine and

study the molecular structure of a substance in either a solid, liquid or gas state. The example of substances could be polymer, textile coating material, or leather. The principle of this technique is based on the irradiation of the infrared beam from the FTIR machine to the crystal, which has high density, and then scattered to the sample with lower density. Some of the incident infrared wave is reflected and when the angle of incidence is equal to the critical angle, it will be totally reflected at the surface of the junction between two mediums, which is called the evanescent wave. The reflected energy of the evanescent wave is measured and expressed in spectral form, as shown in figure 5 [42]. This is related to the vibration or rotation of the functional groups of the molecules of the substance, as shown in figure 6. These mechanisms would absorb the infrared energy and cause the decrease in infrared transmittance as a result.

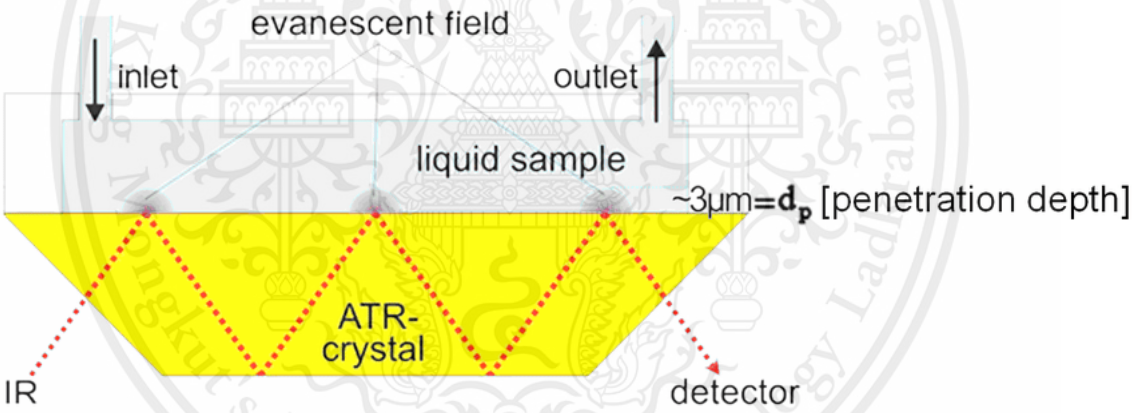

Figure 5. The reflected of IR beam inside the crystal of ATR machine [42].

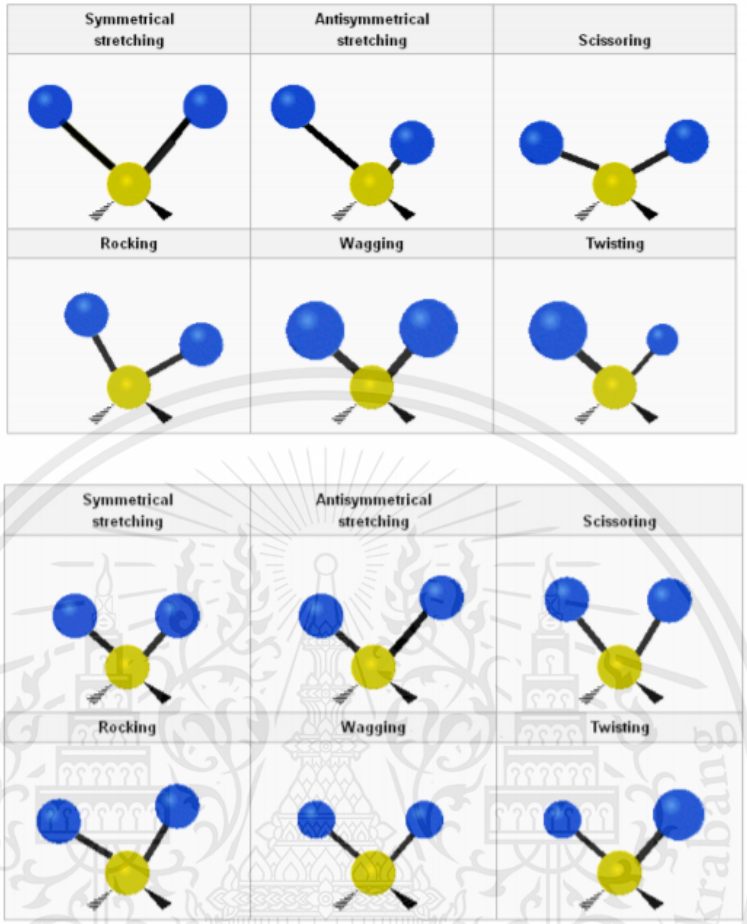

Figure 6. Types of vibrations of molecules [43]

The processed data were plotted in the form of infrared transmittance (%T) or absorbance (A) against the wavenumber (cm^{-1}). The transmittance or absorbance at each wavenumber is specific to a particular type of functional group as it would vibrate or rotate at different energies. Moreover, the different bonds will affect the stretching vibrations in different frequencies. Table 2 shows the typical functional groups and their associated wavenumber observed by FTIR [44]. Moreover, the overall FTIR spectrum from 4000-500 cm^{-1} and the observed functional groups are shown in figure 7.

Table 2. The common functional groups and their associated infrared absorption spectra [44].

Functional group	Type of vibration	Characteristic absorptions (cm^{-1})	Intensity
Alcohol			
O-H	Stretch, H-bonded	3200-3600	Strong, broad
O-H	Stretch, free	3500-3700	Strong, sharp
C-O	Stretch	1050-1150	Strong
Alkane			
C-H	Stretch	2850-3000	Strong
-C-H	Bending	1350-1480	Variable
Alkene			
=C-H	Stretch	3010-3100	Medium
=C-H	Bending	675-1000	Strong
C=C	Stretch	1620-1680	Variable
Alkyl halide			
C-F	Stretch	1000-1400	Strong
C-Cl	Stretch	600-800	Strong
C-Br	Stretch	500-600	Strong
C-I	Stretch	500	Strong
Alkyne			
C-H	Stretch	3300	Strong,sharp
C=C	Stretch	2100-2260	Variable, not present in symmetrical alkynes
Amine			
N-H	Stretch	3300-3500	Medium (primary amines have two bands; secondary have one band, often very weak)
C-N	Stretch	1080-1360	Medium-weak
N-H	Bending	1600	Medium
Aromatic			
C-H	Stretch	3000-3100	Medium
C=C	Stretch	1400-1600	Medium-weak, multiple bands
Analysis of C-H out-of-plane bending can often distinguish substitution patterns			
Carbonyl			
C=O	Stretch	1670-1820	Strong (conjugation moves absorptions to lower wave numbers)
Ether			
C-O	Stretch	1000-1300 (1070-1150)	Strong
Nitrile			
C-N	Stretch	2210-2260	Medium
Nitro			
N-O	Stretch	1515-1560 and 1345-1385	Strong, two bands

According to the infrared theory [45], there are two important IR infrared absorption ranges that provide a basic information of functional group: 4000-1300 cm^{-1} range which is called functional group region that contains the peak of infrared spectrum of many important functional groups, such as OH, NH, and C=O stretching; and 900-650 cm^{-1} range which contains the peaks of the aromatic group. On the other hand, 1300-900 cm^{-1} range, which is called fingerprint region, represents a complex spectrum. This range is very useful for identifying the substances by comparing with the reference spectrum. The absorption ranges of the infrared spectrum are shown in figure 7.

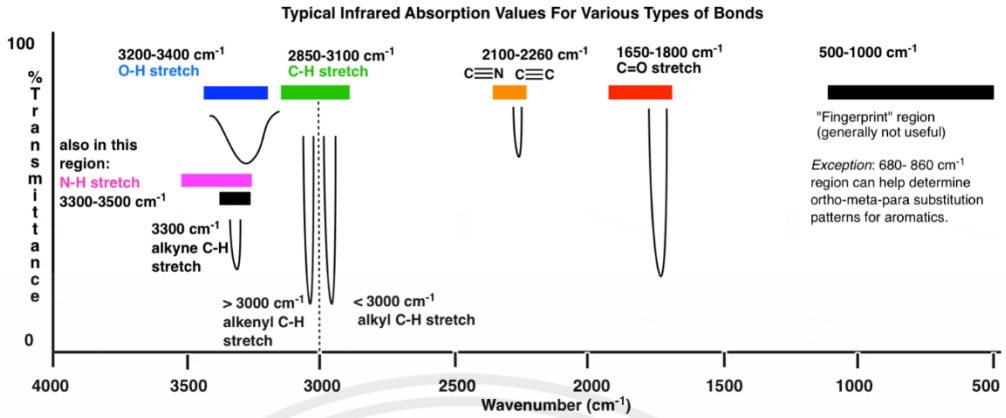

Figure 7. The absorption range of the infrared spectrum [45].

CHAPTER 3
METHODOLOGY

The experimental procedures in this study are divided into four parts: H_2O_2 disinfection device and testing; parameter optimization; and mask properties characterization.

3.1 H_2O_2 disinfection device and testing

We assemble the H_2O_2 disinfection box, which is used to spray H_2O_2 on both sides of the masks. The components of the box are acrylic sheet, 0.3 mm nozzles, pipe, 6V DC water pump, valve, solution tank, and mask hanger. The first step in assembling the box is to assemble the acrylic sheet into 30x30x30 cm^3 box then drill holes on both sides of the box to insert the nozzle into the box. Then, water tubes, valve, pump, reservoir, and a mask hanger were installed to the box, as shown in figure 8.

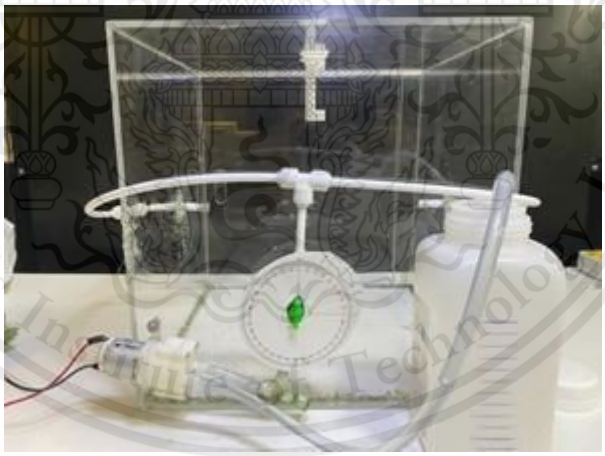

Figure 8. H_2O_2 sterilization box

3.2 Parameter optimization

Following the completion of the box, the next experiment was carried out to optimize the parameters, which are H_2O_2 flow rate and exposure time. In the case of H_2O_2 concentration, the guideline for disinfection and sterilization in healthcare facilities [46] suggests that H_2O_2 concentration for disinfection is ranging from 0.5 to 30% with the contact time of 1-10 minutes. However, the commercially available 3%

H_2O_2 is used in this study as it could decontaminate the surface and is less harmful than higher concentration. This is consistent with the regulations from Thailand public health that 3% H_2O_2 could be used for cleaning personal belongings and non-metallic surfaces with the contact time of approximately 1 minutes [47]. Therefore, we use 3% H_2O_2 in this study with the contact time from 1 minutes to 10 minutes.

On the other hand, the flow rate of H_2O_2 is not widely reported in the literature, so we conducted an experiment to measure and optimize the flow rate using water as a sample, as shown in figure 9. The flow rates were controlled by adjusting the valve position at 0 degree (0% open), 22.5 degree (25% open), 45 degree (50% open), 72.5 degree (75% open), and 90 degree (100% open). The flow rate was measured by determining the time it took to spray 50 or 100 ml of water at each position of the valve. The measurement was done three times per valve position. The measured flow rates and the average flow rates at each valve position are shown in table 3 and plotted in figure 10. As the contact time was set 1, 2.5, 5, 7.5, and 10 minutes, the total volume of the solution was calculated for each flow rate in order to sufficiently fill the solution in the reservoir. The calculated total volumes for each experimental condition are shown in table 4.

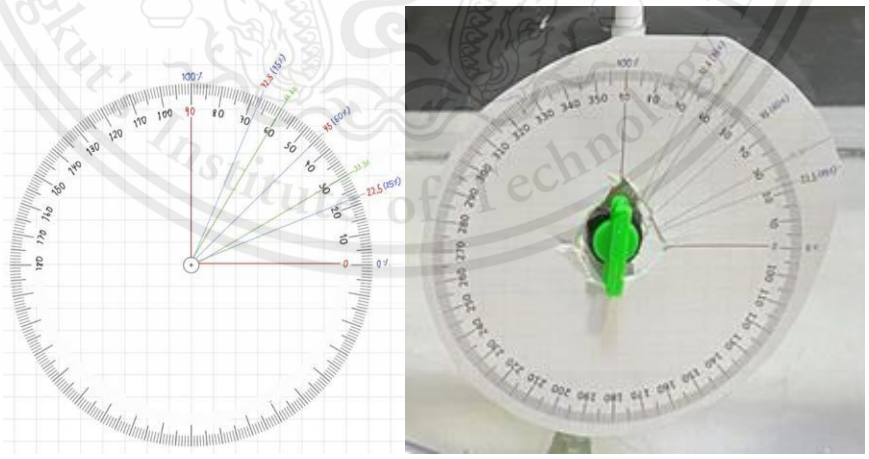

Figure 9. The angular reference used to control the valve position during the flow rate optimization experiment.

Table 3. Measured water flow rates at each valve position (ml/s)

	Measured Water Flow Rate

Valve Position	Measurement 1 (ml/s)	Measurement 2 (ml/s)	Measurement 3 (ml/s)	Average (ml/s)	SD
0 degree (0%)	0	0	0	0	0
22.5 degree (25%)	0.362	0.294	0.303	0.320	0.037
45 degree (50%)	0.450	0.423	0.403	0.425	0.024
72.5 degree (75%)	0.532	0.459	0.439	0.477	0.049
90 degree (100%)	0.684	0.649	0.617	0.650	0.326

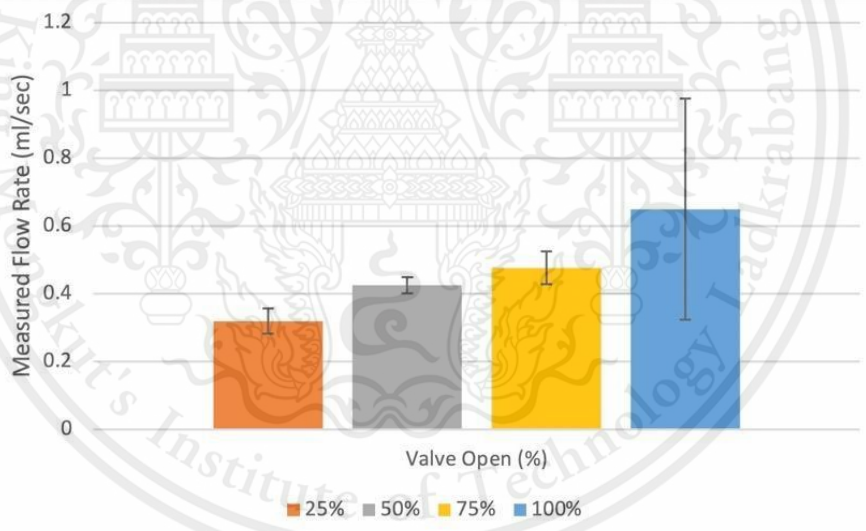

Figure 10. Average measured flow rates at each valve position. Error bars represent SD (n = 3 measurements).

Table 4. The calculated total solution volume for each experimental condition.

	Total Solution Used (ml)				
Valve Position	1 min	2.5 mins	5 mins	7.5 mins	10 mins
22.5 degree (25%)	19.2	48	96	144	192
45 degree (50%)	25.5	63.75	127.5	191.25	255
72.5 degree (75%)	28.62	71.55	143.1	214.65	286.2
90 degree (100%)	39	97.5	195	292.5	390

Following the water flow rate and volume determination, next experiment was done to evaluate the performance of each experimental condition based on the effective area and wetting of the surgical mask samples. The effective area was determined using the green color staining, whilst the wetting was observed visually. Each experiment was done three times using three samples. Table 5, 6, and 7 show the stained samples after being sprayed with 50 ml of green colored water at 25%, 50%, and 75% valve opening, respectively. It is noted that 100% valve opening was not carried out as it excessively wetted the sample and flooded the whole box.

Table 5. The stained samples after being sprayed with green colored water at 25% valve opening using 50 ml of green colored water

Sample	1	2	3
			

Table 6. The stained samples after being sprayed with green colored water at 50% valve opening using 50 ml of green colored water

Sample	1	2	3
			

Table 7. The stained samples after being sprayed with green colored water at 75% valve opening using 50 ml of green colored water

Times	1	2	3
			

The results show that at 25% valve opening was not as effective in terms of area coverage. On the other hand, those in 50% and 75% valve opening provide the samples with thoroughly covered area. However, it is noticeable that the samples from 75% valve opening were excessively wetted. Therefore, 45% valve opening was considered as the optimal condition for the following experiments.

3.4 Testing by using hydrogen peroxide solution.

After obtaining the optimal valve opening, the experiments were moved on to

the next part to test with 3% H_2O_2 solution. The samples and 3% H_2O_2 are as shown in figure 11. The first attempt was to check whether or not the experiment using 3% H_2O_2 would produce similar results as the colored water. The results are shown in figure 12, which were consistent with the colored water presented previously. Subsequently, the experiments were done at contact times as planned, and the samples were dried at room temperature before analysis, as shown in figure 13.

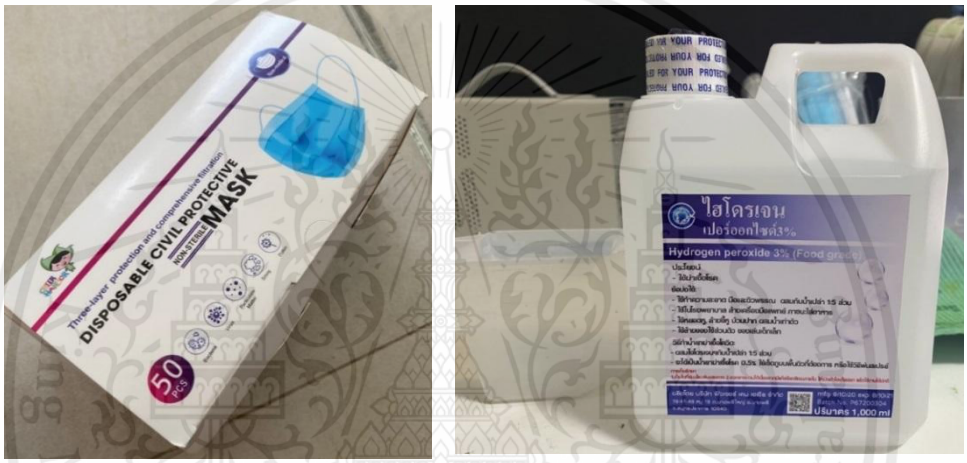

Figure 11. The surgical masks samples (left) and 3% H_2O_2 solution (right) used in this study.

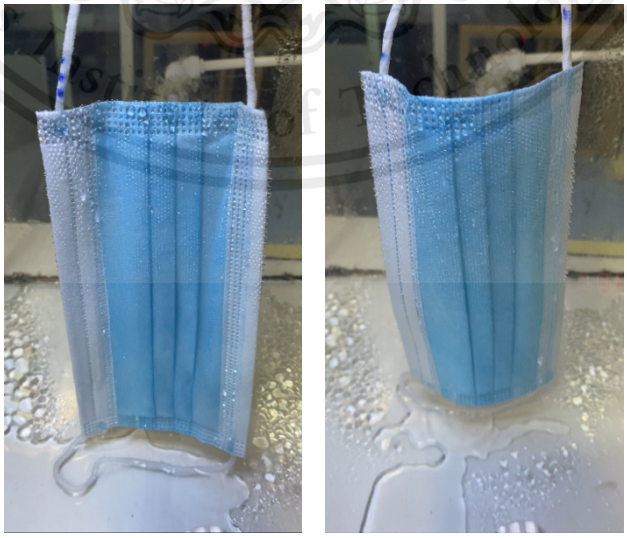

Figure 12. The first experimental attempt with 3% H_2O_2 solution.

Figure 13. The samples sprayed with 3% H_2O_2 being dried at room temperature.

3.5 The contact angle measurement methodology

The first analysis carried out in this study was contact angle analysis, which is based on the geometry of the water droplet located on the surface of the sample. The front-view images of the droplet were captured using a mobile camera, and the shape of the droplet was analyzed by using ImageJ Version 1.52v, as reported by a guide from Durham university, as shown in figure 14 [48]. Macro lens clip was equipped on the mobile camera for better visibility of the water droplet placed onto the samples, as shown in figure 15. The example of the obtained image is shown in figure 16.

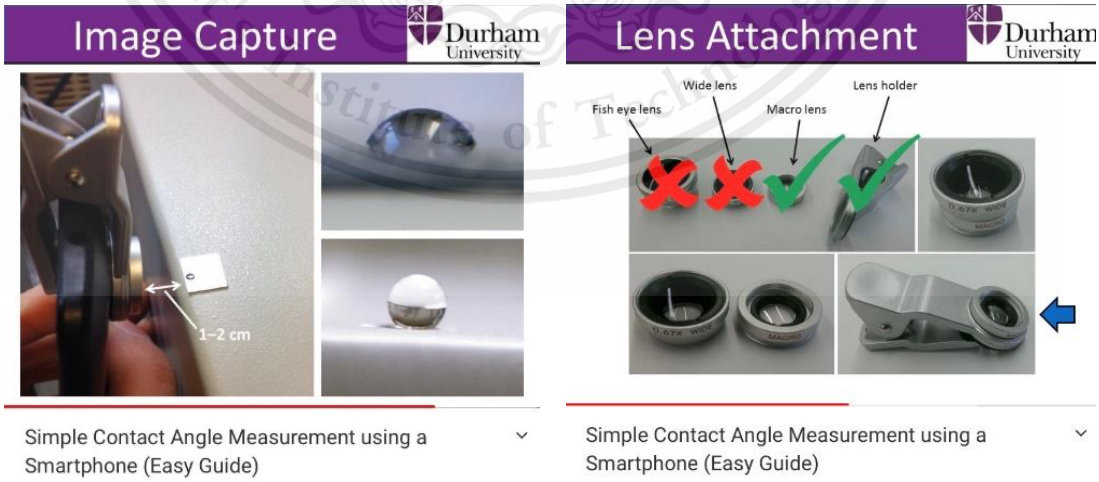

Figure 14. The reference methodology of a simple contact angle measurement using a smartphone [48].

Figure 15. A macro lens clip (left) and the experimental setup with 2 cm distance between lens and the droplet (right)

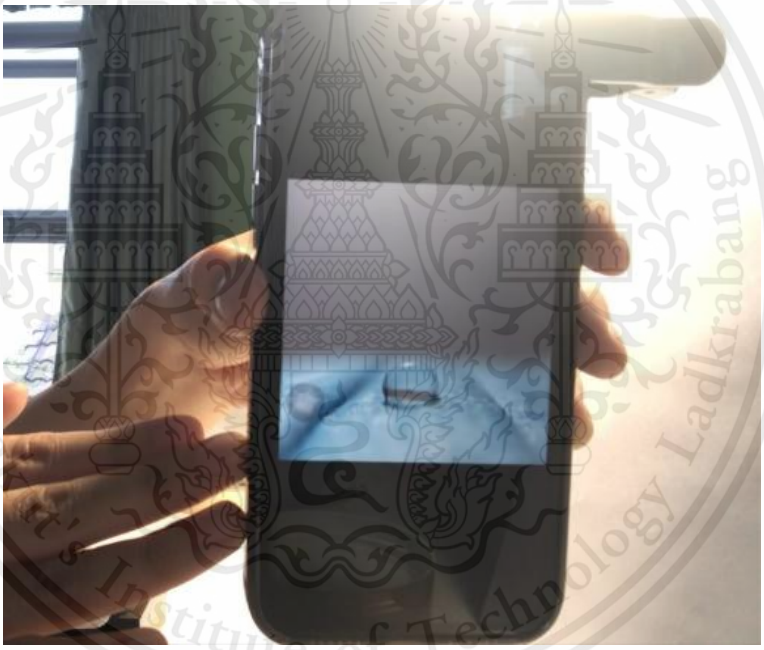

Figure 16. An example of the captured liquid droplet image.

3.6 The ImageJ for analysis of contact angle

After we got the images, we used the ImageJ software version 15.2v to analyze the contact angle of liquid droplets on the mask samples. The measurement starts by drawing a baseline of the droplet along the sample surface and the first tangential line of the droplet circumference that intercepts the baseline using the angle tool, as shown in figure 17 [48]. The example of the measured contact angle value is shown in figure 18. The data were taken from three samples per each H_2O_2 contact time, and the

measurement was done twice by two people.

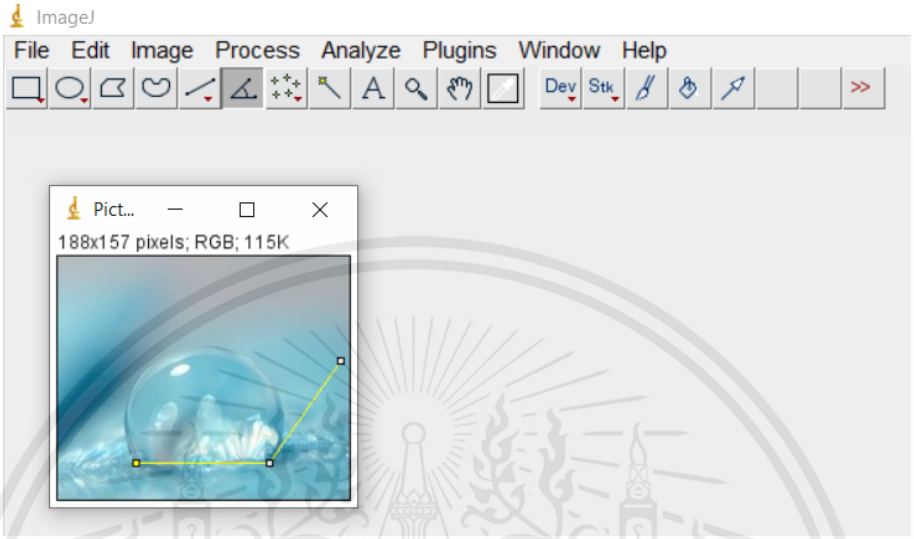

Figure 17. Using the Angle tool to determine the contact angle.

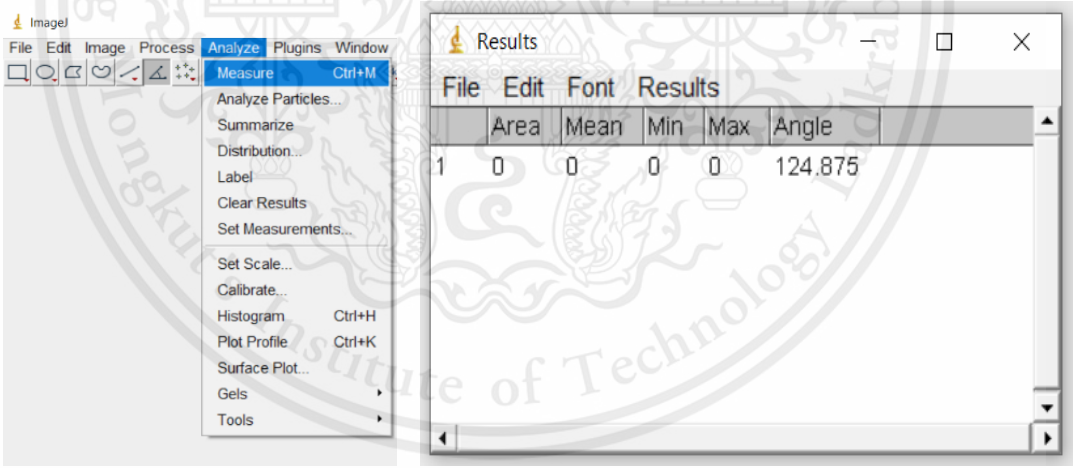

Figure 18. Measurement of the contact angle.

3.7 One-way ANOVA in the SPSS statistics program

Data were statistically analyzed using IBM SPSS software statistics Version 27. One-way ANOVA was used for hypothesis testing as there was one independent variable with more than two conditions. The independent variable was the H_2O_2 exposure time, whereas the dependent variable was the measured contact angle. The

pairwise comparison was carried out using Tukey's post-hoc test. p-values of less than 0.05 were considered significant.

3.8 Fourier transform Infrared Spectroscopy (FTIR)

The FTIR spectra of the samples from each H_2O_2 contact time was obtained from the FTIR spectrometer (JASCO). The infrared transmittance of each sample was characterized using wavenumber ranging from 500 to 4,000 cm^{-1}. All spectra were compared against each other for analysis,

CHAPTER 4

EXPERIMENTAL RESULTS

This chapter presents the results obtained from the experiments described in the previous chapter. The first part is the contact angle and the second part is the FTIR results.

4.1 The results of the contact angle measurement by ImageJ.

The images of the droplet taken from the experiments are shown in table 8. It can be seen that the droplets located on the surgical mask samples were exhibiting the semispherical shape. Moreover, the measured contact angles by ImageJ from the samples at each H_2O_2 exposure time was shown in table 9 and plotted in figure 19. The measured results show that the contact angle from all exposure times are above 90°, including the original samples. However, the average values tend to decrease with increasing H_2O_2 exposure time.

Table 8. The results of the liquid droplet images capture.

Sample	1	2	3
No H_2O_2			
1 min			

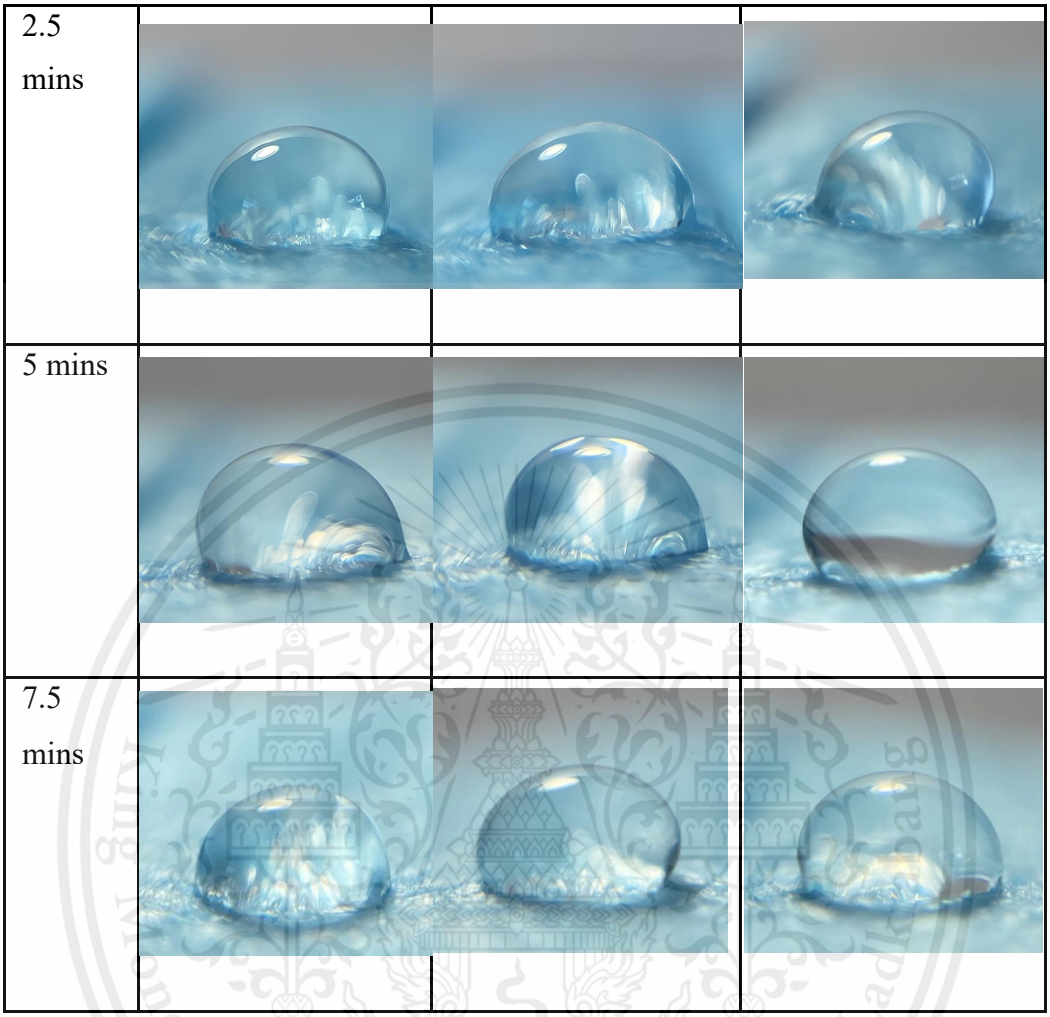

Table 9. The measured contact angles from the samples at each H_2O_2 exposure time.

H_2O_2 Exposure Time	Sample 1 (Degree)	Sample 2 (Degree)	Sample 3 (Degree)	Average (Degree)	SD
0 min	107.195	109.552	125.946	114.23	10.21
1 min	123.185	114.745	103.878	113.94	9.68
2.5 min	100.8955	98.88	103.249	101.01	2.19
5 min	93.6865	103.688	108.965	102.11	7.76
7.5 min	87.3315	108.3445	97.9875	97.89	10.51
10 min	114.8335	102.422	103.5435	106.93	6.86

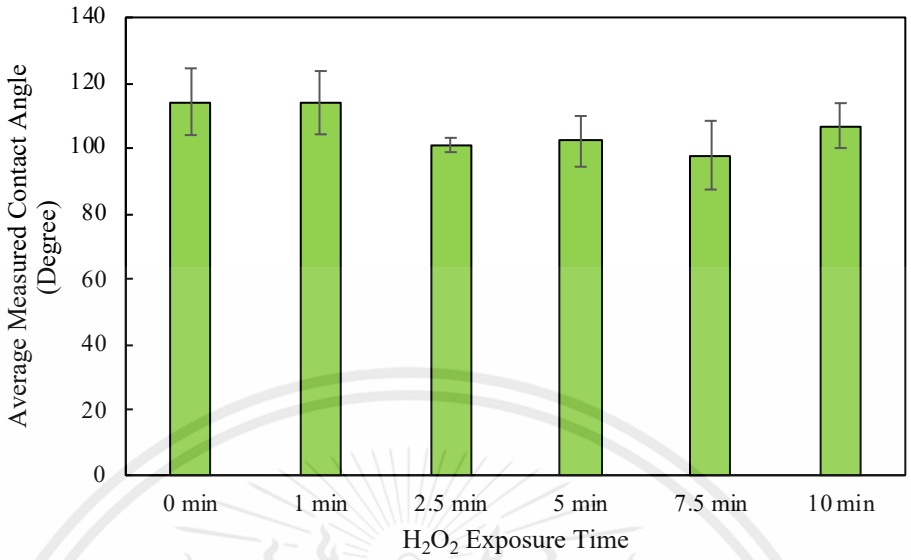

Figure 19. The average measured contact angle at each H_2O_2 exposure time. Error bars represent SD (n =3 measurements).

4.2 The results of using One-way ANOVA in the SPSS statistics

The measured contact angles were further being analysed by one-way ANOVA, and the data are shown in Table 10. Based on the results, it could be seen that the p-values from all pairwise comparison exceed 0.05. This finding implies that the contact angles of the H_2O_2 exposed samples were not significantly different from the original samples, despite exhibiting the decreasing trend.

Table 10. The one-way ANOVA with Tukey's pairwise comparison results using SPSS software.

Contact angle	ANOVA				
	Sum of Squares	df	Mean Squares	F	Sig
Between Groups	712.293	5	142.459	2.033	.146
Within Groups	841.045	12	70.087		
Total	1553.33	17			

Tukey HSD		
Time	N	Subset for alpha = 0.05
7.50	3	97.8878
2.50	3	101.0082
5.00	3	102.1132
10.00	3	106.9360
1.00	3	113.9360
.00	3	114.2310
Sig.		.233

Mean for group in homogeneous subsets are displayed.

Multiple Comparisons

(I) time	(J) time	Mean Difference (I-J)	Std.Error	Sig	95% Confidence Interval	
					Lower Bound	Upper Bound
.00	1.00	.29500	6.83555	1.000	-22.6651	23.2551
	2.50	13.22283	6.83555	.428	-9.7372	36.1829
	5.00	12.11783	6.83555	.515	-10.8422	35.0779
	7.50	16.34317	6.83555	.233	-6.6169	39.3032
	10.00	7.29800	6.83555	.885	-15.6621	30.2581
1.00	.00	-.29500	6.83555	1.000	-23.2551	22.6651
	2.50	12.92783	6.83555	.451	-10.0322	35.8879
	5.00	11.82283	6.83555	.539	-11.1372	34.7829
	7.50	16.04817	6.83555	.248	-6.9119	39.0082
	10.00	7.00300	6.83555	.901	-15.9571	39.0082
2.50	.00	-13.22283	6.83555	.428	-36.1829	29.9631
	1.00	-12.92783	6.83555	.451	-35.8879	10.0322
	5.00	-1.10500	6.83555	1.000	-24.0651	21.8551

	7.50	3.12033	6.83555	.997	-19.8397	26.0804
	10.00	-5.92483	6.83555	.948	-28.8849	17.0352
5.00	.00	-12.11783	6.83555	.515	-19.8397	10.8422
	1.00	-11.82283	6.83555	.539	-34.7829	11.1372
	2.50	1.10500	6.83555	1.000	-21.8551	24.0651
(I) time	(J) time	Mean Difference (I-J)	Std.Error	Sig	95% Confidence Interval	
					Lower Bound	Upper Bound
	5.00	4.22533	6.83555	.987	-18.7347	27.1854
	10.00	-4.81983	6.83555	.978	-27.7799	18.1402
7.50	.00	-16.34317	6.83555	.233	-39.3032	6.6169
	1.00	-16.04817	6.83555	.248	-39.0082	6.9119
	2.50	-3.12033	6.83555	.997	-26.0804	19.8397
	5.00	-4.22533	6.83555	.987	-27.1854	18.7347
	10.00	-9.04517	6.83555	.768	-32.0052	13.9149
10.00	.00	-7.29800	6.83555	.885	-30.2581	15.6621
	1.00	-7.00300	6.83555	.901	-29.9631	15.9571
	2.50	5.92483	6.83555	.948	-17.0352	28.8849
	5.00	4.81983	6.83555	.978	-18.1402	27.7799
	7.50	9.04517	6.83555	.768	-13.9149	32.0052a

Dependent Variable: Contact angle and Turkey HSD

4.3. The ATR-FTIR analytical technique result.

Following the contact angle analysis, we got the results from FTIR analysis. The infrared transmittance data were plotted against the wavenumber ranging from 500 to 4,000 cm^{-1}, as shown in the figure 20-25. The data were collectively plotted again for comparison, as shown in figure 26. Based on the results, it is found that every sample has exhibited the FTIR characteristics of polypropylene (PP), which are illustrated in figure 27 [49]. Moreover, differences in the peak characteristics are also found within the wavenumber region between 1,600 and 1,800 cm^{-1} that the shape of the peak started to change at the H_2O_2 exposure time of 5 minutes and longer.

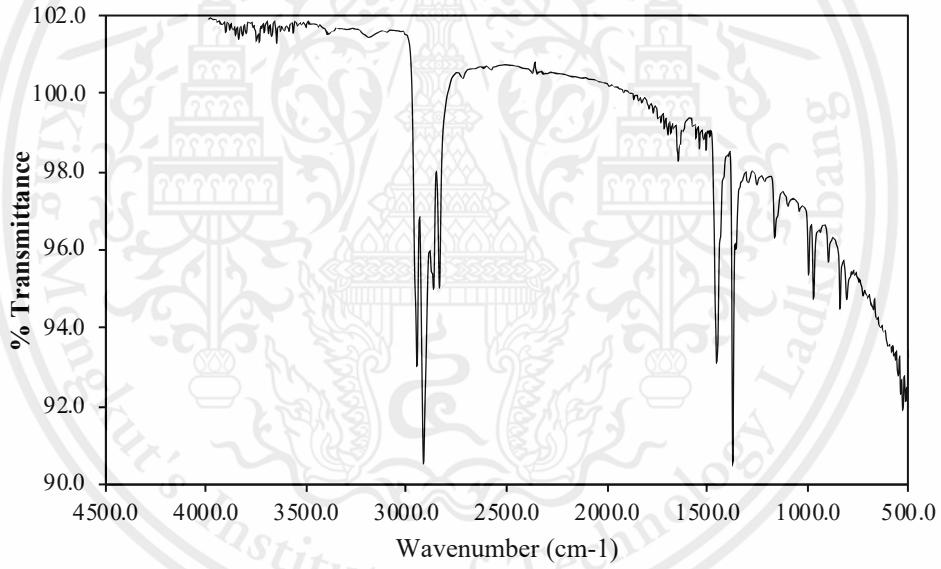

Figure 20. The FTIR spectrum of the original sample without exposure to H_2O_2

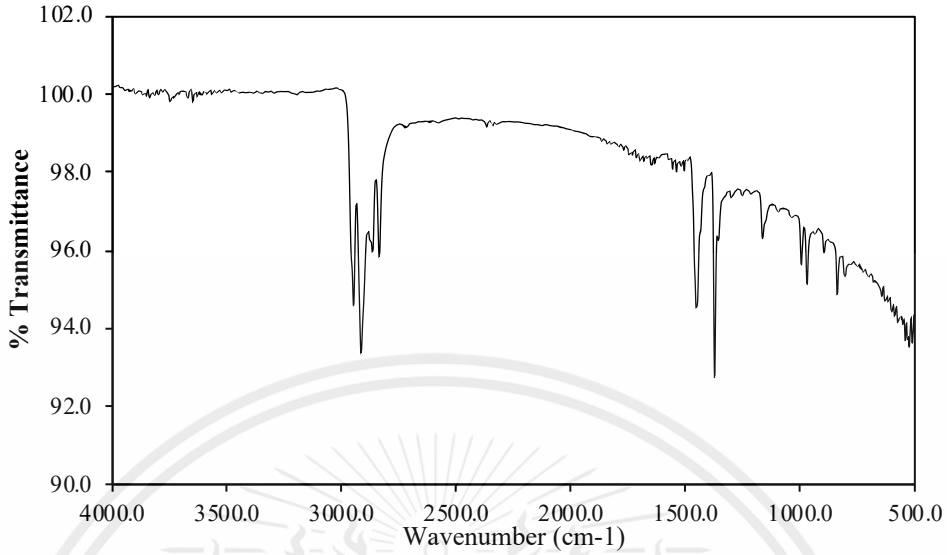

Figure 21. The FTIR spectrum of the sample after 1 min exposure to H_2O_2

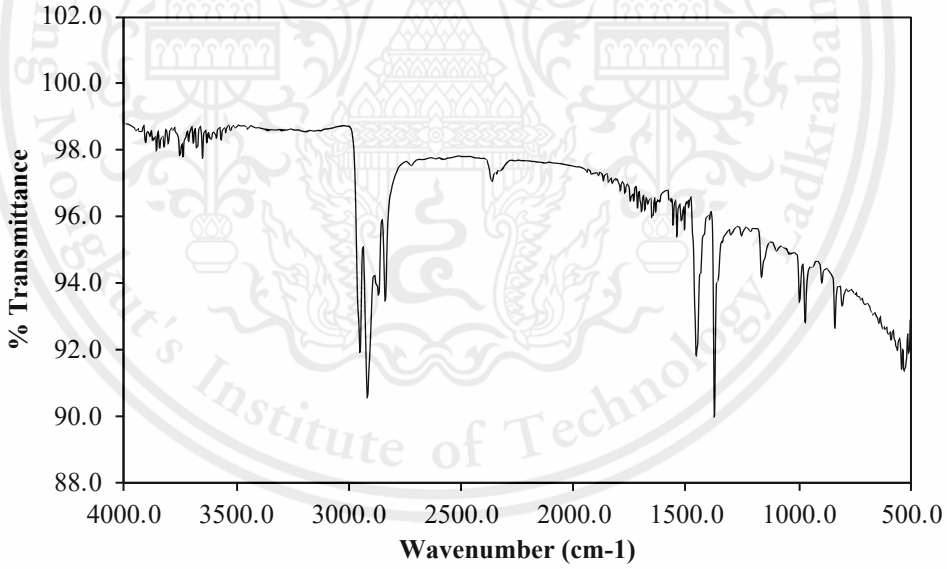

Figure 22. The FTIR spectrum of the sample after 2.5 min exposure to H_2O_2

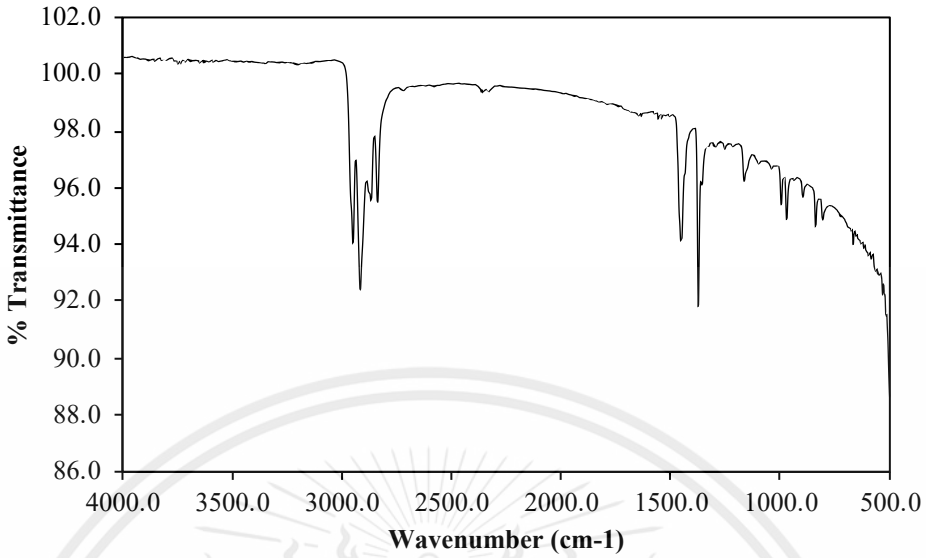

Figure 23. The FTIR spectrum of the sample after 5 min exposure to H_2O_2

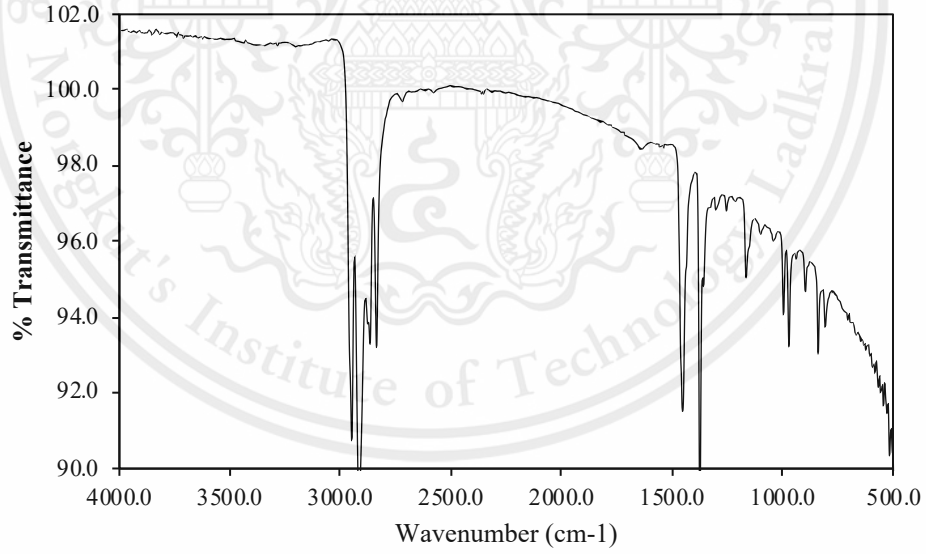

Figure 24. The FTIR spectrum of the sample after 7.5 min exposure to H_2O_2

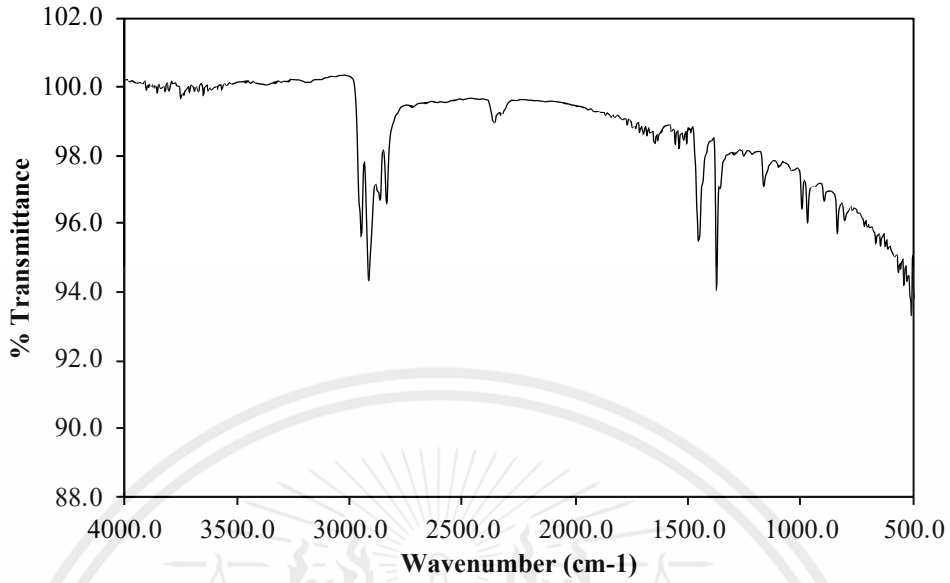

Figure 25. The FTIR spectrum of the sample after 10 min exposure to H_2O_2

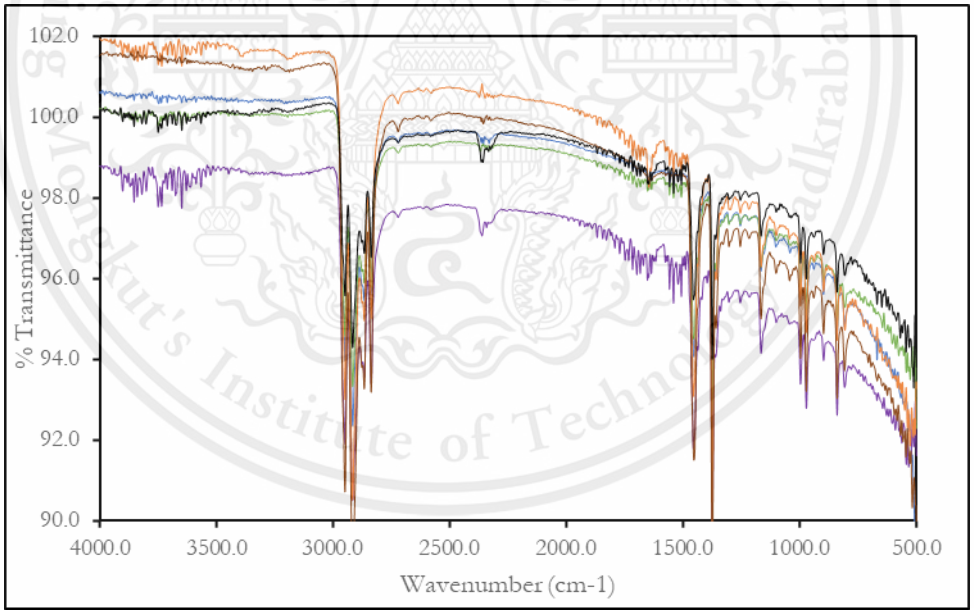

Figure 26. The comparison of FTIR spectrum from every condition. (Orange) 0 min or original sample, (Green) 1 min, (Purple) 2.5 mins, (Blue) 5 mins, (Brown) 7.5 mins, and (Black) 10 mins exposure to H_2O_2.

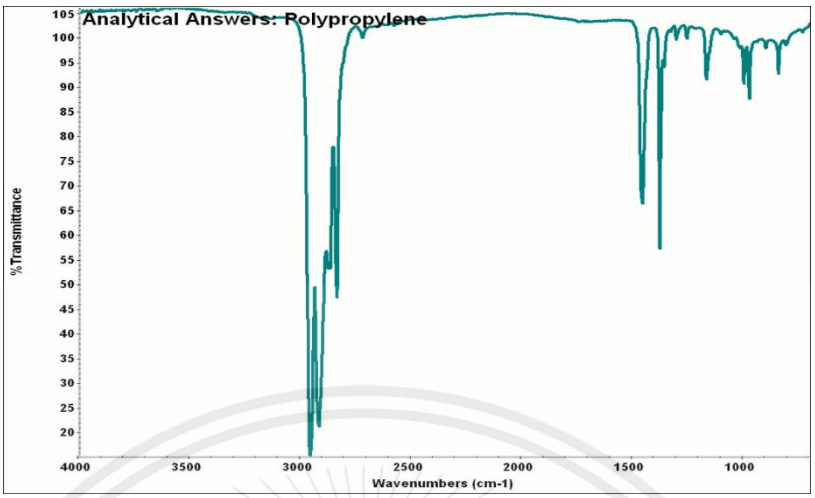

Figure 27. The FTIR spectrum of polypropylene (PP) [49]

CHAPTER 5
DISCUSSION AND CONCLUSION

5.1 Contact angle measurement discussion

Based on the results, it is found that the contact angle of the original samples were around 114°. This implies that the original mask samples are hydrophobic, which is sensible as it is intentionally used to prevent the airborne disease transmission through the liquid aerosols. Furthermore, disinfection with 3% H_2O_2 for up to 10 minutes did not significantly affect the masks' hydrophobicity as the p-values from one-way ANOVA with Tukey's pairwise comparison were higher than 0.05. However, although the contact angles were measured in this study, it would be worth investigating further in terms of the protective performance of the disinfected masks in order to discuss whether the used PPEs should be disinfected and reused or not during the shortage. Likewise, there are also factors which could affect the fluid resistance as well, and this aspect has not been investigated in this study.

5.2 FTIR analysis discussion

From the FTIR results, the characteristic of FTIR spectrum after the exposure to H_2O_2 1 min to 10 mins did not significantly differ from the original sample, or 0 min, because there was no dramatic change in the shape of the peaks which relate to the functional groups within the sample structure. The results also show that the samples were primarily made of polypropylene (PP), based on the comparison with the reference spectrum.

Polypropylene (PP) is a common material used for medical masks in order to protect the user from diseases spreading through the air, since PP has the ability to filter germs, particles and liquids as well. According to the literature [50], the combination of FTIR spectrums contain the C-H stretching region, including the asymmetric CH_2 and CH_3 stretching, the =C-H bending region, including isotactic polypropylene band, vinylidene C-H out-of-plane bend, and the rocking of C-H and CH_3, and C-C stretching region, which involves the CH_2 deformation and symmetrical CH_3 bending.

These are the functional groups of polypropylenes containing carbon to carbon Bonds (C-C), carbon to hydrogen bonds (C-H), and the methyl groups (CH_3) [51]. Therefore, the observed FTIR spectra indicated that the samples used in this study are PP.

On the other hand, only slight changes in the FTIR spectrum between 1600-1800 cm^{-1} of the samples exposed to H_2O_2 longer than 5 minutes in comparison with the original sample, which are in the region of the carbonyl compounds (C=O) and the alkenes compounds (C=C). Peaks in this region are not found in the reference FTIR spectra of the PP from the literature, and thus they could be exhibited from the additives used for surgical mask production. It could be thought from the peak changes that may be interactions within this region between the carbonyl compounds (C=O) and the alkenes compound (C=C) and the hydroxyl radicals via the oxidative reaction.

According to the literature [43], the potential carbonyl compounds (C=O) in this region could be ketones, aldehyde, ester, or carboxylic acid, an alpha, beta-carbonyl in the region 1665-1760 cm^{-1}. The carbonyl group is a polar functional group that can react with radicals and form hydroxyl group [52]. Moreover, in the case of alkenes compounds, it contains the stretching vibration of the C=C bond in the region 1680-1640 cm^{-1} [43]. The hydroxyl radicals generated from H_2O_2 contain unpaired electrons that could oxidize the double or unsaturated bonds, such as C=C and C=O, to become more stable [53]. Therefore, it is possible that the carbonyl compounds (C=O) and the alkenes compound (C=C) have reacted with the hydroxyl radicals of H_2O_2, which causes the changes in the FTIR spectra of the samples exposed to H_2O_2 for 5 minutes and longer.

5.3 Conclusion

It can be concluded from this study that disinfection with 3% H_2O_2 solution for up to 10 minutes does not significantly affect the contact angle of the surgical masks, which could be related to their hydrophobicity. The FTIR results show that the surgical mask samples were primarily made of polypropylene (PP). Furthermore, slight changes in the FTIR spectra were observed in the region between 1600 and 1800 cm^{-1} from the samples exposed to H_2O_2 for 5 minutes and longer in comparison with the original

sample. These findings could be related to the reaction between the C=O and/or C=C within the material structure with the radicals, and these could imply that H_2O_2 disinfection could change the material properties of the surgical masks to some extent. However, further experiments are required to evaluate the protective performance of the disinfected masks.

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