AN INVESTIGATION OF PPE DEGRADATION UPON DISINFECTION WITH UV IRRADIATION

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ABSTRACT

Since December 2019, our world has encountered the COVID-19 pandemic outbreak. The number of infected cases is approach nearly 150 million with approximately 3 million death tolls. Surgical mask shortage was once a serious issue as the infected cases increase since it is used to protect the wearer from spreading and receiving pathogens. As a result, there was some guidance that disinfecting the used surgical masks with UV irradiation and reusing them could mitigate this issue. It is widely accepted that UV radiation has an ability to kill the virus or any infectious agents, and it is also being able to change the properties of most polymeric materials, which are used to produce surgical masks. Therefore, the concept of this project is to investigate whether UV disinfection could affect the protective properties of surgical masks. It was found from the water contact angle analysis that disinfecting the surgical masks by UV irradiation for 15 minutes and longer has significantly reduced their hydrophobicity. Moreover, it was also found from the air flow measurement that UV irradiation for 30 minutes and longer could increase the air flow velocity passing through the masks, which indicates that the filtration properties and breathability of the masks may be affected. This study highlights that UV disinfection could affect the properties of surgical masks whilst removing pathogens, although it could not discuss further on the protective performance of the disinfected masks.

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LIST OF SYMBOLS/ABBREVIATIONS

Symbols/Abbreviations	Terms
WHO	World Health Organization
DNA	Deoxyribonucleic acid
RNA	Ribonucleic acid
SAR-CoV-2	Severe acute respiratory syndrome 2
COVID-19	Corona Virus Disease 2019
UV	Ultraviolet
AID	Acquired Immune Deficiency Syndrome
FIV	Feline immunodeficiency virus
GI	Gastrointestinal tract
UTI	Urinary tract infection
COPD	Chronic obstructive pulmonary disease
Fe	Iron
Ni	Nigel
Cr	Chromium
HALS	Hindered amine light stabilizers
ANOVA	Analysis of variance
SPSS	Statistical Package for the Social Science

CHAPTER 1
INTRODUCTION

1.1 Statement of problem

Over a century that humanity must fight against the disease, not only the advancement of medical knowledge and technology but also capability and characteristic of the pathogens to mutate too. Therefore, the existing vaccines could be ineffective in such cases. There are some statistic of global death case and infection case for a past century shown in Table 1.1 [1].

Table 1.1 The list of notable global pandemic outbreak [1].

Years	Pathogen	Commonly location affected	Death/Infected
1918-1920	Spanish Flu	*Worldwide*	100 mill/500 mill
1957-1958	Asian Flu	*Worldwide*	1-2 mill/8-9 mill
1968-1969	Hong Kong Flu	*Worldwide*	1-2 mill/0.5-2 mill
1960-Now	HIV/AIDS	*Worldwide*	35 mill/70 mill
1961-Now	Cholera	*Africa*	21, 000-143000/1.4-4mill
1974	Smallpox	*India*	130,000/26,000
1994	Plague	*India*	56/693
2002-2003	SARS	*China*	774/8089
2009	Swine Flu	*Worldwide*	1 mill/284,000
2014-2016	Ebola	*Worldwide*	11,325/286,600
2015-Now	Zika	*Brazil*	Unknown
2019-Now	Sars CoV 2	*Worldwide*	428,578 /7.6Mill

Since December 2019 that humanity have been encountering with the most uproar pandemic crisis called COVID-19, which is a fifth global plague pandemic since 1918. World Health Organization (WHO) reported the early COVID-19 cases found in Wuhan, China, which then spread to 6 continents within days [2]. The origin of this

virus is still being unclear. However, it is certain that no existing vaccines could be used against this type of coronavirus called COVID-19 (SARS-CoV-2) [3].

In term of the typical coronaviruses, the first species of coronavirus were found in chicken during 1930s by medical scientists named Tyrrell and Bynoe. At that time the virus was called “B814” virus, and during 1960s, Tyrrell and Bynoe renamed this virus from B814 to coronavirus because of its characteristic that is similar to crown (In Latin corona means crown). Moreover, that time was also when the first case of coronavirus infection was found in human. SARS-CoV was later discovered in 2002, which is an original strain of SARS-CoV-2 or COVID-19 [4]. Currently, there are 7 types of coronavirus have been identified, 4 of them can cause only mild symptom and the rest can cause a fatal death. Coronaviruses are the family of infectious pathogens that can infect human respiratory system. It could cause mild fever to pneumonia. For the person who have congenital disease must be cautious because COVID-19 could cause severe exacerbation [5]. The symptoms of COVID-19 are the same as normal fever, though the symptoms could develop to having difficulty in breathing and chest pain [6].

Since the vaccine is not widely available and accessible, there are 2 possible ways to kill this virus the first one is using high temperature that the virus will die immediately, and the second is using 70% alcohol. In other words, it could be suggested that the optimal way to reduce the risk of COVID-19 infection are eating a cooked food, washing hands, avoiding the crowded places, as well as wearing face surgical masks [7]. The brief statistics on global COVID-19 situation and timeline are shown in Figure 1.1 and Table 1.2 [8-9]. The timeline of COVID-19 pandemic in Thailand since the outbreak from Wuhan, China is shown in Table 1.3 [10].

It is also worth mentioning that the face mask shortage could be one of the concerning issues as the number of infected cases increases, and disinfecting and reusing the face masks were among the suggestions to mitigate this issue [11]. However, despite being able to kill pathogens, UV irradiation could also potentially change the properties of polymers. Therefore, this aspect has become of interest to this study.

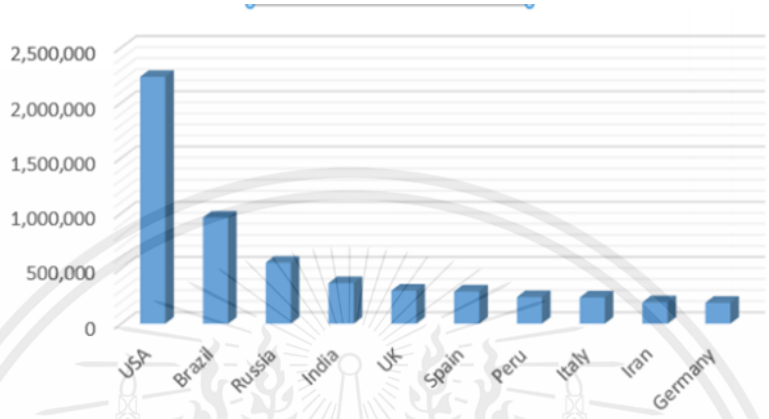

Figure. 1.1 Global situation COVID-19 (From 25th December 2019- 26th June 2020) [8].

Table 1.2 COVID-19 global situation from 31st December 2019 to 26th June 2020 [9].

Date	Incident
31-Dec-19	A large-scale pandemic in Wuhan city, China
1-Jan-20	World Health Organization (WHO) reported that Coronavirus have been in third level and be caution to people for this outbreak
5-Jan-20	Coronavirus has been already spread globally
12-Jan-20	China has studied that this virus has been developed its DNA sequence from SAR-CoV-1
2-Feb-20	The first case death has been reported from other country
11-Feb-20	WHO organization change the virus name from Coronavirus to CO-VID 19
19-Mar-20	China have been reported that there is no increasing of infection cases in China, it is a first time since there was an outbreak
31-Mar-20	1/3 of humanity must be under lockdown circumstance due to outbreak
2-Apr-20	Over 1 Million death tolls and 51,000 infected cases
17-Apr-20	Scientist has tried a vaccine
26-Apr-20	200,000 Global death case and over 2.8 million global infected case
15-May-20	300,000Global death case and over 4.4 million are global infected case
21-May-20	5 Million people got infected, Globally
26-June-20	Overall,9.6 Million people got infected, and 489,578 people death converted into 5.12% death rate

Table 1.3 Timeline table of COVID-19 in Thailand from 25th December 2019 to 25th June 2020 [10].

Date	Incident
13-Jan-20	There is first infected case in Thailand from reported, a 61-year-old Chinese woman came from Wuhan city, China and in that time, she lives in Bangkok
17-Jan-20	The second infected case in Bangkok
22-Jan-20	First Thai people infected case
29-Jan-20	Government declared that, every airport must install temperature checking before entering a country
2-Feb-20	The first case death has been reported from other country
1-Mar-20	First death case reported in Thailand.
17-Mar-20	Government announced whether education area must close and change to online class instead
21-Mar-20	Government announced close all public place, the infected case still increases rapidly,
29-Mar-20	Overall, 1,200 infected cases so government must use an emergency decree
21-Apr-20	Overall, 2,839 infected cases and over 50 death cases
27-Apr-20	2960 infected and government extended the emergency decree for another 1 month
10-May-20	Until now the number of infected cases is slightly increasing, overall, 3009 infected cases and government announced A public place can open but, in an obligation, instruction of Government such as wearing a Hygiene mask, Check temperature before entering
13-May-20	It is a first time since COVID-19 pandemic in Thailand, there is not increasing number of infected cases with overall 3017 cases.
26-June-20	Government decided to cancel an emergency decree with overall 4514 infected case and 60 death cases

1.2 Objective

1.1.1 To design and assemble the UV irradiation box that can be used for UV disinfection.

1.1.2 To investigate the changes in the properties of surgical masks after being disinfected by UV irradiation.

1.3 Research scope

In this research will focus on 2 main parts. The first part is the design and manufacturing of the UV irradiation box using 5 main components: 254 nm UV bulb;

304 stainless steel; wooden box; timer switch; and polycarbonate sheet. The second part of this study is observe the changes in the contact angle and air flow velocity through the masks after being exposed to UV irradiation.

CHAPTER 2
LITERATURE REVIEW AND THEORY RELATED

This chapter describes theories and details related to this study, including the infectious agents and diseases, as well as the ways to manage and reduce the risk of infections.

White blood cells are the marvelous thing in a human body. Without this substance, just a single breath human can be fatal because in the air there are bacteria, germ or virus. White blood cell works as soldier surveillance to deal with the intruder. Infection is the condition that the white blood cells could not handle the contaminated pathogens, which could later develop into the diseases. In this case, antibiotic, which is a medicine used to reduce the ability of pathogens, is used to treat the patient. The symptoms of infection varies dependently on the type of infectious agents, including coughing [12].

2.1 Infectious agents

Infection it is an invasion of germ or infection agent through the wound or blood vessel and then it will increase their population rapidly and making some bad reaction to human cell. There 4 mains categories of infection agent virus, bacteria, fungi, and protozoa [13]. Virus is the smallest unit of infection agent normally their range are from 0.02 μm to 0.3 μm but maybe can be as large as 1 μm, viruses are a particle made up of DNA or RNA for making a specific task to produce virus and surrounded by a protective coating called capsid this coating will protect DNA and RNA, so it is very significant to wash your hand with soap because it can dissolve this envelope and destroy its structure so it cannot reproduce virus anymore. Plant and animal are also a source of virus too, such as bats that consist of many kinds of microbes in their body, including coronavirus, so scientist presume that they were a cause of COVID-19 pandemic or cat that was having a feline immunodeficiency virus (FIV) which can cause AID to human [14].

Bacteria are a single cell organism without nucleus and coating with a capsule that can live in every climate from very hot to very cold. Usually, bacteria are not

harmful to human and some of them are given some beneficial to human too, such as in gastrointestinal tract (GI tract), bacteria called *Lactobacillus* that help large intestine to absorb nutrient and, in an excretion too. *Haemophilus* influenza diseases are derived from bacteria that make a serious health usually can be found in a child under 5-years old it can transmit their infected to the other by respiratory droplets [15].

Fungus is complex cellular organism which coating with histone protein. Approximately, 150,000 species type of fungi including yeast, rusts, smuts. Basically, fungi can be found in everywhere in the air, water, soil, and in human body too. Some of them can be used in food industry such as beer, bread, mushroom truffle or food with a high protein, but some species are causing an infectious disease to human, such as *onychomycosis* which is a fungal infection that always occur in athlete foot because it is a very perfect condition for fungal to grow with a moist environment in a dumping area. The symptoms of this disease could be redness on the feet, cracking skin and nail, and itching [16].

Protozoa is a unicellular eukaryote with complex structure and is classified to be in the kingdom of Protista with more than 50,000 species. Most of them can be seen by naked eye with 0.01-0.05 mm in length. Protozoa can also be called parasites, which refer to organism that live in the host without any benefit and making host sickness too. Malaria is one of the examples of the parasite infection transmitted through mosquito bites. People who suffer from malaria usually feel sick, have high fever and shaking, this infection is commonly found in tropical region [17].

For the symptoms of infectious disease is certainly depends on what type of infection and where infection take place. Some people may not reveal a symptom, but they could transmit to other people. There are 3 main reasons why people got infected: 1. Immune system is not strong enough to fight against with infection agent; 2. There may be a chronic opening wound or cutting area which will allow germ migrating into human body; and 3. Bacteria are too strong that white blood cell cannot get rid of it [18].

2.2 Infectious diseases

2.2.1 Skin infection

It occurs when germ or infectious agents are able pass to through the open wound, which causes irritation, redness or itching in a certain area. Skin infection can be classified in 2 main types.

- **Cellulitis**

This normally occurs when bacteria can enter through the inner skin layer, which could cause an allergic reactions, redness, or itching, as shown in Figure 2.1 [19]. It usually disappears within 3-4 days.

Figure 2.1 Cellulitis infection [19].

- **Herpes**

It is the infection caused by HSV-1 virus; 30-90 percent of infected cases are not showing their symptoms until several years later the symptoms were revealed. This virus cannot be completely cured, and the viruses are remaining in patient body after the treatment. Therefore, people may be re-infected if their health condition is not good. The symptoms of this type of infection include swollen gland, tingling, and clear fluid around the affected area, as shown in Figure 2.2 [20]. It is not imperative to treat it because it will disappear in 7-10 days, but patient must avoid some activities to prevent transmission of this infection.

Figure 2.2 Herpes infection [20].

2.2.2 Eye infection

The most common eye infection is “Conjunctivitis” disease caused by a bacterial called Staphylococcus aureus from contact lens used in daily life. The symptoms include an inflammation or redness in the eye layer called “conjunctiva”, increased amount of tear, redness in the white eye, irritation, or itching around the eyes. Antibiotic eye drop is used to treat this infection, and patients are also advised to avoid some activities for prevent the transmission of this infection [21].

2.2.3 Urinary tract infection (UTI)

It is the condition that the urinary system got infected form a bacterium, fungus, and virus microbe, though it is mostly caused by Escherichia coli (E. coli). The symptoms include bleeding urine and kidneys pain, although nausea is also observed in some cases. UTI infection can be treated by drinking water or using antibiotics [22]. For persistent cases, surgical methods are carried out to manage the infection [23].

2.2.4 Nose infection

The most common nose infection is sinus infection which can also be called “Sinusitis”. It is an inflammation occur in a nostril air passage airway that will be blocked and accumulate with a germ or bacteria. Usually for sinus infection, it is not required to take an antibiotic. The symptoms are similar with normal cold, but pressure in the eye and cheek can be felt for the sinus infection [24].

2.2.5 Gastrointestinal (GI) tract infection

It is also known as “food poisoning” caused by infectious agent (mostly from *E. coli* and *Shigella*) contaminated in food passing through GI tract. The symptoms are diarrhea and vomiting. Though they are not fatal, the symptoms could be more severe in infants and elders. Clinical intervention for this type of infection is generally not required [25].

2.2.6 Lung infection COPD (Chronic obstructive pulmonary disease)

It is the most common disease in lung infection causes when they are a pathogen accumulate in the air sacs. They will gradually bigger and filled with yellow abscess fluid, which will eventually block the respiration passageway. At the beginning stage, it causes just only a mild symptom with a mild cough or sneeze. Subsequently, symptoms lead to a difficult breath, chest pain and a roughly cough. In the final stage, the symptoms are more severe, including fatigue, weight loss and lack of energy. Now there is no method to completely cure COPD, current treatments are only slowing down their progression and mitigating the symptoms, and surgical intervention may be needed in severe cases [26]. The coronavirus (also known as COVID-19) can cause lung infection either. That can be infected to upper part and lower part of human respiratory system. When this virus comes to human's lung. It splits into small pieces into lung's trachea and eventually into alveoli [27].

2.3 Coronavirus

Coronavirus (CoV) is one of the viruses that can cause from mild illness to more severe disease. For instance, Severe Acute Respiratory Syndrome (SARS-CoV) and Middle East Respiratory Syndrome (MERS-CoV). In 2019, a novel coronavirus (COVID-19) is a new strain that has not been identified yet. Coronavirus (CoV) are zoonotic. Which means, the viruses are transmitted between people and animal. An investigation of scientists was found that SAR-CoV has been transmitted from civet cats to human, and MERS-CoV was transmitted from dromedary camel to human [28].

Over the past four decades, 3 types of coronavirus are transmitted from animal to human species, such as from bat to human or form cat to human. As of now, COVID-19 has rapidly spreading. It causes from acute up to severe symptoms with 2.2 percent of fatality rate. This virus can be jumping between species, causing a peculiar and a complex form of pathogen. Currently, there is no clear evident enough that which specific type of animal is the virus origin [29].

2.3.1 Recent pharmaceutical to treat COVID-19

Due to an existence of this virus is in influenza season, the antibiotic and neuraminidase, such as oseltamivir, is widely used to treat COVID-19 in China. However, there is no clear evidence that this type of drug can completely cure COVID-19 at present time [30]. There is an antiviral drug to provide an effective protection with COVID-19. Nevertheless, some cases was reported that the antiviral drug can also have a severe side-effect and be fatal. Nowadays, doctors have used Griffithsin inhibitor for inhibition of MERS and SARS spike, for instance faavipiravir, unifenovir and EK1 peptide are used as optional drug for curing respiratory infection. All these drugs have been used to cure coronavirus before whether SARS, MERS or HIC. Choloroquine was shown to be capable of inhibiting COVID-19 function through the increment of endomal pH and effect to COVID's cellular receptor. Choloroquine is safe and relatively cheap. This drug can be used via user's mouth and lung [31].

2.3.2 Symptoms of COVID-19

Most common symptoms of COVID-19 are fever, dry cough and shortness of breath. Some of patients have experienced others sign either, for instance myalgia, fatigue, and headache. The initial symptoms of this disease can be called as afebrile. Afebrile refers to the appearance of respiratory symptoms and minor fever. Most of patients with pneumonia are having sore throat, cough, and fever, although they did not obviously show their symptoms. Some of the patients are reportedly having a respiratory infection (URI), decrease in lymphocytes or white blood cells. Patient with exacerbate pneumonia and suffer at acute respiratory syndrome (ADS) tends to cause severe pulmonary infection. In some cases, for pulmonary dysfunction, it can cause sepsis and septic shock and increasing death rate. According to recent research, pregnant women do not have severe symptoms, while older people tend to have high risk of fatality rate. For chronic disease such as endocrine systems disorder, high blood pressure, diabetes. COVID-19 can make these chronic diseases to be more severe and fatal eventually [32]. COVID has also been researched that it can affect for male (55-year-old) than women, due to the role of X chromosome and sex hormone of female that is more resistant to the virus [33].

2.3.3 Mechanism of COVID-19

Humans have been infected by COVID-19 for a long time. It is a contagious virus that can be passed through ingestion or inhalation of water droplets via sneezing and coughing. Coronavirus genome is composed of > 30,000 nucleotides. Which is encoded by these 4 structural proteins. Spike protein (S), Envelope protein (E), Nucleocapsid protein (N) and Membrane (M) protein as shown in Figure 2.3 [34].

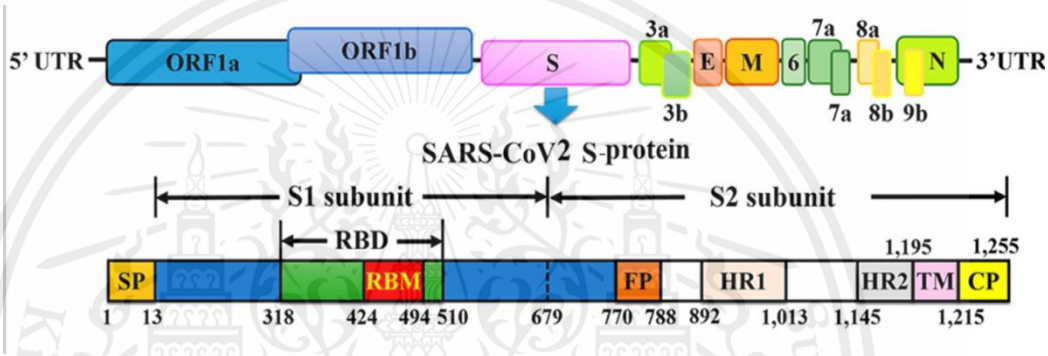

Figure 2.3 COVID-19 sequence [34].

A capsid is a protein shell which consists of N protein. N protein is attached with the single RNA that makes the virus infectious to humans. N protein is covering the viral RNA genome, which is responsible for replication and transcription. The M-protein can be mostly found at a central part of the virus's surface. S protein is integrated at the surface of a virus. S protein is taking part of the host cell receptor, which is the make-up of the host cell membrane. E protein is a tiny membrane which is composed of 76 to 109 amino acids and some of tiny viruses. E protein plays an important role in membrane permeability and virus assembly at the host cell. The mechanism of the virus entry to the human body is mapped in Figure 2.4 [34].

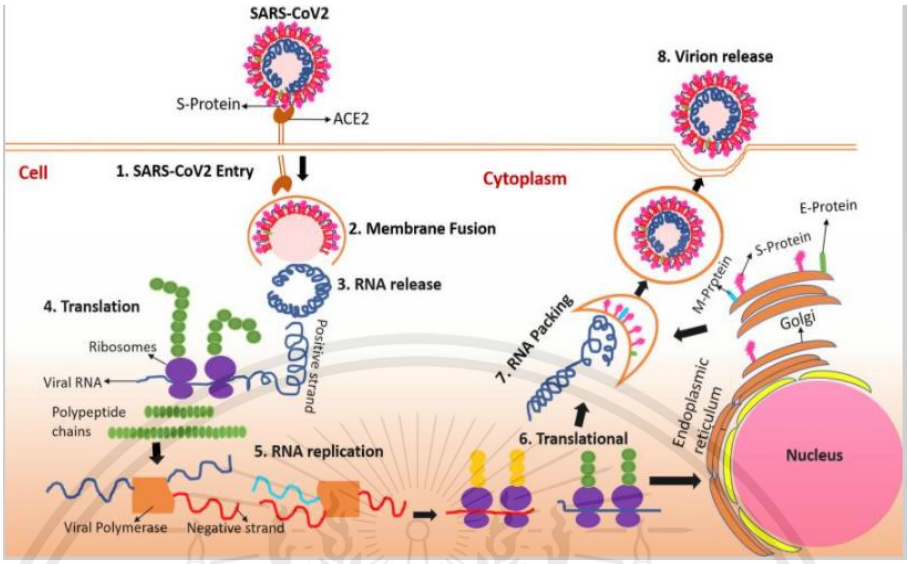

Figure 2.4 SARS-CoV2 reach to human cells [34].

The S protein binds with angiotensin converting enzyme 2 (ACE 2). ACE2 is a receptor that can be found in human cells and human's lungs. The S protein is cleaved by trypsin and furin. These 2 sites are located at S1 and S2 sites. Subsequently, the cleavage of S2 site releases the fusion peptide. This scenario will trigger the opening of fusion mechanisms. Basically, the virus is ingested within human cells by endocytosis mechanism. One the COVID-19 is employed through cytoplasm. It will induce the conformational changes in spike protein by cathepsin L proteolysis via intracellular proteases for further fusion mechanism in the endosome. Endosome is then releasing the coronavirus into cytoplasm. Finally, the virus's RNA is fully released through cytoplasm. Consequently, the virus is exported from infected cells to membrane smooth-walled by exocytosis. These are how COVID-19 cells kill human healthy cells [34].

2.4 Disinfection strategies

Infectious diseases are caused by infectious agents, including viruses, rickettsia, bacteria, protozoa, fungi, etc. The preventive approach that could reduce the risk of committing these agents is the use of disinfectant that could kill the pathogens or inhibit

their functions [35]. This section describes the methods which could be used for disinfection.

Hand sanitizer is a public health innovation that has been invented since 1966 by American nurses [36]. It contains approximately 75% of alcohol and is effective in killing germs, bacteria and viruses by damaging their surface proteins. The key constituent, i.e. alcohol, is a substance that has antimicrobial properties, which can eliminate a variety of microbes and stop the spreading of the infection. Alcohol can be prepared in gel or spray hand sanitizer with the concentration of at least 70% for convenient use [37]. This can be used when water and soap is not available. It should be noted that the alcohol used for disinfection should be ethyl alcohol and not methyl alcohol, of which the latter is highly toxic [38]. These products could be used to disinfect the touching surfaces and personal belongings to reduce the transmission of the pathogens.

2.5 Mechanism of UV disinfection

In addition to the strategies mentioned in the previous section, ultraviolet or UV light is the spectrum of electromagnetic waves can also be used for disinfection, which has higher frequency than the visible light. Normally, ultraviolet light mainly composed of 3 type UVA, UVB, and UVC [39]. UVA is a radiation with a wavelength of 315 nm to 400 nm, which reaches surface of the earth most because it is not absorbed by ozone layer. UVA light can penetrate through human skin. This causes skin aging, whether wrinkles or dark spots on the skin. The second type is UVB which has wavelength 280 nm to 315 nm. A light that can damage DNA in human skin, this type of UV light is a cause of sunburn or even skin cancer. UVC light has the shortest wavelength, 100 nm to 280 nm, and the highest energy that is harmful to all living things. It is completely absorbed by ozone layer before it reaches to our planet. From the properties of UVC light, scientists have found its benefits [40]. The appropriate UVC wavelength range for disinfection is 200 nm to 280 nm. UVC light is the most commonly used devices in the market to disinfect household objects. However, UVC rays could not be used to disinfect humans. Once the pathogens are exposed to UVC rays, they lose their functions or ability to reproduce. This is expected to be a result of the damaged nucleic

acids that inactivate the microorganisms. The wavelength generally with 254 nm could be absorbed by RNA and DNA, which leads to the death or inhibition of pathogens, including bacteria, fungi, viruses, protozoa, parasitic disease [41].

In terms of the UV disinfection device design, engineering students from University of Cincinnati, Ohio creates a box equipped with UV light bulbs called “dis-box” that could kill germ and virus during the COVID-19 situation, as shown in Figure 2.5 [42]. It was designed to disinfect the N95 masks for reuse during the shortage. The box is 3.8 cubic foot that consists of 6 walls with 0.25-inch thickness [42]. It should also be noted that there should be protective equipment to protect the users during the disinfection process.

Figure 2.5 An ultraviolet disinfection device called “dis-box” [42].

Another design is from Pittsburgh, Pennsylvania called “YouVee” [43]. This device uses 6-watt fluorescent lamp combine with 9W UVC bulbs 254 nm wavelength, and the inner surface was covered with aluminum foil to reflect the UV light, as shown in Figure 2.6 [43]. The recommend irradiation time for mask is 30 minutes per side and other object is 20 minutes total.

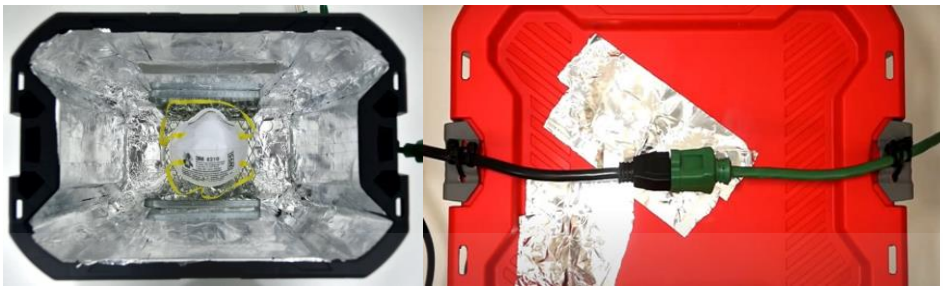

Figure 2.6 Plastic tube cover with aluminum foil [43].

2.6 UV protective materials

2.6.1 Polycarbonate

Polycarbonate is composed of high performance of amorphous structure that is polyester of carbonic acid, as shown in Figure 2.7 [44]. Polycarbonate, also known as “Macrolon”, is very renowned for UV and heat resistance, as well as its strong mechanical properties. However, its limitations could be low wear and abrasion resistance.

Figure 2.7 The repeating unit of polycarbonate [44].

According to American Institute of Aeronautics and Astronautics, the relationship between exposure time of UVC and the UVC transmittance of polycarbonate was investigated for up to 503 hours. The results are shown in Figure 2.8, which suggest that there were no significant changes in UV resistance of polycarbonate below 390 nm wavelength after 503-hour exposure [45].

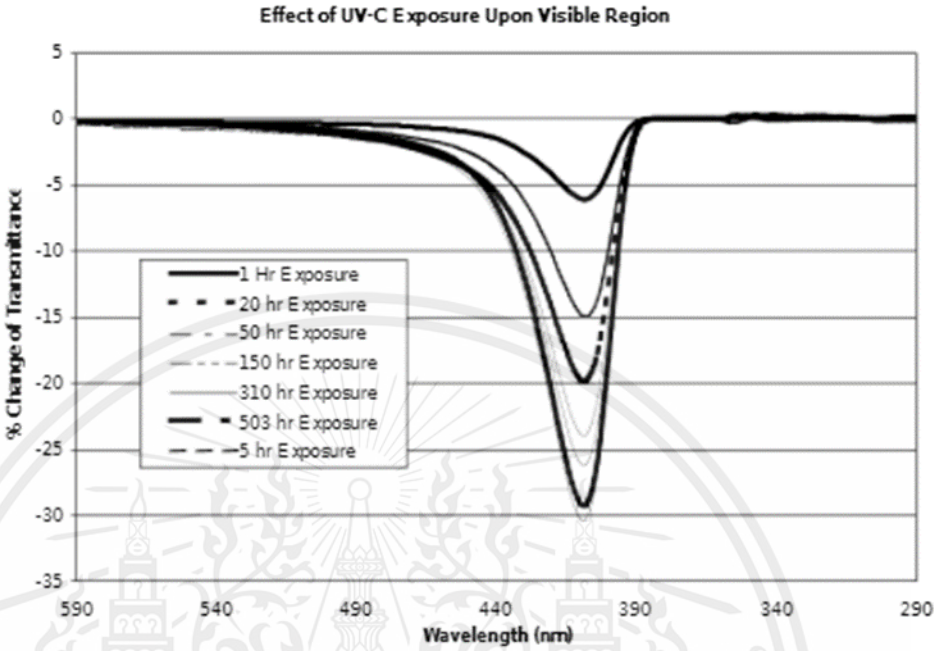

Figure 2.8 The relationship between exposure time of UVC and the UVC transmittance of polycarbonate [45].

2.6.2 304 stainless steel

Most stainless steel consist of 18% chromium, 8% nickel, and the rest of it are an ordinary steel component. Stainless steels are widely used for industry or exterior household as they have strong mechanical properties and high resistance to UV and corrosion [46]. The UV resistance of stainless steel has been studied previously in comparison with other metals, including titanium, stainless 304, iron, copper, zinc, silver, nickel, zirconium). The reported results are shown in Table 2.1 [47]. The study has reported that most of the metal could withstand the UV exposure after 3 months; however, zinc and A366 iron appeared to degrade, based on the reduced weight [47].

Table 2.1 Initial and final weight of several metal after having an UV radiation exposure for 3 months [47].

Metal	Sample #	Initial Weight	Weight After 3 months	Weight. Change	Exposure
Titanium	1	3.0156	3.0224	0.0068	UV
	3	2.9272	2.9276	0.0004	UV
	4	2.8851	2.8874	0.0023	Dark
	2	2.9371	2.9399	0.0028	Dark
304 Stainless Steel	13	7.5604	7.5667	0.0063	UV
	16	7.3368	7.34	0.0032	UV
	15	7.3964	7.402	0.0056	Dark
	14	7.3655	7.3611	-0.0044	Dark
Nickel	20	8.9163	8.9158	-0.0005	UV
	18	8.6255	8.629	0.0035	UV
	19	8.9187	8.9205	0.0018	Dark
	17	8.5903	8.591	0.0007	Dark
Zirconium	21	2.0706	2.0727	0.0021	UV
	22	2.0881	2.0915	0.0034	UV
	23	2.1637	2.1676	0.0039	Dark
	24	1.9956	1.9983	0.0027	Dark
A366 Iron	41	8.1583	8.01469	-0.14361	UV
	44	8.1046	7.9795	-0.1251	UV
	43	8.1952	8.0739	-0.1213	Dark
	42	7.9456	7.8271	-0.1185	Dark
Aluminum	45	2.3294	2.3056	-0.0238	UV
	46	2.2257	2.1873	-0.0384	UV
	47	2.3021	2.2937	-0.0084	Dark
	48	2.2314	2.237	0.0056	Dark
Copper	49	7.9672	7.954	-0.0132	UV
	52	8.1207	8.1029	-0.0178	UV
	51	7.8098	7.8001	-0.0097	Dark
	50	8.058	8.047	-0.011	Dark
Zinc	55	6.4533	6.2997	-0.1536	UV
	56	6.5704	6.3938	-0.1766	UV
	53	6.6565	6.7453	0.0888	Dark
	54	6.4844	6.3672	-0.1172	Dark
Brass	60	5.6697	5.6306	-0.0391	UV
	58	5.6632	5.6243	-0.0389	UV
	59	5.5367	5.4979	-0.0388	Dark
	57	5.6015	5.5627	-0.0388	Dark
Silver	63	6.7373	6.7425	0.0052	UV
	64	7.3023	7.2998	-0.0025	UV
	61	6.8385	6.8427	0.0042	Dark
	62	7.4309	7.4368	0.0059	Dark

2.7 Contact angle analysis

Contact angle is a traditional method of calculating wettability of a material's surface. A contact angle, also referred as a wettability angle, is a geometry of the liquid water droplet formed on material surface determined by the angle between the material surface and the tangential line between the edge of the droplet and its circumference, as shown in Figure 2.9 [48].

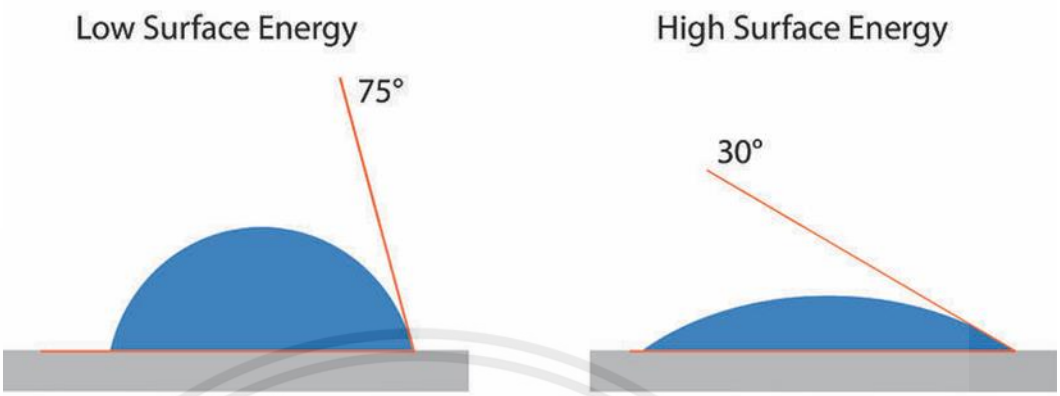

Figure 2.9 Surface energy of surface [48].

Moreover, the contact angle can also be used to determine the material's surface energy. If these surface energies are every high, it will pull water tension down and cause water dome spread further over the material's surface, which could also be called hydrophilic surface. The opposite characteristic of hydrophilic is hydrophobic. Young's equation, $\Upsilon s = \Upsilon sl + \Upsilon l \cos\theta$, is used to calculate surface energy from contact angle, as shown in Figure 2.10 [49]. Where Υs is solid surface tension, Υl is liquid surface tension, and Υsl is the surface energy [49].

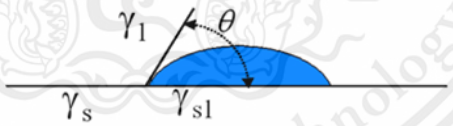

Figure 2.10 Young equation with contact angle [49].

Alternatively, the hydrophobicity and hydrophilicity of the material surface can also be determined by the contact angle itself, using 90° as the threshold. Contact angle between 90-150 degrees will be considered as hydrophobic, as shown in Figure 2.11 [50]. Likewise, smaller contact angles than 90 degree are hydrophilic.

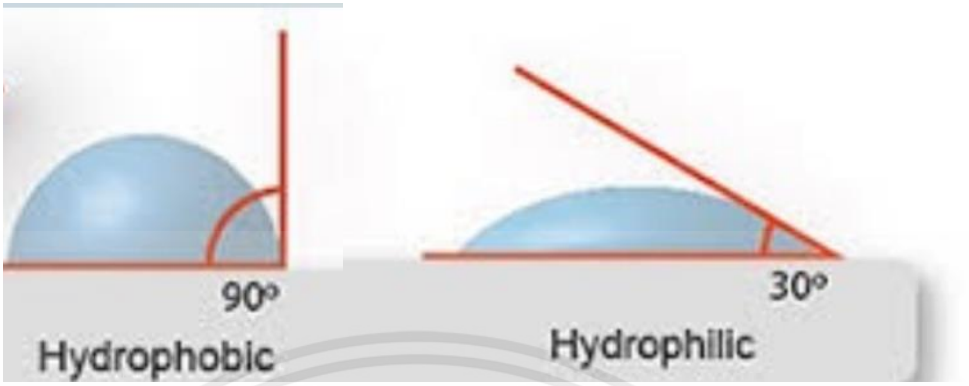

Figure 2.11 Hydrophobic water droplet (left) and hydrophilic water droplet (right) [50].

2.8 Polymer

Polymer is a plastic material that is very useful for various applications. A polymer can be 3-dimensional structure or 2-dimensional structure. Each part of the structure is repeating unit with the word “mer”. Repeating unit are commonly made up of hydrogen, carbon, and sometimes it can be repeating with oxygen and hydrogen either. To make a chain, these repeating unit are chemically hook or merged. Polymers can be manufactured synthetically, such as some types of thermosetting polymers. Polymers can also be found in nature, including the deoxyribonucleic acid (DNA) and rRNA, such as hair and silk [51].

2.8.1 Structure of polymer

Mostly, classes of polymer are made up of carbon, hydrocarbon, and hydrogen. These components are bonded together into an extremely long chain called backbone of the polymer, as shown in figure 2.12 [52].

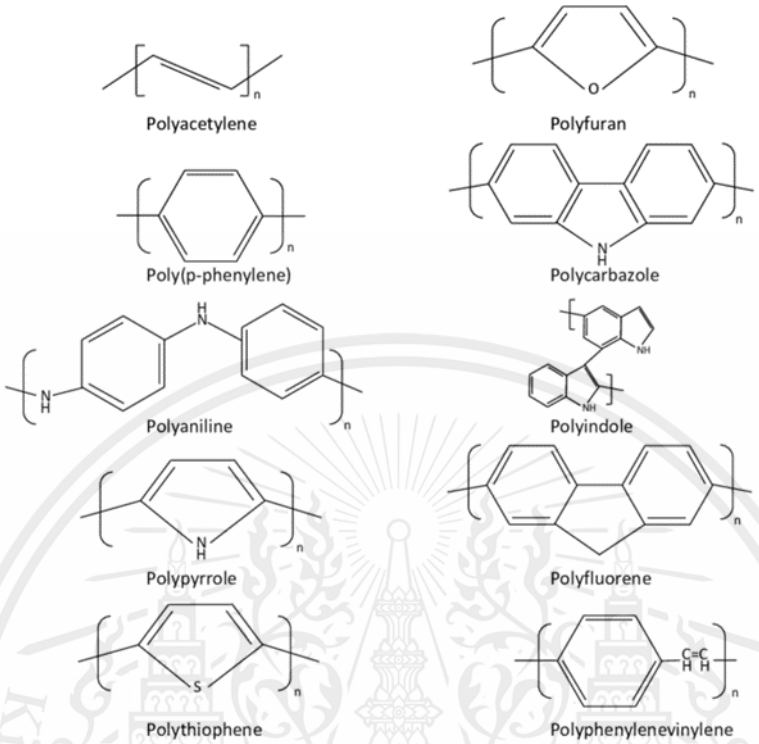

Figure 2.12 Polymer backbone [52].

The synthetic polymer could contain another element, for example nylon. Nylon consists of repeating sequence of nitrogen atom. This polymer is considered as an inorganic polymer.

2.8.2 Molecular arrangement of polymers

Its molecular shape looks like Spaghetti. Polymers arranged in form of linear with the lack of specific order can be called as amorphous, as shown in Figure 2.13 [53]. Amorphous arrangement in polymer is normally transparent. This is commonly found in many household items, such as food wrap.

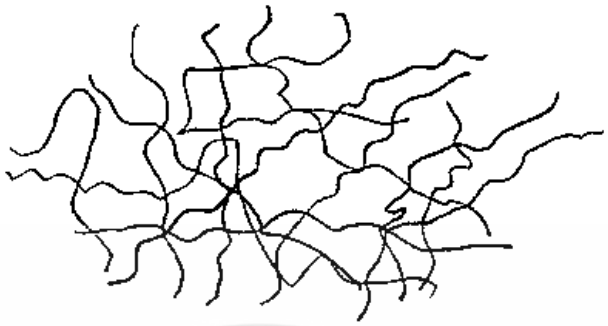

Figure 2.13 Amorphous structure within polymer [53].

2.8.3 Characteristic of polymer

The commonly used polymers are thermoplastic. Thermoplastics are polymers which could reversibly change their shape upon the exposure to heat. This property makes it easy to process and recyclable. Moreover, every polymer has unique characteristic which makes it suitable for a wide range of applications, such as chemical resistance, thermal, and electrical insulation [54]. Furthermore, polymer can also be used for creating non-existing material, for example the flexible films and clear sheet [55].

2.9 Surgical mask layers

For disposable masks, they consists of 3 layers as shown in Figure 2.14 [56]. Each of the layer is made up of polypropylene. The second layer provides the highest filtration property and the third layer is against the user's face.

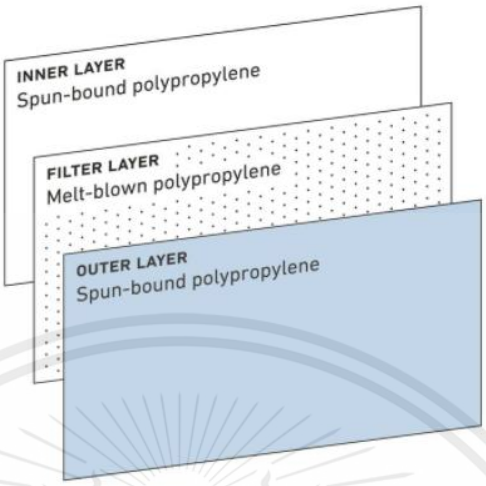

Figure 2.14 Surgical mask layers [56].

2.10 Polyolefin

Polyolefin is a synthetic resin which is a polymerization process of olefin. Olefin is a hydrocarbon (compound that contains with carbon and hydrogen). Olefin are usually derived from a natural gases. Olefin is commonly use in versatile plastic that need to be applied with extreme quantities. The chemical structure of olefin as shown in Figure 2.15 [57].

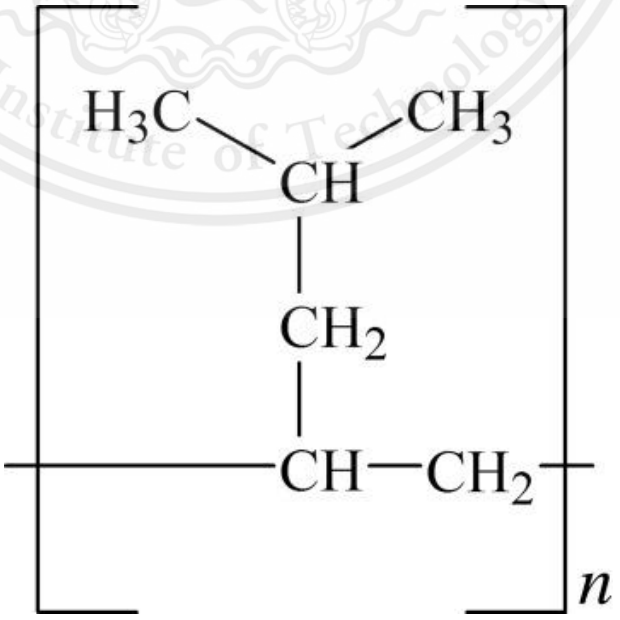

Figure 2.15 Polyolefin structure [57].

2.11 Polypropylene

Polypropylene is the macromolecule which comprises 5,000 to 200,000 as shown in Figure 2.16, which can be classified as polymers. It is one of the versatile polymers in the market in the form of solid plastic and fiber. Polypropylene fabric can be used for industrial, manufacturing and upholstery applications. It is extremely soft and easy to clean. Polypropylene can be called Olefin, which is synthetic thermoplastic derived from natural gas and oil. Originally, it was called under the name of "Moplen". Polypropylene can be classified into 4 main types. A-Homopolymer (propylene), B-Random Copolymer (propylene-ethylene), C-impact copolymer (propylene-ethylene), D- Terpolymer [58].

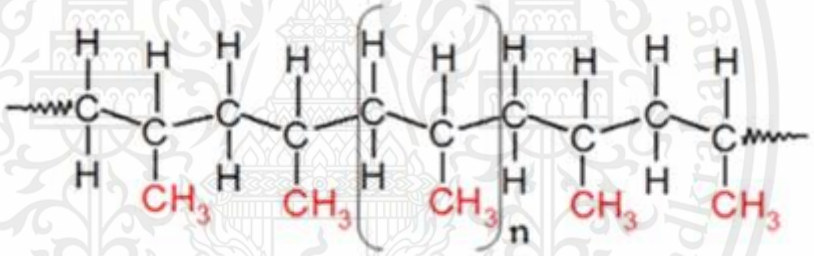

Figure 2.16 Polymer structure [58].

- **A Homopolymer**

This polymer is composed with polymeric chains. Propylene is a molecule is asymmetrical arrangement, its corporation and the chain generate 3 types of basic structures: atactic, syndiotactic and isotactic.

- **B-Random copolymer**

Polypropylene segments are joined by ethylene (comonomer molecules) which are randomly placed throughout its chain. Consequently, this polypropylene has extremely high transparency and low melting point.

- **C-Impact copolymer**

This propylene is performed by a 2 cascade of vertical reactor sequences. For the first reactor is the copolymer matrix and second reactor is non-reactive propylene with ethylene is added within the second reactor. Therefore, from these 2 reactors. The reaction gives material with a high tenacity even though. It stays at low temperatures.

- **D-Teropolymer**

This polypropylene has a different polymeric chain with chemical composition. It consists of propylene parts attached with a molecule of comonomer (1 butane and ethylene). This polymer has a high crystallinity degree in order to improve sealing properties [58].

2.12 Polyethylene

Polyethylene is the most common plastic that human use in daily life. For instance, plastic bag, plastic film, plastic bag including with bottles. For most of the polyethylene are known $(C_2H_4)_n$. Polyethylene is a combination of polymer of ethylene with a number of n term as shown in Figure 2.17 [59]. Which is undergoes of polymerization with the double bond and the result of extra single bond. Hydrogen atoms are connected to a polymer backbone.

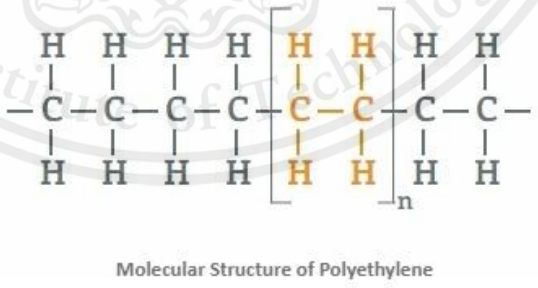

Figure 2.17 Polyethylene chemical structure [59].

2.13 Polymer degradation

Most of the polymer is commonly consisted of covalent organic that are extremely susceptible and damaged b UV light, and occur the mechanism called chain scission by photolysis. Which will be breaking down long chain of polymer into a

shorter chain by the action of direct method. That make UV energy breaking the backbone of the polymer. This shorter chain causes a reduction of molecular weight or resulting in a degradation of physical properties. A degradation of polymer can be released by surrounding environment. UV is induced some of polymer properties for example, formation of radical of molecule and atoms with electron that can greatly react with other bonds nearby, which cause a chain scission and degradation. The basic concept of the degradation is an absorption of high-level of UV light that can arise an electron level and consequently, dissociate a chemical bond within polymer.

It is a change in polymer's property. Whether its color, tensile strength, shape, or molecular weight, which is influenced by environmental factors, for instance, heat, light, or UV. A degradation is often caused by an alteration of polymer structure and physical structure with polymer chain. A susceptibility of polymer is depending on its structure. Aromatic and Epoxies chains are vulnerable to UV (Ultraviolet light). For the polymer degradation can be induced by these several ways; Chemical degradation, Thermal degradation, Bio degradation, Oxidative degradation, Photo degradation and UV degradation [60].

2.13.1 Factor of degradation

- **Internal impurities**

Internal impurities contain with chronotropic group that can performed into macromolecules throughout the polymerization process which include with catalyst residue, carbonyl, hydroperoxide, unsaturated bonds [61].

- **External impurities**

External impurities contain with chromophoric groups which are trance of metal oxide such as Fe, Ni, or Cr, Trace of the solvent such as catalyst [61].

2.13.2 Biodegradation

Biodegradation initiates by microbial attack. Microbes can produce a variety of enzymes which can degrade material.

2.13.3 Chemical degradation

Chemical degradation initiates by microbial attack. Microbes can produce a variety of enzymes which can degrade material.

2.13.4 Thermal degradation

Thermal degradation can be divided into 3 processes as shown in Figure 2.18 [62].

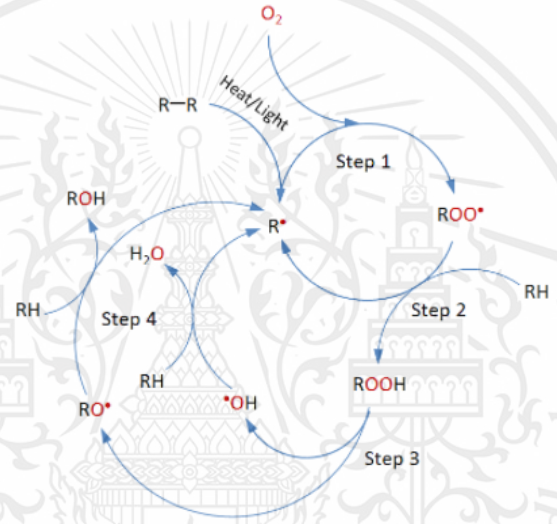

Figure 2.18 Thermal degradation processes [62].

1) Thermal degradation Initiation

Is typically started with a polymer chain from hydrogen abstraction or homolytic scission. This can occur from exposing UV by light and heat. The initiation process as shown in Figure 2.19 [64].

$$R\text{–}H \rightarrow R\cdot + H\cdot$$

Figure 2.19 Thermal degradation Initiation equation [62].

2) Thermal degradation Propagation

The first step is free radical (R·) reacts with oxygen molecule (O_2) to forming a peroxy radical (ROO·*). Peroxy radical is then accepting hydrogen from another polymer to form a hydrogen peroxide (ROOH). Hydrogen peroxide is the split into another 2 free radical chains RO·) + (·OH). The overall propagation process as shown in Figure 2.20 [62]. The process can speed up depending on how easy it is to remove the hydrogen atom from the polymer.

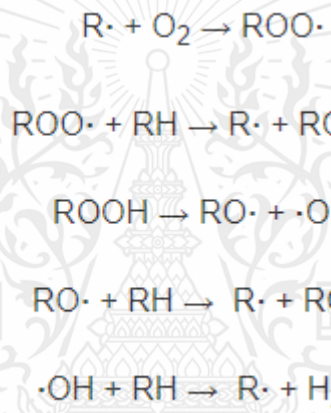

Figure 2.20 Thermal degradation Propagation equation [62].

3) Thermal degradation Termination

This degradation is occurred by recombination of 2 radicals' chain by hydrogen abstraction and disproportional. The mechanism process as shown in Figure 2.21 [62]. The result is an increase of crosslink density and molecular weight.

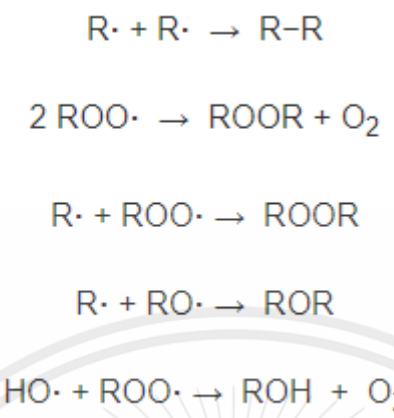

Figure 2.21 Thermal degradation Termination equation [62].

2.13.5 Oxidative degradation

It is the deterioration of the polymer surface. From a combination of light and oxygen action. It causes the breaking of the polymer chain. That makes a brittle material. The effect is performed by a radiation of radiant energy for instance, artificial light and UV light. As the material becomes more fragile. It makes a reduction in its tensile strength or elongation strength [63].

2.13.6 Photo degradation

It is performed by the photochemical reaction and light that arises from an assimilation of UV exposure by a carbonyl group on the polymer backbone. However, apart from UV light the electromagnetic can cause photodegradation either. Photodegradation is included with photodissociation with breaking up small molecules by photons. Breaking up molecule's shape into small pieces and make it unalterable. Light is one of the important factors that induces photo-degradation. Photodegradation can occur from lack of oxygen molecules either (cross link or chain breaking). Ketones and peroxide can be an initiator of degradation. They can absorb light up to 380nm, which can cause cleavage and excitation. Photooxidation is following these 3 steps Initiation, Propagation, and Termination.

1) Photo degradation Initiation

Both of external and internal chromophoric absorb light and create a relatively low molecular weight (R.) and micro radical (P·.) by equation

$$PH \rightarrow P \cdot + H \cdot$$

This reaction can occur using methods for example heat, UV radiation or some mechanical effect. A chemical called hydroperoxide (POOH) is one of the most initiators in the initiation process. Moreover, hydrogen peroxide is photolabile. It always composes with quantum yield and product radical, that can be spread hydrogen atoms from polymer and occurred photooxidation process by equation

$$POOH \rightarrow PO \cdot + OH \cdot$$

2) Photo degradation Propagation

Which can be divided into 2 different steps. Subsequent reaction between poly alkyl radical (P·.) and low molecular radicals (R·.) in a chain reaction to the abstraction of hydrogen molecule within a polymer by equation

$$PH + R \cdot (P \cdot) \rightarrow \cdot PH + \cdot P$$

3) Photo degradation Termination

The radical is then formed in a polymer that is degraded by numerous combinations of reaction between 2 radicals. Which is a form of inactive product. As shown in Figure 2.22 [64].

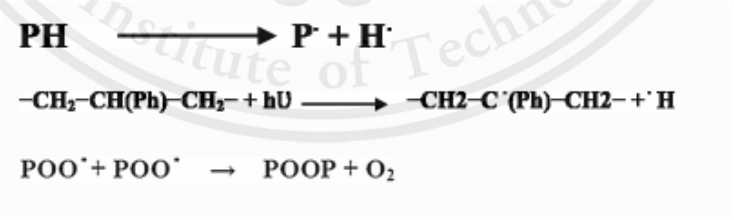

Figure 2.22 Photo degradation Termination equation [64].

At low oxygen pressure, the termination takes place. For the degradation of solid polymers occurs when enough oxygen cannot be maintained properly. Polymer radical can mutually in reaction and form a crosslink within.

2.14 Polymer stabilizer

It is a chemical that can be added with polymeric material for example plastic or any polymeric material for protecting their degradation properties. Typically, degradation of polymers are occurred with a process include thermal degradation. Ozonolysis, photo-oxidation. Different type of polymer is vulnerable for several types for to degradation, which causes different type stabilizer to be used [65].

2.14.1 Antiozonants

This type of polymer stabilizer is used to prevent and slow the degradation which is caused by ozone. Ozone is originally existing in the air. However, in the small amount. Ozone can extremely quickly react with unsaturated polymer such as rubber, which causes cracking of material surface. In this case, it needs specific polymer stabilizer name antiozonant [66]. Phenylenediamine (IPPD) is one of the antiozonant. For Structure of IPPD as shown in Figure 2.23 [67]. IPPD achieves by having relatively low ionization level. Which allows it to react with ozone by electron transfer mechanism.

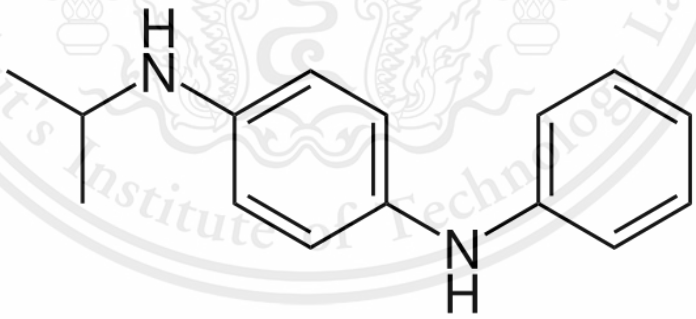

Figure 2.23 IPPD structure [67].

2.14.2 Light stabilizer

Light stabilizer is used to restrict polymer from photo oxidation degradation, which is a reaction of light and oxygen. Hence, this stabilizer is effectively inhibiting agent UV absorber and quencher [68].

- **UV absorbers**

It is commonly used for polycarbonate and polyester. UV absorbers will absorb and disband the energy from UV rays and intramolecular proton transfer. This absorber reduces the assimilation of UV rays from polymer matrix and can diminish a rate of weathering. Hydroxyphenyl triazines is commonly used with polycarbonate and acrylic material and Benzotriazoles are commonly for PVC material. One of the main disadvantages of UV absorber is they need a certain depth to achieve a relatively good protection within polymer. The mechanism of UV absorber is simple by interact with the first step of photooxidation process. Hydroxyphenyl benzotriazole and Hydroxy benzophenone is commonly used at UV absorber [69].

- **Quencher**

Photo-oxidation can initially start with an absorption of light by chromophore within polymer that causes an exciting state. This is a structure nickel-phenoxide quencher as shown in Figure 2.24 [70]. This quencher will react with oxygen and converting it into singlet oxygen. Quencher is greatly absorbing energy at exciting molecule by foster mechanism and then absorb heat and fluorescent.

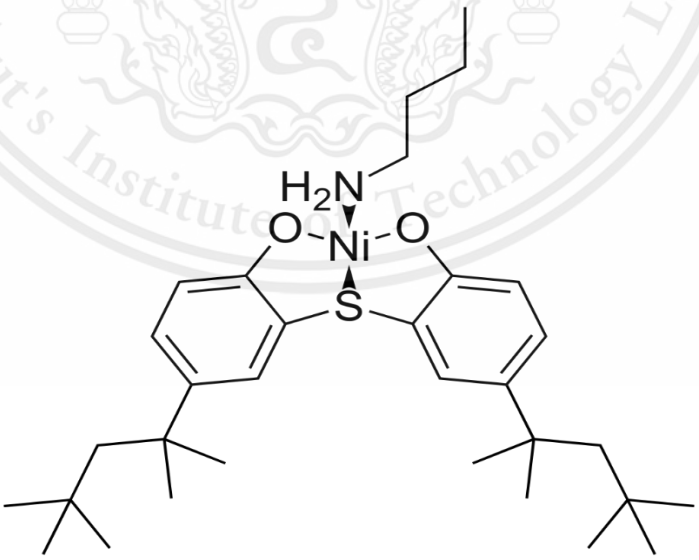

Figure 2.24 Nickle-phenoxide quencher structure [70].

- **Carbon black**

Carbon black is one of the most effectively for a light absorber. It consists of fine particles comprise together. The structure if carbon black as shown in Figure 2.25 [71]. Carbon black contains with different groups of quinone, ether, hydroxyl. Carbon black can absorb UV radiation than other conventional method. Because its ability inner filter for UV absorption. The effectiveness of carbon black it depends upon which type of carbon black and the size of the polymer. The optimal concentration carbon black is 4-5 %. Higher concentration of carbon black makes polymer loses its tensile strength and some mechanical properties.

Figure 2.25 Carbon black structure [71].

- **Hindered amine peroxide decomposer (HALS)**

HALS is one the most effective for polymer photo stabilizer and have been commonly used with traditional polymer. The mechanism of HALs including with scavenging $R\cdot$ and ROO and deactivated of ROOH. Nitroxide is the main mediator in HALS, that prone alkyl and from *O*-alkylhydroxylamines. Consequently, HALS is to be able to convert in cyclic pathways, which can destroy a condition of degraded within polymer and coatings against polymer. 2,2,6,6- tetramethyl piperidine is commonly used in HALS. During UV irradiation it produces radicals and oxygen that produces hindered piperidinyl radical, to give a reaction as shown in Figure 2.26 [72].

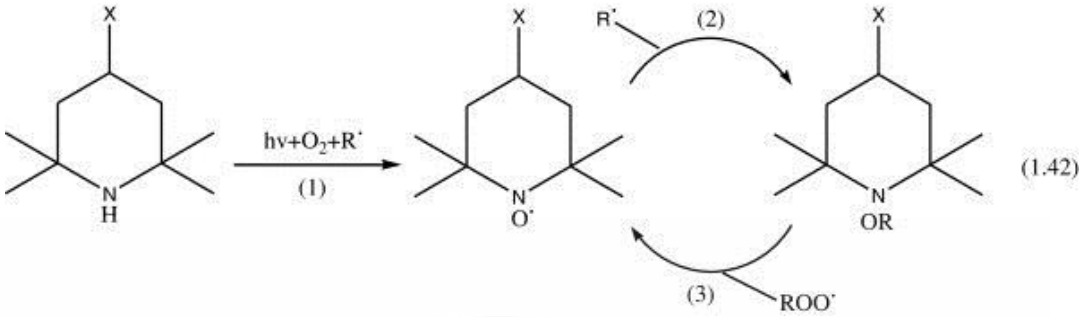

Figure 2.26 Protecting polymer degradation by HALS mechanism [72].

- **Photochemical**

Photochemical protection is used for polymer by traditional UV absorber for example Tinuvin 327 and 2-hydroxy-4methy-methoxybenzophenone, which involves triplet energy from polymer's excited state. The structure of these compound as shown in Figure 2.27 [73].

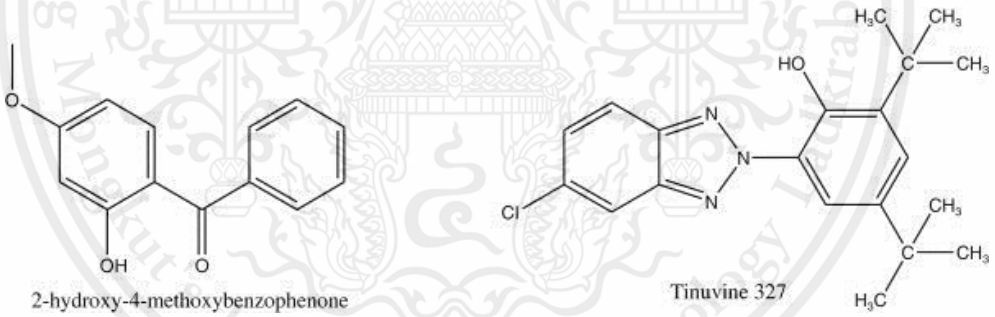

Figure 2.27 Structures of 2-hydroxy-4-methoxybenzophenone (left) and Tinuvin 327 (right) [73].

2.15 Cell inactivation formula

The amount dose of UV light depends on which type of bacteria was disinfected as shown in Figure 2.28. 1 log reduction, 2 log reduction and 3 log reduction refer to the effectiveness of UV to kill pathogen 90 %, 99% and 99.99 % respectively. UV Dose can be found by the intensity of UV light bulb (mW/cm^2) multiply with time (s) [74]. In the other word, the time that was used for killing the bacteria can be found by UV dose divide by intensity of UV light.

Average UV Dose Required for Inactivation (mJ/cm²)				
Pathogen	**1-Log**	**2-Log**	**3-Log**	**4-Log**
Cryptosporidium parvum oocysts	1.3	2.5	4.3	5.7
Giardia lamblia cysts	0.3	0.7	1.3	1.7
Vibrio cholerae	0.8	1.4	2.2	2.9
Shigella dysenteriae	0.5	1.2	2	3
Escherichia coli 0 157:H7	1.5	2.8	4.1	5.6
Salmonella typhi	1.8 - 2.7	4.1 - 4.8	5.5 - 6.4	7.1 - 8.2
Shigella sonnei	3.2	4.9	6.5	8.2
Salmonella enteritidis	5	7	9	10
Hepatitis A virus	4.1 - 5.5	8.2 - 13.7	12.3 - 22	16.4 - 29.6
Poliovirus Type 1	4.1 - 6	8.7 - 14	14.2 - 23	21.5 - 30
Coxsackie B5 virus	6.9	13.7	20.6	30
Rotavirus SA 11	7.1 - 9.1	14.8 - 19	23 - 25	36

Figure 2.28 Cell inactivation dose required [74].

2.16 One-way ANOVA

The one-way ANOVA compares the means between different groups that we are interested in and determines whether the difference between those means are statistically significant or not by using null hypothesis formula as shown in Figure 2.29 [75]. Where μ = group mean and k = number of groups. If the One-way ANOVA result is statistically significant, we will reject null hypothesis and using the alternative hypothesis (HA), which means, there are at least two means groups are statistically significantly different from each other [76].

$$H_0: \mu_1 = \mu_2 = \mu_3 = \cdots = \mu_k$$

Figure 2.29 One-way ANOVA equation [75].

A one-way ANOVA is one type of statistical test that compares the variance in the group means within a sample while considering one independent variable or factor. It is a hypothesis-based test, meaning that this method evaluates multiple set of pair at once. Before we can conclude a hypothesis, we need to know whether what is your independent and dependent variable. For instance, in our case we want to study an alteration of contact angle and breathability by UV irradiation of surgical mask;

therefore, independent variable or factor (these 2 terms refer same meaning) is the amount of UV exposure time, and our dependent variables are contact angle values [77].

CHAPTER 3
METTHOLOGY

3.1 Introduction

This chapter presents the experimental procedures and the materials used throughout the study. There are four main procedures as follows:

3.2 Design and manufacture of UV sterilizer box

3.3 Surgical mask sample preparation

3.4 Contact angle experiment

3.5 Air flow measurement

3.2 Design and manufacture of UV sterilizer box

3.2.1 A wooden box preparation

Wood is selected as our material to assemble the UV irradiation box due to its ability to block UV and it is widely available, as shown in Figure 3.1.

Figure 3.1 A wooden box

3.2.2 304 stainless steel preparation

304 stainless steel sheets with 1 mm thickness are used as the inner surface of the box due to their ability to block and reflect the UV light, as well as their durability, as shown in Figure 3.2.

Figure 3.2 Pieces of stainless

3.2.3 UV sterilizer box's window

The required properties for UV box window would be UV resistant, whilst maintaining visibility. Therefore, polycarbonate with 5 mm thickness was used, as shown in Figure 3.3. The polycarbonate sheet was cut accordingly to the size of the prepared box and attached to the box using the hinges. The magnetic holder was also installed the hold the window in close position, as shown in Figure 3.4. The handle was also installed to the outer side of the window for the ease of use, as shown in Figure 3.5.

Figure 3.3 Polycarbonate window preparation

Figure 3.4 Implant door hinge and magnetic holder to a wooden box

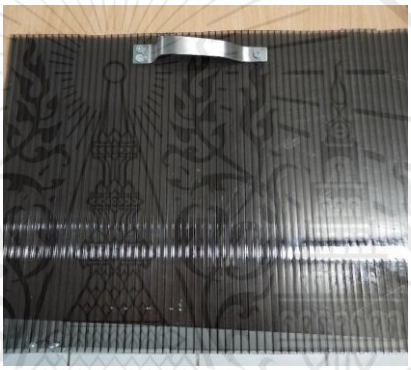

Figure 3.5 Door handle for polycarbonate window

3.2.4 UVC light bulb installation

Commercial UVC light bulb [Phillips's brand, TUV 11w] with 254 nm wavelength was used in this study the bulb was placed at the center of the box ceiling alongside the fuse at the back for safety, as shown in Figure 3.6. Since this is the commercial item, it comes with the AC power cord and is ready to use. To ensure that the user will not be accidentally exposed to UVC irradiation, door switch was installed to ensure that the bulb only works when the window is closed, as shown in Figure 3.7.

Figure 3.6 UVC light bulb installation

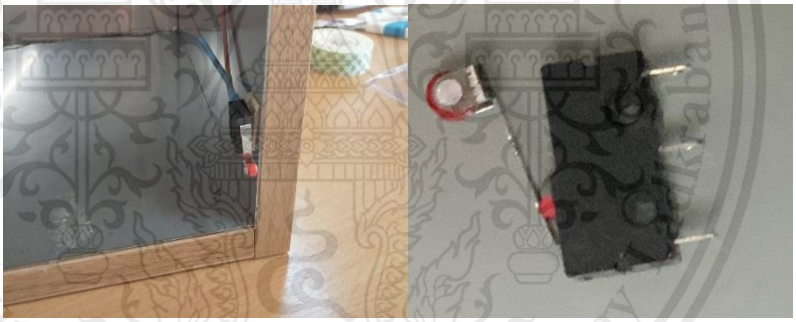

Figure 3.7 Door switch installed at the window close position

3.2.5 Timer and switch installation

To control the UV irradiation time, automatic timer switch was also installed to stop the irradiation when reaching the desired time, as shown in Figure 3.8.

Figure 3.8 Timer and manual switch

3.3 Surgical mask samples preparation

In this experiment, we use a non-medical 95% BFE disposable 3-layers masks as samples, which are widely used locally during the pandemic, as shown in Figure 3.9. The samples were undergoing UV irradiation for 5, 15, 30, and 45 minutes before being characterized in the following sections. There were 8 samples per experimental condition.

Figure 3.9 Disposable 3-layers mask

3.4 Contact angle experiment

As introduced in the previous chapter, contact angle could be used to determine the hydrophobicity of the face mask. It is known that the outer surface of the mask should exhibit hydrophobic properties so as to protect the wearer from the aerosols from the surrounding people and environment. Hence, the following procedures were carried out to determine the changes in the hydrophobicity of the mask before and after being exposed to UV disinfection using contact angle as an indicator.

3.4.1 Contact angle analyzer assembly

The front-view images of the droplet need to be captured in order to analyze the contact angle. This study used the selfie stick that could hold the mobile digital camera, as shown in Figure 3.10. Light bulb was placed behind the sample stand in order to enhance the visibility, as shown in Figure 3.11.

Figure 3.10 Selfie stick and mobile digital camera used in this study

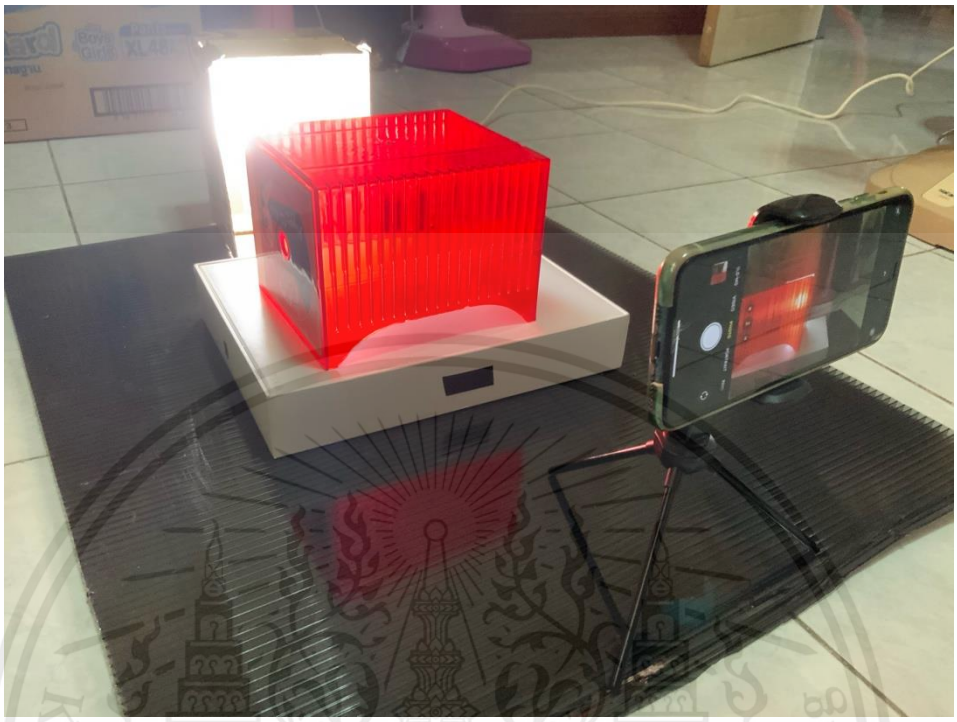

Figure 3.11 Overall contact angle value equipment

3.4.2 Contact angle measurement

The samples were cut into small pieces to make them suitable for placing onto the sample stand of the contact angle analyzer. A drop of water was placed on the samples using plastic dropper. Front-view images of the sample from every experimental condition were taken for image analysis. ImageJ software (Version 1.8.0) was used to measure the contact angle from the images in this study. The captured images were converted into 32 bits and grayscale before being analyzed. Contact angle values were measured from each image using the angle tool, as shown in Figure 3.12

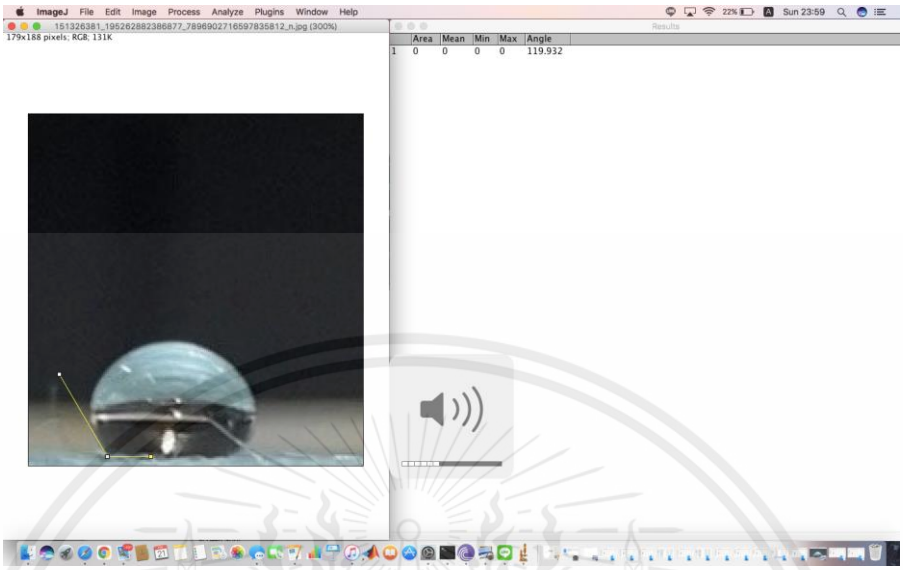

Figure 3.12 ImageJ program analyze contact angle value automatically

3.4.3 Contact angle statistical analysis

SPSS software (Version 26) was used for statistical analysis. One-way ANOVA method was used to compare the statistical significance of the mean difference among the samples from all the conditions, each of which has 8 samples. UV exposure time was defined as independent variable, whilst the contact angle was the dependent variable. Tukey's post-hoc was used for pairwise comparison. *p*-values of less than 0.05 were considered statistically significant.

3.5 Air flow measurement

Apart from the contact angle, air flow velocity through the mask was also measured in order to relate the results to the filtration ability and breathability of the mask after UV disinfection. Blower (400 Watt) was used as the air flow generator, and digital anemometer (GM8908, Protonic) was used to measure air flow velocity through the mask. The blower was held in place using a 3D printed stands, and the sample was held at the tip of the blower using elastic band, as shown in Figure 3.13. The air flow velocity through each sample group was measured and compared against each other for analysis.

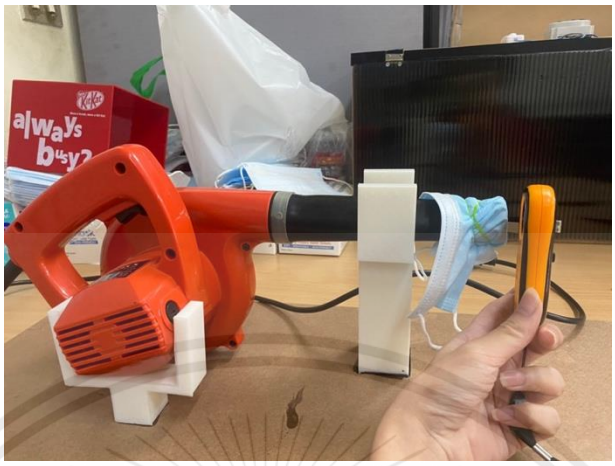

Figure 3.13 Experimental setup for air flow measurement

3.5.1 Air flow statistical analysis

Statistical analysis in this part was done similarly to the contact angle measurement using 8 samples for each experimental condition. UV exposure time was defined as independent variable, whilst the air flow velocity was the dependent variable. Tukey's post-hoc was used for pairwise comparison. *p*-values of less than 0.05 were considered statistically significant.

CHAPTER 4
EXPERIMENTAL RESULTS

4.1 Contact angle

The qualitative results from contact angle analysis are shown in Figure 4.1. The results were the representative images of the droplet on the sample from each experimental condition. It could be seen that the difference in the droplet shape and contact angle were not visually distinguishable. On the other hand, the quantified contact angles are shown in Table 4.1 and plotted in Figure 4.2. It is seen from the results that the contact angle tend to decrease with increasing UV exposure time. Moreover, the statistical analysis has shown that the reduction in contact angle was significant at the UV exposure time of 15 minutes and higher in comparison with 0 minute, as shown in Table 4.2.

0 Minute 5 Minutes 15 Minutes 30 Minutes 45 minutes

Figure 4.1 Qualitative contact angle result from 0 minute to 45 minutes

Table 4.1 The quantified contact angle results.

	UV Exposure Time (Minutes)				
Sample	**0**	**5**	**15**	**30**	**45**
1	122.4	119.4	114.3	114.8	109.8
2	119.3	118.6	115.5	110.7	109.6
3	117.1	118.6	114.1	110.1	107.5
4	119.1	119.6	116.5	111.9	108.8
5	121.8	119.7	115.3	110.1	109.8
6	120.6	119.2	116.3	110.4	109.4
7	118.5	118.4	115.0	110.3	110.8
8	121.7	118.9	115.0	111.7	103.6
Average	**120.1**	**119.0**	**115.3**	**111.2**	**108.7**

Contact Angle (Degree)					
SD	**1.9**	**0.5**	**0.9**	**1.6**	**2.3**

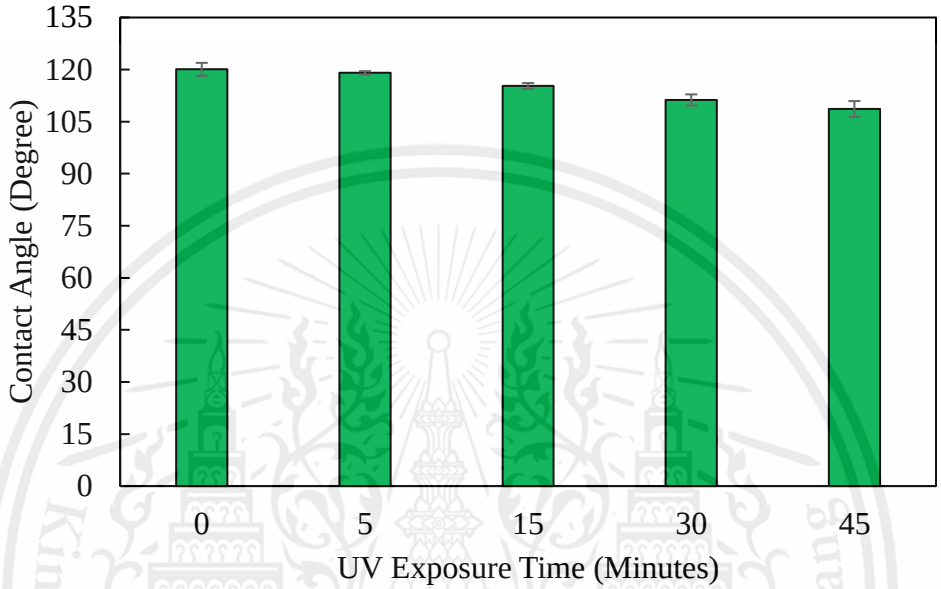

Figure 4.2 Plotted contact angle results. Error bars represent SD (n = 8 samples)

Table 4.2 The one-way ANOVA with Tukey's post-hoc test of the contact angle results.

Multiple Comparisons						
Dependent Variable: contact angle						
Tukey HSD						
(I) UVtime	**(J) UVtime**	**Mean Difference (I-J)**	**Std. Error**	**Sig.**	**95% Confidence Interval**	
					Lower Bound	**Upper Bound**
0	5	1.01250	.77624	.690	-1.2192	3.2442
	15	4.81250*	.77624	.000	2.5808	7.0442
	30	8.81250*	.77624	.000	6.5808	11.0442
	45	11.40000*	.77624	.000	9.1683	13.6317
5	0	-1.01250	.77624	.690	-3.2442	1.2192
	15	3.80000*	.77624	.000	1.5683	6.0317
	30	7.80000*	.77624	.000	5.5683	10.0317
	45	10.38750*	.77624	.000	8.1558	12.6192
15	0	-4.81250*	.77624	.000	-7.0442	-2.5808

	5	-3.80000*	.77624	.000	-6.0317	-1.5683
	30	4.00000*	.77624	.000	1.7683	6.2317
	45	6.58750*	.77624	.000	4.3558	8.8192
30	0	-8.81250*	.77624	.000	-11.0442	-6.5808
	5	-7.80000*	.77624	.000	-10.0317	-5.5683
	15	-4.00000*	.77624	.000	-6.2317	-1.7683
	45	2.58750*	.77624	.016	.3558	4.8192
45	0	-11.40000*	.77624	.000	-13.6317	-9.1683
	5	-10.38750*	.77624	.000	-12.6192	-8.1558
	15	-6.58750*	.77624	.000	-8.8192	-4.3558
	30	-2.58750*	.77624	.016	-4.8192	-.3558
*. The mean difference is significant at the 0.05 level.						

4.2 Air flow velocity measurement

The measured air flow velocity values passing through the mask are shown in Table 4.3 and plotted in Figure 4.3. The results show that UV irradiation tend to increase the air flow velocity through the masks. The statistical analysis has shown that the increased velocity was significant at the UV exposure time of 30 minutes and longer, as shown in Table 4.4.

Table 4.3 The measured air flow velocity through the mask after UV irradiation.

	UV Exposure Time (Minutes)				
Sample	**0**	**5**	**15**	**30**	**45**
1	6.2	5.7	6.5	6.2	6.6
2	5.9	5.7	5.7	6.6	6.8
3	6.3	6.2	6.6	5.8	6.8
4	5.9	6.0	6.2	6.5	6.4
5	6.2	6.1	6.1	6.8	6.8
6	6.3	6.2	5.8	6.5	6.8
7	5.9	6.1	5.9	7.0	6.2
8	5.9	6.0	6.0	6.7	7.2
Average Air Flow Velocity (m/s)	**6.1**	**6.0**	**6.1**	**6.5**	**6.7**
SD	**0.2**	**0.2**	**0.3**	**0.4**	**0.3**

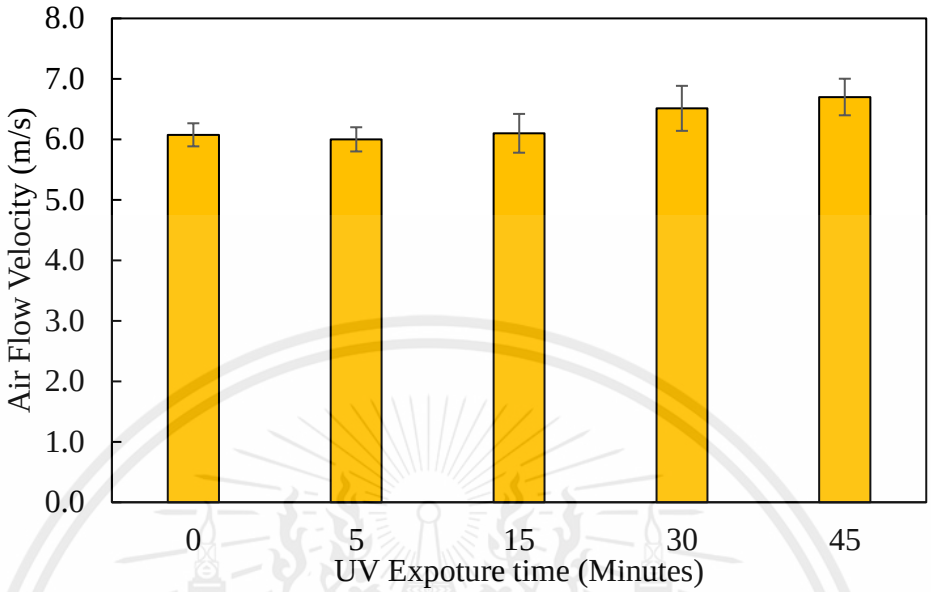

Figure 4.3 Plotted air flow velocity data. Error bars represent SD (*n* = 8 samples)

Table 4.4 The one-way ANOVA with Tukey's post-hoc test of the air flow velocity results.

Multiple Comparisons						
Dependent Variable: Velocity						
Tukey HSD						
(I) UVtime	**(J) UVtime**	**Mean Difference (I-J)**	**Std. Error**	**Sig.**	**95% Confidence Interval**	
					Lower Bound	**Upper Bound**
0	5	.0750	.1430	.984	-.336	.486
	15	-.0250	.1430	1.000	-.436	.386
	30	-.4375*	.1430	.032	-.849	-.026
	45	-.6250*	.1430	.001	-1.036	-.214
5	0	-.0750	.1430	.984	-.486	.336
	15	-.1000	.1430	.955	-.511	.311
	30	-.5125*	.1430	.008	-.924	-.101
	45	-.7000*	.1430	.000	-1.111	-.289
15	0	.0250	.1430	1.000	-.386	.436
	5	.1000	.1430	.955	-.311	.511
	30	-.4125*	.1430	.049	-.824	-.001
	45	-.6000*	.1430	.002	-1.011	-.189
30	0	.4375*	.1430	.032	.026	.849

	5	.5125*	.1430	.008	.101	.924
	15	.4125*	.1430	.049	.001	.824
	45	-.1875	.1430	.686	-.599	.224
45	0	.6250*	.1430	.001	.214	1.036
	5	.7000*	.1430	.000	.289	1.111
	15	.6000*	.1430	.002	.189	1.011
	30	.1875	.1430	.686	-.224	.599
*. The mean difference is significant at the 0.05 level.						

CHAPTER 5
CONCLUSION

5.1 Discussion

It could be seen from the results that the water contact angle of the surgical masks was significantly reduced following the UV irradiation for 15 minutes and longer. Since the contact angle could be related to the hydrophobicity of the surface, this finding could be interpreted that UV irradiation could also potentially reduce the hydrophobicity of the masks when used for disinfection. Moreover, the air flow velocity through the mask was also found to increase following the UV irradiation for 30 minutes and longer. The increased air flow velocity suggests that air could pass the mask more easily and thus it could be correlated with the filtration properties and breathability of the masks. This study shows that UV irradiation could affect the properties of PPEs, i.e., the surgical face masks, to some extent. Despite these findings, it should be noted that the current results are not sufficiently conclusive to discuss on the protective performance of the masks after disinfection, or whether UV disinfection should be used for PPEs application.

5.2 Conclusion

It could be concluded that disinfection by UV irradiation could affect the hydrophobicity of the surgical masks when the exposure time is 15 minutes or longer. Moreover, it could also affect the air flow velocity through the mask at the exposure time of 30 minutes and longer. However, it would require further study to investigate the protective performance of the UV-disinfected masks.

5.3 Suggestion

This study mostly used the in-house made equipment with custom design owing to the several limitations, including equipment and funding. Hence, the suggestions for the future work would be to use the standard equipment to characterize the samples, as well as improving the experimental designs to improve the data reliability. For example,

apart from the UV irradiation box, the images for contact angle analyses were captured by camera phone. Consequently, the insufficient quality in terms of angle and resolution would affect the data reliability obtained by ImageJ. On the other hand, in the case of airflow measurement, the air flow generator used in this study was the all-purpose blower, and thus the generated airflow was not as stable as required. Besides, the used blower also got overheated after 10 minutes of continuous use, which prolonged the experiment time. Similarly, the values measured by the digital anemometer were also fluctuating. However, we have tried to mitigate these problems by increasing the sample size to provide more repeated data. It is also noted that the UV wavelength from the light bulb used in this study could not be verified, although there was a certificate suggested that it was 254 nm.

For future experiments, it is suggested that SEM (scanning electron microscope) should also be used for characterization as this microscope can provide microscopic morphology of the samples. Likewise, more parameters related to the UV disinfection would also need to be investigated.

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