DISCOLORATION AND EFFECTIVENESS OF GAFCHROMIC EBT3 FILM IN MEASURING SOLAR ULTRAVIOLET IRRADIANCE USING SPECTROSCOPIC METHOD

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by

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TABLE OF CONTENTS

CHAPTER 2 – LITERATURE REVIEW

CHAPTER 3 – INSTRUMENTATION AND METHODOLOGY

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS AND ABBREVIATIONS

1CMA	1 cm Absorbance
AES	Atmospheric Environment Service
BCC	Basal Cell Carcinoma
cm	Centimetre
CCA	Closed Contact Absorbance
R^2	Coefficient of Determination
°C	Degree Celcius
DNA	Deoxyribonucleic
EOS	Earth Observing System
EM	Electromagnetic
EBT	External Beam Therapy
IR	Infrared
LED	Light Emitting Diode
µm	Micrometre
mJ	MilliJoules
mW	MilliWatts
MED	Minimum Erythemal Dose
nm	Nanometre
OD	Optical Density
OMI	Ozone Monitoring Instrument
%	Percentage
RMSE	Root Mean Square Error
RMSEC	Root Mean Square Error of Calibration
RMSEc	Root Mean Square Error of Lower Dose Calibration
RMSEp	Root Mean Square Error of Lower Dose Prediction
RMSEP	Root Mean Square Error of Prediction
SiC	Silicon Carbide

SZA	Solar Zenith Angle
SCC	Squamous Cell Carcinoma
SPF	Sun Protection Factors
TOMS	Total Ozone Mapping Spectrometer
UV	Ultraviolet

PENYAHWARNAAN DAN KEBERKESANAN FILEM EBT3 *GAFCHROMIC* DALAM PENGUKURAN SINARAN ULTRAUNGU SOLAR MENGGUNAKAN KAEDAH SPEKTROSKOPIK

ABSTRAK

Filem Terapi Pancaran Luaran 3 *Gafchromic* (EBT3) telah dikenalpasti keupayaannya dalam mengukur sinaran (dos, dalam mJ/cm^2) ultraungu (UV) yang didedahkan secara terus dibawah cahaya matahari. Lima eksperimen berbeza telah dijalankan menggunakan filem-filem EBT3 pelbagai saiz untuk mengkaji keberkesanan filem tersebut terhadap sinaran UV solar dan diukur menggunakan teknik spektroskopi kebolehserapan. Semua filem didedahkan terhadap sinaran UV solar pada keadaan awan, durasi masa dan tempat yang pelbagai. Penyahwarnaan filem adalah bergantung kepada masa diambil untuk pendedahan, kadar sinaran dan kondisi awan. Eksperimen dilakukan pada suhu dan kelembapan sekitaran yang diukur. Perubahan warna filem dari hijau muda ke hijau tua telah dianalisa menggunakan teknik spektroskopi kebolehserapan nampak serta spektra kebolehserapan bagi kesemua eksperimen melalui perisian *Minitab* telah dibentangkan bersama analisis kuantitatif. Nilai pekali penentuan, R^2 dan ralat punca min kuasa dua, RMSEC bagi set data kalibrasi ialah 99.3 % dan 414.571 mJ/cm^2 manakala bagi set data jangkaan pula ialah 97.1 % dan 176.752 mJ/cm^2. Kesemua nilai R^2 dan RMSE menunjukkan korelasi yang tinggi antara dos UV dan perubahan warna filem EBT3 yang telah didedahkan, menunjukkan bahawa filem EBT3 memberi keberkesanan yang tinggi dalam mengukur dos UV solar.

DISCOLORATION AND EFFECTIVENESS OF GAFCHROMIC EBT3 FILM IN MEASURING SOLAR ULTRAVIOLET IRRADIANCE USING SPECTROSCOPIC METHOD

ABSTRACT

Gafchromic External Beam Therapy 3 (EBT3) films were investigated for its ability to measure the ultraviolet (UV) irradiance (dose, in mJ/cm^2) exposed directly to sunlight. Five different experiments were conducted by using different EBT3 films prepared to study the effectiveness of the films towards measuring solar UV irradiance using absorbance spectroscopy technique. Those films were exposed to the solar UV irradiance at various condition of sky, duration of time and places. The discoloration of the films is dependent on the exposure time, irradiance rate and condition of the sky. The experiments were conducted under measured ambient temperature and humidity. The changes of films' color from light green to dark green were analysed using visible absorbance spectroscopy technique. The absorbance spectra obtained from Minitab Software for all the experiments presented with quantitative analysis. The values of coefficient of determination, R^2 and root mean square error, RMSEC obtained for calibration data set was 99.3 % and 414.571 mJ/cm^2 respectively while for the prediction data set, the R^2 and RMSEP was 97.1 % and 176.752 mJ/cm^2. The value of R^2 and RMSE showed high correlation between UV dose and color changes of exposed EBT3 film, indicating that EBT3 film gives high effectiveness in measuring solar UV dose.

CHAPTER 1:
INTRODUCTION

Sun is a primary natural source of ultraviolet (UV) radiation. It is made up of gas (hydrogen, helium, oxygen, carbon, neon, iron) and plasma (Nall & Laflamme, 2015). It was converted into energy and released as heat and light (ultraviolet (UV), infrared, visible). The converted energy characterised by its wavelength, expressed in nanometers (1 nm = 10^{-9} m) (Melkin *et al*, 1994). The structure of the Sun consists of few layers starting at the centre of the Sun called core. Next layer is radiative zone, tachocline, convertive zone, photosphere, atmosphere (corona) and photons and neutrinos layer. Figure 1.1 shows the structure of the Sun.

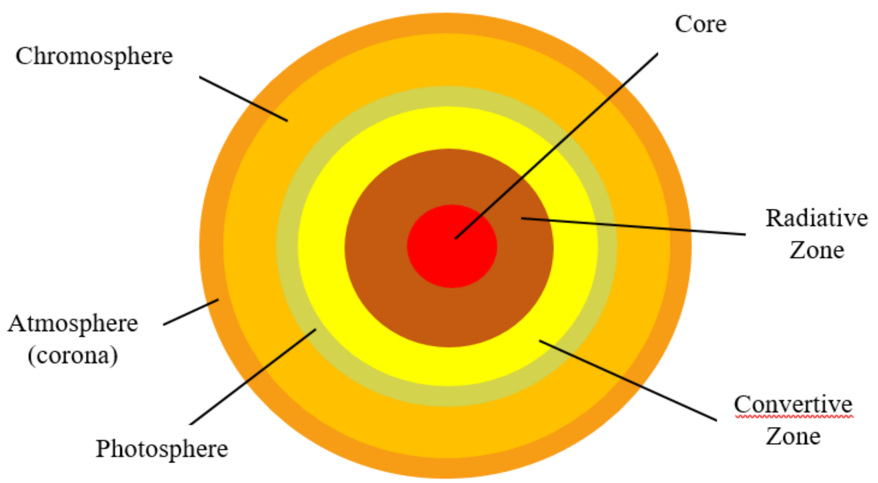

Figure 1.1 The structure of the Sun

The balance exposure of sunlight is good and beneficial to the living things like humans, animals and plants. For human, the exposure of sunlight is good to increase the producing of hormone from the brain called serotonin. This hormone is useable in the process of boosting mood and helps a person to feel calm and focused (Nall & Laflamme, 2015; Juzeniene & Moan, 2012). Not only that, the exposure to the sunlight can also built strong bones due to the present of UV-B type in the Sun's rays. This UV-B will trigger the skin to produce vitamin D, that is good to the bones. Instead of bones, enough sunlight exposure also can build strong muscles and higher the immune system of a body. Enough and moderate amount of sunlight gives benefits to the cancer prevention. Some cancers like colon cancer, Hodgkin's lymphoma, ovarian cancer and pancreatic cancer are more likely occurred to the person who is living in areas with fewer daylight hours, according to the Environmental Health Perspective study. Some skin conditions like psoriasis, eczema, jaundice and acne need enough exposure to the sunlight to heal (Nall & Laflamme, 2015; Melkin *et al*, 1994). This action takes place under the medical supervision and the benefits of treatment versus the risks of UV radiation exposure are a matter of clinical judgement (Science Learning Hub, 2008).

The common effect of sunlight is due to the extra or overexposure of it. Long-term exposure may lead to the severe and chronic skin cancer, eye diseases such as cataracts and immune systems fault (Ng, 2003). Short-term over-exposure may cause the sunburn and snow blindness. Those severe and chronic diseases may lead to the long-period healing while the common diseases can be cured in short-period of time, depending on the stage of the illness (Melkin *et al*, 1994). Sunburn or so called as erythema is a change of skin color from normal to red (Science Learning Hub, 2015) as shown in Figure 1.2. This happened due to the rises of blood flow caused by the dilatation of the superficial blood vessels in dermis layer of skin. UV-B radiation is known to be the mainly responsible for sunburn because it is more erythmogenic. Other physical risk included fair skin, red or blond hair, blue eyes and freckles.

Figure 1.2 Redness of skin by sunburn effect

Not only sunburn, tanning, premature aging of skin, suppression of immune systems, the damaging of eyes and skin cancers are the effect of prolonged UV exposure. The delayed pigmentation of the skin or melanin pigmentation was referred to the tanning that was noticeable in one to two days after the exposure to the sun. The increases of pigment cells functions numbers resulted from tanning process will increase the activity of the enzyme tyrosinase. This leads to the formation of the new melanin and the increases of melanin granules number (Kane & Kumar, 1999). The premature aging is one of the result of degenerative changes in elastin and collagen. It will accumulate over the time and are largely irreversible. Over 20 years of human life, 80 % of premature aging of the skin may occur. For premature aging of the skin, UV-B radiation is only 20 to 50 times more efficient than UV-A (Diffey, 1991). Figure 1.3 and Figure 1.4 show the effect of tanning process and premature aging to the human skin.

Figure 1.3 Effect of tanning process to the human skin

Figure 1.4 Premature aging effect on human skin

Suppression of the immune system resulting from exposure to UV radiation was believed to be an important contributor to the development of non-melanoma skin cancers. UV radiation induces a state of relative immunosuppression that prevents tumor rejection. This is mainly accomplished by interfering with the normal surveillance function of antigen-presenting Langerhans cells in the epidermis, which are responsible for T-lymphocyte activation in response to foreign antigens (Kane & Kumar, 1999). The number of cells and their characteristics are altered from exposure of UV radiation while similar cells that responsible for the selective induction of suppressor lymphocyte pathways are resistant to damage caused by UV. This creates an imbalance in the local T-cell function and a shift from helper to suppressor pathways, which ultimately favour the tumorigenesis and progression. Grossman and Leffell (1997) concluded that the immunosuppressive effects of UV may be as important as the carcinogenic effects of UV radiation in the establishment and progressive growth of UV-induced skin tumors (Grossman & Leffell, 1997).

UV rays can also damage the eyes because more than 99 % of UV radiation is absorbed by the front of the eyes. Corneal damage, cataracts, and macular degeneration are all possible chronic effects from UV exposure and can ultimately lead to blindness. Melanoma, a type of skin cancer, can also develop within the eye (non-skin melanomas). The annual age-adjusted incidence of non-skin melanomas is 0.7 per 100000 persons in U.S. of which ocular melanomas constitute 80 %. The risk of intraocular melanomas is 8-fold higher in whites than blacks (Kane & Kumar, 1999). Figure 1.5 shows the damaging effects on human eyes.

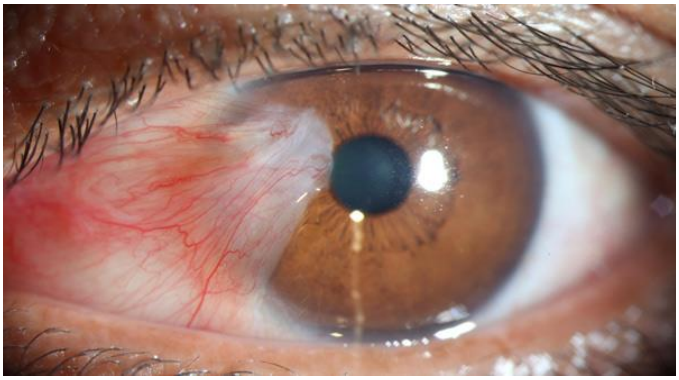

Figure 1.5 Damaging effects on human eyes

Skin cancers are the most commonly occurring cancers in terms of incidence in the world. There are different types of skin cancer including the non-melanoma skin cancers, basal cell carcinoma (BCC) and squamous cell carcinoma (SCC), and melanoma as shown in Figure 1.6 and Figure 1.7 (Science Learning Hub, 2015). For the non-melanoma skin cancers, cumulative sun exposure is believed to be important, whereas for melanoma the intermittent exposure hypothesis has been postulated. For BCC, they are commonly found on the head and neck, areas subject to chronic sun exposure. They occur just as frequently in men as in women. For SCC, the tumors are the most common skin cancers on sun-exposed sites in older people. SCCs are more common in men than women. SCCs have similar genetic risk factors as BCCs. SCCs have precursor lesions called actinic keratoses. These lesions represent dysplasia that occurs as result of chronic exposure to sunlight with build-up of keratin (Kane & Kumar, 1999). According the multistage model of carcinogenesis, these precursor lesions represent the first genetic hit on the pathway to carcinoma development (Grossman & Leffell, 1997). For melanoma skin cancer, it derived from the melanocytes pigment cells. They have marked tendency to metastasize and therefore are more likely than nonmelanoma skin cancers to cause death.

Figure 1.6 BCC and SCC

Figure 1.7 Melanoma skin cancer

Radiation is defined as the emission of energy in form of electromagnetic (EM) waves or as moving subatomic particles through space or material medium, especially high-energy particles that resulting in ionization (Weisstein, 2007). Radiation can be divided into four categories that are electromagnetic (EM) radiation, particle radiation, acoustic radiation and gravitational radiation. EM radiation included heat, radio waves, visible light, x-rays and gamma radiation. Alpha, beta and neutron are included in the particle radiation types. Neutron radiation consists of particles of non-zero rest energy. Ultrasound, sound and seismic waves are parts of acoustic radiation, while gravitational radiation takes the form of gravitational waves or ripples in the curvature of space time.

Radiation is often categorised as ionizing radiation and non-ionizing radiation depending on the energy of the radiated particles. Any types of EM radiation that does not carry enough energy per quantum (photon energy) to ionize atoms or molecules was categorised as non-ionizing radiation. Instead of producing charged ions when passing through matter, the EM radiation has sufficient energy only for the excitation or the movement of an electron to a higher state (Ng, 2003). Main source of non-ionizing radiation is the Sun's light. Near UV, near infrared and visible light are some types of light emitted by the Sun, while microwave, radio waves and thermal radiation are part of non-ionizing radiation (Environmental Health and Radiation Safety, 2013).

EM radiation is a form of energy around us in a form of radio waves, microwaves, x-rays and gamma rays. Sunlight is also a form of EM energy, but visible light is only a small portion of EM spectrum, which contains a broad range of EM wavelengths. EM radiation is created when an atomic particle, such as an electron, is accelerated by an electric field, causing it to move. The movement produces oscillating electric and magnetic fields, which travel at right angles to each other in a bundle of light energy called a photon (NASA, 2013).

EM spectrum was divided into seven regions, in order of decreasing wavelength and increasing energy and frequency. The common orders were radio waves, microwaves, infrared (IR), visible light, ultraviolet (UV), x-rays and gamma rays. Typically, lower-energy radiation was expressed as frequency; for the other was expressed as wavelength but for higher-energy radiation will be expressed in terms of energy per photon (Lucas, 2015).

1.1 Ultraviolet (UV) Radiation

UV radiation is defined as that portion of the EM spectrum between x-rays and visible light. The wavelengths for UV radiation are between 100 to 400 nm (Parisi, 2005). The Sun is the primary natural source of UV radiation. UV radiation is divided into three types according to its biological effects and the level of penetration through the skin. The first type is UV-A which has wavelengths from 315 to 400 nm. Second type is UV-B with its wavelengths between 280 and 315 nm. Lastly is UV-C with wavelengths from 100 to 280 nm (Saleh, 2015; Osman & Omar, 2017; Tajuddin & Omar, 2017; Ng, 2003). Those three types of UV radiation are shown in the EM spectrum in Figure 1.8.

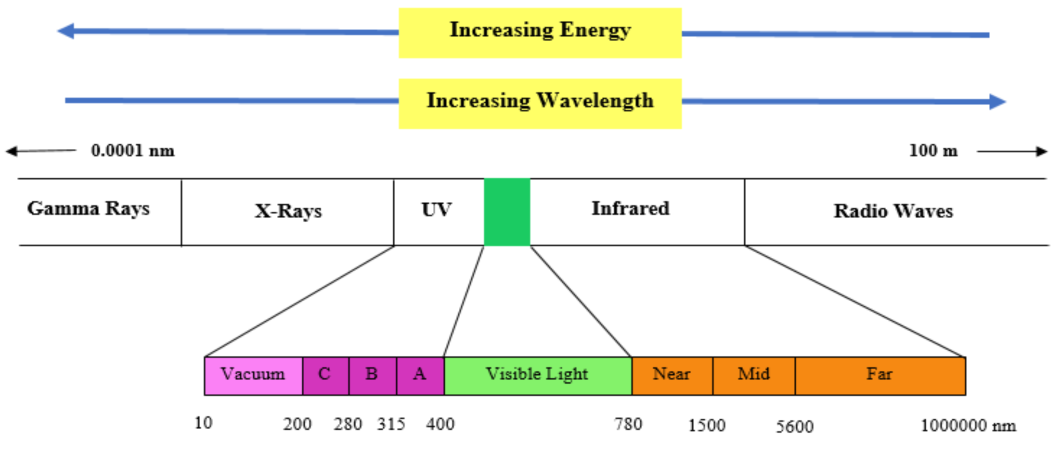

Figure 1.8 Electromagnetic (EM) spectrum (Osman & Omar, 2017)

Between those three types of UV radiation, the most dangerous type is UV-C. Fortunately, UV-C is totally blocked by the atmospheric ozone layer from reaching the Earth's surface. If there is UV-C exposure on Earth, that is not coming from the Sun, but it is accidental exposure that occurs from any manmade sources such as germicidal lamps (Matsumura & Ananthaswamy, 2004). UV-C has the ability for killing the bacteria. The germicidal lamps were designed to emit UV-C radiation in the process of killing the bacteria on human skin. Overexposure to UV-C radiation can give negative effects to human. It can cause snow blindness, severe sunburn to the human face and corneal burns, commonly termed as welders' flash (Saleh, 2015).

Only 10 percent of UV-B passes through the Earth's surface and the other 90 percent were absorbed by ozone, water vapour oxygen and carbon dioxide. UV-B has enough energy to cause photochemical damage to cellular deoxyribonucleic acid (DNA), yet not enough to be completely absorbed by the atmosphere. Therefore, UV-B is the most destructive form of UV radiation. For human, UV-B is needed for the synthesis of vitamin D, however the overexposure to it will give harmful effects include erythema (sunburn) (Matsumura & Ananthaswamy, 2004), cataracts and development of skin cancer. The individuals with the high daily outdoors activities are the greatest risk of UV-B effects.

The largest amount of UV radiation that passes through the Earth's surface is UV-A, because it is less affected by the atmosphere. At the present time, there is a concern that reductions of atmospheric ozone layer could increase the prevalence of skin cancer. UV-A exposure has an initial pigment-darkening effect or tanning followed by erythema if the exposure is excessive. UV-A exposure is also needed in the synthesis process of vitamin D (Fioletov, McArthur, Mathews, & Marrett, 2010), however excessive exposure to it has been associated with toughening of the skin, cataract formation and suppression of the immune system. UV-A is often called as back light and UV-A lamps are mostly used in phototherapy and tanning booths.

1.2 Solar UV Index

UV index is defined as a measure of the intensity of UV radiation on the Earth's surface that is relevant to affecting the human skins. The UV index was developed by the World Health Organisation and represented as a single value rounded to the nearest whole number where it predicts the UV intensity (WHO, 2002; Parisi, 2005). This index tells us how much UV radiation is reaching us from the Sun. During the summer, solar UV index is used to indicate how quickly our skin burn when we are outside and how concern we are to prevent the skin burning. There are three factors that affecting the Solar UV index forecasts included the position of the Sun on the sky, the cloud cover and the amount of ozone in the stratosphere. Table 1.1 below gives the listed of UV indexes with its own risk level and prescriptions.

Table 1.1 UV Indexes with its risk level and prescription (HSC, 2017)

UV Index	Risk Level	Prescription
1-2	Low	The Sun is unlikely to burn the skin whatever the skin type.
3-4	Low – Medium	For fair or sensitive skin, the risk is at medium and should use adequate Sun protection. Children usually fall into this category.
5-6	High	Everyone needs to use Sun protection if they are outside with the recommended SPF of 15+. People with black skin however are at low risk.
7-9	High – Very High	Everyone should cover up as well as using sunscreen regardless of his or her skin color.
10+	Very High	People with white skin are at a very high risk. People with brown skin are at medium to high risk. People with black skin are at medium risk.

1.3 UV Radiation Terminology

The quantities of UV radiation can be expressed by using radiometric terminology. Terms relating to a beam of radiation passing through space are radiant energy and radiant flux. Terms relating to a source of radiation are radiation intensity and radiance. The term ‘irradiance’ is commonly used in photobiology where the photobiology is the effect of non-ionizing radiation (Diffey, 2002).

UV irradiance is defined as the ratio of the radiant power (milliWatts, mW) and the area of the detector (centimetres square, cm^2). The unit for UV irradiance is mW/cm^2. The other definition of UV irradiance is the amount of UV arriving at the cure surface in unit of W/m^2. Radiant exposure is defined as the rate of energy (milliJoules, mJ) on a certain area (centimetres square, cm^2). The radiant exposure usually called as exposure dose or simply dose and its unit is mJ/cm^2 (Parrish, 2012). To find the dose, time taken for the exposure is one of the quantities that is very important. Equation 1.1 below shows the dose equation in unit of mJ/cm^2.

$$\mathbf{Dose}\left(\frac{\mathbf{mJ}}{\mathbf{cm^2}}\right) = \mathbf{Irradiance}\left(\frac{\mathbf{mW}}{\mathbf{cm^2}}\right) \times \mathbf{Time\ of\ Exposure\ (s)} \quad \ldots 1.1$$

Most of the instruments were developed for measuring the UV irradiance in unit of mW/cm^2. To measure the UV dose received on the Earth’s surface, the time taken of UV exposure need to be recorded manually, so that the equation above can be applied in the UV measurement calculation.

1.4 Factors Affecting UV Exposure Level

The exposure level of solar UV to the Earth’s surface are depending on several natural factors either from the Earth or from the ozone layer. Some of the factors are discussed in this section like ozone layer, cloud cover, ground reflection, altitude and latitude, aerosols and pollutants and sun elevation (McKenzie *et al*, 2003; Parisi, 2005; McKenzie *et al*, 2011).

Ozone is an important part of our atmosphere and high levels of ozone will absorb higher level of UV radiation, like stated by WHO and the Cancer Council WA. Ozone levels vary over the year and even across the single day. Since the discovery of the hole in the ozone layer over the Antarctic in early 1980s, ozone levels have been observed to be decline or lower worldwide, it resulted in the increasing levels of solar UV radiation that reached the Earth's surface (WHO, 2017; Cancer Council, 2017). As ozone layer becomes thinner, the protective filter provided by the atmosphere is progressively reduced. This issue consequently gave high risks on human, animal also the Earth.

Cloud cover is another factor that affecting the UV exposure levels on Earth (Exell, 2000). Having a cover of cloud over the sky can reduce the amount of UV radiation reaching the Earth's surface. UV radiation levels will be increased under the cloudless skies. Even though with the high level of cloud cover, UV radiation levels can be high due to the scattering of UV radiation by the water molecules and fine particles contain in the cloud. So, it is not particularly thicker the cloud resulted in lower UV radiation.

Another factor is the ground surface reflectivity (Exell, 2000). Playing with solar UV radiation, some people probably think that the threat comes from the above, however there are some surfaces that can increases the ambient levels of UV radiation through the reflection. Metal surfaces, concreate and beach sands are some of the materials that can reflect the UV rays back onto a person, resulted in the increases of the skin damage risks. Because of the body natural defences of face such as eyebrows, eye sockets and eye lids are not providing the protection against the angle of UV reflected, it is very harmful for those face parts. The result from a study by WHO, snow can reflect as much as 80 % of UV radiation, dry beach sands reflecting about 15 % and sea foam will reflect about 25 % (WHO, 2017).

Altitude and longitude of the Earth are one of the other factors that affecting the solar UV radiation levels. UV radiation will be increased at the higher altitudes as the atmosphere has less chance to absorb the incoming UV rays from sun (Blumthaler, Ambach & Ellinger, 1997). It has been found that UV levels will be increased by 4 % for every 300 m increases in altitude (Cancer Council, 2017). The closer the equator gives the higher of UV radiation levels.

Aerosols and pollutants like air pollution, water pollution and ground pollution like waste will gives some increases of solar UV radiation. Small particles suspended in the air can scattered the solar UV rays (Torres, Bhartia, Herman, Ahmad, & Gleason, 1998). Not only that, the small particles and organisms in water also can increased the level of UV radiation in the water ecosystems. Whilst the effect is minor, it still can have a negative impact on the levels of UV reaching the Earth’s surface. For example, the oil spillage at the vast ocean can lead to the reflectivity levels of solar UV radiation (Cancer Council, 2017).

Another natural factor that affecting the level of UV radiation on Earth is the sun elevation or the position of the sun on the sky. The higher the sun in the sky, the higher the UV radiation levels. Thus, the UV radiation varies with the time of the day and year. The maximum levels occurred when the sun is at its maximum elevation, around the midday or noon especially during the summer months.

1.5 Problem Statement

EBT3 film is the latest model of the EBT films that has been designed to overcome Newton's Rings artefact and the orientation problem during scanning process of the film, especially for the clinical dosimetry purpose (Tajuddin & Omar, 2017; Sorriaux *et al*, 2013). Recently, in the field that involving its application in solar UV dose measurement, EBT3 film is known as one of the erythemal dosimeter that have its own characteristics such as cost-saving, portable, higher sensitivity, water resistant and immersible design (ISP, 2011; Devic, 2011). In this research, visible absorbance spectroscopy measurement technique by using the spectrometer is used in measuring the color changes of the films after UV exposure was done, instead of using conventional instrumentation such as scanner or camera (Yusof, Osman and Omar, 2017). The calibration algorithm can be developed by using the spectroscopy spectra data and can be used to predict the UV dose for the other measurement. Thus, this research focused on three problem statements to achieve the objectives. Those three problem statements were listed below.

1. Does the discoloration of Gafchromic EBT3 films can be measured by using visible spectroscopy technique?
2. Does the stability and reliability of developed measuring technique of solar UV can be tested?

3. Are there any effects of accumulated dose on wavelengths selection and the developed algorithm?

1.6 Research Objectives

Gafchromic EBT3 film was known as an erythemal dosimeter in measurement of solar UV irradiance. The manufacturing of this dosimeter gives high potential to the film to absorb the UV irradiance and change its color based on the level of UV exposure (Saleh, 2015). The overexposure of UV irradiance gives the saturated absorbance on the film. Overexposure of UV radiation to human being also can give negative effects. People tend to get severe diseases like skin cancer and cataracts (Diffey, 1982). The present of dosimeter likes EBT3 film managed to give the predicted UV level for human awareness on solar UV radiation.

This research will present the study on the effectiveness of Gafchromic EBT3 films in measuring solar UV irradiance in ambient conditions by using an optical system. One of the main focuses is on the measuring technique used and the spectral analysis that are capable in reproducing the consistent result from the samples. All the experiments were done to fulfil all the objectives below:

1. To analyse the discoloration of Gafchromic EBT3 films toward solar UV irradiance (λ = 280 to 400 nm), in dose (mJ/cm^2) using visible absorbance spectroscopy technique under measured environmental conditions.

2. To test the consistency and the repeatability of the absorbance measurements of the exposed films towards solar UV radiation dose.
3. To observe the effects of accumulated dose on the wavelengths selection and the developed algorithm.

1.7 Scope of Research

This study focuses on the discoloration of the Gafchromic EBT3 films and its effectiveness in measuring the solar ultraviolet irradiance by using specific absorbance spectroscopy technique. Manufactured Gafchromic EBT3 film was used as a sample and specific spectrometer used as a measuring equipment. Some extra analysis was included in the results (Chapter 4) to briefly explain the overview of the research analysis before the main results explained clearly. A quantitative data was interpreted in different ways to various the research findings.

1.8 Outline of Thesis

Chapter 1 presents the introduction of this research. It explains the basic aspects of solar irradiance, including UV radiation and UV index. It also explains the terminology used in this research, the problem statement and the objectives of this research.

Chapter 2 presents the literature review. Several studies related to the research are summarised in this chapter, including the portable dosimeter, satellite UV measurement and erythemal UV dosimeter. This chapter also focusing mainly on the usage of Gafchromic EBT3 films based on the previous study done the researchers.

Chapter 3 tells about the instrumentation used in overall researches. 7 instruments were explained its own characteristics with the labelled figures. The methodology applied in this research also explained clearly after the instrumentation. The techniques and the setups used for every single experiment were mentioned and told clearly with the figures. These parts divided into three steps that are sample preparation, solar UV exposure and absorbance measurement procedure with the extended analysis at the last section.

Chapter 4 talks about the data, results and discussion of the research outcomes. First part tells us about the environmental conditions during the solar exposure. Then, the absorbance spectroscopy technique measurement results were explained clearly included solar UV distribution test, films size effect and background color effect. In this sub-chapter, the selection of same wavelengths for both calibration and prediction data sets, the development of calibration algorithm, the prediction accuracy test and the recalibration test were analysed with the graph presented. Next to it, the results and analysis for the extended experimental tests were shown clearly.

Chapter 5 states the conclusion of the research and the future recommendations for the improvement of next coming research. The findings of every research experiment were stated in this chapter.

CHAPTER 2
LITERATURE REVIEW

Many instruments were manufactured and produced by the industry that able to measure the solar UV irradiance and predict the outdoor UV indexes. The instruments are designed with an easy-to-operate function or user friendly, portable and having high precision and reproducibility. But most of the instruments are expensive. Besides, there are also film-based dosimeters designed for the measurement of UV dose. In addition to the current existence of commercial and most accepted technology and techniques of measuring solar UV irradiance, indexes and dose, until now researchers continually moving forward to coming out with the new ideas about the study on UV. This chapter elaborates on the research that had been conducted by various researchers around the world using different dosimeters.

2.1 Portable Dosimeter

Most of the portable dosimeters are available in the market with its different features and characteristics. This section will explain some of the dosimeters that applicable for the solar UV irradiance measurement like pyranometer, pyrheliometer and UV meters.

2.1.1 Pyranometer

Pyranometer functioning as an instrument that measure global and diffuse solar radiation (Eltbaakh *et al*, 2011). Global solar radiation is the total amount of solar energy received by the Earth's surface, expressed as Watt per square meter (W/m^2).

About 99% of global solar radiation has wavelengths between 300 and 3000 nm includes ultraviolet (300-400 nm). Diffuse solar radiation is scattered in the atmosphere before reaching the Earth's surface (LI-COR.inc, 2016). Pyranometer have a shading disk to prevent direct solar radiation from reaching the sensor. The measurement for diffuse radiation involves correcting for the portion of the radiation shielded from the sensor by the shading disk. The sensor use in pyranometer is a thermopile with alternate blackened junctions heated by the Sun. The unheated junctions are near ambient temperature. This may be ensured by putting the unheated junctions in thermal contact with a white surface heating by the Sun. It can be done by placing the junctions in contact with a black surface with high thermal conductivity or by placing a black coating on the junctions. The instrument is positioned in a level where the sensor must be facing up towards the sky.

McArthur *et al* (1999) used pyranometer to measure the global and diffuse solar radiation independently, equipped with tracking shading disc. This instrument was placed in the highest location on the roof of the Atmospheric Environment Service (AES) building, so that the distribution of the radiation will be higher than other places (McArthur *et al*, 1999). Lam and Li (1996) also used pyranometer manufactured by Kipp and Zonen in their data collecting experiment at the City Polytechnic of Hong Kong for three years period from 1991 to 1993 (Lam & Li, 1996; Eltbaakh *et al*, 2011). Less expensive pyranometers may use a photovoltaic sensor to measure solar radiation. Figure 2.1 shows certain designs of pyranometer that available for the measurement of global and diffuse solar radiation.

Figure 2.1 Various design of Pyranometer

2.1.2 Pyrheliometer

Pyrheliometer is an instrument that measure direct solar radiation at normal incidence, passes directly through the atmosphere to the Earth's surface (McArthur *et al*, 1999; Solar Energy, 1990). Pyrheliometer will measure direct radiation that coming out to an angle of about 3° away from the Sun's disk. The sensor is a temperature-compensated thermopile placed at the bottom of a blackened collimator tube that limits the angular acceptance of solar radiation to about 5° to 6° (Solar Energy, 1990). The instrument is oriented such that the direct radiation from the sun is parallel to the axis of the collimator tube (Eltbaakh *et al*, 2011). In all previous experiments done by researchers, it often used in the same way of setup with pyranometer and the unit measured in Watt per square meter (W/m^2). Figure 2.2 shows the pyrheliometer design that available at the market to measure the direct solar radiation.

Figure 2.2 Pyrheliometer

2.1.3 UV Meter

UV meter is an instrument used to detect ultraviolet light or radiation on a wide range of sensitivities (Tajuddin & Omar, 2017). The level of UV radiation can be recorded by UV meter, thus give idea toward the protection that is needed to avoid negative effect of UV exposure (Ellis & Harris, 2016). UV meter is portable handheld instrument units that are battery operated and is very light weight. There are lots of UV meters manufactured with its specification based on the multipurpose usage. Tajuddin and Omar (2017) used a UV meter model of YK-35UV in their research to measure the UV irradiance throughout the experiment. This UV meter is designed to detect UV-A and UV-B with detector spectrum from 290nm to 390nm. The UV meter has two ranges that are 2mW/cm^2 (1.999 mW/cm^2 x 0.001 mW/cm^2) and 20 mW/cm^2 (19.99 mW/cm^2 x 0.01 mW/cm^2) (Tajuddin & Omar, 2017). Figure 2.3 shows the UV meter model of YK-35UV. The consideration in measurement of UV irradiance using UV meters is the Solar Zenith Angle (SZA). SZA is defined as the angle between the centre of the solar disk (Sun) and the vertical to the UV meter probe detector. The maximum solar irradiance occurred when the Sun's rays are parallel to the vertical, or in other words the SZA in a zero degree. The smaller the

SZA, the smaller the absorption due to the small light path through the atmosphere (Madronich *et al*, 1998).

Figure 2.3 UV meter model of YK-35UV

Figure 2.4 shows the example of UV data distribution measured by YK-35UV UV meter, taken at the rooftop of School of Physics, Universiti Sains Malaysia between March and June 2016 with different condition of sky. The reading was taken for 3 times per day (at 1000, 1200 and 1400) during relatively sunny weather (Osman & Omar, 2017).

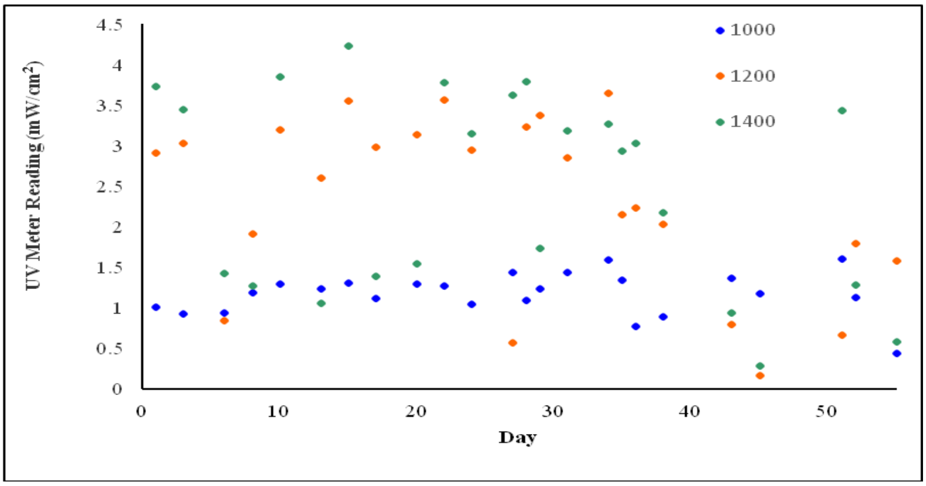

Figure 2.4 UV data distribution measured by YK-35UV UV meter.

2.2 Satellite UV Measurement

Nowadays, a standardised scale for reporting UV to the public has gained wide acceptance among all. There has been increased use of satellite data to review the geographical variability and trends in UV irradiance on Earth. Some research was done in assessing the utility of satellite retrievals in UV irradiance especially in term of radiation by comparing the satellite data measurement with ground-based surface measurement (McKenzie *et al*, 2003). Until now, global indexes of UV radiation are available on the Internet and in form of cell phone applications too.

Madronich *et al* (1998) done an experiment to measure the trends of UV using the satellite to observe the estimation of UV irradiance from satellite. The measurements from satellite provide the potential for deriving the accurate trends in UV, since only a single sensor needs to be characterized for the lifetime of satellite instrument (Madronich *et al*, 1998). The instruments will measure the backscattered UV radiation from the surface of Earth (McKenzie *et al*, 2003). But in the same time, few factors like ozone depletion layer, clouds boundary and aerosols were needed to be considered while recording the data, especially for model calculations of erythemal daily dose (Arola *et al*, 2002). To have a good trends of UV radiation, the satellite reading measurements need to be done continuously in a long period of time, so that the data has enough information for public.

Arola *et al* (2002) done an experiment by using the satellite data obtained in four different methods listed in the Table 2.1, and compared them against the ground-based measurements. Those four methods derive the surface UV radiation from satellite data. Every single method has their own spatial and temporal