# MEASURE THE ULTRAVIOLET PROTECTION FACTOR (UPF) OF FABRICS ON UV-VIS SPECTROPHOTOMETER

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**ABSTRACT**

Ultraviolet Protection Factor has been interested in the textile industry in the field of protective clothing, but measuring devices are quite rare and expensive compared to their effectiveness, so they are not easily found in textile material laboratories in our country. The UV-VIS spectrophotometer is equipped in biochemical or food laboratories and is commonly used to determine the concentration of solutions or chemical groups present in the solution, and the machine is not used to measure solid materials. This study introduces a method to measure the penetration (transmission) of fabrics in the ultraviolet radiation region and builds software to automatically calculate the UPF from the results received on the UV-VIS spectrophotometer at the Center of Experiment and Practice of our HUFI University.

*Keywords:* UPF, UVI, UV-VIS spectrophotometer.

## 1. INTRODUCTION

The past few decades have witnessed an alarming increase in the incidence of skin cancer worldwide. The main reason is the depletion of ozone in the stratosphere of the atmosphere, which reduces the efficiency of ultraviolet (UV) absorption of solar radiation [1].

As is known from studies [2, 3, 4, 5], although sunlight is essential for all life forms on earth, it can also be harmful to humans through overexposure to some of its radiation components of the sun, such as ultraviolet radiation. Long-term exposure to solar UV radiation can cause acute and chronic health effects on the skin, eyes, and immune system. Depletion of stratospheric ozone increases the intensity of UVB radiation received at ground level, and sunburn or erythema is the most common acute consequence commonly detected when people are active outdoors. In response to growing concerns, in 1994 [6] the World Meteorological Organization (WMO) and the World Health Organization (WHO) released a standard index for levels of UV rays in the environment (UVI), garment products' UV protection (UPF) and recommends that everyone use protective clothing that provides adequate coverage and UV resistance for outdoor activities to protect skin from this radiation.

UVI or ultraviolet irradiance index is a quantity representing UV radiation originating from the sun with a weighting of the reddening effect on human skin as a single number. This amount of radiation is measured at a specific location. They come from many different directions of the sky, so it depends on many variables such as coordinates, geographic altitude of the measuring point, date and time, angle and altitude of the zenith, the absorption of the ozone layer, the scattering of clouds and aerosols in the atmosphere, the reflection of the water surface or surrounding objects, [7] ... Quantitatively, the UV index is determined from the following formula:

$$I_{UV} = k_{er} . \int_{250\,nm}^{400\,nm} E(\lambda).S(\lambda).d\lambda \qquad (1)$$

Where

$E(\lambda)$ - relative erythemal spectral effectiveness is calculated according to the standard ISO 17166:1999/CIE S007/E-1998;

$S(\lambda)$ - solar spectral irradiance at wavelength $\lambda$ in $W/(m^2.nm)$;

$k_{er}$ - factor equal to 40 $m^2/W$.

To make easily understood information about UV radiation and its harmful effects, the $I_{UV}$ value is rounded up and called the UV index. With the above calculation, UVI has 12 values from 0 to 11+, which are conventionalized by the colors from green to red-violet representing the level of danger to health as described in Figure 1.

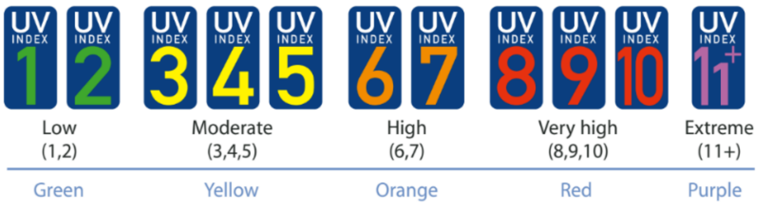


*Figure 1.* Color convention of UVI according to international codes
(*Source:* World Health Organization, 2002, [7])

The UVI at ground level can be measured with spectrophotometers, but they are relatively expensive and can be complicated to operate and maintain, so they are often located at national meteorological stations. Some countries now forecast and publish UVI values on the internet.

It is very necessary to provide useful recommendations for preventing UV radiation and ozone depletion. The public in many countries is becoming more and more aware of the negative effects of ultraviolet radiation, so they are always looking for ways to protect their health. In professional magazines, daily newspapers, and cyberspace... we can find many different sections where dermatologists, meteorologists, biologists, and other experts warn us about the sun's rays.

The problem of UV radiation is interdisciplinary, so it is also the subject of textile scientists. Outdoor activity can significantly affect UV exposure and the use of personal protective equipment such as clothing, hats, parasols, tinted glasses or sunscreen, etc., as a barrier between the source radiation to human skin to minimize that dose of exposure.

**UPF** is the UV protection factor of a person's outer protective layer that prevents ultraviolet radiation from penetrating. UPF is determined by measuring the transmission spectrum of ultraviolet radiation perpendicular to the surface of this protective layer and evaluating it according to the following formula [2, 4, 5, 8]:

$$UPF = \frac{ED}{ED_m} = \frac{\sum_{\lambda=290}^{400} E(\lambda).S(\lambda).\Delta\lambda}{\sum_{\lambda=290}^{400} E(\lambda).T(\lambda).S(\lambda).\Delta\lambda} \qquad (2)$$

Where

- $E(\lambda)$ is the relative erythemal spectral effectiveness is calculated according to the standard ISO 17166:1999/CIE S007/E-1998;

- $S(\lambda)$ is the solar UVR spectral irradiance in Wm-2nm-1 according to the CIE [9, 10];

- $T(\lambda)$ is the spectral transmittance at wavelength $\lambda$;

- $\Delta\lambda$ is the wavelength (in nm).

UPF in formula (2) is the ratio between ED and $ED_m$ values with

- ED is the average effective UV radiation irradiance transmitted and calculated through the air;

- $ED_m$ is the average effective UV radiation irradiance transmitted and calculated through the fabric.

Clothing is the most natural and common way to protect the human body from external environmental factors, so the UPF is often used for fabrics or apparel. In the above definition, the UPF indicates how much longer a person can stay in the sun when fabric covers the skin compared to the time in the sun without fabric covering to obtain the same erythemal response. The higher the UPF of the fabric, the better the skin protection. The UPF value is, therefore a number representing the UV protection factor, indicating how well the item protects the user from sunburn.

*Table 1.* UPF classification system according to AS/NZS and ASTM standards
(*Source*: AS/NZS 4399:1996 [10])

| UPF Range | UVR protection category | Effective UVR transmission (%) | UPF Ratings |
|---|---|---|---|
| 15 to 24 | Good protection | 6.7 to 4.2 | 15, 20 |
| 25 to 39 | Very Good protection | 4.1 to 2.6 | 25, 30, 35 |
| 40 to 50, 50+ | Excellent protection | ≤2.5 | 40, 45, 50, 50+ |

Like the UVI, measuring the UPF requires an instrument with the same working principle as a spectrometer; measuring the UPF means measuring the function $T(\lambda)$ in the wavelengths of UV rays present in the surface medium. Due to recent research, discovery, and development of standards in this field, UPF testing equipment is not popular, expensive, but relatively complicated to operate and maintain. Spectrophotometers in laboratories of biochemistry, food, and medicine are only designed to measure solutions, if they are used to measure the UPF of fabrics, it is necessary to have appropriate methods and calculations.

While the UVI of a certain region is updated hourly on the weather forecast information, the UPF is almost nowhere to be checked and confirmed in our country today. Textile manufacturing and finishing technologists do not have quantitative data on the UV protection of their fabrics. The designers of protective clothing fail to determine the safety of the clothing when worn outdoors in extreme weather. It is difficult for fashion retailers and consumers to access the actual UPF of each garment and know the risk of skin cancer when it is used under the sun.

Therefore, this study proposes a method to measure the UPF of fabric on the available UV-VIS spectrophotometer of the Center of Experiment and Practice, based on that, building software to calculate and report appropriate results with current international testing standards.

## 2. MEASUREMENT METHODS AND BUILDING EXCEL REPORT RESULTS

### 2.1. Measurement method

The photo Lab 7600 UV-VIS spectrophotometer from WTW (Germany) in the laboratory [12] is a typical, relatively compact, single-beam spectrophotometer that measures absorption or transmission through fabrics from wavelength (200 - 400 nm) UV rays with a bandwidth of 4 nm. The working principle diagram and machine structure are shown in Figures 2 and 3.

The radiation source is a xenon flashlamp reflected by a concave mirror creating a parallel beam that passes through the filter to the grating diffraction detector - stepper motor, so when working, each monochromatic radiation band will shine through a quartz cuvette containing the sample solution.

The cuvette size used during the experiment is 45 x 10 (mm x mm). Since the test object is fabric and does not use any chemicals in the experiment, the prepared specimen will be 9 x 48 (mm x mm) flat ironed, folded at the top 5 mm to be held against the top edge of the cuvette when hanging freely. This keeps the fabric flat during the measurement. The fabric face is then parallel to one of the inside faces of the cuvette, perpendicular to the incident radiation. These samples were measured under standard conditions of the laboratory at the Center of Experiment and Practice (25oC, 65% Rh)

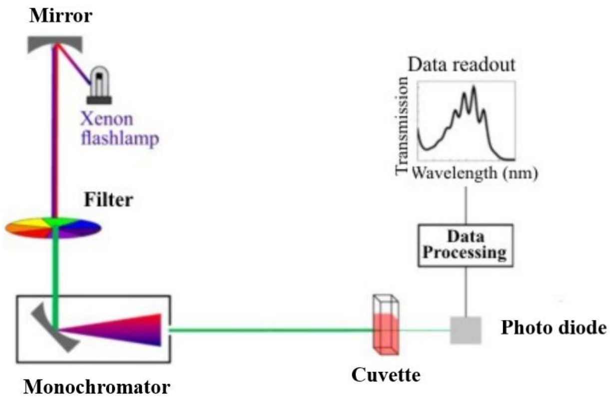


*Figure 2.* Schematic diagram of the spectrophotometer.

*Figure 3.* WTW 7600 photo Lab UV-VIS spectrophotometer.

After the UV light passes through the fabric specimen located in the cuvette, the penetrating component enters the photodiode sensor; the radiation intensity is converted into potential and recognized by the microprocessor chip located in the electronic circuit. Here the microprocessor compares this obtained value with the initial calibration potential value when the light ray passes through the cuvette in the unpatterned state; % of radiation penetration is calculated and the result is stored in the form of transmission spectrum T(λ).

After measuring each sample, the T(λ) function of the measurement results can be printed out or saved to USB as a *.csv file as shown in Table 2.

*Table 2.* Report on the spectral measurement results

| Photo Lab 7600 UV-VIS | 22021773 | 2.89-WTW-2.50 | |
|---|---|---|---|
| 1650057619<br>4/15/2022 14:20:19<br>#Data (visible) | Transmission | Smoothing | 0<br>Blue |
| 290 | 1.603 | | |
| 291 | 1.607 | | |
| 292 | 1.610 | | |
| 293 | 1.613 | | |
| 294 | 1.610 | | |
| 295 | 1.614 | | |
| 296 | 1.616 | | |
| 297 | 1.618 | | |

## 2.2. Processing measurement results

The UPF of the fabric is determined when there is a transmission function T(λ) in the UVA - UVB range with the calculation completely according to the formula (2) described above. Currently, many standards have been developed and published for specifying UPF for textiles and garments such as AATCC TM 183:2004 [9] of the United States, AS/NZS 4399:1996 [10] of Australia and New Zealand, BS EN 13758-1:2002 [11] the UK and Europe. Measurement results, calculated according to the above standards are different but not significant, so they can be applied to the whole world. Therefore, this study will use AS/NZS standard 4399:1996 to process the measurement results.

In addition to the T(λ) function obtained from the spectrometer, calculating the UPF according to equation (2), it is necessary to have the values of the relative radiation spectrum that produces effective erythema on human skin E(λ) and the radiation spectrum sun S(λ). With a wavelength range Δλ = 5 nm, the AS/NZS standard 4399:1996 provides these functions according to Table 3.

*Table 3.* Functions E(λ) and S(λ) according to AS/NZS 4399:1996 [10]

| Wavelength<br>λ [nm] | Relative spectral effectiveness E(λ) | Spectral irradiance<br>S(λ) [Wm-2.nm-1] |
|---|---|---|
| 290 | 1.000 | 0.757 x 10-4 |
| 295 | 1.000 | 0.134 x 10-2 |
| 300 | 0.649 | 0.136 x 10-1 |
| 305 | 0.220 | 0.767 x 10-1 |
| 310 | 0.745 x 10-1 | 0.172 |
| 315 | 0.252 x 10-1 | 0.282 |
| 320 | 0.860 x 10-2 | 0.375 |
| 325 | 0.290 x 10-2 | 0.494 |
| 330 | 0.136 x 10-2 | 0.629 |
| 335 | 0.115 x 10-2 | 0.602 |
| 340 | 0.970 x 10-3 | 0.675 |

| Wavelength λ [nm] | Relative spectral effectiveness E(λ) | Spectral irradiance S(λ) [Wm-2.nm-1] |
|---|---|---|
| 345 | 0.810 x 10-3 | 0.650 |
| 350 | 0.680 x 10-3 | 0.692 |
| 355 | 0.580 x 10-3 | 0.743 |
| 360 | 0.480 x 10-3 | 0.647 |
| 365 | 0.410 x 10-3 | 0.849 |
| 370 | 0.340 x 10-3 | 0.876 |
| 375 | 0.290 x 10-3 | 0.780 |
| 380 | 0.243 x 10-3 | 0.902 |
| 385 | 0.204 x 10-3 | 0.693 |
| 390 | 0.172 x 10-3 | 0.879 |
| 395 | 0.145 x 10-3 | 0.693 |
| 400 | 0.122 x 10-3 | 1.180 |

Because the structure of the fabric is often hollow, and not as homogeneous as the liquid solution, measurements for the same sample always have very variable results. The process of scanning the spectrum for each measurement also takes a long time, so the standards allow the number of measurements per fabric specimen to be in the range of 4 to 10, the calculated UPF value is the average of the above measurements.

The calculation volume for each fabric specimen is relatively large, so we designed an Excel sheet to report the measurement results by automatically calculating the intermediate values as well as determining the final UPF when pasting the measurement data from the output *.csv file of the spectrometer in Table 4.

According to formula (2), the numerical element of the spectral multiplication can be calculated directly from the data in Table 2 as follows:

$$ED = \sum_{\lambda=290}^{400} E(\lambda).S(\lambda).\Delta\lambda = 0.2863174 \quad (3)$$

The denominator component of the EDm spectrum multiplication is a variable value and depends on the Ti(λ) function of each measurement.

$$ED_m i = \sum_{\lambda=290}^{400} E(\lambda).T_i(\lambda).S(\lambda).\Delta\lambda \quad (4)$$

For i = 1 - 10 and Δλ = 5 nm, formula (4) takes the form of the sum of 23 multiplicative expressions, so the UPFi value of the worksheet in figure 6 is formatted in Excel by the formula:

$$UPFi = \frac{ED}{ED_m i} = \frac{0.2863174}{ED_m i} \quad (5)$$

According to AS/NZS standard 4399:1996, the average UPF of the specimens after many measurements is determined as follows:

$$UPF_{tb} = \frac{UPF_1 + UPF_2 + ... + UPF_N}{N} \quad (6)$$

Where N = 10 is the number of times to measure or measure 10 specimens for this test case. The SD standard deviation of the mean UPF is as follows:

$$SD = \sqrt{\frac{\sum_{i=1}^{N}(UPF_i - UPF_{tb})^2}{N-1}} \quad (7)$$

The Standard Error in the mean UPF, calculated for the 99% confidence level is as follows:

$$E = t_{k.\alpha} \times \frac{SD}{\sqrt{N}} = 1{,}03SD \quad (8)$$

Where

$t_{k.\alpha}$ = t variate ($\alpha = 0.005$), $t_{k.\alpha} = 3.25$;

k = N - 1 = 9;

The Rated UPF is as follows:

$$UPF_{tt} = UPF_{tb} - E \quad (9)$$

Rated UPF = $UPF_{tb}$ – E

The rated UPF or marked on the label of a textile product as the nominal UPF according to AS/NZS 4399:1996, AATCC TM 183:2004 or BS EN 13758-1:2002 …is a rounded $UPF_{tt}$ number smallest integer multiple of 5. If UPF ≥ 55, it is recorded as UPF 50+.

*Table 4.* Excel sheet reporting UPF measurement results

**HOCHIMINH CITY UNIVERSITY OF FOOD INDUSTRY** **CENTER OF EXPERIMENT AND PRACTICE**

**TEST REPORT**

Instrument: PhotoLab 7600 UV-VIS
Testing Period: 04/15/2022

Test according to AS/NZS 4399:19
Manager: Nguyen Mai Thanh Thao

SAMPLE INFORMATION

Assortment: Mau 004
Materials: Cotton
Weave: Plain

Name: Calicot
Color: Grey
GSM: 150

**TEST RESULTS**

| λ [nm] | E(λ) | S(λ) | T1(λ) | T2(λ) | T3(λ) | T4(λ) | T5(λ) | T6(λ) | T7(λ) | T8(λ) | T9(λ) | T10(λ) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 290 | 1.000000 | 0.0000757 | 0.01784 | 0.02116 | 0.03314 | 0.01655 | 0.02115 | 0.03358 | 0.02257 | 0.02097 | 0.02080 | 0.03358 |
| 295 | 1.000000 | 0.0013400 | 0.01784 | 0.02117 | 0.03311 | 0.01669 | 0.02132 | 0.03350 | 0.02254 | 0.02109 | 0.02079 | 0.03350 |
| 300 | 0.649000 | 0.0136000 | 0.01790 | 0.02121 | 0.03317 | 0.01670 | 0.02125 | 0.03365 | 0.02255 | 0.02105 | 0.02068 | 0.03365 |
| 305 | 0.220000 | 0.0767000 | 0.01793 | 0.02125 | 0.03310 | 0.01683 | 0.02139 | 0.03364 | 0.02273 | 0.02119 | 0.02085 | 0.03364 |
| 310 | 0.074500 | 0.1720000 | 0.01797 | 0.02128 | 0.03308 | 0.01688 | 0.02137 | 0.03360 | 0.02281 | 0.02122 | 0.02089 | 0.03360 |
| 315 | 0.025200 | 0.2820000 | 0.01808 | 0.02120 | 0.03319 | 0.01699 | 0.02132 | 0.03373 | 0.02274 | 0.02132 | 0.02090 | 0.03373 |
| 320 | 0.008600 | 0.3750000 | 0.01800 | 0.02147 | 0.03312 | 0.01698 | 0.02156 | 0.03364 | 0.02307 | 0.02131 | 0.02098 | 0.03364 |
| 325 | 0.002900 | 0.4940000 | 0.01814 | 0.02139 | 0.03320 | 0.01698 | 0.02150 | 0.03368 | 0.02291 | 0.02135 | 0.02109 | 0.03368 |
| 330 | 0.001360 | 0.6290000 | 0.01804 | 0.02153 | 0.03310 | 0.01703 | 0.02158 | 0.03353 | 0.02310 | 0.02137 | 0.02105 | 0.03353 |
| 335 | 0.001150 | 0.6020000 | 0.01815 | 0.02150 | 0.03298 | 0.01715 | 0.02159 | 0.03363 | 0.02310 | 0.02130 | 0.02116 | 0.03363 |
| 340 | 0.000970 | 0.6750000 | 0.01804 | 0.02153 | 0.03308 | 0.01706 | 0.02165 | 0.03343 | 0.02313 | 0.02151 | 0.02112 | 0.03343 |
| 345 | 0.000810 | 0.6500000 | 0.01808 | 0.02149 | 0.03298 | 0.01711 | 0.02164 | 0.03343 | 0.02325 | 0.02141 | 0.02113 | 0.03343 |
| 350 | 0.000680 | 0.6920000 | 0.01827 | 0.02169 | 0.03304 | 0.01725 | 0.02184 | 0.03342 | 0.02310 | 0.02148 | 0.02134 | 0.03342 |
| 355 | 0.000580 | 0.7430000 | 0.01816 | 0.02168 | 0.03306 | 0.01725 | 0.02186 | 0.03336 | 0.02313 | 0.02161 | 0.02123 | 0.03336 |
| 360 | 0.000480 | 0.6470000 | 0.01833 | 0.02166 | 0.03300 | 0.01711 | 0.02182 | 0.03348 | 0.02308 | 0.02151 | 0.02127 | 0.03348 |
| 365 | 0.000410 | 0.8490000 | 0.01826 | 0.02156 | 0.03304 | 0.01731 | 0.02173 | 0.03356 | 0.02304 | 0.02150 | 0.02109 | 0.03356 |
| 370 | 0.000340 | 0.8760000 | 0.01822 | 0.02170 | 0.03291 | 0.01730 | 0.02180 | 0.03343 | 0.02326 | 0.02158 | 0.02123 | 0.03343 |
| 375 | 0.000290 | 0.7800000 | 0.01825 | 0.02182 | 0.03287 | 0.01732 | 0.02187 | 0.03322 | 0.02320 | 0.02175 | 0.02125 | 0.03322 |
| 380 | 0.000243 | 0.9020000 | 0.01834 | 0.02170 | 0.03289 | 0.01731 | 0.02186 | 0.03343 | 0.02325 | 0.02162 | 0.02135 | 0.03343 |
| 385 | 0.000204 | 0.6930000 | 0.01838 | 0.02178 | 0.03293 | 0.01737 | 0.02192 | 0.03330 | 0.02337 | 0.02175 | 0.02135 | 0.03330 |
| 390 | 0.000172 | 0.8790000 | 0.01836 | 0.02187 | 0.03283 | 0.01736 | 0.02193 | 0.03333 | 0.02329 | 0.02175 | 0.02146 | 0.03333 |
| 395 | 0.000145 | 0.6930000 | 0.01832 | 0.02183 | 0.03289 | 0.01737 | 0.02194 | 0.03345 | 0.02327 | 0.02165 | 0.02143 | 0.03345 |
| 400 | 0.000122 | 1.1800000 | 0.01834 | 0.02180 | 0.03281 | 0.01738 | 0.02183 | 0.03331 | 0.02346 | 0.02162 | 0.02134 | 0.03331 |
| UPFi | | | 55.61 | 46.96 | 30.20 | 59.23 | 46.73 | 29.74 | 43.89 | 47.11 | 47.88 | 29.74 |

The mean UPF of the sample: **43.7**
The number of specimens tested: **32.8**

The Standard Error: **10.9**
The rated UPF: **30**

## 3. CONCLUSION

The study showed a way to measure the UPF of fabric on a UV-VIS spectrophotometer of the Center of Experiment and Practice, data processing according to AS/NZS 4399:1996 standard. Laboratory measurements on 8 fabric samples have shown that this method is feasible.

Data processing software based on an Excel sheet is relatively easy to use. Each fabric sample takes 10 measurements and the data link from the spectrophotometer to the final report is relatively convenient. The process of determining the UPF becomes fast and reliable.

Testing the fabric's UPF at biochemical laboratories in our country with a UV-VIS spectrophotometer in line with international standards will allow designers of protective clothing to find the right fabric requirements. Textile and fabric finishing manufacturers will select appropriate materials and technological processes to ensure the quality of UV protection products supplied to the garment industry. Fashion merchants and end-users will know the safety of their clothing when outdoors in extreme weather.

The expansion of measuring equipment in the biochemical laboratory of our HUFI University to serve research and study for lecturers and students of the textile industry will serve as the foundation for scientific research projects related to the field of UV protection in the Faculty of Garment Technology and Fashion in the upcoming period.

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## TÓM TẮT

ĐO HỆ SỐ KHÁNG TIA CỰC TÍM (UPF) CỦA VẢI
TRÊN MÁY SPECTROPHOTOMETER UV-VIS

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Hệ số kháng UV của vải được ngành dệt may quan tâm ở những năm gần đây trong lĩnh vực trang phục bảo hộ nhưng thiết bị đo khá hiếm và đắt tiền so với hiệu quả đem lại nên không thấy chúng trong các phòng thí nghiệm vật liệu dệt may nước ta. Máy đo quang phổ UV-VIS được trang bị ở các phòng thí nghiệm sinh hóa hay thực phẩm phổ biến dùng để xác định nồng độ dung dịch hay nhóm hóa học hiện diện trong dung dịch, máy không sử dụng đo vật liệu rắn. Nghiên cứu này đưa ra phương pháp đo phổ xuyên thấu (transmission) qua vải trong vùng bức xạ cực tím và xây dựng phần mềm tự động tính hệ số UPF từ kết quả nhận được trên máy quang phổ UV-VIS ở Trung tâm Thí nghiệm Thực hành - HUFI.

*Từ khóa:* UPF, UVI, quang phổ kế tử ngoại - khả kiến.