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Photodecomposition Profile of Organic Material during the Partial Solar Eclipse of 9 March 2016 and Its Correlation with Organic Material Concentration and Photocatalyst Amount

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A B S T R A C T

The present study investigated the photodecomposition of an organic material during the partial (88.76%) solar eclipse phenomenon of 9 March 2016 in Bandung, Indonesia. Curcumin and anatase titanium dioxide (TiO_2) particles were used as models of organic material and photocatalyst, respectively. The influence of the process parameters (i.e., curcumin concentration and the amount of TiO_2) on the photodecomposition process was also investigated. The results showed that the curcumin was decomposed along with the solar light irradiation time. During the solar eclipse, the photodecomposition rate is suddenly down. The partial solar eclipse provided a slower photodecomposition process than the process under sunny days (conducted on 8 and 10 March 2016). The concentration of curcumin and the amount of TiO_2 also have played an important role in the photodecomposition, in which the lower concentration of curcumin and the higher amount of TiO_2 have a correlation to the obtainment of higher photodecomposition rate.

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1. INTRODUCTION

Studies on photodecomposition of organic materials using metal oxide catalysts (such as TiO_2, ZnO, WO_3, and others) have attracted tremendous attention.(Kormann *et al.,* 1991) Photodecomposition process has shown considerable potentials for research and applications, particularly for solar-related applications, such as waste water treatment, dye-sensitized solar cell, and many others.

A number of studies have reported the development of photodecomposition process. Their reports have been completed with information about parameters involved in the photodecomposition, such as photocatalyst dosage,(Eskizeybek *et al.,* 2012) initial concentration of organic materials,(Matthews 1991) properties of organic materials and catalyst,(Iskandar *et al.,* 2007; Nandiyanto *et al.,* 2009; Nandiyanto *et al.,* 2013; Arutanti *et al.,* 2014) temperature, pH,(Sun *et al.,* 2008) reaction volume, light intensity, type of light sources(Matthews 1991; Eskizeybek *et al.,* 2012) (i.e., artificial UV/visible light source and natural sunlight), turbidity , oxygen gas flow rate , additional chemical (i.e., oxidant,(Sun *et al.,* 2008), reducing agent, co-catalyst,(Arutanti *et al.,* 2014; Arutanti *et al.,* 2015) and dopant(Arutanti *et al.,* 2015)), and consideration of inhibitor. However, there is no report on the photodecomposition of organic materials during the solar eclipse phenomenon. In fact, when the solar eclipse occurs, the Sun is masked by the Moon and this causes the darkness for a shorter duration.(Fabian *et al.,* 2001; Foken *et al.,* 2001; Nishanth *et al.,* 2011) The solar intensity, light spectrum, and UV irradiation decrease,(Fabian *et al.,* 2001; Foken *et al.,* 2001; Koepke *et al.,* 2001; Zerefos *et al.,* 2001; Nishanth *et al.,* 2011) and this disturbs the light-dependent chemical reaction in the Earth, such as photosynthesis process.(Abram *et al.,* 2000)

Solar eclipse phenomenon has attracted researchers from various fields. Many researchers investigated the incidents related to the meteorological parameters (e.g., temperature,(Foken *et al.,* 2001; Nishanth *et al.,* 2011) wind speed,(Nishanth *et al.,* 2011) gravity,(Altadill *et al.,* 2001; Šauli *et al.,* 2006) humidity,(Nishanth *et al.,* 2011) geomagnetic field,(Özcan *et al.,* 2004) ionospheric electron content,(Liu *et al.,* 1999) and light irradiation(Koepke *et al.,* 2001; Zerefos *et al.,* 2001; Nishanth *et al.,* 2011; Libra *et al.,* 2016)) and the photochemical properties in the atmosphere(Hunt 1965; Bojkov 1968; Eastman *et al.,* 1980; Abram *et al.,* 2000; Chudzyński *et al.,* 2001; Tzanis *et al.,* 2008; Sharma *et al.,* 2010; Nishanth *et al.,* 2011). However, no research investigates on the impact of solar eclipse to the photodecomposition of organic material in the Earth. Although some reports examined the photochemical properties,(Hunt 1965; Bojkov 1968; Eastman *et al.,* 1980; Abram *et al.,* 2000; Chudzyński *et al.,* 2001; Tzanis *et al.,* 2008; Sharma *et al.,* 2010; Nishanth *et al.,* 2011) they were limited to the chemical components in the atmosphere and did not consider the incidents in the ground, such as photodecomposition process.

Taking a lesson from our previous approaches in the photocatalytic processes,(Iskandar *et al.,* 2007; Nandiyanto *et al.,* 2009; Nandiyanto *et al.,* 2013; Arutanti *et al.,* 2014; Arutanti *et al.,* 2014; Arutanti *et al.,* 2015; Nandiyanto *et al.,* 2016) we investigated the photodecomposition of organic materials during the partial solar eclipse phenomenon in Bandung, Indonesia. As models of organic

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material and photocatalyst, curcumin and anatase titanium dioxide (TiO2) powder were used, respectively.

Curcumin was selected because it can be easily obtained from turmeric, which is commonly used and largely available in Asia.(Sogi *et al.,* 2010) Therefore, understanding the photodecomposition of curcumin will give benefits due to high usage of this material (e.g., food, drugs, antioxidant, solar-related materials, and many others). Furthermore, the amount of curcumin in the aqueous solution relates to the color and the turbidity of the mixed solution. Therefore, the decrease in its concentration can be distinguished easily even using direct visual observation. (Bonsnes *et al.,* 1945) Although curcumin can be decomposed by exposing light, its decomposition rate is relatively low.(Zebib *et al.,* 2010) Thus, curcuminoid compounds are used as a photoprotective molecules for lignocellulosic materials. Curcumin is also highly stable to heat(Sogi *et al.,* 2010). Thus, the change in the temperature will have no impact to the decomposition of curcumin. These reasons make photodecomposition of curcumin being studied. (Kumavat *et al.,* 2013; Buddee *et al.,* 2014)

Another material used in the present study was TiO2 as the photocatalyst. This material was selected due to its affinity for light, and its ability to degrade organic compounds and transfer energy (known as solar cell).(Nandiyanto *et al.,* 2009) In addition, this material is relatively cheap, easily accessible, and non-toxic (Buddee *et al.,* 2014). Anatase-TiO_2 was used because it has been proven to be the best for photocatalytic activity.

To simplify the investigation on the photodecomposition process during the solar eclipse, we conducted an experimental procedure in a 500-mL batch-process photoreactor system. The reactor was equipped with a mixer, bubbler (connected to the air compressor), and several sensors (i.e., a light sensor, a voltage measurement analysis, a thermocouple, conductivity meter, and pH meter). The sensors were connected to the computer system; thus, a real-time decomposition of curcumin in the solution can be investigated precisely.

Different from other reports on the photodecomposition process that utilize spectrophotometer for measuring the concentration, this study employed a turbidity analysis based on the light penetration into the curcumin solution to measure the real-time analysis of concentration. In addition, the proposal of the photodecomposition mechanism during the solar eclipse phenomenon was added to qualitatively explain the experimental observations.

As the present study focused on the effect of solar eclipse on the photodecomposition of curcumin, commercial anatase titanium dioxide particles were used to simplify the experimental procedure. To confirm the photodecomposition behavior of curcumin during the solar eclipse, the photodecomposition process in the solar eclipse day (9 March 2016) and two sunny days (8 and 10 March 2016) were compared. The influence of the process parameters (i.e., curcumin concentration (10 and 25 ppm) and the amount of TiO2 (3 and 6 ppm) on the photodecomposition process was also examined. In addition, higher concentration of curcumin and TiO2 in this study was not used because of limitation of our sensor (higher concentrations of these materials have correlation to lowering preciosity of the measurement analysis).

In addition, although this study has no direct correlation to the industrial applications, understanding the phenomena during the solar eclipse is important in the scientific point of view. In general, this study

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can be used for assisting further scientific studies and technological developments concerning the solar-related applications.

2. HYPHOTETICAL PHOTODECOMPOSITION OF ORGANIC COMPONENT USING PHOTOCATALYST AND SOLAR ECLIPSE PHENOMENON

2.1. Photodecomposition of organic component using TiO_2 photocatalyst

The illustration of the photodecomposition of organic material using a photocatalyst in the common process is shown in **Figure 1**. In the common process, the photocatalytic activity is mainly influenced by the existence of photon, which is provided from the solar light. (Sucahya *et al.,* 2016)

The catalyst is activated by appropriate amount of energy from photons (**Route R1**). Photon leads to the formation of holes (h^+) in the valence band (VB) and electrons (e^-) in the conduction band (CB) (**Route R2**) . TiO_2 (as a model of catalyst) with a band gap of 3.35 eV is activated by absorbing UV light.(Arutanti, *et al*., 2014; Kormann, *et al*., 1991;Devipriya & Yesodharan, 2005)

When there are e^- and h^+ in the catalyst, unique phenomenon (known as charge separation) occurs. In the presence of water, e^- can attract and convert oxygen (O_2) (**Route R3**), whereas h^+ can convert water molecule (H_2O) (**Route R4**).(Arutanti, 2014; Arutanti, 2015) Both reactions enhance the production of OH radicals, in which the OH radical is effective for degrading organic compound ($C_xH_yO_z$) (**Route R5**).(Arutanti, 2014; Arutanti, 2015; Arutanti, 2014; Nandiyanto, 2013; Kormann, 1991; Devipriya & Yesodharan, 2005) Therefore, when there is a curcumin in the photocatalytic system, the concentration of curcumin would presumably decrease during the solar light illumination.(Buddee, 2014)

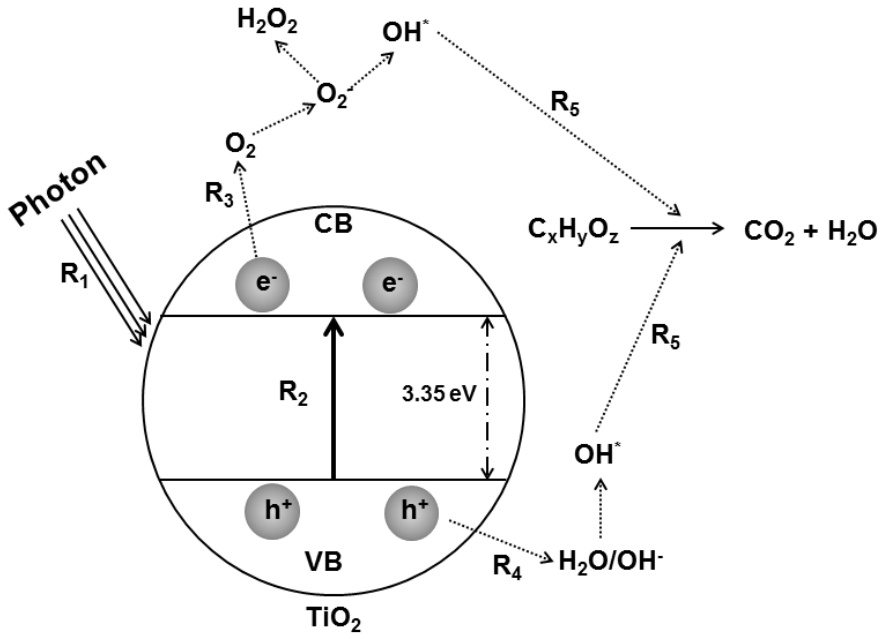

Figure 1. The proposal of photodecomposition of organic material ($C_xH_yO_z$) using TiO_2 catalyst under solar light irradiation

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2.2. Solar eclipse phenomenon

Solar eclipse is an astronomical phenomenon when the Sun's disc is masked by the Moon. During the solar eclipse, several incidents can be observed, such as the changing color of the sky, the moving shadow, shadows bands, the Sun's chromospheres, the corona and its prominences, the diamond ring as well as planets and stars that suddenly become visible against the darkening sky.(Fabian, *et al*. 2001) The solar eclipse also causes almost complete darkness for a shorter duration.(Nishanth, *et al.*, 2011; Fabian, *et al*., 2001; Foken, *et al*., 2001)

An illustration of phases occurring during the solar eclipse phenomenon is depicted in **Figure 2**. There are three types of solar eclipses depending on the distance of the Moon from the Earth:(Tiwari, 2015)

(i) Total solar eclipse occurs when the Moon obscures the Sun (see **Figure 2a**). In this type of eclipse, the apparent size of the Moon is bigger than that of the Sun, allowing the solar corona to be visible. This eclipse happens only in umbra region (the darkest part of the Moon's shadow).

(ii) Annular solar eclipse occurs when the Sun and the Moon are exactly in line but the Moon does not cover the Sun completely (see **Figure 2b**). In this type of eclipse, the Moon is far from the Earth; thus, the apparent size of the Moon is smaller than that of the Sun, allowing the bright ring (annulus) to be visible. This eclipse happens only in antumbra region (the part of the Moon's shadow that extends beyond the umbra).

(iii) Partial solar eclipse occurs when the Sun and the Moon are not exactly in line and the Moon partially obscures the Sun (see **Figure 2c**). This eclipse happens only in the penumbra region (the weak or the pale part of the Moon's shadow).

During the solar eclipse, the following phases happen:

(i) The first contact. The edge of the Moon starts to overlap the edge of the Sun.

(ii) The second contact. Almost the entire disc of the Sun is covered by the Moon.

(iii) The maximum eclipse phase. For the total solar eclipse, the Moon completely covers the Sun's disc. For the annular and the partial solar eclipse, the distance between the center of the Moon's disc and the Sun's disc is minimum. In addition, in the total solar eclipse and the annular solar eclipse, this phase is known as totality and annularity, respectively.

(iv) The third contact. The Moon starts to move away from the Sun's disc. The maximum eclipse phase end.

(v) The fourth contact. The Moon's disc stops to overlap the Sun's disc. The solar eclipse ends.

The interval between the second and the third contacts is known as the length of maximum eclipse phase. For the partial solar eclipse, the second and the third contacts cannot be observed easily; hence, these phases sometimes are known as the **partial phase I** and **II**, respectively.

In addition, when solar eclipse phenomenon occurs, solar intensity, light spectrum, and UV irradiation are suddenly down,(Nishanth *et al*., 2011; Zerefos, *et al*., 2001) specifically just after the first contact.(Founda, *et al*., 2007; Zerefos, *et al*., 2001) Therefore, this condition disturbs some photochemical reactions both in atmosphere and in the ground.(Sharma, *et al*., 2010; Tzanis, *et al*., 2008; Bojkov, 1968; Nishanth, *et al*., 2011; Eastman & Stedmand, 1980;Hunt, 1965; Chudzyński, *et al*., 2001; Abram, *et al*., 2000).

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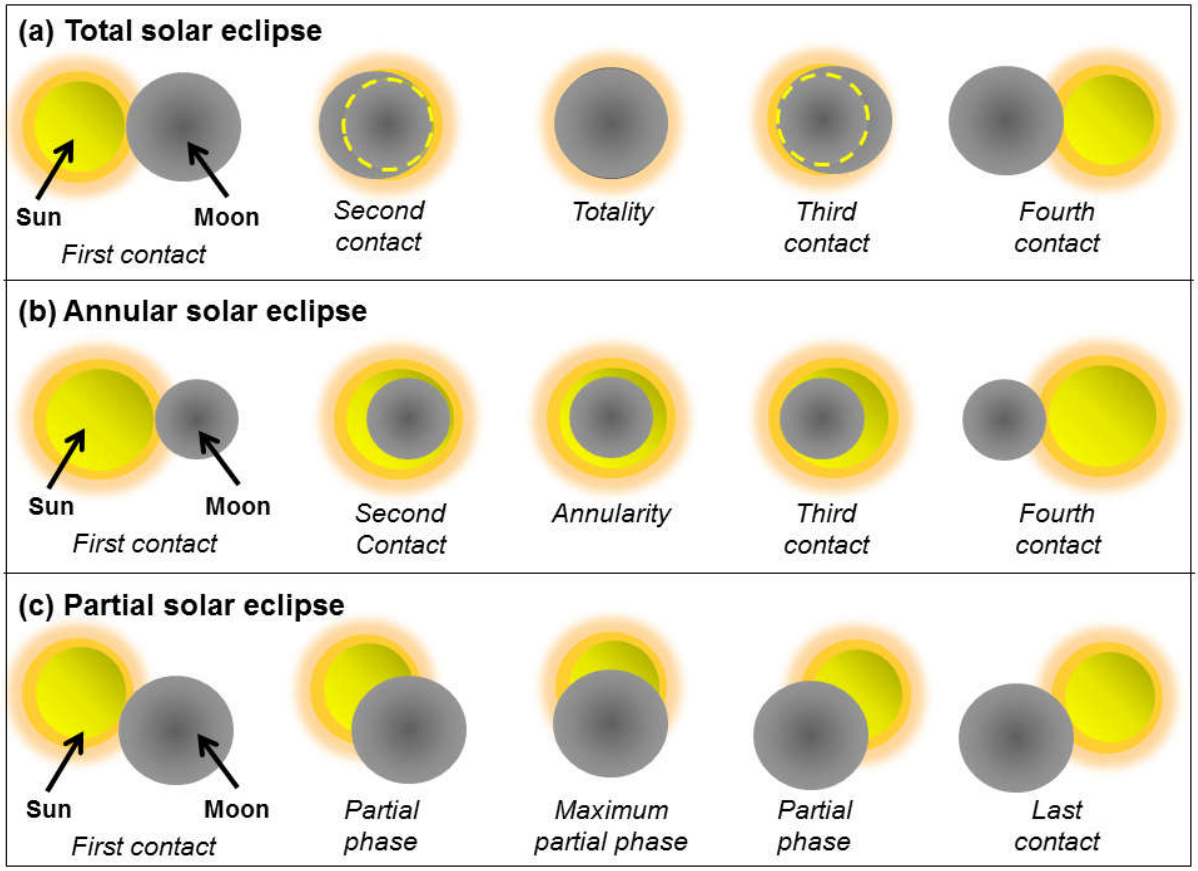

Figure 2. The illustration of phases in the solar eclipse phenomenon: (a) total solar eclipse, (b) annular solar eclipse, and (c) partial solar eclipse.

Indeed, when the photodecomposition process of organic material was conducted during the solar eclipse, the concentration of organic material was presumably constant. Then, when the solar eclipse ended, the photodecomposition would occur normally.

3. EXPERIMENTAL METHOD

3.1. Materials

The study was conducted using the following raw materials: curcumin and TiO_2 particles (anatase titanium dioxide; Bratachem Co., Indonesia). Curcumin was extracted from Turmeric (Curcuma longa L) collected from Bandung, Indonesia. The purchased TiO_2 was used without further purification.

To get the extracted curcumin, a piece of turmeric was washed and cut into small pieces (sizes of about 1 x 1 cm). The small pieces of turmeric were then dried at 70°C to remove the water content in the turmeric. Next, the dried sample was dissolved into the ethanol solution (95%) and heated at 50°C for 1 hour in the water bath. The heated solution was then filtered, and the filtrate was subsequently put into the rotary evaporator (at 90°C) to get curcumin gel.

3.2. Photodecomposition process

The photodecomposition of curcumin investigations was carried out at the experimental eld of the Universitas Pendidikan Indonesia (6.86340 SL,107.59430 EL) in Bandung, Indonesia (See **Figure 3**). The site was selected because Bandung was

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thorough the path of the solar eclipse (about 88.76%) on 9 March 2016.

In the experimental procedure for the photodecomposition process, curcumin and TiO_2 particles were dissolved in the aqueous solution and placed in the batch photoreactor. The mixed suspension was then illuminated by a solar light naturally. The reactor itself consisted of a batch-glass reactor (500 mL), a magnetic stirrer (800 rpm), and a bubbler. The reactor was also equipped with several sensors (i.e., a light sensor (lux meter; BH1750FVI, Rohm Co. Ltd., Japan), a voltage measurement analysis (DIY Mini Solar Cell; 3V, 0.42 Watt; sizes of 54 x 54 x 3 mm; Guangzhou Future Solar Technology Co. Ltd., China), and a thermocouple. During the photodecomposition process, 600 mL/min of air was bubbled into the reactor to keep the concentration of dissolved oxygen in the solution constant.

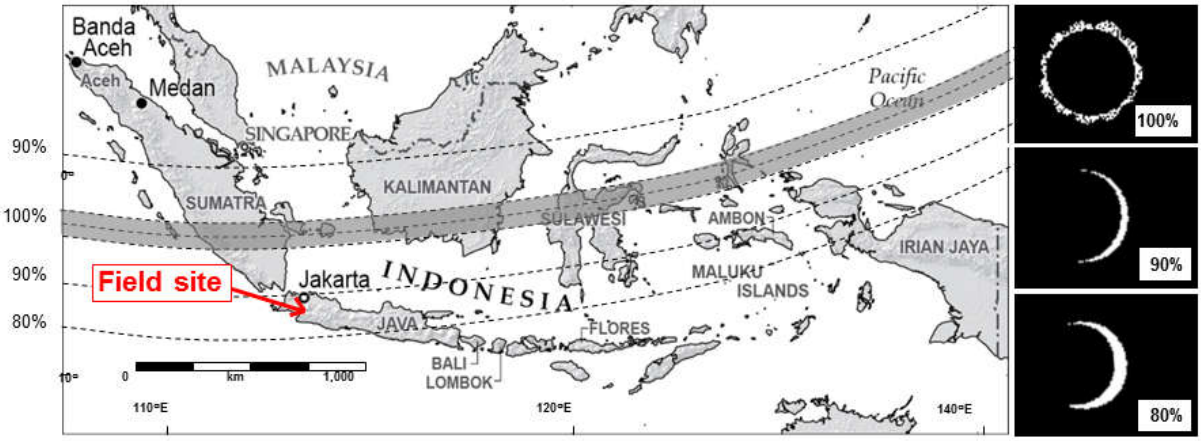

Figure 3. The path of the total solar eclipse over Indonesia on 9 March 2016. The field site was located at Universitas Pendidikan Indonesia, Bandung, about 550 km from the central axis of the eclipse totality, and experienced a 88,76 % eclipse at 07:21 local time (LT) (00:21 Universal Time (UT)). The insert figures in the right side are the illustration of solar eclipse at 100%, 90%, and 80% of coverage of Moon's disc to the Sun's disc. The map was adopted from http://asiapacific.anu.edu.au/mapsonline/base-maps/indonesia-relief , whereas the solar eclipse path was from http://eclipse.gsfc.nasa.gov/SEgoogle/SEgoogle2001/SE2016Mar09Tgoogle.html and Badan Meteorologi, Klimatologi, dan Geofisika (BMKG) Indonesia.

The concentrations of curcumin were 10 and 25 ppm, whereas the amounts of TiO_2 were 3 and 6 ppm. As a comparison, the experiment using curcumin solution only (without additional TiO_2) was also conducted. In this study, the photodecomposition process in the solar eclipse day (9 March 2016) and two sunny days (8 and 10 March 2016) was compared.

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3.3. Characterizations

To confirm the type of raw materials used in this study, several analyses were conducted, such as a Scanning Electron Microscope (SEM; JEOL JSM-6360 LA, JEOL Ltd., Japan), an X-Ray Diffraction (XRD; PANalytical X'Pert PRO PW3040/x0, PANalytical, the Netherlands), and a Fourier Transform Infra Red (FTIR; Prestige 21, Shimadzu Corp., Japan)).

To measure the concentration of curcumin over the photodecomposition process time, we approximated the concentration using a turbidity analysis based on the light penetration into the mixed suspension. The analysis was conducted in the batch photoreactor based on the light sensor and voltage measurement analysis that were integrated with the computer system to get information in the real-time measurement of concentration. A spectrophotometer (UV-Vis mini 1240, Shimadzu Corp., Japan) was also used to confirm the concentration of curcumin gained from the turbidity analysis in the real-time measurement.

To confirm the analysis of the photodecomposition process, measurement of the solar intensity was conducted using a lux meter (BH1750FVI, Rohm Co. Ltd., Japan) and an ultraviolet sensor (UV sensor; ML8511). To measure the solar irradiation precisely, all sensors to the computer were connected. Since the solar eclipse occurred in the morning, the sensors were oriented to be perpendicular to the ground to get the maximum absorption of solar light.

In addition, the Langmuir–Hinshelwood kinetic model was used to calculate the photodecomposition rate that involves solid–solute photochemical reactions. Based on this model, the photodecomposition rate can be written as

$$-\frac{dC}{dt} = \frac{k_1.k_2.C}{1+k_2.C} \qquad (1)$$

where *C* and *t* are the concentration and the photoreaction time, respectively. k_1 and k_2 are the apparent reaction rate constant and the apparent equilibrium constant for adsorption of the chemical on the catalyst surface, respectively.(Nandiyanto, *et al*., 2009) Since the concentration of curcumin used in this study was very low (less than 100 ppm), the **Equation (1)** can be re-expressed as a first-order rate constant, as follows:

$$-\frac{dC}{dt} = k.C \qquad (2)$$

where *k* is the reaction rate constant. Then, the photodecomposition rate (as *k* value) was obtained by solving the differential problem in the **Equation (2)**.

4. RESULTS AND DISCUSSION

4.1. Physicochemical properties of extracted curcumin and commercial TiO_2

Figure 4 shows the FTIR results of TiO_2 particles, dried turmeric, and curcumin (obtained from the isolation of turmeric). The result showed that the peaks of dried turmeric and curcumin are almost similar. A broad peak at about 3404 cm^{-1} indicates the presence of OH. Characteristics peaks of curcumin were identified, located at 3404, 1625, and 1512 cm^{-1}.(Kumavat, 2013)

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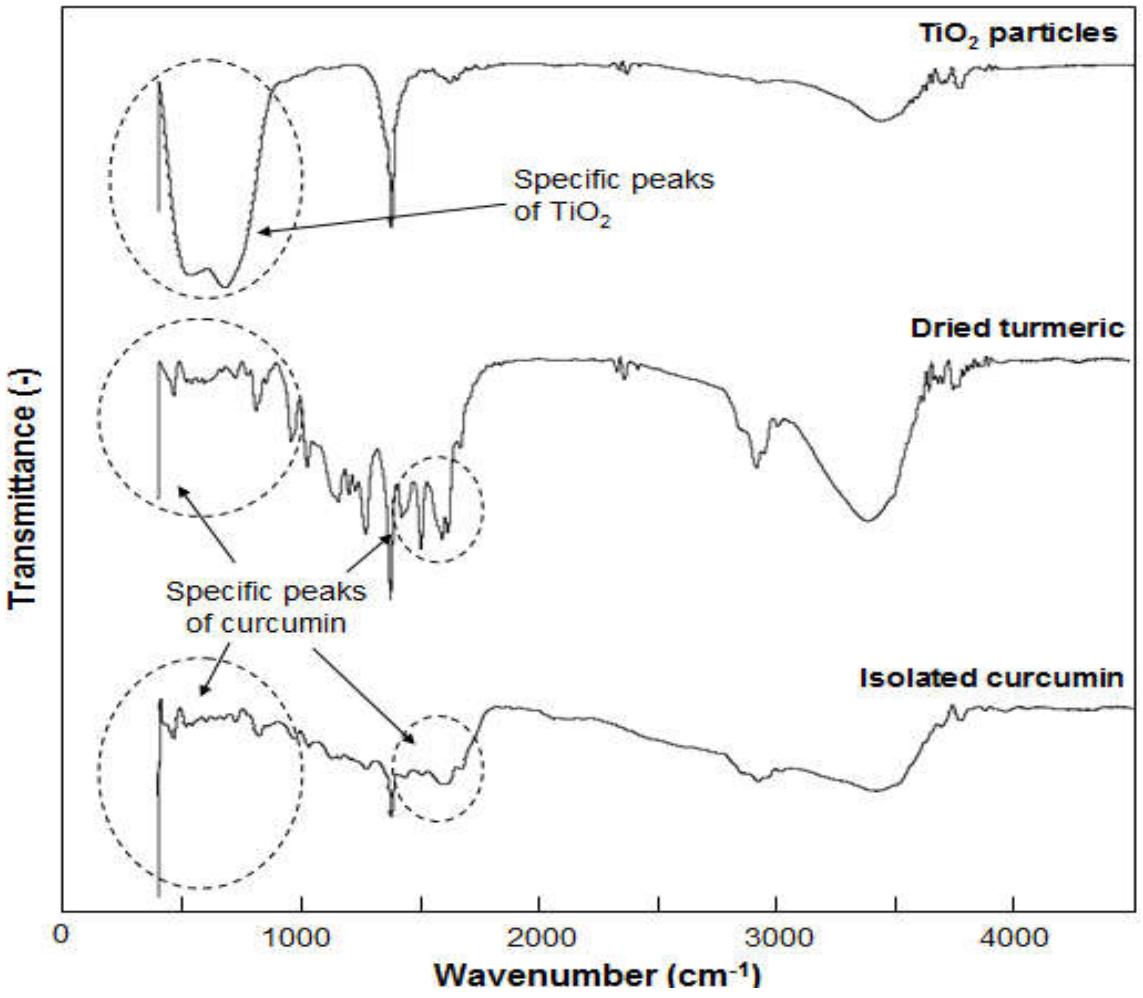

Figure 4. FTIR analysis results of TiO_2 particles, dried turmeric, and isolated curcumin.

Regarding the TiO_2 sample, several peaks at about 3448, 1382, 680, and 543 cm^{-1} were detected in the FTIR analysis. Peaks at 3448 and 1382 cm^{-1} related to stretching hydroxyl (O-H) and O-H bending. The other peaks at 680 and 543 cm^{-1} was assigned to the Ti-O stretching bands. Although those peaks are a typical pattern of anatase, the detection of peaks can not be used directly to clarify the structure of material. Therefore, additional analyses (e.g., XRD) are required.

Figure 5a depicts the SEM images of TiO_2 particles used in this study. The Ferret analysis indicated that the mean size of TiO_2 particles was about 28 micrometers. **Figure 5b** shows the XRD analysis of TiO_2 particles. The detection of diffraction peaks at 2θ of 25.30; 37.78; 47.88; 54.50; and 63.32° replied to the crystallographic structure of anatase phase (based on JCPDS No. 84-1286).(Nandiyanto, *et al*., 2009) No other phase was detected in the pattern, confirming that the sample was pure anatase.

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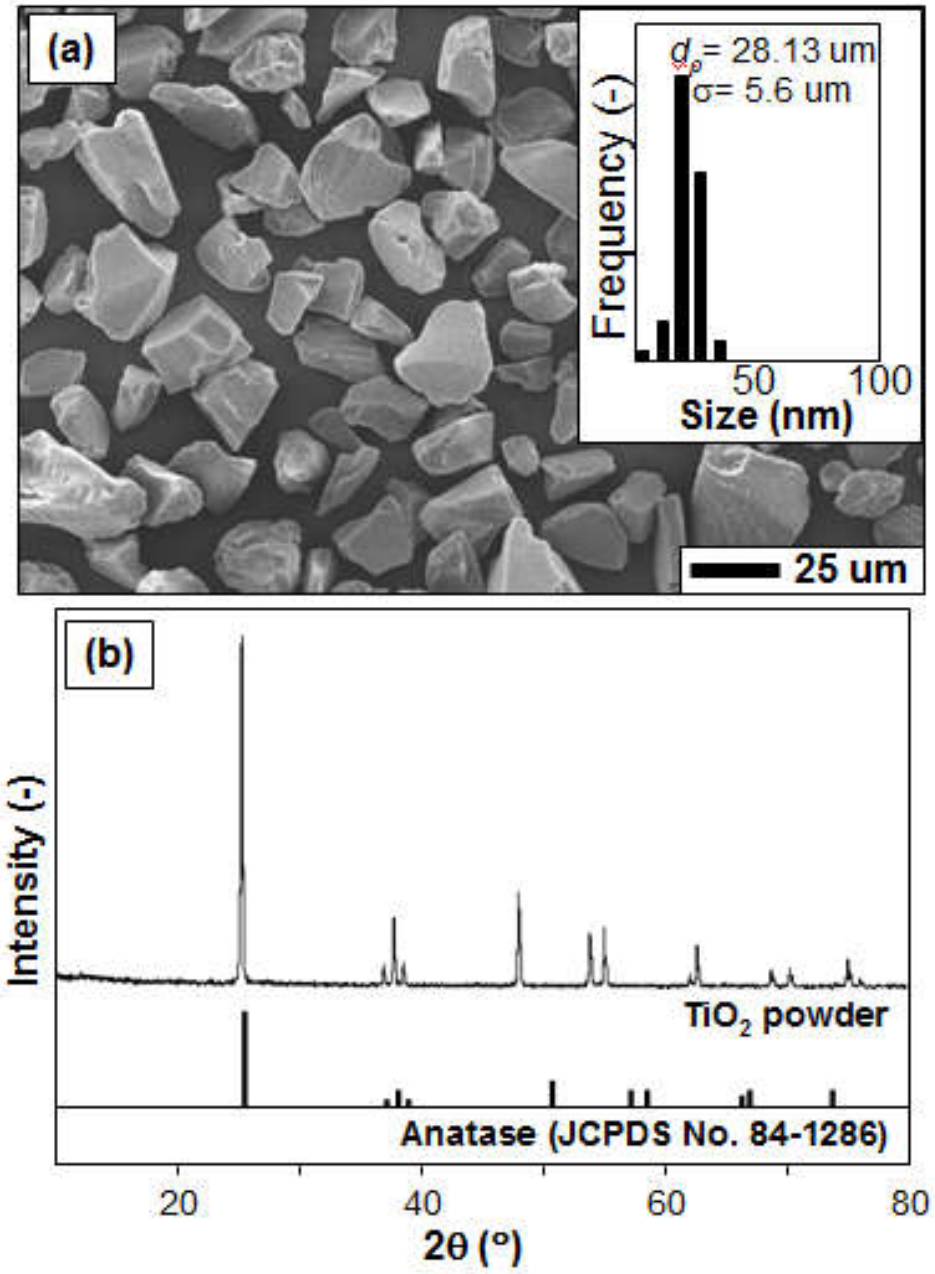

Figure 5. SEM image (a) and XRD analysis result (b) of TiO_2 particles

4.2. SOLAR RADIATION DURING THE SOLAR ECLIPSE

The photograph images of the Sun during the solar eclipse phenomenon are depicted in **Figure 6**. The day of the eclipse was characterized by mostly clear skies, with some light cloud in the beginning of the solar eclipse, slight westerly winds, and comparatively low pollution. The photograph images of Sun were taken at 06:20; 06:46; 07:08; 07:18; 07:21; 07:37; 08:00; and 08:32 LT, corresponding to **Figures 6a-h**, respectively. An illustration image attached in each photograph image was added to make clearer discussion about the partial solar eclipse phenomenon.

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The first contact occurred at 06:21 LT as depicted in **Figure 6a**. However, since the sky was cloudy, the first contact could not be observed clearly. The first contact occurred when the edge of the Moon started to overlap the edge of the Sun. This contact indicated the beginning of solar eclipse. Then, the significant reduction of the solar radiation was observed just after the first contact(Founda, *et al*., 2007). The Moon obscured a few part of the Sun's disc, indicating the occurrence of partial phase (**Figures 6b-d**). The Sun could be clearly observed as the clouds moved away from it. This partial phase continuously occurred until the distance between the center of the Moon's disc and the Sun's disc was minimum (**Figure 6e**). As the Moon blocked the Sun, the sky turned gray. Since Bandung experienced the maximum Sun's obscuration about 88.76% at 07:21 LT (00:21 UT) for about two minutes, the Sun was observed to be red and crescent shape by the camera. The ending of the maximum phase was indicated when the Moon's disc moved away from the Sun, and the Sun reappeared (**Figures 6f-g**). At 08:32 LT (**Figure 6h**), the Moon stopped overlapping the Sun's disc and the daylight returned. This step was known as the fourth contact, indicating the ending of solar eclipse.

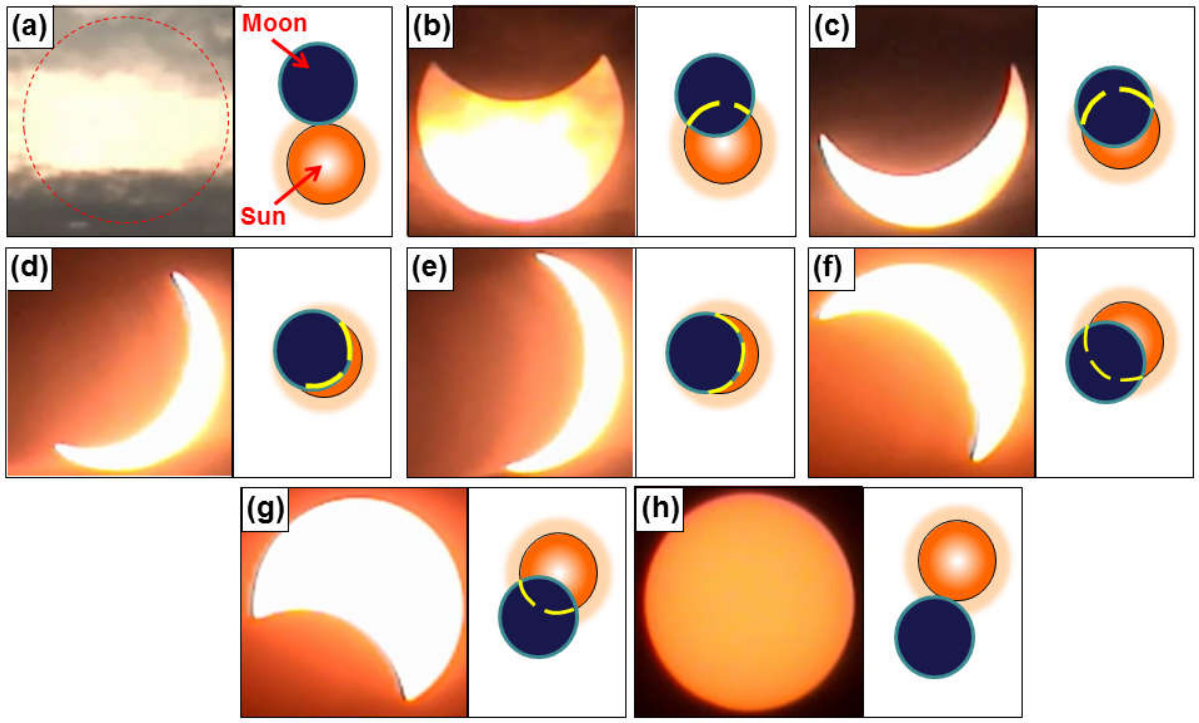

Figure 6. Photograph images of the Sun during the partial solar eclipse with illustration model. The pictures were taken in the specific local time: (a) 06:20; (b) 06:46; (c) 07:08; (d) 07:18; (e) 07:21; (f) 07:37; (g) 08:00; and (h) 08:32 LT.

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Figure 7 shows a plot of the solar radiation intensity during three sunny days (from 8 to 10 March 2016) between near to sunrise (06:00 LT) and morning (09:00 LT). The results showed that the intensity of the solar radiation increased along with the increasing time from sunrise to morning. The results were in a good agreement with the Kimball result that the midday has richer luminous radiation than the morning. (Kimball, 1924)

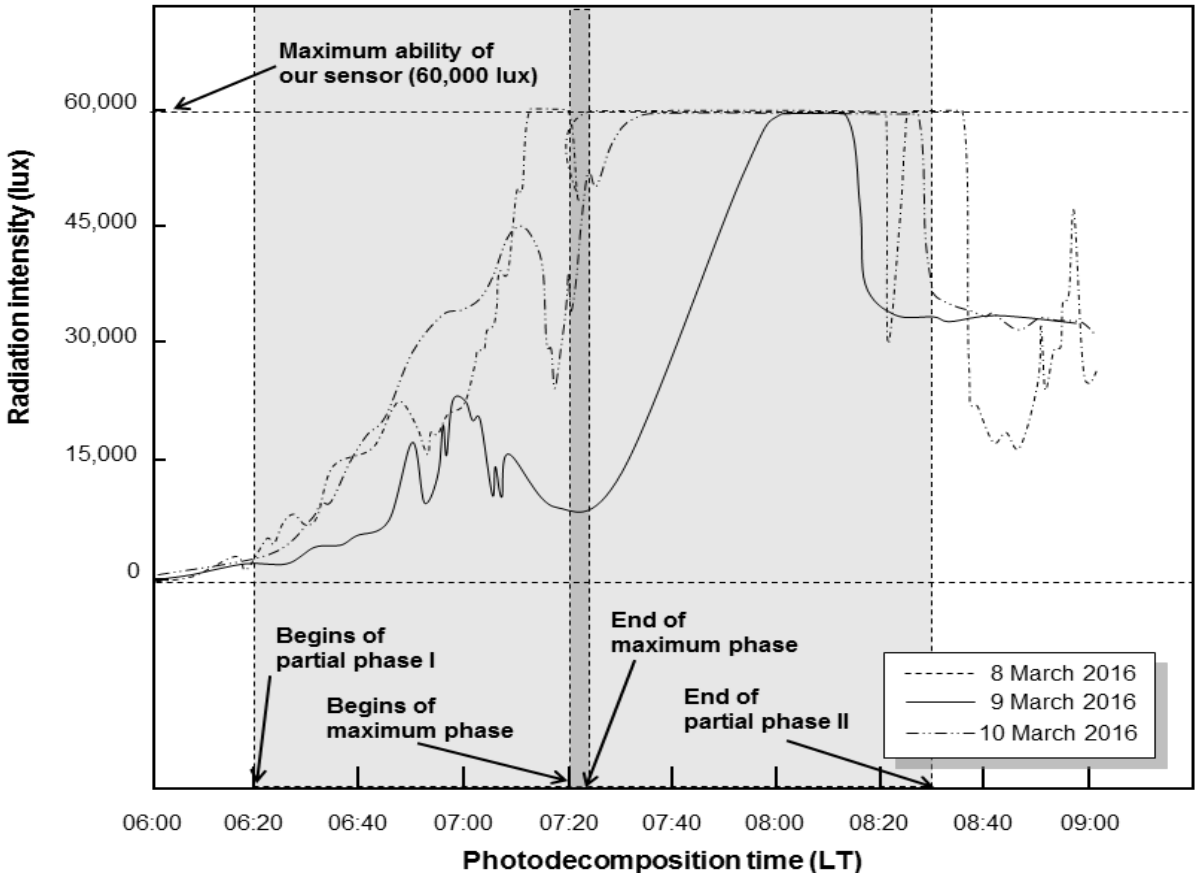

Figure 7. Solar radiation intensities over time during the solar eclipse and two sunny days

The intensity of solar radiation during the solar eclipse (9 March) was identified to be lower than that during two sunny days (8 and 10 March). The intensities in both two sunny days were from about 300 to 45,000 lux with the rate of increasing solar intensity was about 1,200 lux/min. The rate of increasing solar intensity during the solar eclipse depends on the phases. Before the partial phase I (06:00-06:20 LT), the rate was similar to that in the sunny days. The rate during the partial phase I (06:20-07:21 LT) was about 75 lux/min. Then, in the maximum eclipse phase (07:21-07:23 LT), the rate was almost zero. Finally, in the partial phase II (07:23-08:32 LT), the rate was about 1,430 lux/min.

The decreases in the radiation intensity in the partial phase I were due to the increases in the blockage area of the Sun by the Moon's disc. Then, in the maximum phase, the rate was almost zero because the blockage of Moon disc reached the maximum. The intensity in the maximum phase was about 10,000 lux, whereas the intensity of sunny day was more than

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60,000 lux with regard to the minor differences of measurement conditions in two consecutive sunny days in 8 and 10 March 2016. Approximating the ratio of intensities, we found that the intensity in the maximum eclipse phase was at least 16% of the intensity of solar radiation in the sunny time. During the eclipse, part of the Sun's disc was covered by the Moon, leading the reduction of solar radiation intensity(Koepke, *et al*., 2001). The result was in a good correlation to the shinning area of the Sun's disc that was about 12% (the coverage area of the Sun's disc by the Moon in Bandung was about 88.76%; see **Figure 6e**). The decrease in solar intensity during the eclipse has been mentioned in the current literatures (Libra, 2016;Koepke, 2001) When the partial phase II started, the rate increased rapidly (rate = 1,430 lux/min), confirming the appearance of the Sun to reach normal. In addition, the intensities after 08:20 in all samples fluctuated between 30,000 and 60,000 mV due to the hysteresis and the limitation of our lux sensors.

A plot of the UV radiation during the three sunny days between near to sunrise and morning is shown in **Figure 8**. The results showed that the intensity of UV radiation increased along with the increasing time from sunrise to morning.

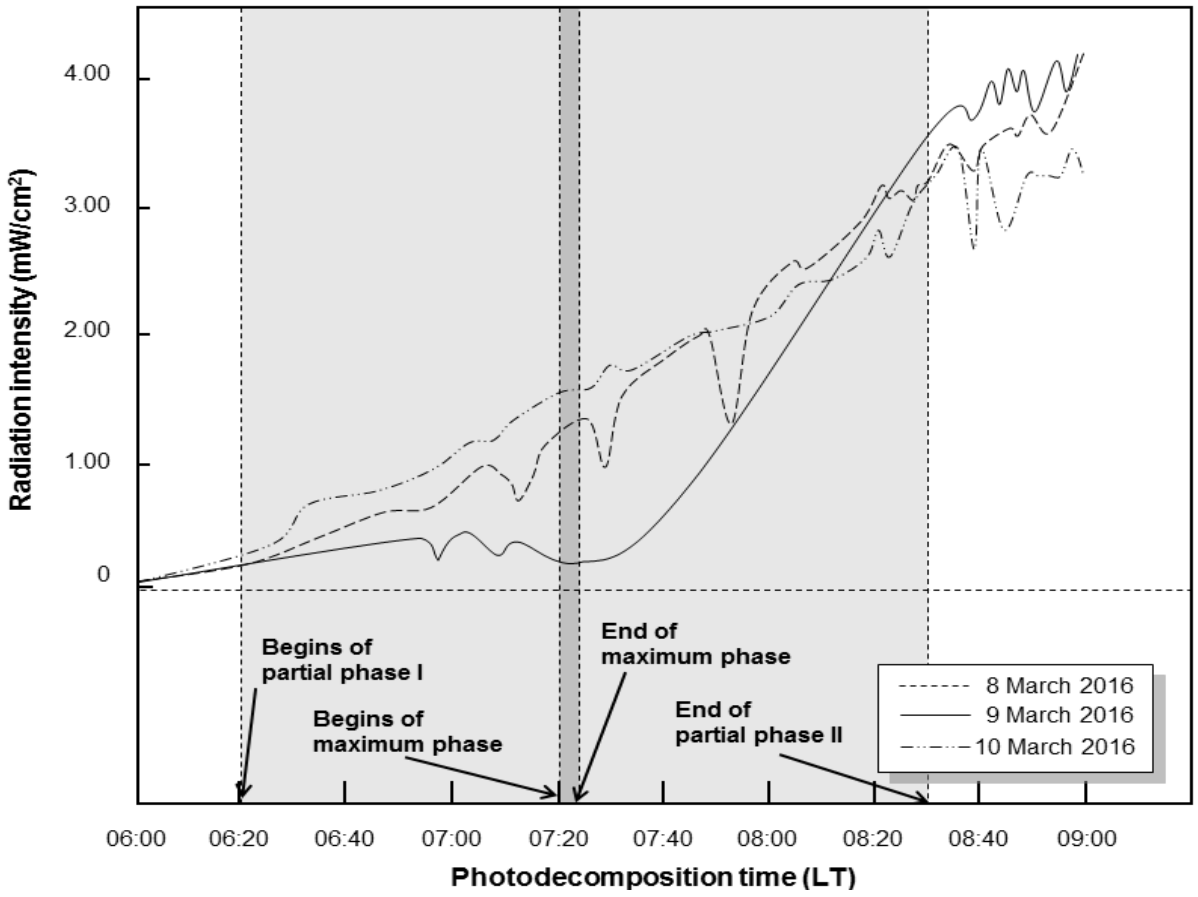

Figure 8. The profile of UV radiation over time during the solar eclipse day and two sunny days.

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For the two sunny days, the intensity increased with the increasing rate of 0.02 mW/cm^2.min. However, the intensity of UV radiation during the solar eclipse was identified to be lower than that during two sunny days. Prior to the partial phase I, the increasing rate was similar to that during two sunny days. In the partial phase I from 06:20 to 07:00 LT, the intensity of UV radiation increased (increasing rate of about 0.006 mW/cm^2.min). Then, the intensity decreased when reaching the maximum phase. The UV intensity did not reach zero because Bandung experienced the partial solar eclipse. Thus, Sun still provides light during the maximum phase. Finally, when the maximum phase passed, the intensity drastically increased (increasing rate in the partial phase II of about 0.05 mW/cm^2.min). The present result in the profile of UV radiation was in a good agreement with the current literatures.(Zerefos, *et al*., 2001; Koepke, *et al*., 2001)

4.3. Photodecomposition of curcumin under TiO_2 powder during the solar eclipse and sunny days

The UV-vis spectra of 25-ppm curcumin solutions photodecomposed by TiO_2 particles during the partial solar eclipse is depicted in **Figure 9**. The insert figures are the photograph image of curcumin solution during the solar eclipse, respectively. **Figures 9a** and **b** are the curcumin solutions with 6 and 3 ppm of TiO_2 particles, respectively.

Curcumin concentrations during the experiments were determined based on the Beer Law(Arutanti, *et al*., 2014; Arutanti, *et al*., 2015; Nandiyanto, *et al*., 2009; Nandiyanto, 2013) at the absorbance of 425 nm wavelength light. At the initial condition (at 06:00 LT), curcumin solution spectra had a maximum absorption at a wavelength of around 425 nm, confirming the yellow color. The absorbance at all wavelengths decreased over the time, which was due to the degradation of curcumin during the partial solar eclipse.(dos Santos, *et al*., 2014) The decreases in absorbance of curcumin solution over time during the solar eclipse were in a good agreement with the change of color by a visual observation (displayed in the insert figures in **Figures 7a and b**), in which the color of solution became brighter.

In the case of sample containing 6 ppm of TiO_2 (**Figure 7a**), the absorbance decreased down to about 60% at 06:20 LT. Further decreases in the absorbance were found at 07:21 LT (in the beginning of maximum solar eclipse) and 09:00 LT (in the end of experiment), in which the absorbances were about 40 and 20%, respectively. Regarding the sample containing 3 ppm of TiO_2 (**Figure 7b**), the absorbance decreased down to about 75% at 06:20 LT and 55% at 09:00 LT. Based on the results, the final absorbance of sample containing 6 ppm of TiO_2 was lower than that containing 3 ppm of TiO_2. The result confirms that the TiO_2 plays a role in the photodecomposition process.

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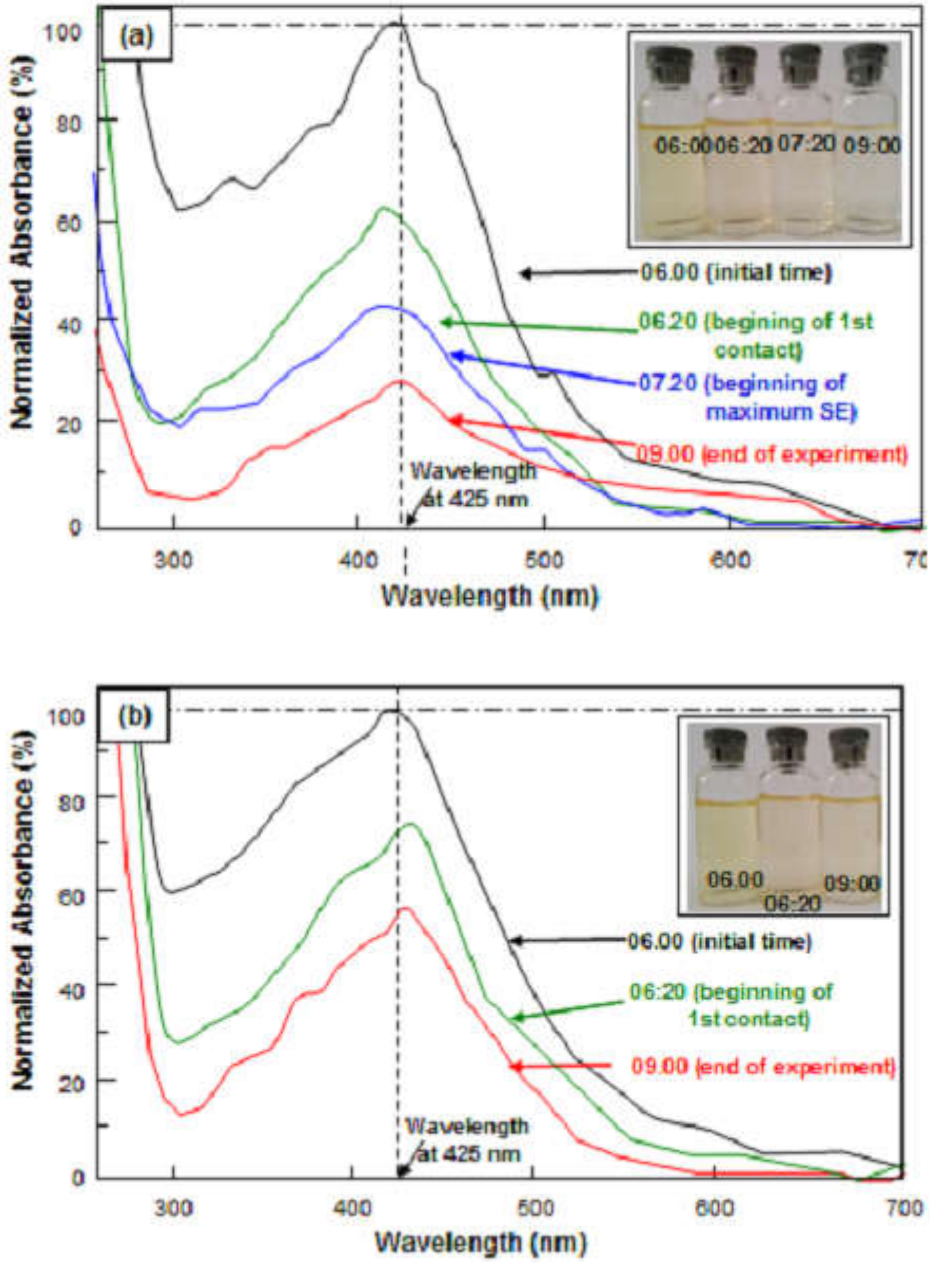

Figure 9. UV-vis spectra analysis results of samples containing 25-ppm curcumin with TiO_2 catalyst during the partial solar eclipse. Figures (a) and (b) are the samples with 6 and 3 ppm of TiO_2 particles, respectively.

4.3.1. Effect of solar eclipse

When suspension containing curcumin and TiO_2 was irradiated by natural sunlight, changes in physical appearances (i.e., degradation of color) were observed in all variations. The experiments conducted in both two sunny days (8 and 10 March 2016) resulted in the degradation of color from clear amber to transparent color. Then, in the solar eclipse day, the color changed from clear amber to light yellow. The different changes in color confirmed that the photodecomposition rates of solar eclipse and two sunny days were different.

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Figure 10 presents the effect of solar eclipse on the photodecomposition of curcumin with various curcumin concentrations and TiO_2 amounts. **Figures 10a** and **b** are the profile of photodecomposition of 25-ppm curcumin, whereas **Figures 10c** and **d** are the profile when using 10 ppm of curcumin. **Figures 10a** and **c** are the profile of the process using 6 ppm of TiO_2, whereas **Figures 10b** and **d** are the process using 3 ppm of TiO_2.

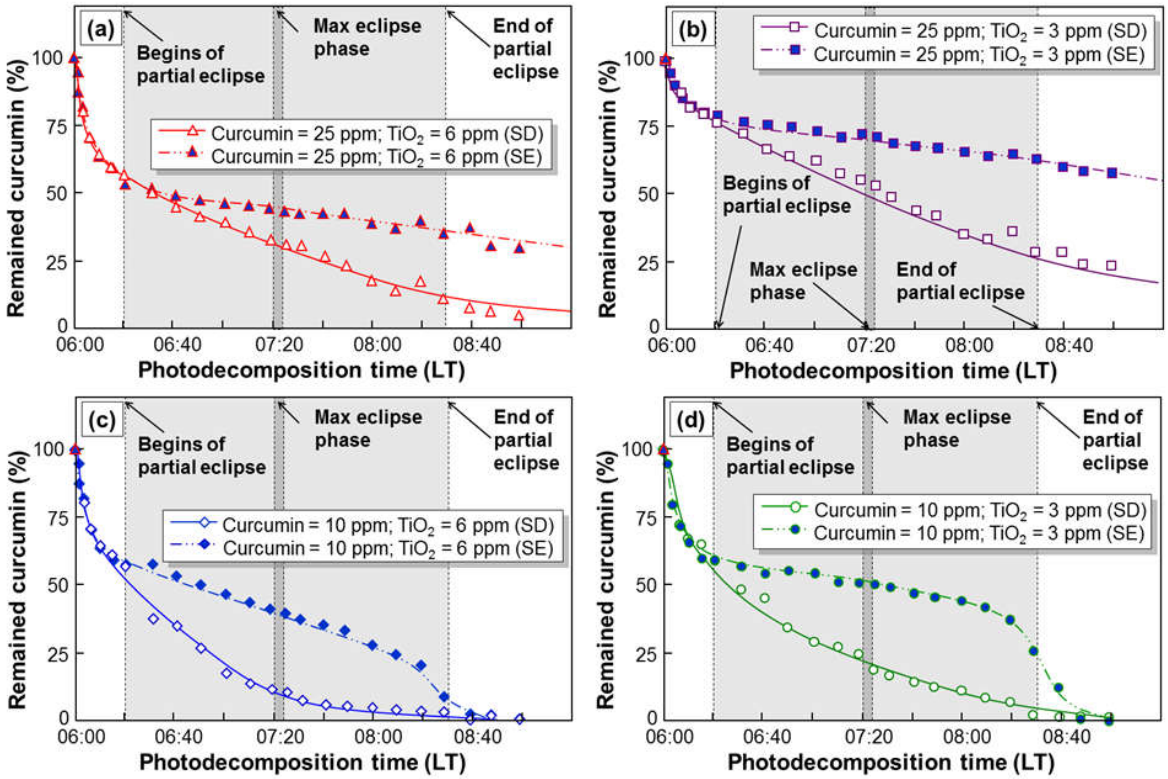

Figure 10. Effect of solar eclipse condition on the photodecomposition of curcumin. Figures (a) and (b) are the samples using 25 ppm of curcumin, whereas Figures (c) and (d) are using 10 ppm of curcumin. Figures (a) and (b) are the samples using 6 ppm of TiO_2, whereas Figures (b) and (d) are using 3 ppm of TiO_2. SE and SD are the samples for solar eclipse and sunny day, respectively.

The experimental results showed that the concentration of curcumin decreased along with the photodecomposition time from sunrise to morning for all variations. Then, the changes in the experimental condition allowed to the obtainment of different photodecomposition profiles.

In all variations in **Figure 10**, the experiments performed in the solar eclipse day (showed as dashed line) had a lower photodecomposition rate than that in the sunny days (showed as solid line), confirmed by the higher final concentration (*C*/*Co*). The fundamental reason for the lower photodecomposition rate in the solar eclipse day is because the solar eclipse phenomenon provides the decreases in the solar radiation and UV intensity (verified in **Figures 7** and **8**). Light intensity is a major factor in the photocatalytic reactions because electron–hole pairs are produced only by the light. As the consequence, the decrease in light intensity would disturb the photodecomposition process.(Abram, *et al*., 2000)

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To confirm the effect of the solar eclipse condition on the photodecomposition of curcumin, the rates for the photo-decomposition process of 25 ppm of curcumin were calculated based on five phases in the solar eclipse (see **Table 1**): (i) before the solar eclipse (at 06:00-06:20 LT), (ii) the partial phase I (at 06:20-07:21 LT), (iii) the maximum phase (at 07:21-07:23 LT); (iv) the partial phase II (at 07:23-08:32 LT), and (v) after the solar eclipse (at 08:32-09:00 LT). As shown in this table, the rate of photodecomposition during the solar eclipse was slower compared with that in the sunny day.

Before solar eclipse, the rate of photocatalysis in the solar eclipse day was identical to that in the sunny day, indicated by the identical *k* values for samples conducted in solar eclipse and sunny day. The identical light intensities (as shown in **Figures 7** and **8**) in this phase were the main reason for the same photochemical reaction rates in all samples.

In the partial phase I, the rate constant of photodecomposition in the solar eclipse day obtained was slower than that in sunny days. For the case of samples using 25 ppm of curcumin and 6 ppm of TiO_2, conducting the photodecomposition process in the solar eclipse and the sunny days resulted in the *k* values of 1.47 10^{-2} and 1.74 10^{-2} min^{-1}, respectively. The fundamental reason is due to the decreases in solar intensity that affects the intensity of UV radiation.

In the maximum eclipse phase, the rate constant of photodecomposition of 25 ppm of curcumin with 6 ppm of TiO_2 in the solar eclipse reached was 0.97 10^{-2} min^{-1}. The different concentrations of samples before and after the maximum phase were about 1%. In this phase, the rate did not reach to zero because the experimental site (Bandung) experienced the partial solar eclipse event. Therefore, the Sun still provides solar light for the photodecomposition process.

Next, the partial phase II had similar trends to the partial phase I and the maximum phase, where the photodecomposition rates of samples conducted in the solar eclipse day were lower than that in the sunny days. Finally, after the solar eclipse, the rates were still lower. This was due to the limitation of photodecomposition process time (conducting from 08:32 to 09:00 LC).

Tabel 1. The rate of photodecomposition of 25-ppm curcumin under various conditions

Sample*	Final concentration at 9:00 LT (%)	*k* value (min^{-1})				
		Before SE* (06:00 – 06:21 LT)	Partial phase I (06:20 – 07:21 LT)	Maximum phase (07:21 – 07:23 LT)	Partial phase II (07:23 – 08:32 LT)	After SE* (08:32 – 09:00 LT)
Curcumin only	95	0.21×10^{-2}	0.06×10^{-2}	0.04×10^{-2}	0.04×10^{-2}	0.03×10^{-2}
TiO_2 = 6 ppm (SD)	6	4.60×10^{-2}	1.74×10^{-2}	1.45×10^{-2}	1.39×10^{-2}	1.57×10^{-2}
TiO_2 = 6 ppm (SE)	30	4.61×10^{-2}	1.47×10^{-2}	0.97×10^{-2}	0.87×10^{-2}	0.69×10^{-2}
TiO_2 = 3 ppm (SD)	23	2.15×10^{-2}	0.84×10^{-2}	0.72×10^{-2}	0.80×10^{-2}	0.81×10^{-2}
TiO_2 = 3 ppm (SE)	60	2.19×10^{-2}	0.58×10^{-2}	0.40×10^{-2}	0.35×10^{-2}	0.29×10^{-2}

Note: *SE is the experiment provided in solar eclipse, and SD is experiment conducted in sunny day

4.3.2. Effect of photocatalyst amount

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The profile of photodecomposition of curcumin using various catalyst amounts (i.e., 0, 3, and 6 ppm of TiO_2) is shown in **Figure 11**. The reaction was performed from near sunrise (06:00 LT) to morning (09:00 LT), which was an ample time for comparing the effect of catalyst amount on the photodecomposition rate. To confirm the effect of catalyst amount, the figure based on the constant curcumin concentration was classified. The profile of photodecomposition process using 25 ppm of curcumin is depicted in **Figures 11a** and **c**, and that using 10 ppm of curcumin is in **Figures 11b** and **d**. In addition, to confirm that catalyst has an impact on the photodecomposition in all process conditions, the catalyst amounts were varied in the experiments conducted in the sunny day (**Figures 11(a-b))** and the solar eclipse day (**Figures 11 (c-d)).**

The results showed that the concentration of curcumin decreased along with the photodecomposition time from sunrise to morning, and the photodecomposition rate increased as the increases in the amount of TiO_2. In contrast, the photodecomposition rate was the lowest for all cases in the absence of the TiO_2.

The photodecomposition rate is strongly influenced by the number of active sites and the photoabsorption ability of the catalyst (Sakthivel, *et al.*, 2003). The increase in number of active sites available would have a positive impact to the increasing photocatalytic activity and efficiency. This was confirmed by the fact that the absence of the TiO_2 resulted in the obtainment of the lowest photodecomposition rate in both solar eclipse and sunny day cases. In general, the higher amount of TiO_2 catalyst resulted in more effective photocatalytic process than that using lower concentration of TiO_2. This corroborates the hypothesis of other studies.(Zhu, *et al.*, 2014; Sobana & Swaminathan 2007; Mills, 1993) In addition, although the concentration of curcumin decreases, the required processing time for decomposing curcumin takes longer compared to previous study. It occurs due to the use of less concentration of catalyst.

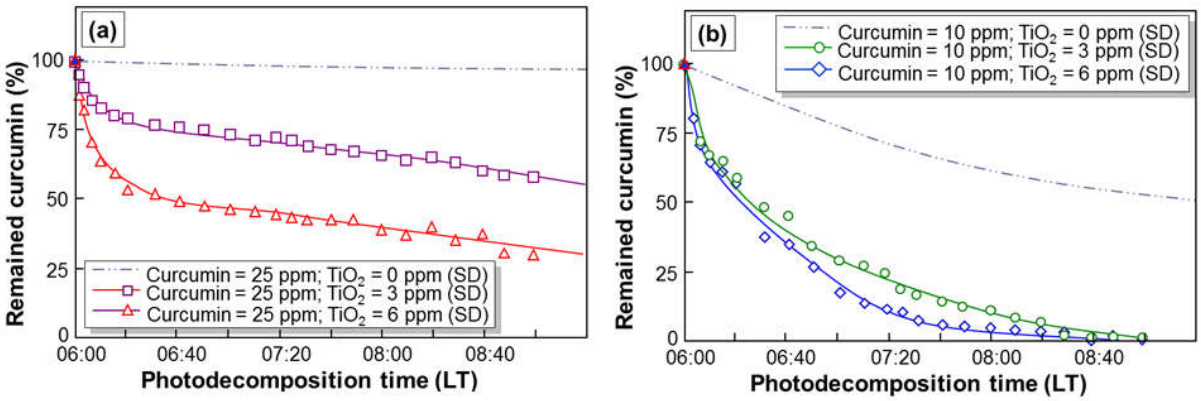

Figure 11.(a-b) Effect of TiO_2 amount on the photodecomposition of curcumin. Figures (a) and (c) are the samples using 25 ppm of curcumin, whereas Figures (b) and (d) are using 10 ppm of curcumin. Figures (a) and (b) are the process conducted in the sunny day.

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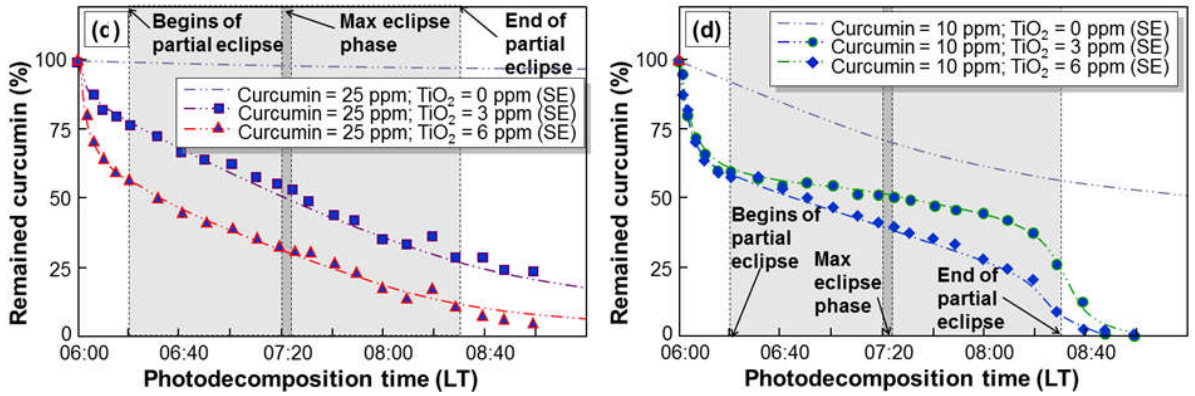

Figure 11(c-d). Effect of TiO_2 amount on the photodecomposition of curcumin. Figures (a) and (c) are the samples using 25 ppm of curcumin, whereas Figures (b) and (d) are using 10 ppm of curcumin. Figures (c) and (d) are that performed in the solar eclipse day. SE and SD are the samples for solar eclipse and sunny day, respectively.

4.3.3. Effect of initial organic material concentration

Figure 12 presents the effect of initial concentration of curcumin (i.e., 10 and 25 ppm) on the photodecomposition rate during the sunny day (from near to sunrise (06:00 LT) to morning (09:00 LT)). The profile of photodecomposition process using 6 ppm of TiO_2 is shown in **Figures 12a** and **c,** whereas that of the process using 3 ppm of TiO_2 is shown in **Figures 12b** and **d**. The comparison of the process in the sunny day and the solar eclipse day is shown in **Figures 12 (a-b)** and **(c-d)**, respectively. The result showed that the concentration of curcumin decreased along with the photodecomposition time from sunrise to morning.

As shown in **Figures 12a** and **b**, at the constant TiO_2 amount, the photodecomposition rate depended on the initial curcumin concentration. The lower concentration of curcumin led to the obtainment of faster photodecomposition process.

The photodecomposition of curcumin during the partial solar eclipse (shown in **Figures 12c** and **d)** yielded some unique phenomena. Although the curcumin concentration varied, the decomposition profile during the solar eclipse (specifically from 06:20 to 07:23 LT) was almost similar. Also, the concentration of curcumin was almost unchanging during the eclipse. It started to decrease drastically after the passing the solar eclipse (after 08:32). The results confirmed that the solar eclipse phenomenon had higher impact to the photodecomposition process than the initial concentration of curcumin. In addition to this factor, the effect of curcumin concentration on the photodecomposition rate was obtained. The use of lower concentration of curcumin had faster photodecomposition process than that of higher concentration.

When high concentration of organic molecules (i.e., curcumin) is used, more organic molecules absorb on the surface of catalyst. The amount of absorbed organic molecule is thought to have an inhibitive effect. Further, high concentration of organic molecules may absorb a significant amount of solar light (photon).(Mills, *et al*., 1993) Thus, the less number of photons are available to reach the catalyst surface, making fewer catalyst areas be activated by

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solar light and less OH radicals be formed.(Byrappa, *et al*., 2006) Therefore, increases in the concentration have a negative impact to the photodegradation rate.(dos Santos, *et al*., 2014; Zhu, *et al*., 2014; Sobana, *et al*., 2007; Mills, *et al*., 1993; Byrappa, *et al*., 2006).

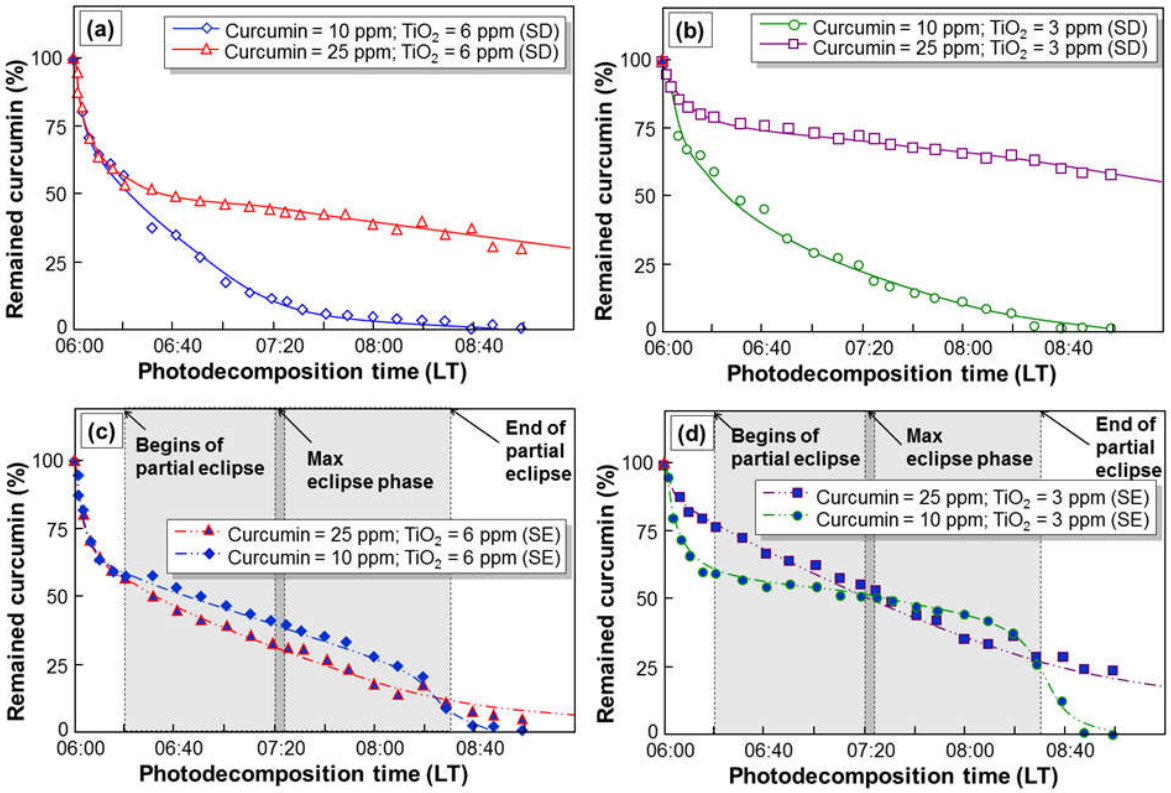

Figure 12. Effect of initial curcumin concentration on the photodecomposition of curcumin. Figures (a) and (c) are the samples using 6 ppm of TiO_2, whereas Figures (b) and (d) are using 3 ppm of TiO_2. Figures (a) and (b) are the process conducted in the sunny day, whereas Figures (c) and (d) are that performed in the solar eclipse day. SE and SD are the samples for solar eclipse and sunny day, respectively.

5. CONCLUSION

This study investigated the behavior of photodecomposition of organic material during the partial (88.76%) solar eclipse phenomenon of 9 March 2016 in Bandung, Indonesia. In the experiments, curcumin and anatase titanium dioxide particles were used as models of organic material and photocatalyst, respectively. These materials were dissolved in water, mixed, and placed into the reactor that was integrated to the computer system to get a real-time concentration analysis. The results showed that the solar eclipse provides a change in the solar light intensity. Indeed, the intensity disturbed the photodecomposition process. To confirm the influence of solar eclipse phenomenon on the photodecomposition process, curcumin concentration and the amount of catalyst were also varied.

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7. AUTHORS' NOTE

The author(s) declare(s) that there is no conflict of interest regarding the publication of this article. Authors confirmed that the data and the paper are free of plagiarism.

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