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TEMPERATURE ON THE EFFECTIVENESS OF ARDUINO-BASED PORTABLE SPECTROPHOTOMETER WITH WHITE LIGHT-EMITTING DIODE (LED) AS A LIGHT SOURCE FOR ANALYZING SOLUTION CONCENTRATION

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Abstract

The aim of this study was to evaluate the effects of temperature on the measuring ability of Arduino-based portable spectrophotometer in analysing solution concentration. In the experimental procedure, curcumin solution (as a model of dye) was put into the present spectrophotometer instrument consisting of a single white Light-Emmiting-Diode (LED) as a light source, a light sensor, a thermometer, a heater, and arduino electronic card as an acquisition system. The temperature of the curcumin solution was varied from 20 to 50 °C, which is an ample variation for understanding the effect of temperature on the measurement analysis in the spectrophotometer. The results showed that portable spectrophotometers were effective as a concentration analyser due to its successfulness in measuring and distinguishing different concentrations in the sample. When there is a change in the temperature, analysis measurement showed the ability in this apparatus to distinguish different analyses. Analysis result for samples that heated with higher temperature still can be accepted. However, when higher temperature is used, solution has less fluid density and the possibility for the decomposition of material must be concerned.

Keywords: Arduino, Concentration, Spectrophotometer, Temperature, Turmeric.

1. Introduction

Spectrophotometer is one of the tools that can be used in many purposes [1]. One of the potential applications from the spectrophotometer is for analysing concentration in the sample. Many reports have shown the ability of spectrophotometer. Albert et al., [2] reported the use of spectrophotometer for analysing blue bromothymol. Other studies utilised this apparatus system for determining iron in river water samples [3] and even chromate in drinking water [4].

Although the spectrophotometer is highly used for many applications, the use of this apparatus met problems for being used in developing countries, especially for the availability of standard UV-Visible spectrophotometer that can be classified as a sophisticated apparatus due to its high price [1]. To address these limitations, many researchers have tried to find out the problem solvers [1, 2].

However, the current available reports showed the potential design of cost-effective spectrophotometer without consideration of the environmental condition during the analysis. One of the most important environmental conditions that must be concerned is temperature. Myers et al. [5] explained that temperature is a quantity value that relates to the process for giving heat or cold to the material. Temperature can affect the properties of substances and devices [6-8].

Here, the purpose of this study was to evaluate the effect of temperature on the effectiveness of spectrophotometer for analysing solution concentration. As a model of spectrophotometer, we used Arduino-based portable spectrophotometer, which was design in our previous studies [1]. This type of spectrophotometer was selected because of its simplicity, portability that can be used regardless place and time, cost-effective design that is fit for developing countries, and effectiveness for being used in analysing solution concentration.

In short of the experimental procedure used, curcumin was diluted in an aqueous solution with different concentrations. This solution was then heated at a specific temperature, and its concentration was analysed using the present spectrophotometer. In this study, the temperature is limited to 50 °C since the higher concentration will not be used in most applications of spectrophotometer. Indeed, higher temperature will give impacts on the decomposition of material.

2. Experimental Method

2.1. Preparation of curcumin for analysing the solution concentration

To test the effectiveness of a portable spectrophotometer, measurement of the concentration of the solution was carried out by analysing the curcumin solution whose concentration and temperature were made vary. In conducting this test, curcumin solution was made from turmeric (*Curcuma Longa*, purchased in Bandung, Indonesia).

In short, the turmeric was washed, thinly cut (1 × 1 cm in sizes), dried at 70 °C, and saw-milled. Based on studies by Nandiyanto et al. [9], detailed information for the saw milling apparatus is explained in previous literature. Then, the powder obtained from the saw-milling process was then extracted using our method shown in our previous study [10, 11]. The extracted curcumin was then diluted in an ultrapure water. In addition, to confirm the chemical composition of turmeric, Fourier transform infrared (FTIR-4600, Jasco, Japan) was also used.

2.2. Design of Arduino-based portable spectrophotometer

Figure 1 shows an illustration of the Arduino-based portable spectrophotometer based on our previous report [1]. The present portable spectrophotometer consisted of several components: luxmeter as a measuring instrument for the light intensity transmitted from the light sensor, a cuvette as a reactor to contain curcumin solution for being analysed, white LED as a light source, and LED driver. The spectrophotometer was assembled in an acrylic box with length, width, and height dimensions of 200, 130, and 150 mm, respectively. The total mass of this portable spectrophotometer is around 1 kg.

In this tool, the white light from the LED is emitted and focused by insulating the room and giving a hole in the part to be passed by light. The light is emitted into the solution in the cuvette, and the translucent light will be detected by the sensor so that it is readable by the luxmeter. The measurement results are shown by luxmeter in the form of light intensity.

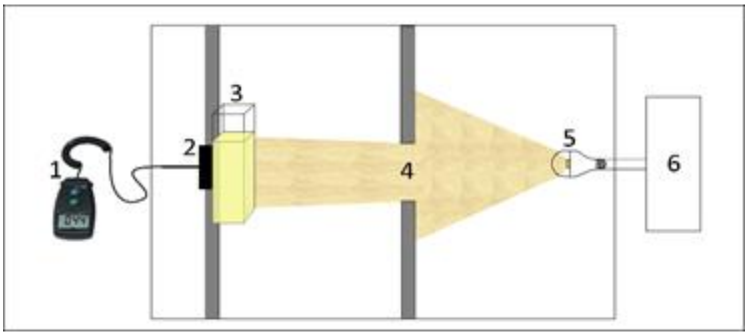

Fig. 1. Illustration of components in a portable spectrophotometer, (1) Luxmeter, (2) Light intensity sensor, (3) Cuvette with solution, (4) Hole for focusing light beam, (5) White LED, and (6) LED driver.

2.3. Experimental procedure for analysis of curcumin concentration at various temperatures

To analyse the concentration of curcumin, the diluted curcumin with a specific concentration was heated at a specific temperature. The concentration of curcumin was varied from 0 to 100 ppm. Then, the temperature was varied from room temperature to 50 °C. The heated solution was then put into the cuvette inside the spectrophotometer as shown in Fig. 1. To ensure the effectiveness of the present spectrophotometer, a standard UV-visible spectrometer (Jenway, US) was also used.

3. Results and Discussion

3.1. Characterisation of turmeric

To ensure the purity of the extracted curcumin solution, FTIR characterization was carried out. Figure 2 shows the results of FTIR analysis of curcumin. Several peaks were detected, which confirmed the detection of chemical bonds in the material. According to Nandiyanto et al. [10, 11], the peaks are in a good agreement with the curcumin material as shown in previous literature.

In general, several peaks were detected. The peak at around 3030 cm^{-1} indicated the presence of CH aromatic bonds, which is correspond to turmeric that has 2 benzene aromatic rings. Other peaks at about 1650 cm^{-1} were detected, in which, these peaks are peaks for C = O bonding. Peaks at 2962 cm^{-1} in the FTIR analysis indicated a C-H bonding. FTIR wavenumber at 3650 cm^{-1} is an O-H related peak, confirming that the curcumin can be dissolved in water. A peak at 1540 cm^{-1} is a C-O group.

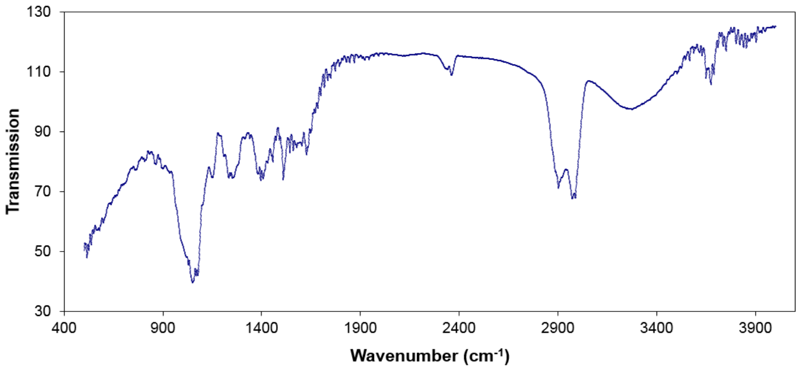

Fig. 2. FTIR analysis result of curcumin.

3.2. Analysis curcumin solution using a standard UV-visible spectrophotometer

Prior to the analysis of curcumin solution using the present spectrophotometer, physical observation of the curcumin solution with different concentrations is shown in Fig. 3. The differences in colors and turbidities were obtained. The less amount of curcumin in the solution has a correlation to the observation of more transparent solution. On the contrary, the higher concentration can result higher turbidity. This result will create difference in the light transmission, which can give advantages for the analysis of spectrophotometer.

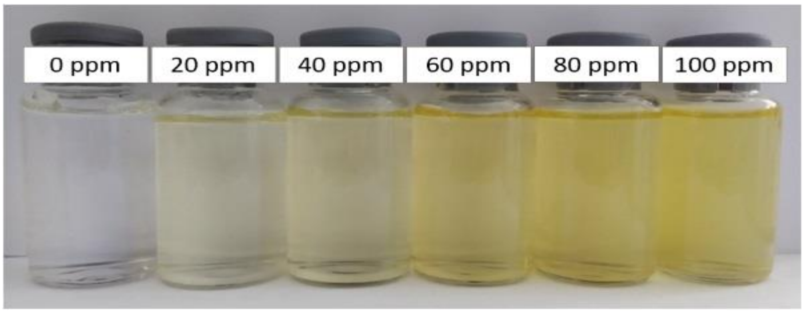

Fig. 3. Photograph image of curcumin diluted in ultrapure water at various concentrations from 0 to 100 ppm.

The standard UV-Visible spectrophotometer result of curcumin at specific concentrations is presented in Figs. 4 and 5. Figure 4 shows the UV-visible spectrophotometer results of curcumin solution at 25 °C, whereas Fig. 5 shows the analysis for solution heated at 50 °C. The figures detected the absorbance of the samples at different concentrations. From the figures, it can be detected that the main peak of the curcumin solution is at a wavelength of 283 nm. Then, the more concentration will give the more peak intensities.

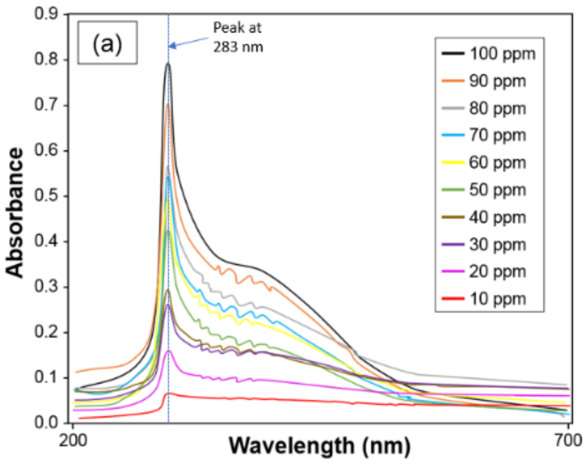

Fig. 4. Standard UV-vis analysis results of curcumin solution at room temperature (25 °C).

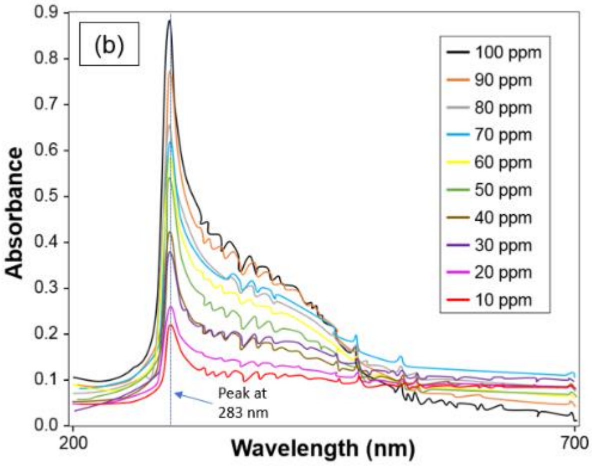

Fig. 5. Standard UV-vis analysis results of curcumin solution heated at 50 °C.

Absorbance at both temperatures shows different results for each concentration. The figure confirmed the increases in absorbance intensity for both types of samples. The increasing curves were in a good correlation to the increases in concentration from 0 to 100 ppm. At sample heated at temperature of 25 °C, the lowest absorbance was at 0 ppm at 0.102 and the highest concentration at 100 ppm was 0.785.

This condition was also found not only for the sample heated at a temperature of 25 °C but also for that of 50 °C. After raising the heating temperature to 50 °C, the absorbance value increased. The lowest absorbance was 0.116 at a concentration of 0 ppm and the highest was 0.884 at a concentration of 100 ppm.

The change in temperature from 25 °C to 50 °C affected the properties of the curcumin solution. This is confirmed by the detection of the results gained from UV-Visible spectrophotometer analysis. For samples with concentration of 0 ppm (ultrapure water only) and heated at temperatures of 25 and 50 °C, the absorbances of curcumin solution were 0.102 and 0.116, respectively. Then, the absorbances increased with increasing the concentrations, and all trends showed that the higher heating temperature (50 °C) will always result higher peak intensities compared with room temperature. The change of this absorbance indicates that increasing temperature can affect its absorbance value, which is due to the existence of the change in the viscosity and the density of the molecules in the curcumin solution.

3.3. Evaluation of portable spectrophotometer as an effect of temperature

Measurement of curcumin solution with a concentration of between 0 and 100 ppm was carried out using a portable spectrophotometer (Fig. 6). Figure 6 shows curves of the relationship between the concentration of curcumin solution and the intensity of light. Changes in the light intensity of the analysed solution were obtained. In the figure, there are several lines that each point is given a different symbol. The line shows the results of measuring curcumin solution at various temperatures. The curve for temperatures of 25, 30, 40, and 50 °C are shown in Figs. 6(a) to (d), respectively. Overall results showed a decrease in light intensity when increasing concentration. The light intensity obtained decreased from 562 to 444 lux.

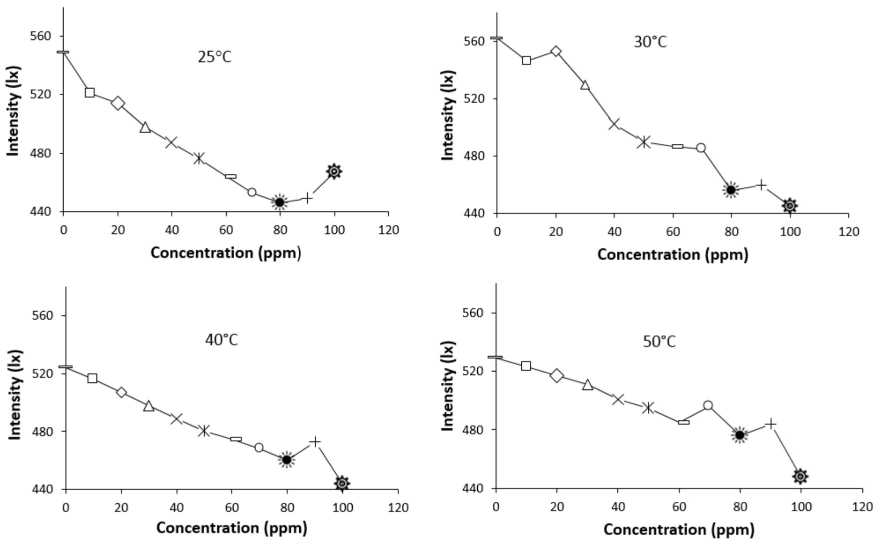

Fig. 6. Effect of concentration of curcumin solution on the intensity of light obtained from the Arduino-based spectrophotometer at various temperatures: (a) 25, (b) 30, (c) 40, and (d) 50 °C.

Similar trend for the correlation of concentration and light intensity was found. The higher concentration of curcumin is used, the less light will be transmitted. The main reason is because some lights are absorbed by the curcumin solution. The phenomena is in a good agreement with the facts in the realistic condition. If the solution contained high concentration, the solution will have more molecules that can be hit by the light. When the light passes through the solution, some lights are blocked and absorbed by molecules. Because less light can get through, this condition causes the visual appearance of solution to get darker. Indeed, when we added the sensor in the solution, less light transmission value can be detected.

For sample heated at the temperature of 25 °C, the intensity of the light decreases with increasing temperature. However, there is an increase in the intensity after the concentration is more than 90 ppm. The hysteresis condition was also found for samples heated at 30, 40 and 50 °C. This condition happened due to the existence of coagulation phenomenon of curcumin since the maximum solubility of curcumin is 100 ppm.

Based on the figure, the result showed that there is a decrease in light intensity when increasing the temperature. However, the fluctuation of the intensity is not much as shown in the standard UV-Visible spectrophotometer (See Figs. 4 and 5). This confirmed that the present spectrophotometer is more stable than the standard UV-Visible spectrophotometer.

To confirm the hysteresis in the UV-Vis spectrophotometer, Fig. 7 shows the relationship between the temperature of the curcumin solution and the light intensity. To clarify the discussion, figure was equipped with several lines that are corresponding to the specific concentration. The concentration was varied from 0 to 100 ppm. The overall results showed that the light intensity increased at 30°C and decreases at 40 °C.

Changes in detection of light intensities in this measurement occur because of the influence of temperature changes in the curcumin solution. When the heat is applied to the solution, the process of molecule movements (namely diffusion) happens faster, and the molecules can spread out or mix with other molecules quicker in the solution. This makes the fact that when light passes through the solution, more interactions between light and molecules happen. This contact, indeed, disturbs the light travels. In short, the higher temperature used, the smaller the density of the molecules in the curcumin solution can be obtained. Thus, the number light absorbed are less.

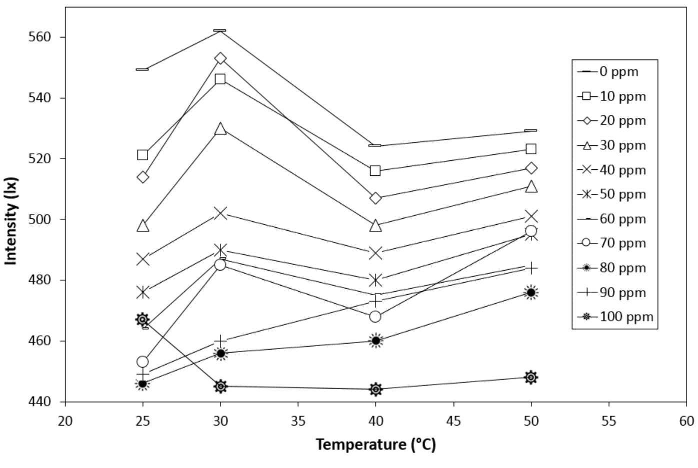

Fig. 7. Graph of temperature of curcumin solution to intensity obtained from the Arduino-based portable spectrophotometer with a concentration of curcumin solution of 0-100 ppm.

Table 1 shows the comparison analysis results of samples characterised by the present portable spectrophotometer and the standard UV-vis spectrophotometer. Data for the present portable spectrophotometer was calibrated based on previous reports [1]. The result showed that the present method is effective to be used for concentration analyser since this spectrophotometer is prospective for measuring the solution of curcumin with a concentration of up to 100 ppm and at high temperatures reaching 50°C. Although the standard UV-vis spectrophotometer shows good result, the high cost for the apparatus still becomes problems. But, the use of the present spectrophotometer is relatively good for rough analysis.

Table 1. Comparison between portable spectrophotometer and standard UV-visible spectrophotometer. Data was validated and calculated based on previous references [1].

Curcumin concentration (ppm)	Portable spectrophotometer				Standard UV-visible spectro
	25 °C	30 °C	40 °C	50 °C	25 °C
0	0	0	0	0	8.31
10	7.12	7.46	7.05	7.15	4.83
20	20.08	21.60	19.81	20.20	16.50
30	32.43	34.51	32.43	33.28	30.11
40	43.9	45.25*	44.08	45.16*	34.83*
50	52.92	54.48	53.36	55.03*	54.00
60	66.94*	70.75**	68.76*	70.42*	63.58
70	66.92	71.65	69.14	73.27	69.97
80	78.85	80.39	81.01	83.48	73.72*
90	89.26	91.45	94.03	96.22	91.50
100	98.03	93.41*	93.20	94.04*	103.17

Note: *error obtained more than 5 ppm, **error obtained more than 10 ppm

4. Conclusion

The existence of this study has shown how the Arduino-based portable spectrophotometer works to measure light intensity in the analysis of curcumin solution samples. Based on the research, the Arduino-based portable spectrophotometer is effective for analysing curcumin solution samples with different concentrations even in high temperature conditions. Although the present study is effective to analyse the samples heated with higher temperature, several problems must be considered, including the change in the fluid density and viscosity, as well as the possibility for the decomposition of material.

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