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Journal of Electrical, Electronics and Informatics,

p-ISSN: 2549–8304 e-ISSN: 2622–0393
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Journal of Electrical,

Electronics and Informatics, Vol.10 No. 1, June 2026

Measurement of Used Cooking Oil Turbidity Using TCS3200 Color and Turbidity Sensors

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Abstract Used cooking oil is a waste product from frying that has the potential to be reused, but its quality needs to be monitored to ensure its suitability for use. This study aims to develop an Internet of Things (IoT)-based used cooking oil quality monitoring system with turbidity (NTU) and color (RGB) parameters. The system uses a turbidity sensor and a TCS3200 color sensor integrated with an ESP32 microcontroller and the Blynk IoT platform for real-time data monitoring. Testing was conducted on used cooking oil before and after microfiltration and transesterification using ethanol and methanol with varying concentrations and temperatures. The results showed that the system was able to read NTU and RGB values stably and consistently and detect changes in oil characteristics at each treatment stage. The turbidity value decreased from 203–206 NTU to 184–188 NTU in the best treatment, namely 2% methanol transesterification at a temperature of 50 °C. Although NTU measurements in oil have limitations, this system is effective as a relative indicator of changes in waste oil quality through a combination of turbidity and color parameters.
Keywords—used cooking oil, Internet of Things, turbidity, color sensor, ESP32

INTRODUCTION

Excessive use of palm oil can produce waste in the form of used oil known as used cooking oil [1]. To reduce this impact, efforts are needed to reuse used cooking oil into more useful products, one of which is biodiesel [2].

Biodiesel is an alternative fuel derived from vegetable oil or animal fat [3]. One of its advantages is that its exhaust emissions are cleaner than diesel fuel. Physically, biodiesel has characteristics similar to diesel fuel. However, chemically there are differences between the two [4].

One of the efforts to develop biodiesel that is currently being widely carried out is by utilizing used cooking oil as raw material [5]. Previous research has successfully produced biodiesel with used cooking oil as the main raw material. However, this production system is still carried out manually. In addition, The turbidity level of the biodiesel produced cannot yet be measured accurately, so it cannot be used as a basis for setting biodiesel quality standards [6].

With the development of Internet of Things (IoT) technology, monitoring and automation systems can be applied to the biodiesel production process [7]. In this study, an ESP32-based monitoring system equipped with a TCS3200 color sensor and turbidity sensor and integrated with the Blynk platform was developed. This system allows real-time monitoring of changes in the color and turbidity level of biodiesel through a smartphone application and data storage in Google Sheets [8]. This supports process efficiency and quality standardization of biodiesel from used cooking oil [9].

I. Literatur Review

A. TCS3200 Color Sensor

The TCS3200 color sensor is an optical sensor capable of detecting the intensity of red, green, and blue (RGB) colors of an object. This sensor works by converting the intensity of the light received into a frequency signal which is then processed by a microcontroller [10]. The RGB values produced by the TCS3200 sensor can be used as an indicator of changes in the physical quality of oil. The darker the color of the oil, the greater the decrease in the specific RGB intensity value [11]. Therefore, the TCS3200 color sensor can be used as a quick, objective, and real-time method of monitoring the quality of used oil as a simple alternative to chemical testing in a laboratory.

B. Turbidity Sensor

The turbidity sensor functions to measure the level of clarity or turbidity by detecting light scattering that passes through the liquid sample. In this study, used cooking oil samples were used, where the more turbid the oil becomes due to the accumulation of combustion residue particles, oxidation, and compound degradation during repeated use, the less light intensity the sensor will receive [12]. This turbidity value is used as an additional indicator of the decline in used cooking oil quality, so that the turbidity sensor can complement the color sensor in providing an objective and real-time assessment of the oil condition [13]. However, in oil-based samples, the turbidity value obtained does not fully represent the actual clarity level due to differences in the optical properties, color, and refractive index of oil compared to water-based liquids [14].

C. Microfiltration Method

Microfiltration is a separation technique used to filter solid particles, frying residues, and micro-sized impurities from used cooking oil using a fine-pored membrane, generally measuring 0.1–10 μm, so that the resulting oil is clearer. This method aims to improve the physical quality of the oil by reducing the level of turbidity and dark color without significantly altering the chemical composition [15].

D. Transesterification Method

The transesterification method is a chemical process that aims to convert triglycerides in used cooking oil into esters (biodiesel) and glycerol through a reaction between oil and alcohol (methanol or ethanol) with the help of a base or acid catalyst. This method is used to utilize waste oil as a raw material for biodiesel, where the transesterification process can reduce oil viscosity, improve combustion properties, and produce more environmentally friendly fuel, so that waste oil that is unfit for consumption can be processed into high-value products [16].

E. NTU Value

The NTU (Nephelometric Turbidity Unit) value is a unit that expresses the level of turbidity in a liquid based on the intensity of light scattered by suspended particles [17]. In general, for water-based liquids, NTU values can be classified as very clear (<1 NTU), clear (1–5 NTU), slightly turbid (5–25 NTU), turbid (25–100 NTU), and very turbid (>100 NTU) [18].

II. Research Methodology

The method used was the R&D (Research and Development) research method. Research and Development is a process or stage that aims to create new products or improve existing products [19].

A. Research Flow Diagram

Fig. 1. Research Flow Chart

Figure 1 shows the research flowchart with problem identification to determine the focus of the study, followed by a literature review to examine theories and previous studies as a basis for system design, method selection, and result analysis. Based on this review, the tool design stage was carried out, which included the selection and design of hardware and software for the monitoring system. Next, in the tool development stage, the system was implemented using a TCS3200 color sensor,

turbidity sensor, ESP32 microcontroller,

and integration with the Blynk IoT platform and Google Sheets. The assembled tool then underwent a testing stage to ensure that all components and systems worked as intended. The final stage was data collection and analysis based on the results of monitoring the tool's performance during testing.

B. Software Design

This section describes the process of developing a program that controls and operates an IoT-based monitoring system for the clarity of used cooking oil. The software used in designing this system is as follows:

1) Arduino IDE

Arduino IDE functions as a tool for developing,

programming, and testing microcontroller systems,

making it very important in the creation of tools. In this test, Arduino is used to monitor sensor output on a serial monitor.

2) Blynk IoT

Blynk is an IoT platform that simplifies the creation of remote control systems and interface displays for monitoring and controlling Internet of Things-based electronic systems via Android and iOS devices[20]

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"The use of lights and air conditioners (AC) in cadet dormitories sometimes often forget to turn off when not in use so that this becomes a waste of electrical energy and can cause a short circuit. So, the research objective is to develop an efficient solution for users to control and monitor electrical devices in a system. The system development process begins with selecting the appropriate hardware for control and monitoring needs using the NodeMCU ESP8266 microcontroller and additional components such as relay modules to control loads and PZEM-004T sensors that can function like kWH meters. In addition, it also uses the Blynk IoT application as a user interface that allows users to control and monitor electrical devices through mobile devices. So this research method is a development that will be tested to determine the feasibility of a tool. The result is that the developed tool has good test results and can be applied in the cadet dormitory."

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0},"schema":"https://github.com/citation-style-language/schema/raw/master/csl-citation.json"}[21]. With the installed widget, sensors connected to Blynk can be activated and monitored in real-time via mobile devices.

3) Google Sheets

Google Sheets functions as a spreadsheet-based data processing application used to manage, store, and analyze data online.

C. Hardware Design

Fig 2. Hardware Design

Figure 2. Shows the wiring design of the device made using the ESP32 microcontroller, where the TCS3200 color sensor is connected to the ESP32 digital pins (IO4, IO5, IO18, IO19, and

IO21) for color filter control and frequency pulse reading, while the turbidity sensor is connected to the GPIO36 analog pin to read the ADC value, with both sensors using the same VCC (3.3 V) power source and ground from the ESP32.

D. Flowchart System

Fig 3. Flowchart System

The process begins by turning on the system. At this stage, the ESP32 microcontroller will execute the initial instructions that have been programmed in the Arduino IDE. Then, the color sensor and turbidity sensor are initialized. Once functional, the sensors will read the monitored oil parameters in real time using Blynk IoT and store them in Google Sheets.

E. Tool Design

Fig 4. Tool Design

Figure 4 shows the architecture of an IoT-based used cooking oil quality monitoring system, in which the TCS3200 color sensor and turbidity sensor read the color (RGB) and turbidity (NTU) parameters of the oil. The sensor data is processed by the ESP32 microcontroller and sent via a WiFi network to the Blynk IoT platform to be displayed in real-time on a smartphone, as well as stored in Google Sheets as a data recording medium.

III. Result And Discuddion

This research was conducted at the Muhammadiyah University Laboratory in Sidoarjo. Sensor testing was carried out by comparing used cooking oil from frying chicken, eggs, tofu, and tempeh ten times with used cooking oil that had undergone microfiltration and transesterification processes. The microfiltration process was carried out using 25μm porous filter paper, while the transesterification process used methanol and ethanol alcohol with several variations in conditions,

namely 1% methanol at 50 °C, 2% methanol at 50 °C,

and 2% ethanol at 65 °C. Each treatment variation was carried out ten times with a sample oil volume of 200 mL in each experiment.

A. Testing Used Cooking Oil Before Purification

This table presents the results of sensor testing on used cooking oil from frying chicken, eggs, tofu, and tempeh, which has been used ten times with ten trials to observe the consistency of the sensor readings.

TABLE I

Test Results Of Jelantah Oil Before Purification

Experiment	NTU	R	G	B
1	205	146	104	72
2	205	146	104	72
3	203	144	104	70
4	204	145	102	70
5	204	145	102	70
6	205	146	103	71
7	205	146	103	71
8	206	146		

			104	72
9	205	146	104	72
10	203	146	104	72

Table 1. the turbidity value of used cooking oil is in the range of 203–206 NTU. For the color parameter, the average R value is in the range of ±145, G is around ±103, and B is around ±71, which indicates that used cooking oil tends to be dark brown before the purification process, so it does not yet meet the requirements as a raw material for used cooking oil.

Fig 5. Graph of Used Cooking Oil Test Results Before Purification

Based on Fig. 5, the graph shows the stability of NTU and RGB values throughout the experiment. This consistency indicates that the sensor is capable of repeatedly reading turbidity and color parameters accurately.

B. Testing with Microfiltration

This table presents the results of sensor testing on used cooking oil after undergoing microfiltration with ten trials to observe the consistency of sensor readings.

TABLE 2

Test Results With Microfiltration

Experiment	NTU	R	G	B
1	199	176	158	96
2	198	176	158	96
3	199	175	157	97
4	199	176	158	96
5	197	176	158	96
6	197	178	159	97
7	199	178	159	97
8	199	178		

			159	97
9	198	178	159	97
10	197	175	157	97

Table 2. the turbidity value of microfiltered oil is in the range of 197–199 NTU, indicating a decrease in turbidity compared to used cooking oil before purification. For the color parameter, the average R value is in the range of ±170, G is around ±155, and B is around ±95, which indicates that the color of the oil has become brighter. These results show that the microfiltration process is capable of improving the physical characteristics of used oil, although the NTU value is still relatively high due to measurement limitations in oil-based samples. This process can be considered suitable as a raw material for biodiesel.

Fig 6. Graph of Test Results Using Microfiltration

Based on Fig. 5, the graph shows the stability of NTU and RGB values throughout the experiment. This consistency indicates that the sensor is capable of repeatedly reading turbidity and color parameters accurately.

C. Testing with 2% Ethanol at 65℃

This table presents the results of sensor testing on used cooking oil after undergoing transesterification using 2% ethanol at a temperature of 65°C with ten trials to observe the consistency of the sensor readings.

TABLE 3

Test Results With 2% Ethanol At 65℃

Experiment	NTU	R	G	B
1	189	170	151	95
2	189	170	151	95
3	188	171	151	96
4	190	171	151	96
5	189	170	150	96
6	188	171	151	96
7	190	172	151	98
8	190	172	152	98
9	190			

		170	151	96
10	189	170	151	96

Table 3. the oil turbidity values were in the range of 188–190 NTU, indicating a decrease in turbidity compared to the microfiltration results. For the color parameters, the average R value was in the range of ±168, G was around ±152, and B was around ±98, indicating that the oil appeared brighter. These results indicate that the transesterification process with 2% ethanol at 65°C can improve the physical characteristics of used cooking oil, although the NTU value is still relatively high due to measurement limitations in oil-based samples. This process can be considered suitable as a raw material for biodiesel.

Fig 7. Graph of Test Results with 2% Ethanol at 65°C

Based on Fig. 5, the graph shows the stability of NTU and RGB values throughout the experiment. This consistency indicates that the sensor is capable of repeatedly reading turbidity and color parameters accurately.

D. Testing with 1% Methanol at 50℃

This table presents the results of sensor testing on used cooking oil after undergoing transesterification using 1% methanol at a temperature of 50°C with ten trials to observe the consistency of the sensor readings.

TABLE 4

Test Results With 1% Methanol At 50℃

Experiment	NTU	R	G	B
1	188	152	149	127
2	186	152	149	127
3	186	152	149	127
4	186	151	147	126
5	189	151	149	127
6	189	151	149	127
7	188	152	149	127
8	188	152	149	127
9	187	153	148	126
10	187			

153
148
126

Table 4. the oil turbidity values ranged from 186 to 189 NTU, indicating a decrease in turbidity compared to the previous stage. For the color parameter, the average R value ranged from ±150, G around ±145, and B around ±125, indicating that the oil color became brighter. These results show that the transesterification process using 1% methanol at 50°C can improve the physical characteristics of used cooking oil, although the NTU value is still relatively high due to the limitations of the measurement method on oil-based samples. This process can be considered suitable as a raw material for biodiesel.

Fig 8. Graph of Test Results with 1% Methanol at 50°C

Based on Fig 8. the graph shows the stability of NTU and RGB values throughout the experiment. This consistency indicates that the sensor is capable of repeatedly reading turbidity and color parameters accurately.

E. Pengujian Dengan Metanol 2% 50℃

This table presents the results of sensor testing on used cooking oil through a transesterification process using 2% methanol at 50℃ based on ten trials to observe the consistency of sensor readings.

TABLE 5

Test Results With 2% Methanol At 50℃

Experiment	NTU	R	G	B
1	186	167	164	131
2	184	167	163	130
3	185	167	164	131
4	184	167	164	131
5	184	166	163	130
6	185	166	163	130
7	186	166	163	130
8	186	167	164	131
9	188	167	164	129

10
188
167
164
129

Table 5. the oil turbidity values ranged from 184 to 188 NTU, indicating a decrease in turbidity compared to the oil before purification. For the color parameters, the average R value ranged from ±160, G around ±150, and B around ±135, indicating a brighter oil color. These results show that transesterification using 2% methanol at 50°C can improve the physical characteristics of used cooking oil, although the NTU value is still relatively high due to measurement limitations in oil-based samples. This process can be considered suitable as a material.

Fig 9. Test Results Graph with 2% at 50℃

Based on Fig 9. the graph shows the stability of NTU and RGB values throughout the experiment. This consistency indicates that the sensor is capable of repeatedly reading turbidity and color parameters accurately.

F. Comparison Chart

Fig 10. Comparison Chart

Figure 10 shows a comparison of the turbidity and color values of used cooking oil in each experiment for three conditions, namely before treatment, after microfiltration, and after transesterification. In general, NTU before treatment had the highest value (around 203–206 NTU), indicating the most turbid oil. After microfiltration, the NTU value decreased (197–199 NTU), and the lowest value occurred after transesterification (185–189 NTU), indicating the clearest oil, especially at a concentration of 2% at a temperature of 50 °C with a value of 184 NTU and an RGB value (184, 166, 130).

G. Discussion

Test results show that the monitoring device has stable and consistent performance. This is demonstrated by relatively uniform NTU and RGB values in each repetition of the experiment, indicating that the sensor has good stability. In used oil before purification, the sensor reads the highest NTU value and the lowest RGB color intensity, indicating that the oil is still dark and cloudy. After microfiltration, there is a decrease in NTU and an increase in RGB, indicating that the sensor is able to detect changes in clarity due to the reduction of solid particles.

The lowest NTU value was obtained in the transesterification process using 2% methanol at a temperature of 50 ℃, accompanied by the most stable and brightest RGB value. Based on the performance of the device, microfiltered oil is suitable for use as raw material for initial biodiesel, while transesterified oil, especially with 2% methanol, is the most suitable. This suitability is based on the decrease in turbidity and increase in color brightness, which indicates a reduction in physical impurities and an improvement in oil quality, in accordance with the literature stating that refined and transesterified waste oil can be used as biodiesel [22].

Although visually the oil appears clearer, the NTU value read is still relatively high because the water-based turbidity measurement method is less suitable for oil samples [23]. Therefore, the device is more appropriately used as an indicator of relative changes in oil quality by combining turbidity and color parameters.

IV. Conclusion

The IoT-based used cooking oil quality monitoring system successfully integrates turbidity sensors and TCS3200 color sensors with ESP32 microcontrollers for real-time data collection. The device shows stable and consistent performance in detecting changes in oil quality based on NTU and RGB parameters at each stage of the process. Oil prior to purification has the highest NTU value and lowest RGB value, while microfiltration and transesterification reduce turbidity and increase color brightness. The best conditions were obtained during transesterification with 2% methanol at 50 °C, resulting in the lowest NTU value (186) and the most stable RGB (167,164,131), making it the most suitable for biodiesel. Although NTU measurements are still affected by the limitations of water-based methods on oil samples, the system is effective as an indicator of relative changes in waste oil quality.

Acknowledgment

The author would like to thank the Electrical Engineering Laboratory of Muhammadiyah University Sidoarjo for the facilities and support provided during this research. Thanks are also extended to the supervising lecturer and all parties who have provided guidance, assistance, and input so that this research could be completed successfully. This research was also supported by the BIMA Research Program of the Directorate General of Higher Education (Dikti) as part of the funding and facilitation of research activities.

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