JPPIPA 11(2) (2025)

Jurnal Penelitian Pendidikan IPA

Journal of Research in Science Education

http://jppipa.unram.ac.id/index.php/jppipa/index

Adsorption Performance of Turmeric as Biosorbent for Free Fatty Acid Removal in Used Cooking Oil

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Received: October 18, 2024
Revised: December 27, 2024
Accepted: February 25, 2025
Published: February 28, 2025

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DOI: 10.29303/jppipa.v11i2.10201

Abstract: Repeated use of cooking oil produces hazardous compounds such as free fatty acids, carbonyls, and peroxides. This study aims to examine the effectiveness of turmeric as a bio-adsorbent in reducing free fatty acid levels, peroxide numbers, and water content in used cooking oil, and determine the appropriate adsorption isotherm model. Turmeric is one of the biopharmaceutical plants whose availability is quite abundant in Indonesia. Adsorption was carried out with variations in adsorbent mass and contact time. The result showed that turmeric is effective in reducing free fatty acid levels, peroxide value, and water content with adsorption efficiency of up to 54.02, 48.78, and 42.89%, respectively. The adsorption isotherm analysis suggested that the adsorption of free fatty acids followed the Freundlich model rather than the Langmuir model. This study reveals that turmeric has the potential to be a viable bio-adsorbent for enhancing the quality of used cooking oil.

Keywords: Adsorption; Free fatty acid; Peroxide value; Turmeric; Used cooking oil; Water content

Introduction

One of the most popular cooking methods is frying, which uses cooking oil. Cooking oil is unstable at high temperatures. Frequent exposure to high temperatures (160 – 200 °C) causes a variety of physical and chemical changes that can produce harmful compounds, including mutagenic, neurotoxic, and hepatotoxic effects (Lopes et al., 2020; Panadare & Rathod, 2015; Rohim et al., 2023; Tsoutsos et al., 2016). Furthermore, the inappropriate disposal of used cooking oil (UCO) increases ecological problems. One litre of UCO can contaminate around 500,000 litres of water, leading to clogged drainage systems, reduced oxygen levels in the water, and ecological imbalances (Awogbemi et al., 2021; Lopes et al., 2020; Okino-Delgado et al., 2017).

According to SNI 7709:2019, the quality of cooking oil is oil that is yellow to orange in color, has a maximum moisture content of 0.1%, a maximum free fatty acid content of 0.3%, and a maximum peroxide value of 10 mEk O_2/kg (SNI-7709-2019, 2019).

Regenerating UCO for safe reuse prevents both health risks and environmental dangers. Although many methods are used to regenerate UCO, adsorption is one of the simple methods due to its advantages, including the availability of various adsorbents, high efficiency, and low cost (Akbar & Hasby, 2023). Adsorption using biosorbent is simple, cost-effective, and sustainable. In addition, biosorbents were chosen because of their abundant availability in nature and their characteristics that can be used for adsorption.

Previous studies have utilized biosorbents from agricultural and plantation waste such as banana peels (Devianti & Arifiyana, 2023; Suryadi et al., 2019), moringa seed powder (Buluk et al., 2023), guava fruit (Fitria et al., 2019), pineapple peel (Chairgulprasert & Nileah, 2019; Hamzah et al., 2021) and sugarcane (Bonassa et al., 2016; Nasukwad & Sulthon, 2019).

How to Cite:
Devianti, V. A., Arifiyana, D., & A'yuni, Q. Adsorption Performance of Turmeric as Biosorbent for Free Fatty Acid Removal in Used Cooking Oil. *Jurnal Penelitian Pendidikan IPA*, *11*(2), 16–24. https://doi.org/10.29303/jppipa.v11i2.10201

However, the use of biosorbents from agricultural and plantation waste requires preliminary treatment to ensure that there are no pesticide residues or other disturbing organic substances (Suryadi et al., 2019). Meanwhile, turmeric is more straightforward to process into biosorbent powder without complex treatment, making it more applicable.

Turmeric is an abundant local Indonesian plant. Indonesia produces 205 million kg of turmeric in 2023 (Badan Pusat Statistik, 2024). Turmeric contains curcumin, which has hydroxyl groups that can bind to free fatty acids in UCO. Curcumin also contains chemical compounds such as phenols that can be utilized as natural antioxidants. These active compounds can inhibit oxidation processes and decrease peroxide value in UCO. Therefore, curcumin could be a potential biosorbent that reduces the free fatty acids level and peroxides value in UCO (Abubakar et al., 2018; Fardani et al., 2025).

The Objectives of this research are to determine the effectiveness of turmeric in reducing free fatty acid levels, water content, and peroxide values in UCO and to analyze its adsorption capacity using isothermal equations. By achieving these objectives, this study contributes to developing an environmentally friendly and economically viable approach to UCO regeneration, aligning with the principles of green chemistry.

Method

The UCO used is palm oil collected from food stalls in Ketintang, Gayungan, Surabaya, East Java, Indonesia. Turmeric was supplied by a local seller in Surabaya, East Java. The chemicals used in the study include NaOH Pro Analysis, oxalic acid (Merck), PP indicator (Merck), 95% ethanol (Fulltime), and distilled water. The instruments used to collect data and results in this research include glassware (IWAKI), Ohaus analytical balance, filter paper, and Heidolph stirrer.

Preparation of Adsorbent

Preparation of the turmeric biosorbent begins with peeling the root's outer layer and thoroughly washing it with water to remove impurities. The turmeric is sliced into thin strips and left to air dry for three days. After that, it is dried in an oven set at a temperature range of 50-80°C. Upon reaching a state of complete dryness, the turmeric is ground into a powder using a blender and then sieved to obtain a uniform powdered sample.

Batch Adsorption

The UCO was filtered through filter paper to remove solid impurities. Subsequently, 100 mL of the oil was transferred into an Erlenmeyer flask and heated to 70°C. Then, turmeric powder (10, 15, 20, 25, and 30 grams) was added while stirring for 35, 45, 50, 55, and 60 minutes at 100 rpm. The mixture was then cooled and filtered using filter paper. The adsorption capacity (qe, mg/g) and adsorption efficiency (E, %) are calculated using the following equations.

$$q = \frac{(C_i - C_t) \times V_{oil}}{W_{ads}} \quad (1)$$

$$E(\%) = \frac{(C_i - C_t) \times 100}{C_i} \quad (2)$$

Where C_i and C_t (mg/L) are the initial and final FFA concentrations. V_{oil} is the volume of oil and W_{ads} (g) is the mass of adsorbent (Paputungan et al., 2023; Prajaputra & Isnaini, 2023).

Free Fatty Acid Analysis

Three grams of each sample is weighed and placed into a 250 mL Erlenmeyer flask, and then 50 mL of 95% ethanol is added. The mixture is heated at 40°C for 10 minutes and shaken to ensure homogeneity. Subsequently, 15 drops of phenolphthalein indicator are added, and the solution is titrated with 0.01 N NaOH until a constant color change occurs from colorless to pink (Putranti et al., 2018). The free fatty acid (FFA) content is calculated using the equation below.

$$FFA(\%) = \frac{N_{NaOH} \times V_{NaOH} \times Mr}{W_{oil}(mg)} \times 100\% \quad (3)$$

Water Content Analysis

5 g of oil was put into a crucible of known weight. Then, it is heated in an oven at 130°C for 30 minutes, cooled in a desiccator to room temperature to avoid measurement errors due to temperature differences, and weighed. Heating is repeated to obtain a consistent weight. Based on SNI 2019, for consistent results, the range of results from two repetitions is a maximum of 10% of the average value of the results of water content and volatile substance content. The test must be repeated if the range is greater than 10%. The formula determines water content.

$$\text{Water Content} = \frac{w1 - w2}{w1 - w0} \times 100\% \quad (4)$$

Where w0 is the weight of the empty cup, w1 is the weight of the cup and sample before drying in the oven, and w2 is the weight of the cup and sample after drying in the oven.

Peroxide Value Analysis

5 g of oil was put into a 250 mL Erlenmeyer, then 30 mL of 95% acetic acid and 97% chloroform (3:2). The mixture was shaken until it became homogenous. This mixture serves as an organic solvent that can dissolve fat. Then, the mixture was combined with a 0.5 mL

saturated KI solution, agitated for one minute, and added 30 mL of distilled water. The addition of saturated KI serves as a source of iodide ions that can reduce hydroperoxide and release iodine (I_2) (Devianti & Arifiyana, 2023; Fitriani, 2018). After that, 4 mL of 1% amylum was added, and the solution was titrated with 0.01 N $Na_2S_2O_3$ until the precise blue color had disappeared. The peroxide number value was then calculated using the following formula.

$$\text{Peroxide Value } \left(\frac{\text{meqO}_2}{\text{kg}}\right) = \frac{V \times N \times 1000}{W} \quad (5)$$

V is the titrant volume (mL), N is the standardized $Na_2S_2O_3$ normality, and W is the oil mass (g).

Result and Discussion

The free fatty acid, initial water content, and peroxide values in UCO used in this study were 1.0181 and 0.1350%, and 11.68 meqO_2/kg respectively. These values exceed the maximum SNI limit, which is a maximum of 0.3% (free fatty acid), a maximum of 0.1% (water content), and a maximum of 10 meqO_2/kg (peroxide value) (SNI-7709-2019, 2019).

Table 1. Free fatty acid and water content in UCO

Sample	Free Fatty Acid (%)	Water Content (%)	Peroxide Value (meqO_2/kg)
UCO	1.0181%	0.1350%	11.68
SNI, 2019	Max. 0.3	Max. 0.1	Max. 10

Biosorbent turmeric was analyzed using IR for functional group analysis. According to Figure 1, a peak at 3272 cm^{-1} was observed, indicating the presence of a hydroxyl group (-OH) on the phenol. A peak at 2921 cm^{-1} indicates the presence of a sp2 C-H stretching group. A peak at 1635 cm^{-1} shows the presence of C=C bonds. Peaks at 1075 and 1150 cm^{-1} indicate C-O stretching in phenyl alkyl ether.

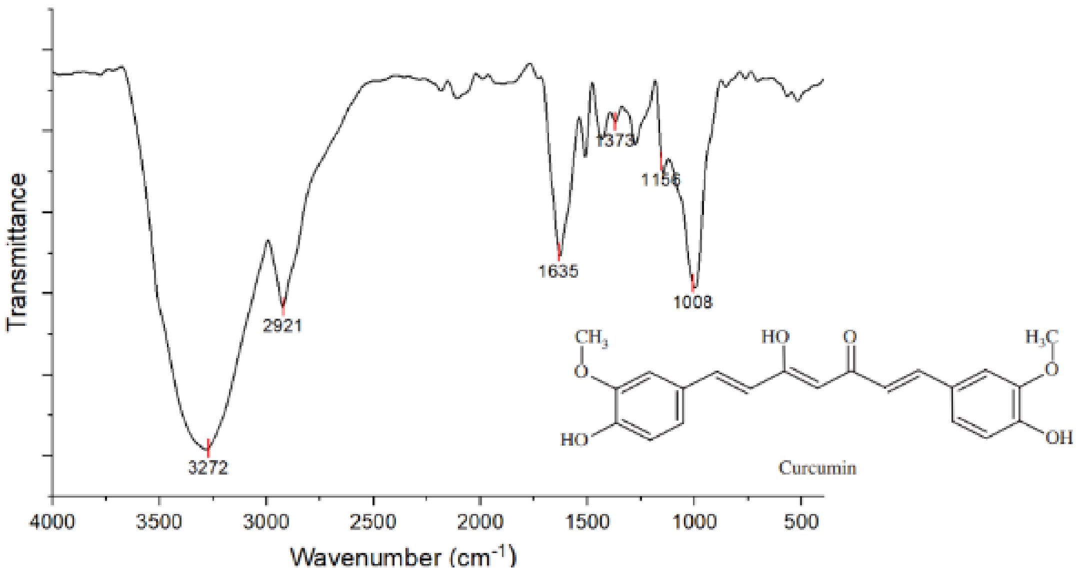

Figure 1. FTIR spectrum of Curcumin

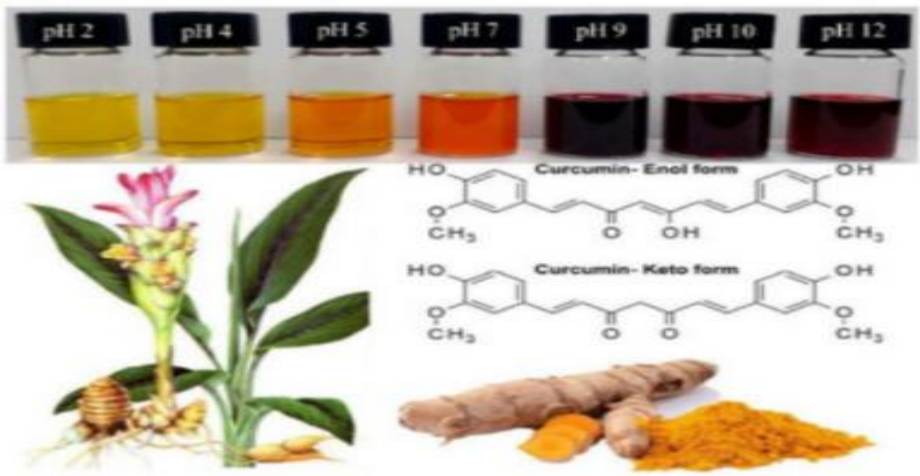

Figure 2. The color change of Curcumin (Ezati & Rhim, 2020)

Free Fatty Acid Analysis

The analysis was carried out by adding the adsorbed UCO and then adding neutral ethanol to dissolve free fatty acids in the sample. The ethanol used is neutral to prevent any alteration in the pH during acid-base titration. Analysis of free fatty acid in the adsorbed UCO does not require the addition of a PP indicator because turmeric contains curcumin, which can act as a natural indicator. Curcumin solution changes color from bright yellow to dark red if there is an increase in pH from pH 2 to 12. In an acidic solution (pH < 4), curcumin is yellow, then turns yellow-orange at pH 5, and the color becomes more intense at pH 7. The higher the pH (pH > 7), the more dominant the red color will be, and it will become dark red in alkaline conditions. In the pH range of 1-7 (acidic conditions), the solution is yellow, while at pH > 7.5, there is a color change to red (Ezati & Rhim, 2020; Liu et al., 2022). The color change of the solution in curcumin according to pH conditions can be seen in Figure 2.

The research results in Figure 3 and 4 showed that the longer the adsorption time and the greater the mass of the adsorbent, the lower the free fatty acid level and the greater the adsorption efficiency because longer contact times increase the opportunity of the adsorbate being adsorbed by the adsorbent and greater adsorbent mass make more active sites that play a role in the adsorption process of free fatty acids (Andrio et al., 2024; Omer et al., 2022).

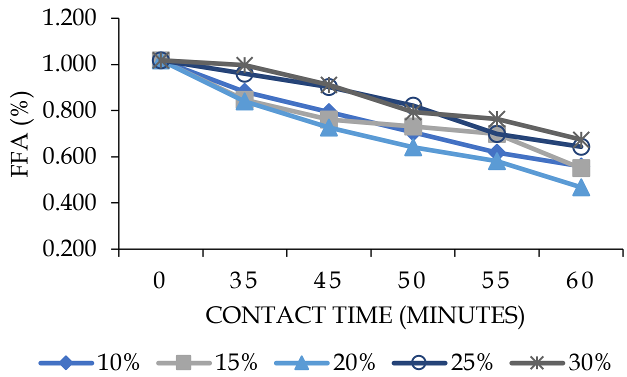

Figure 3. The effect of adsorbent mass and contact time on free fatty acid level

However, when the adsorbent mass was increased from 20 grams to 25 grams and 30 grams, the adsorption efficiency of free fatty acids decreased. Increasing the adsorbent mass reduces the adsorption sites' unsaturation, decreasing the number of such sites per unit mass, which leads to comparably lower adsorption. Also, this reduces the driving forces for adsorption, reducing the diffusion of free fatty acids from the solution into the adsorbent platelets. Furthermore, adsorption sites overlap due to the crowding of adsorbent particles (Hashem, 2012; Sen, 2023). The highest free fatty acid adsorption efficiency (E%) was 54.03% when the adsorption mass was 20 grams with a time of 60 minutes.

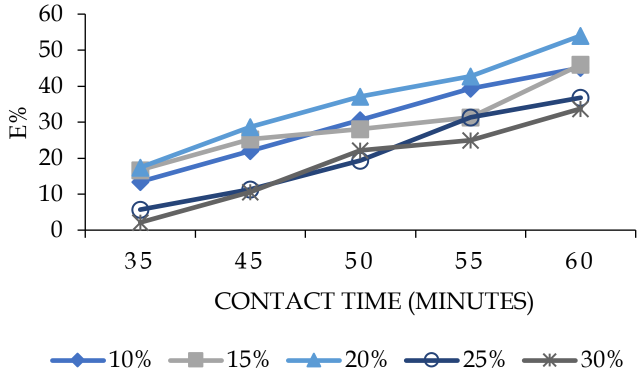

Figure 4. Adsorption efficiency of free fatty acid

Turmeric adsorbent can reduce free fatty acids in UCO because curcumin, one of the active compounds in turmeric, is a phenol compound. Phenol is a compound with a hydroxyl group (-OH) bound to an aromatic ring. The pair of electrons on the oxygen atom conjugates with the aromatic ring, causing some of the negative charge from oxygen to be transferred to the aromatic ring and the charge to be delocalized. Hence, the polarization of the O-H bond can bind to the carboxylate group (-COOH) attached to the free fatty acid compound through hydrogen bonds (Sobiesiak, 2017).

Water Content

Water in cooking oil initiates hydrolysis reactions, breaking triglyceride forms into free fatty acids. These subsequently react with one another, forming aldehydes and ketones. These by-products indicate the rancidity of the cooking oil. The presence of water in cooking oil is in a colloidal form and is stabilized by the presence of proteins in the cooking oil (Yahya et al., 2019). Therefore, to improve the quality of the cooking oil, it is necessary to reduce the amount of water to a minimum.

Figures 5 and 6 show that adding turmeric biosorbent to UCO can reduce its water content. As the adsorption time is extended, the water content of the UCO declines due to an increased interaction. The most favorable water content result obtained in this study was 0.077% when the adsorption time was 60 minutes, with an adsorption efficiency of 42.89%.

The more adsorbent mass is added, the more the water content contained in cooking oil is reduced because the number of water components interacting with the active site of the adsorbent increases. At 25 and 30 grams of adsorbent mass, the maximum limit in adsorbing adsorbate into its pores has been reached, which is indicated by the stability of the obtained water content of 0.077%.

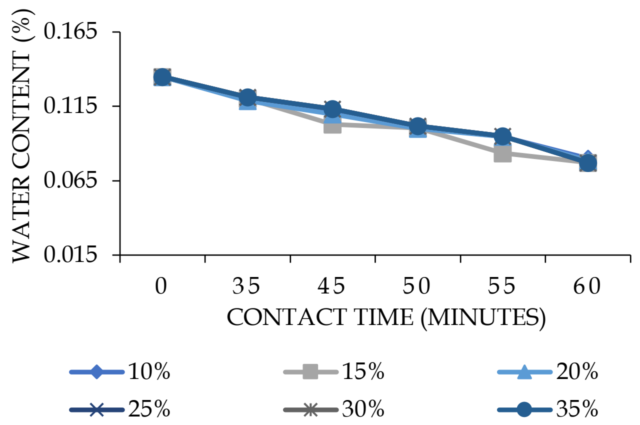

Figure 5. Water content with the influence of contact time and adsorbent mass

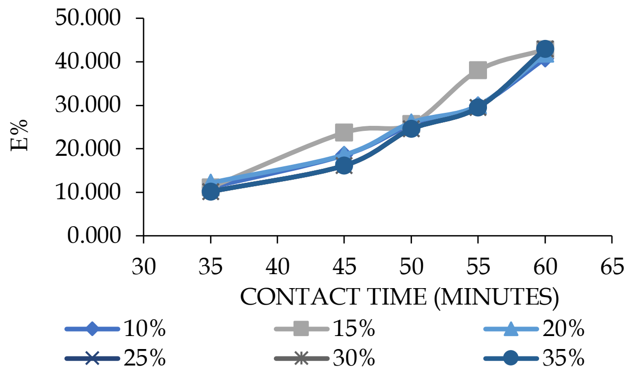

Figure 6. Adsorption efficiency of water content

Water molecules are adsorbed on the OH group due to the formation of hydrogen bonds between the OH group and the water molecules, in which this OH group acts as a proton donor (Collignon et al., 2005; Liu et al., 2017).

Peroxide Value

The peroxide number is one of the values to determine the degree of damage to the oil. Double bonds in unsaturated fatty acids easily undergo oxidation reactions to form unstable peroxides. Peroxides can undergo further reactions to form aldehydes and ketones, which result in brown oil color and rancid odor (Fardani et al., 2025; Rahayu & Supriyatin, 2017). According to SNI 2019, the peroxide number in cooking oil is 10 $meqO_2/kg$. The peroxide number of this study's initial UCO exceeded the SNI provisions of 11.68 $meqO_2/kg$.

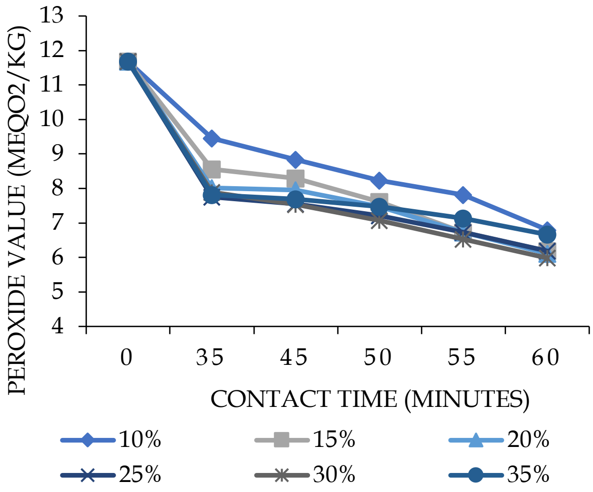

Figure 7. Peroxide value

Figure 7 shows that increasing the contact time between turmeric adsorbent and peroxide in UCO can reduce peroxide levels due to the longer time required to interact with the adsorbate to reach equilibrium. In addition, increasing the adsorbent mass also results in a greater reduction in peroxide levels, as it provides more active sites for adsorption (Chairgulprasert & Madlah, 2018; Padmavathy et al., 2016). However, there is an optimal adsorbent amount, because excessive adsorbent can reduce efficiency. With the increase in turmeric dose, overcrowding of the adsorbent particles occurred, decreasing the effective surface area (Ray et al., 2020). The best peroxide value was achieved when the adsorbent mass was 30 grams and the adsorption time was 60 minutes. This resulted in a 5.98 meqO_2/kg peroxide content and an adsorption efficiency (E%) level of 48.775%. This value meets peroxide quality standards according to SNI (SNI-7709-2019, 2019). This shows that turmeric has the potential to regenerate UCO to meet the standard.

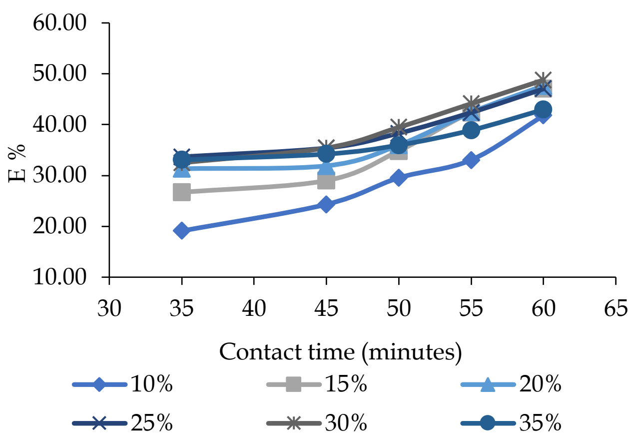

Figure 8. Adsorption efficiency of peroxide value

Adsorption Isotherm

Several factors influence an adsorbent's adsorption process, and it has a specific isotherm pattern. The type of adsorbent, the kind of substance absorbed, the surface area of the adsorbent, the concentration of the substance adsorbed, and temperature are some factors that influence the adsorption process. With these factors, each adsorbent that absorbs one substance with another will not have the same adsorption pattern. The distribution of adsorbed molecules between the liquid phase and the solid phase when the adsorption process reaches equilibrium is explained using the adsorption isotherm. Two types of adsorption isotherm pattern equations are commonly used in the adsorption process in solution, namely the Langmuir and Freundlich adsorption equations (Rengga et al., 2021). The adsorption isotherm in this study was carried out by plotting the levels of free fatty acids absorbed per mass of adsorbent (Qe) against the amount of residual dissolved free fatty acids at equilibrium (Ce) (Chairgulprasert & Nileah, 2019; Popoola, 2019). Langmuir isotherm assumes no interaction between adsorbate molecules; the absorption process forms a monolayer and occurs at specific sites uniformly throughout the adsorbent surface. This Langmuir isotherm model is shown in the following equation.

$$\frac{C_e}{q_e} = \frac{1}{K_L q_{max}} + \frac{C_e}{q_{max}} \quad (6)$$

Where q_e (mg/g) is the mass of FFA adsorbed per mass of turmeric adsorbent, C_e (mg/mL) is the equilibrium concentration of FFA in oil, q_{max} (mg/g) is the monolayer adsorption capacity, and K_L is the Langmuir constant related to the affinity of the bound site. The K_L and Q_{max} values were calculated from the intercept and slope of the C_e/q_e plot against C_e. The adsorption isotherm model in this study can be seen in Figure 9.

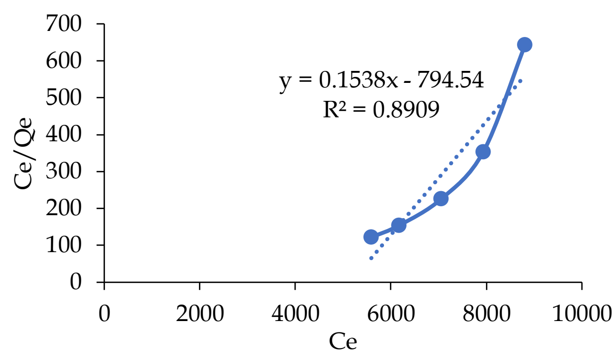

Figure 9. Langmuir isotherm

The Freundlich isotherm is based on multilayer adsorption on a homogeneous surface. The equation in this adsorption model is shown below.

$$\log q_e = \log K_F + \frac{1}{n}\log C_e \quad (7)$$

K_F (L/g) is the Freundlich constant related to the adsorption capacity, and n is an empirical parameter related to the adsorption intensity and surface heterogeneity. The n and K_F values were calculated from the slopes and intercepts of the plot between log q_e and log C_e. The Freundlich isotherm model in this study can be seen in the following figure.

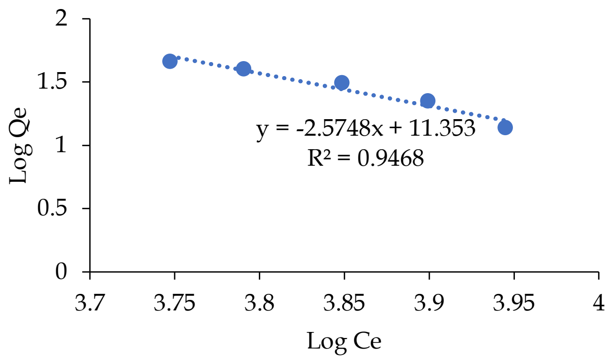

Figure 10. Freundlich isotherm

Based on Figures 9 and 10, the Freundlich isotherm model's R^2 value is closer to 1, reaching a value of 0.9468 compared to the Langmuir isotherm model. Consequently, the adsorption process of free fatty acids on UCO with turmeric adsorbent follows the Freundlich isotherm model.

Conclusion

Turmeric has the potential to regenerate UCO to meet the SNI 7709-2019. The IR spectrum characterization results of turmeric show the presence of hydroxyl groups that play a role in the adsorption of free fatty acids, peroxide compounds, and water content in UCO. The adsorption process follows the Freundlich isotherm model. The free fatty acid value, water content, and peroxide value of used cooking oil before adsorption with turmeric adsorbent were 1.018%, 0.1350%, and 11,68 $meqO_2$/kg. The best free fatty acid results when the adsorption mass was 20 grams at 60 minutes. The best water content and peroxide value was when the adsorption mass was 30 grams at 60 minutes. The best mass adsorbent differs between free fatty acid and peroxide value because the adsorption process has several factors, one is the kind of substance adsorbed. each adsorbent that absorbs one substance with another will not have the same adsorption pattern.

Acknowledgments

We want to thank the various individuals and organizations that have supported and contributed to completing this research. We are grateful to the Surabaya Academy of Pharmacy for providing the necessary facilities and resources to conduct the research and analyze the data. We would also like to thank the research assistants who helped conduct this research. In addition, we would like to thank the Directorate General of Higher Education, Research and Technology for the financial support provided. We would also like to thank all those who have directly or indirectly contributed to completing this research.

Author Contributions

Conceptualization, V.A.D. and D.A.; methodology, writing—original draft preparation, supervision, V.A.D.; writing—review and editing, V.A.D. and Q.A.; project administration, DA. All authors have read and agreed to the published version of the manuscript.

Funding

The research was funded by the Ministry of Research, Technology, and Higher Education of the Republic of Indonesia.

Conflicts of Interest

There is no conflict of interest in this writing.

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