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Optimization of the Iron (Fe) Adsorption Process in Well Water Using Oil Palm Shell Activated Carbon by the Response Surface Methodology (RSM)

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Abstract**—***Water containing high concentrations of iron (Fe) can degrade water quality and cause adverse health effects. This study aimed to determine the optimum adsorption conditions of activated carbon derived from oil palm shell produced through partial oxidation pyrolysis to reduce Fe concentration in well water in accordance with the Indonesian Ministry of Health Regulation (PERMENKES RI) No. 2 of 2023. Optimization was perfomed using Response Surface Methodology (RSM) assited by Design Expert 13 software. The variables studied were contact time (40-80 minutes) and stirring speed (100-200 rpm), with a fixed adsorbent mass of 5 g. Iron concentration was analyzed using AAS 240. The results showed that the optimum conditions were achieved at a contact time of 80 minutes and a stirring speed of 200 rpm, yielding a high desirability value of 0.979. Application of these conditions to well water resulted in a adsorption capacity of 0.195 mg/L, which meets the hygiene and sanitation water quality standards stipulated in PERMENKES RI No. 2 of 2023.*

Keywords**—** *Adsorption, Activated carbon, Palm oil sheel, Iron (Fe), Response Surface Methodology*

I. INTRODUCTION

Clean water is a fundamental human need that must be ensured in both adequate quantity and acceptable quality. Nevertheless, many communities still depend on water sources such as dug wells, bore wells, and rivers, where the water quality frequently fails to meet recommended standards. Groundwater obtained from bore wells often contains dissolved iron (Fe), which may pose potential risks to human health. One common indication of high iron content is the transformation of water color from clear to yellowish when it comes into contact with air. Continuous exposure to elevated iron concentrations over a long period may lead to various health-related issues, highlighting the importance of applying appropriate treatment techniques to reduce dissolved metal levels in water [1]. Iron (Fe) concentrations in bore well water are commonly reported in the range of 5–7 mg/L. In contrast, the Indonesian Ministry of Health Regulation No. 2 of 2023 establishes a maximum permissible limit of 0.2 mg/L for iron content in clean water [2].

Various treatment approaches can be applied to reduce the concentration of heavy metals in wastewater. One commonly used method is adsorption using activated carbon, which is considered simple and effective for treating industrial effluents. The adsorption capacity of activated carbon is strongly influenced by the surface area of its particles. This capacity can be further enhanced through activation processes, either by chemical activation using H_3PO_4 or by physical activation through high-temperature heating up to 850 °C [3]. The adsorption process was evaluated by analyzing experimental data using Design Expert 13 software with the Response Surface Methodology (RSM) approach. RSM is a statistical and mathematical technique widely used to develop empirical models and to determine optimal operating conditions based on specific objectives. This method utilizes experimental data to construct regression models that describe the relationship between independent variables and the response. Through this approach, the interaction effects among variables can be analyzed to identify the most favorable conditions for achieving optimal results [4].

This study aims to determine the optimal conditions for activated carbon adsorption in reducing iron (Fe) concentrations in well water using a Response Surface Methodology (RSM) experimental design implemented through Design Expert 13 software. In addition, this research utilizes oil palm shell waste as the raw material for producing activated carbon, which is applied as an adsorbent to remove iron (Fe) from water used for daily household purposes.

II. METHODOLOGY

2.1 Material

The adsorbent employed in this research was activated carbon produced from oil palm shell waste, which was supplied by PT Dharma Sumber Energi in Palaran District, East Kalimantan, Indonesia. The groundwater samples analyzed in this study were collected from a residential well located at Jalan Manunggal, Gang Hariono Nimpuno, Samarinda Seberang, East Kalimantan, Indonesia.

2.2 Method

The adsorbent was prepared from oil palm shell waste. The shells were first washed and dried, followed by carbonization through a pyrolysis process with partial oxidation at 300 °C to produce charcoal. The resulting charcoal was then chemically activated using a 10% H_3PO_4 solution and subsequently dried to enhance the pore structure and increase the surface area of the adsorbent. Activated carbon characterization was carried out following the SNI 06-3707-1995 standard, which involves the analysis of moisture content, ash content, volatile matter, and fixed carbon to evaluate the physicochemical properties of the adsorbent. Batch adsorption experiments were conducted

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by introducing 5 g of adsorbent into 100 mL of Fe solution. The independent variables investigated in this study included contact time (40, 60, and 80 minutes) and stirring speed (100, 150, and 200 rpm). After the adsorption process, the solution was filtered and the remaining iron concentration was determined. Process optimization was performed using Response Surface Methodology (RSM) with a Central Composite Design (CCD) implemented through Design Expert 13 Software. The iron (Fe) concentrations before and after adsorption were measured using Atomic Absorption Spectroscopy (AAS). Subsequently, the adsorption efficiency and adsorption capacity were calculated based on the obtained data.

III. RESULT AND DISCUSSION

3.1 Characteristics of Activated Carbon

Activated carbon produced from oil palm shells through partial oxidation pyrolysis, followed by chemical activation using 10% phosphoric acid (H_3PO_4), exhibited favorable physicochemical characteristics. Proximate analysis indicated that the activated carbon contained 13.64% moisture content, 8.58% ash content, 7.86% volatile matter, and 69.92% fixed carbon. These values comply with the requirements specified in the Indonesian National Standard (SNI 06-3707-1995).

TABLE I. Proximate Analysis Results of Activated Carbon

Sample	Moisture Content (%)	Ash Content (%)	Volatile Matter (%)	Fixed Carbon (%)	Iodine Number (mg/g)
H_3PO_4-activated carbon (10%)	13.64	8.58	7.86	69.92	785.67
SNI 06-3707-1995 Standard	Max. 15	Max. 10	Max. 25	Min. 65	Min. 750

According to the technical standards for activated carbon, the relatively high fixed carbon content indicates that the carbonization process occurred effectively. In addition, the iodine adsorption capacity of 785.67 mg/g suggests the development of a well-formed pore structure predominantly composed of micropores. An iodine number exceeding 750 mg/g reflects a strong adsorption capability, particularly for small molecules or ions such as Fe^{2+} [5]. Chemical activation using H_3PO_4 is believed to contribute to the enlargement and opening of pore structures through dehydration reactions and the breakdown of structural bonds during the heating process. These mechanisms promote the development of internal surface area and increase the number of active adsorption sites available on the activated carbon [6].

The optimization of Fe removal through adsorption was performed using Response Surface Methodology (RSM) combined with a Central Composite Design (CCD). This experimental design was used to investigate the influence of contact time (40–80 min) and stirring speed (100–200 rpm) on the residual Fe concentration and the overall adsorption efficiency. The statistical evaluation revealed that the quadratic regression model provided the most appropriate description of the experimental data. Results from the Sequential Model Sum of Squares analysis confirmed that the quadratic model significantly improved the predictive capability compared with both the linear and two-factor interaction models. In addition, the Lack of Fit test produced a non-significant result, indicating that the regression model adequately represents the experimental system and that no systematic deviation was observed [7].

The coefficient of determination (R^2) obtained for both responses exceeded 0.90, indicating a strong agreement between the predicted values and the experimental observations. The relatively small difference between the adjusted R^2 and predicted R^2 further confirms that the developed model possesses reliable and consistent predictive performance. Analysis of variance (ANOVA) revealed that both contact time and stirring speed significantly influenced the efficiency of Fe adsorption, and a meaningful interaction between these two variables was also observed. In addition, the presence of a significant quadratic effect suggests curvature in the response surface, indicating that a second-order model is appropriate for representing the experimental system [8].

An increase in contact time resulted in a gradual improvement in adsorption efficiency. This trend indicates that the diffusion of Fe ions from the solution to the adsorbent surface occurs progressively over time. During the initial stage with shorter contact times, the adsorption process mainly takes place on the external surface of the activated carbon. As the contact time increases, intraparticle diffusion becomes more significant, allowing Fe ions to penetrate the micropores and mesopores formed during the chemical activation process. At a contact time of 80 minutes, the adsorption system approaches equilibrium conditions, where most of the available active sites have been occupied and the rate of adsorption begins to decline. This behavior suggests that the adsorption mechanism is influenced not only by external mass transfer but also by diffusion within the pore structure of the adsorbent [9].

Stirring speed was also found to play an important role in determining adsorption performance. Increasing the agitation rate enhances mass transfer by reducing the thickness of the boundary layer surrounding the adsorbent particles. As the stirring speed increased from 100 to 200 rpm, the frequency of collisions between Fe ions and the active surface of the adsorbent became higher, which contributed to improved adsorption efficiency. Within the investigated range, no evidence of pore structure damage in the activated carbon was observed due to agitation. Therefore, the improvement in adsorption performance is mainly attributed to enhanced external diffusion, rather than changes in the intrinsic adsorption capacity of the adsorbent [10].

The three-dimensional response surface plot exhibited an elliptical contour pattern, indicating a significant interaction between contact time and stirring speed.

This synergistic relationship indicates that optimal adsorption conditions are achieved through a balance between sufficient contact time, which allows Fe ions to diffuse into the pore structure of the adsorbent, and adequate stirring intensity, which reduces resistance to external mass transfer. When the agitation rate is low, extending the contact time alone cannot effectively overcome diffusion limitations. Conversely, high stirring speeds without adequate contact time do not allow Fe ions sufficient opportunity to reach the internal adsorption sites. These findings highlight the advantage of Response

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Surface Methodology (RSM) over conventional one-factor-at-a-time approaches, as it enables the simultaneous evaluation of the combined effects of multiple variables while requiring a more efficient number of experimental runs [11].

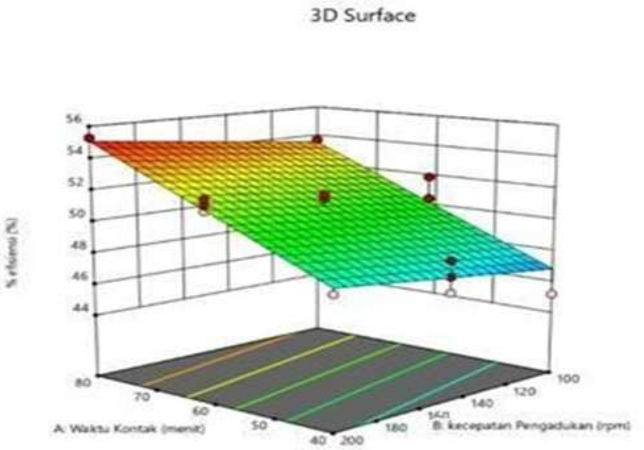

Fig.1. 3D Response Surface of Fe Removal Efficiency as a Function of Contact Time and Stirring Speed

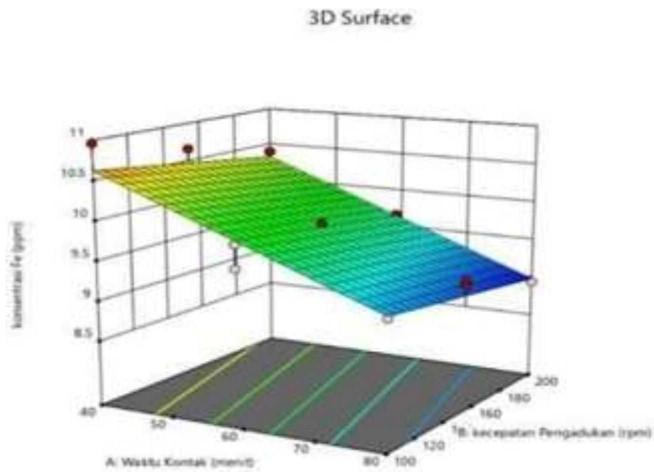

Fig. 2. 3D Response Surface Plot of Fe Concentration as a Function of Contact Time and Stirring Speed

The optimization of multiple responses using the desirability function approach identified the optimal operating conditions at a contact time of 80 min and a stirring speed of 200 rpm, yielding a desirability value of 0.979. A desirability value approaching unity indicates a very high level of agreement between the optimization objectives and the model predictions. To verify the reliability of the model, validation experiments were conducted under the predicted optimal conditions. The experimental results showed values that were in close agreement with those predicted by the model, demonstrating that the developed model provides high predictive accuracy and reliability for describing the adsorption process.

Application of the optimized adsorption conditions to actual well water samples demonstrated a significant reduction in Fe concentration, decreasing from 0.398 mg/L to below 0.2 mg/L. This result meets the water quality standards established by the Regulation of the Indonesian Ministry of Health (PERMENKES RI No. 2 of 2023). The adsorption capacity obtained was 0.190 mg/g, indicating that the active sites of the activated carbon were effectively utilized during the adsorption process. Furthermore, the successful performance of the adsorbent in real water matrices confirms that the optimization model is not only statistically reliable but also practically applicable for the treatment of iron-contaminated groundwater.

TABLE 2. Experimental Results of Fe Removal Efficiency (%) and Final Fe Concentration Fe.

No	Sample	Fe Concentration (ppm)
1	Well Water	0.398
2	Well Water + Activated Carbon	0.190

Compared with conventional optimization techniques, the application of Response Surface Methodology (RSM) in this study effectively reduced experimental complexity while providing comprehensive insight into the interactions among variables and the overall system behavior. This approach enables the prediction of optimal operating conditions using a relatively small number of experimental runs.

Furthermore, the utilization of oil palm shell waste as a precursor for activated carbon production supports the principles of circular economy and sustainable waste management. The transformation of agricultural biomass into high-value adsorbent materials offers a more economical and environmentally friendly alternative for water treatment, particularly in regions where groundwater contains elevated iron concentrations.

Overall, the findings of this study demonstrate that activated carbon derived from oil palm shells, produced through partial oxidation pyrolysis followed by phosphoric acid activation, exhibits effective adsorption performance toward dissolved iron ions. The application of Response Surface Methodology (RSM) proved to be a reliable approach for optimizing the adsorption process and provides a solid foundation for further scale-up studies and potential industrial implementation.

IV. Conclusion

1. The optimum conditions suggested by Design Expert 13 were achieved by setting the process at a contact time of 80 minutes and a stirring speed of 200 rpm. Under these conditions, the optimum Fe removal efficiency obtained was 55.28%, with a final Fe adsorption capacity of 8.945 mg/g, and a desirability value of 0.979**.**
2. The application of oil palm shell activated carbon to well water was able to reduce the Fe content from 0.398 mg/g to 0.190 mg/g. Therefore, adsorption using oil palm shell activated carbon is capable of meeting the water quality standards specified in PERMENKES No. 2 of 2023.

References

[1] A. Ubaidillah and M. Faizal, "Applied Research and Policy Publication," *Applied Research and Policy Publication*, vol. 1, no. 2, 2022.

[2] C. E. Pontoh, R. Mauliddina, and S. Sahraeni, "Reduction of Fe Concentration Using Activated Carbon Adsorbent from NaCl-Activated Gambir Fibers," *Jurnal Inovasi Global*, vol. 2, no. 7, pp. 688–695, 2024, doi:10.58344/Jig.V2i7.122.

[3] H. Najmia and R. P. M. E. S. Mahreda, "Utilization of H_3PO_4-Activated

Oil Palm Shell Activated Carbon for the Removal of Iron (Fe), Manganese (Mn), and pH Adjustment in Acid Mine Drainage," *Jurnal Enviro Scientea*, vol. 17, no. 2, hlm. 21–29, 2021.
[4] E. Noviana, "Study on the Application of Response Surface Methodology (RSM) for Optimization of the Transesterification Reaction Product of Coconut Oil Using Zeolite-A as a Catalyst," Bachelor's thesis, Universitas Lampung, Bandar Lampung, Indonesia, 2023.
[5] N. Laija and Z. Faza, "Adsorption of Cd(II) Metal Using Activated Carbon Adsorbent Derived from Fruit Peels," *Issue 1*, 2021.
[6] Y. A. Warlinda and R. Zainul, "Phosphoric Acid (H_3PO_4): Ionic Transformation of Phosphoric Acid in Aqueous Solution," *INA-Rxiv*, pp. 44–55, 2023
[7] I. A. Widhiantari, S. Sandra, and G. Djoyowasito, "Changes in the Physical Properties of Tomatoes After Transportation Process," *Jurnal Ilmiah Rekayasa Pertanian dan Biosistem*, vol. 7, no. 2, pp. 139–147, 2019.
[8] T. Priscilla, M. Irwan, and Z. Arifin, "Biodiesel Synthesis from Waste Cooking Oil in an Ultrasonic Reactor," *Jurnal Energi Baru dan Terbarukan*, vol. 5, no. 1, pp. 44–56, 2024.
[9] U. K. Saud, M. Rajabzadeh, and H. Aghaie, "Thermodynamic Study of Iron (III) Removal Using Synthesized Adsorbent and Alumina Powder by Evaluating Adsorption Isotherm Models with the Response Surface Method," pp. 4254–4262, 2020.
[10] L. A. Simbolon, B. N. Widarti, and E. Sarwono, "Utilization of Coconut Fiber as a Bioadsorbent for the Removal of Iron (Fe) and Chromium (Cr) from Leachate with Variations in Contact Time and Stirring Speed Using a Batch System," *Jurnal Teknologi Lingkungan Unmul*, vol. 6, no. 1, p. 12, 2022, doi:10.30872/jtlunmul.v6i1.7107.
[11] M. Ebba, P. Asaithambi, and E. Alemayehu, "Development of Electrocoagulation Process for Wastewater Treatment: Optimization by Response Surface Methodology," *Heliyon*, vol. 8, no. 5, 2022, doi:10.1016/j.heliyon.2022.e09383.