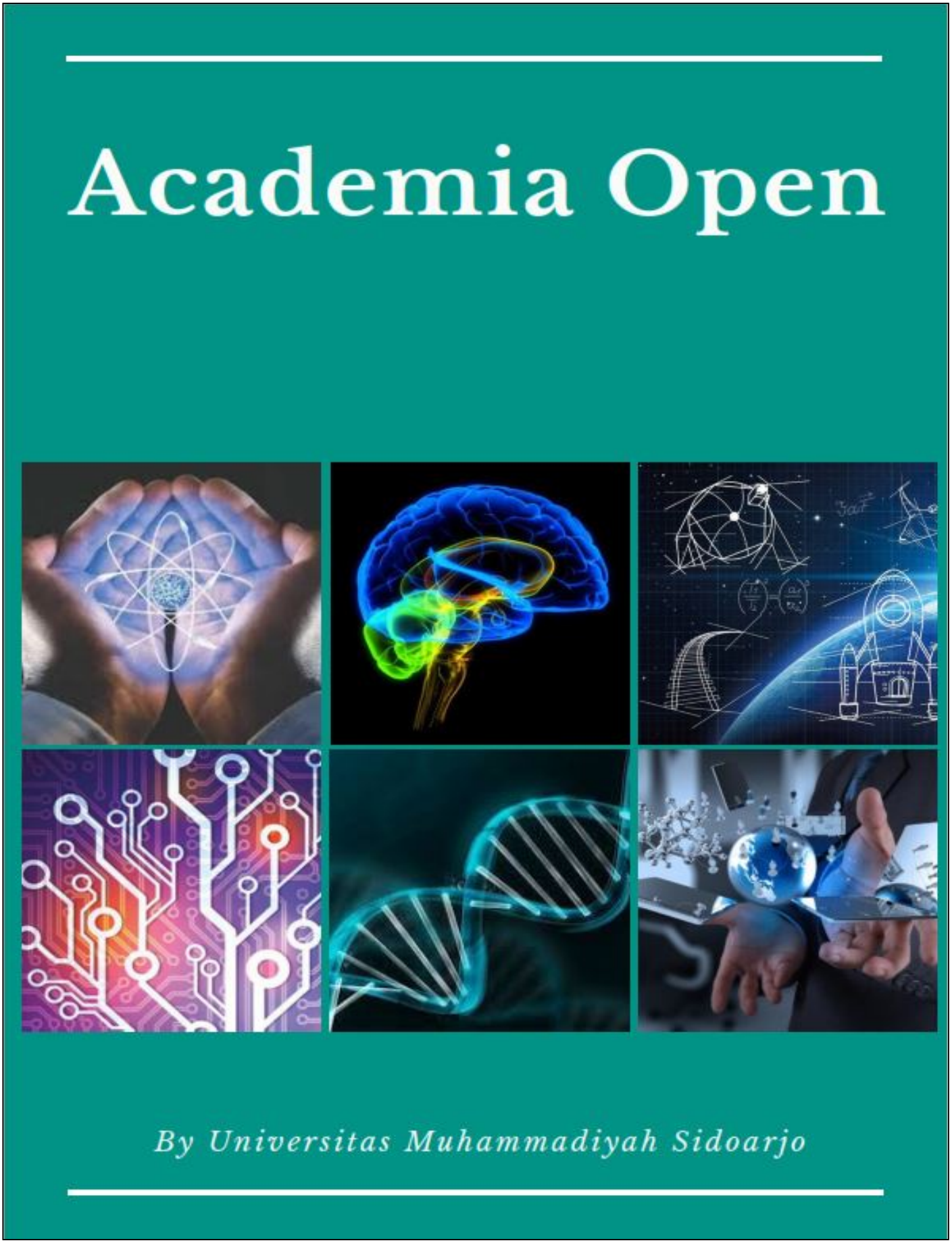
Academia Open
Vol 10 No 1 (2025): June (In Progress)
DOI: 10.21070/acopen.10.2025.10494 . Article type: (Engineering)

Table Of Content

Journal Cover 2
Author[s] Statement 3
Editorial Team 4
Article information 5
Check this article update (crossmark) 5
Check this article impact 5
Cite this article 5
Title page 6
Article Title 6
Author information 6
Abstract 6
Article content 7

ISSN 2714-7444 (online), https://acopen.umsida.ac.id, published by Universitas Muhammadiyah Sidoarjo
Copyright © Author(s). This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY).

Academia Open
Vol 10 No 1 (2025): June (In Progress)
DOI: 10.21070/acopen.10.2025.10494 . Article type: (Engineering)



ISSN 2714-7444 (online), https://acopen.umsida.ac.id, published by Universitas Muhammadiyah Sidoarjo
Copyright © Author(s). This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY).

Academia Open
Vol 10 No 1 (2025): June (In Progress)
DOI: 10.21070/acopen.10.2025.10494 . Article type: (Engineering)

Originality Statement

The author[s] declare that this article is their own work and to the best of their knowledge it contains no materials previously published or written by another person, or substantial proportions of material which have been accepted for the published of any other published materials, except where due acknowledgement is made in the article. Any contribution made to the research by others, with whom author[s] have work, is explicitly acknowledged in the article.

Conflict of Interest Statement

The author[s] declare that this article was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Copyright Statement

Copyright © Author(s). This article is published under the Creative Commons Attribution (CC BY 4.0) licence. Anyone may reproduce, distribute, translate and create derivative works of this article (for both commercial and non-commercial purposes), subject to full attribution to the original publication and authors. The full terms of this licence may be seen at http://creativecommons.org/licences/by/4.0/legalcode

Copyright © Author(s). This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY).

Academia Open
Vol 10 No 1 (2025): June (In Progress)
DOI: 10.21070/acopen.10.2025.10494 . Article type: (Engineering)

EDITORIAL TEAM

Editor in Chief

Mochammad Tanzil Multazam, Universitas Muhammadiyah Sidoarjo, Indonesia

Managing Editor

Bobur Sobirov, Samarkand Institute of Economics and Service, Uzbekistan

Editors

Fika Megawati, Universitas Muhammadiyah Sidoarjo, Indonesia

Mahardika Darmawan Kusuma Wardana, Universitas Muhammadiyah Sidoarjo, Indonesia

Wiwit Wahyu Wijayanti, Universitas Muhammadiyah Sidoarjo, Indonesia

Farkhod Abdurakhmonov, Silk Road International Tourism University, Uzbekistan

Dr. Hindarto, Universitas Muhammadiyah Sidoarjo, Indonesia

Evi Rinata, Universitas Muhammadiyah Sidoarjo, Indonesia

M Faisal Amir, Universitas Muhammadiyah Sidoarjo, Indonesia

Dr. Hana Catur Wahyuni, Universitas Muhammadiyah Sidoarjo, Indonesia

Complete list of editorial team (link)

Complete list of indexing services for this journal (link)

How to submit to this journal (link)

ISSN 2714-7444 (online), https://acopen.umsida.ac.id, published by Universitas Muhammadiyah Sidoarjo
Copyright © Author(s). This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY).

Academia Open
Vol 10 No 1 (2025): June (In Progress)
DOI: 10.21070/acopen.10.2025.10494 . Article type: (Engineering)

Article information

Check this article update (crossmark)



Check this article impact (*)















Save this article to Mendeley



(*) Time for indexing process is various, depends on indexing database platform

ISSN 2714-7444 (online), https://acopen.umsida.ac.id, published by Universitas Muhammadiyah Sidoarjo
Copyright © Author(s). This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY).

Academia Open
Vol 10 No 1 (2025): June (In Progress)
DOI: 10.21070/acopen.10.2025.10494 . Article type: (Engineering)

Thermodynamic Analysis of Activated Walnut Husks in the Adsorption of Iron (III) Ions from Aqueous Solutions: An Assessment of Feasibility and Sustainability

Analisis Termodinamika Sekam Kenari Teraktivasi dalam Adsorpsi Ion Besi (III) dari Larutan Berair: Penilaian Kelayakan dan Keberlanjutan

Ihab. A. Altameemi, Ehab.chemical88@gmail.com, (1)
Basra Education Directorate General, Ministry of Education, Iraq

Ahmed Makki Sadaa, ahmed@gmail.com, (0)
Basra Education Directorate General, Ministry of Education, Iraq

(1) Corresponding author

Abstract

This is the case of global water contamination phenomena for which an economic solution is necessary. Walnut husks have proved to be cost-effective alternatives in iron removal from aqueous solutions. A biosorption study of Fe(III) from aqueous solution using walnut husk powder pointed out that sorption capacity increased as the sorption temperature rose in accordance with various isotherm models. Thermodynamic study says that this is an endothermic process. That would then vindicate this study as showing the potential walnut husks, hence, can be used to efficiently remove heavy metals, which include iron, from water. Under the optimum condition, the maximum percentage removal was 93.28%. Observations during the experiment of the adsorbent showed high degrees of removal; at 25°C, pH=2, concentration = 100ppm, and weight=0.5g, the least percentage removal is up to 89.244 percent. Data shows that the regression coefficients give superiority to the Langmuir isotherm over the Freundlich model. Equilibrium data for the process were tested with the constants of Langmuir, and the constants of Freundlich were calculated. Further, thermodynamic experiments were carried out to ascertain the values of ΔS, ΔH, and ΔG for the adsorption of iron under optimized experimental conditions. Adsorption Capacity of Walnut Husks Powder for the Removal of Iron (Fe+3).

Highlights:

1. Walnut husks effectively remove iron from aqueous solutions (93.28% removal).
2. Sorption capacity increases with temperature; Langmuir model fits best.
3. Thermodynamic study confirms endothermic nature, with positive ΔH and ΔS.

Keywords: Walnut husks, iron removal, biosorption, Langmuir isotherm, thermodynamic study

Published date: 2025-01-18 00:00:00

Copyright © Author(s). This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY).

Academia Open
Vol 10 No 1 (2025): June (In Progress)
DOI: 10.21070/acopen.10.2025.10494 . Article type: (Engineering)

Introduction

Water pollution is identified as a major challenge; therefore, water resource policies need to be under constant review and re-examination at all levels. Securing sources of water is a necessary precondition for ensuring human welfare. At least 5 million people die each year-mostly from water-related diseases, because of using dirty water. There is no fail-safe way to guarantee clean drinking water and, therefore, no 'human' diseases, except not letting any toxin get into the water source in the first place. After this, one needs to understand whether.

Most of the toxic compounds may be taken off by the usual methods for the treatment of water. Among all the impurities present in water, heavy metals need special consideration among an important category. These are elements with an atomic number of more than 50 and more than 5.0 in specific gravity. At least twenty metals have been identified to be toxic, half' being, so to speak, 'dumped' into the environment at toxic levels, no less possibly in mineralized rocks. Chromium and iron are metalloids that constitute these two metals, which are derived from several industrial activities such as electroplating, leather, tanning, mining, processing, refining, etc. [3],[4], quite away from their normal area of habitat. Decreased water friction can lead to other health problems such as stomach and lung cancer, irritable bowel syndrome, acute diarrhea causing death, kidney injury as well as stomach injury, among others [5], [6]. Such forms include precipitation, biotreatment, particle trafficking, electrochemical, layer filtration, and adsorption of heavy metal particles from the wastewater [7], [8]. However, most of these are quite expensive and ineffective for reducing the rate of the metal particles in the wastewater to such levels [8], [9]. When all other cited methods are compared with adsorption preparation, it proves to be most favorable and esteemed, while metal particle evacuation from industrial effluent because it's highly effective treatment and less preparation cost as compared to other preferred methods [10Activated carbon today is produced from a wide range of low-priced readily available materials organic and inorganic materials with a high content of carbon, for example, coconut shells, cherry stones, rice hulls, walnut husks, hazelnut shells, and s walnut husks [16]. They illustrate alternatives to one another as models of air conditioning planning- chemical legislation and physical legislation, especially at continued high temperatures in the presence of gases like Carbon dioxide, steam, etc., where the physical processes are also enforced. Dryers and oxidizers performing chemical operations include HNO3, NaOH, KOH, and ZnCl2. The control, temperature insensitivity, productivity, and lead time give the following advantages over operation by physical means, which has been featured by this technique [18].

Tannin studies in various works have shown that untreated walnut husks do contain tannin. Their structure has hydroxyl groups that show affinity reactions with metals. It has been reported that tannin is capable of efficiently removing heavy metals.

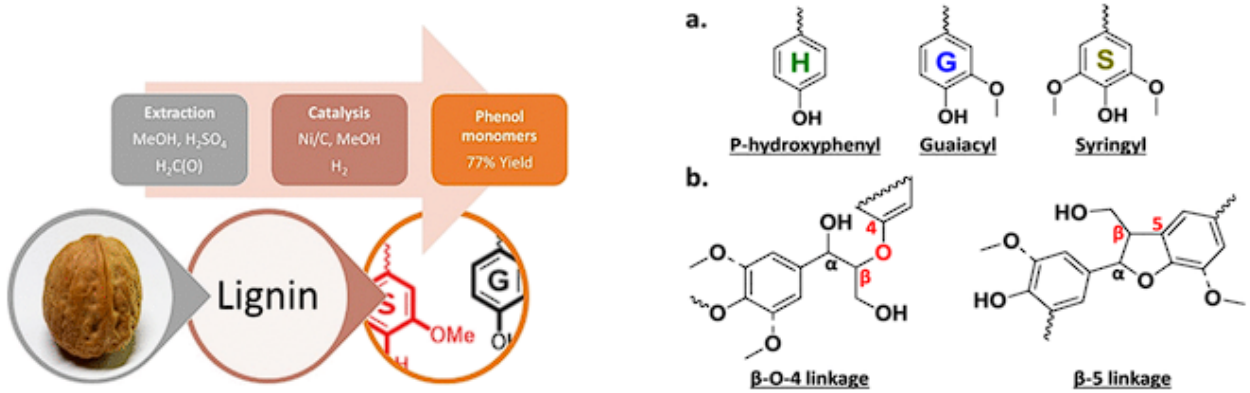


Figure 1.

Fig 1 Walnut husks s, . Lignin (a) monomers and (b) predominant linkages.

This research aimed to study the possibility of using ground walnut husks with a size of (10-100) microns as a low-cost material to expel hump ions from polluted water and to study adsorption thermodynamics and isothermal. At appropriate pH, contact time, and concentrations, walnut husks do far better at repelling mineral particles than the former alone. Primary and adsorbent measurements.

Methods

2.1 Materials

The Cashew nutshell liquid waste was collected from the restaurants after being thoroughly washed with deionized

ISSN 2714-7444 (online), https://acopen.umsida.ac.id, published by Universitas Muhammadiyah Sidoarjo
Copyright © Author(s). This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY).

water to eliminate the impurities. It was then dried at 100°C in an oven overnight and preserved in desiccators for future analysis.

2.2 Preparation of Adsorbents

The sun-dried husks were allowed to cool to room temperature and stored in airtight containers for further use. Equilibrium time for the adsorption process under study is achieved within the first 30 min of initiating the process. Aqueous solutions were prepared using FeCl3.H2O, AgNO3, and thiourea of pro-analysis grade quality in all batch experiments at 30 ± 1 °C temperature maintained, room temperature, and shake speed 140 rpm. Adsorption Kinetics and Isotherms The knowledge from the current work explains the kinetic and isothermal studies of the adsorption of Fe(III) ions from aqueous solutions using walnut husks. All by-products, red bag filters, and other filter media for solution treatment disposed of as hazardous waste shall be disposed of in accordance with all applicable federal, state, and local regulations. Experiments were carried out at different solution pH values varying from 2 to 10, Fe (III) ion initial concentrations ranging between 5 and 100 µg/ml, contact times with the adsorbent fluctuating from 10 to 120 min, for adsorbent quantities of 0.4–2 g, and particle size of 150 µm. Then, after equilibrium was attained, the samples were collected from each flask in 25 ml volume for further analysis. Filtration was done by using Whatman 40 mm filter paper for the samples. The method used for the determination of Fe (III) concentration is Flame Atomic Absorption Spectroscopy (FAAS). The calculated adsorption percentage of removal was aimed to be indicative of the removal efficiency.

To separate conical flasks, 30 mL of 100 µg/mL Fe (III) ion solution was transferred. One hundred µm particle size walnut husks were added to the flasks. It was then made up to the volume of 100 mL with distilled water. These flasks were kept on a shaker at room temperature for a period set at 185 rpm, after which the contents of the flasks were centrifuged after the shaking process. The obtained solution was further studied for the concentration of Fe (III) ions by the FAAS method.

$$\% \text{ Removal} = \frac{(C_\circ - C_e)}{C_\circ} 100 ----(1)$$

$$Q_e = \frac{V_{sol.}(C_\circ - C_e)}{m} ---------(2)$$

Figure 2.

C° and Ce (mg/L) are the concentrations of ions at equilibrium and before adsorption, respectively. V is the volume of the solution (L), and n represents the initial concentration of the solution (in mg/L). The value of Qe denotes the equilibrium adsorption capacity and is expressed in mg/g. The Atomic Absorption Spectrophotometry was employed for the analysis of initial and final levels of Fe. [22]

Result and Discussion

The IR spectrum results show the characteristic bands of walnut powder, as depicted in Figure 2 and Table 1 here. The most important of these are the carbonyl band and the hydroxyl band, which are attributed to the adsorption process.

ISSN 2714-7444 (online), https://acopen.umsida.ac.id, published by Universitas Muhammadiyah Sidoarjo
Copyright © Author(s). This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY).

Academia Open
Vol 10 No 1 (2025): June (In Progress)
DOI: 10.21070/acopen.10.2025.10494 . Article type: (Engineering)

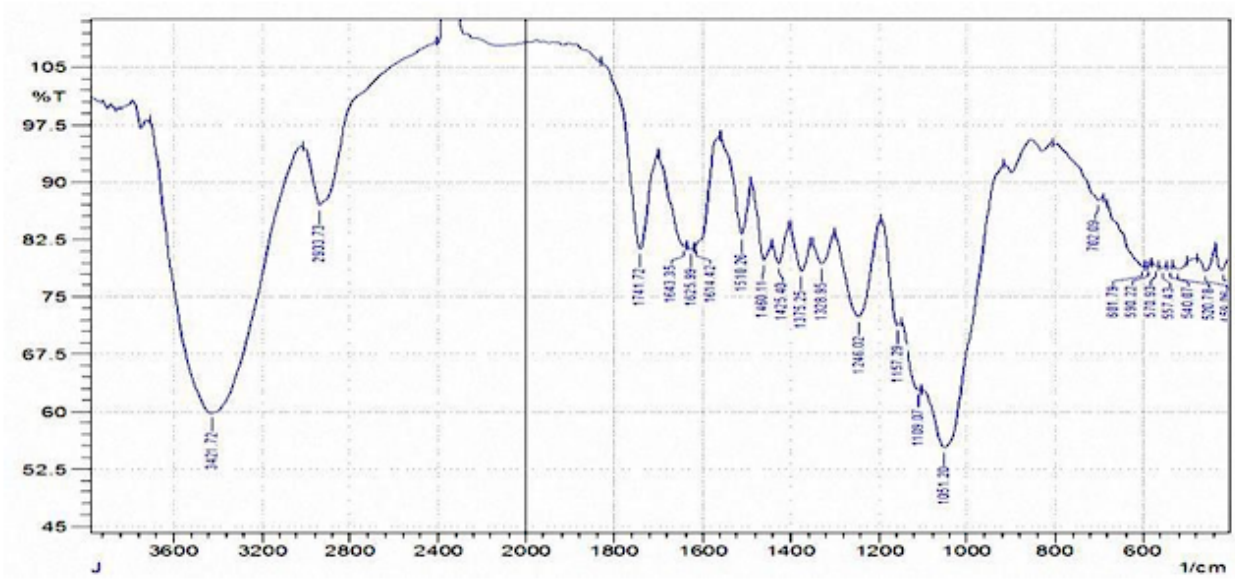


Figure 3. *Walnut husks IR spectra*

Functional groups	formula	Wavelength (cm-1)
Halogen- carbon	C-X	702.09-500
Carbon hydrogen	C-H	2933-3150
Carbonyl	O=C-O	1750-1730
Aromatic	C=C	1600-1475
Hydroxyl	O-H	3421.72-3650
Alkene group	C=C	1680-1600
Carbonyl group	C=O	1700-1725
Carbon oxygen	C-O	1051.20-1300

Table 1. *Study walnut husks functional groups*

3.1. Contact Time Effect.

Figure 3 demonstrates the adsorption of metal particles onto the adsorbent at specific contact times. Results demonstrate that it is a two-step approach. Desorption of mineral particles starts as soon as the suspension of particulate matter is formed, and it decreases gradually with time. Summarizing, at once, within the first 10 min, adsorption was observed t a concentration equilibrium between 10 ppm and 60 ppm when t= 250°C,pH= 7, ppm= 100,rpm= 185,w=0.5, volume 25 mL separately. the adsorption rate was 92% after two h. but no priory adsorption within a concordance level of 60 mm. this behavior type follows from the vacancies, meaning all the sites over the surface of the absorbent are initial vacancies. meanwhile, in increases in the contact time whereby more unfilled sites are bound to a degree thereby achieving a better level of interaction with the pulverized metal particles [23].

ISSN 2714-7444 (online), https://acopen.umsida.ac.id, published by Universitas Muhammadiyah Sidoarjo
Copyright © Author(s). This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY).

Academia Open
Vol 10 No 1 (2025): June (In Progress)
DOI: 10.21070/acopen.10.2025.10494 . Article type: (Engineering)

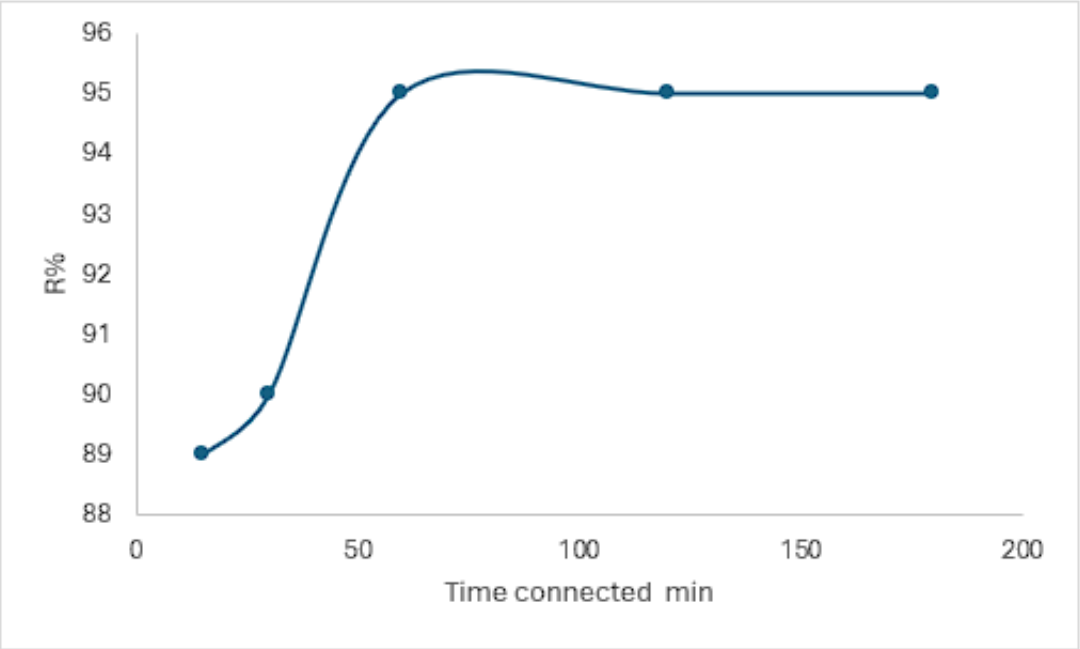


Figure 4. *Relationship between contact time and the ratio of removal*

3.2. pH Effect

The biosorption of crushed minerals was very sensitive to pH. Figure 4, presents Fe(III) biosorption by Walnut husk powder at different pH (2-10) values. The optimum pH for Fe elution is +3 (10). Iron desorption percentages from walnut husk powder at an adsorbent dose of 0.4 g/100 ml of Fe(III) solution and at initial pH = 7 with a feed concentration of 100 ppm are as high as 98%, and this low desorption by admixture appears essentially low at a pH greater than ten due to hydroxides formation. The adsorption at 1000 pH is very low because most of the H+ has been adsorbed jet-like or possibly from mineral particles. At high pH values, the low number of H+ and the fantastic number of negatively bonded atoms in the adsorption of the Fe(III) particles stand out. For instance, COOH carboxylate groups are important groups for mineral uptake by natural materials. At pH above 8-10, the carboxyl bands will become deprotonated and oppositely charged, which would enhance the magic of the charged metal particles. [24]

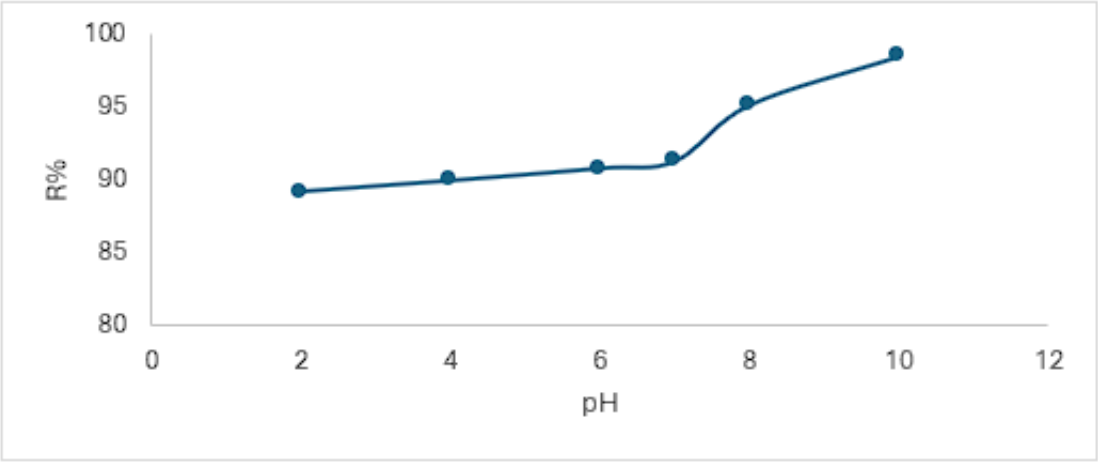


Figure 5. *Relationship between pH and the ratio of removal*

3.3.Wight Effect

Expanding the dosage of the adsorbent usually enhances the efficiency of the adsorption of isotherms at a specified primer concentration. The equilibrium sorbent particle uptake distribution continuously enhances with expanding sorbent size. Fig. 5. Walnut Husks Powder—Observed evacuation efficiencies at 2 grams of sorbent, 98%. Walnut

ISSN 2714-7444 (online), https://acopen.umsida.ac.id, published by Universitas Muhammadiyah Sidoarjo
Copyright © Author(s). This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY).

husk powder—observed an efficacy with 0.2 grams of sorbent, 89%. The increase in the evacuation efficiencies with the sorbent's mass is probably due to the reason that in more massive quantities of walnut husk powder, there is more activation as well as surface area and pore volume available at a higher dose of sorbent to host more active adsorption sites operating at a higher detachable rate. [25]

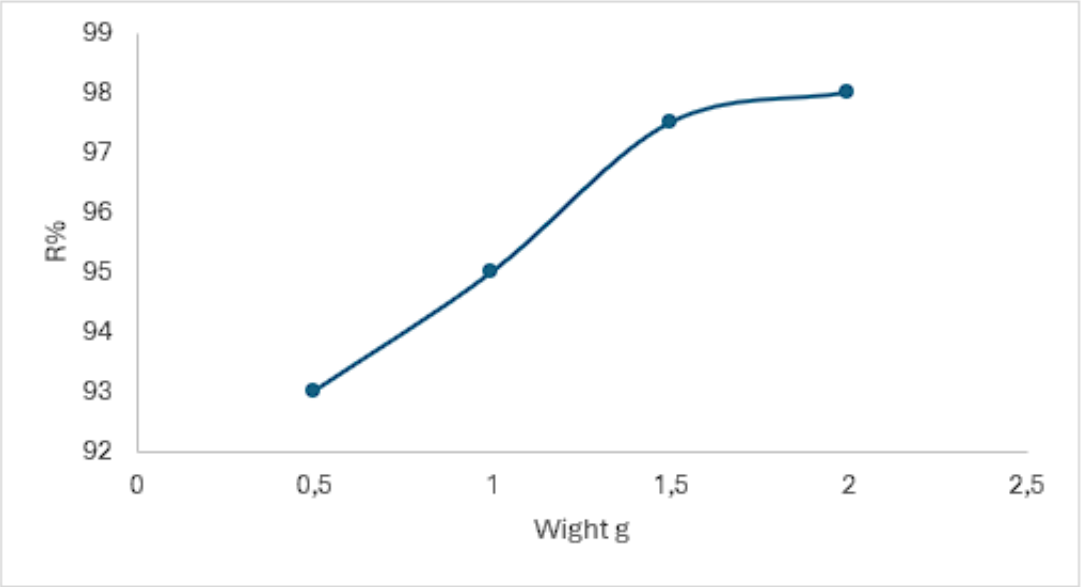


Figure 6. *Relationship between weight and the ratio of removal*

3.4. Contact Conc Effect

The initial concentration creates a driving force strong enough to beat all mass transfer resistances offered during the exchange between the liquid and the solid phases. The initial concentration of metal particles and the equilibrium process are depicted in Figure 6. The effect of initial iron concentration (I1I) was studied at different starting concentrations of 100 mg/L with solutions, and the temperature was 25 °C, with all other parameters kept ideal. In accordance with Figure (Ans), increasing the concentration of metal particles from 10 to 100 mg/L increases the adsorption rate from 93% up to 98 for iron (I1I). Low mineral particle concentrations result in the most available active sites on the adsorbent remaining unsaturated with low adsorption capacities. An increment in the initial concentration enhances adsorption as it provides a better driving force for mass transfer and subsequent mass transfer effective Handle Type Defs absorption capacity [27].

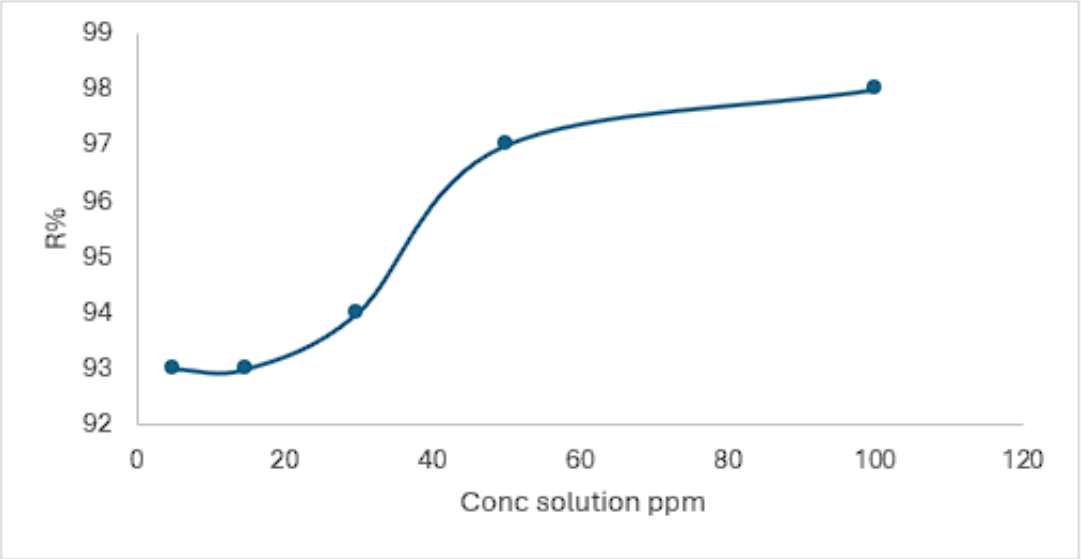


Figure 7. *Relationship between Conc solution ppm and the ratio of removal.*

3.5. Temperature Effect

Copyright © Author(s). This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY).

Academia Open
Vol 10 No 1 (2025): June (In Progress)
DOI: 10.21070/acopen.10.2025.10494 . Article type: (Engineering)

increase in temperature from 25 °C to 55 °C gave a marked increase in the absorption of iron particles (I1I), indicating an endothermic process. Further, the increased uptake of iron particles (I1I) with temperature may relate to more effective desorption of adsorbed species, altered pore sizes, and improved diffusion rates of the adsorbent among the particles since diffusion is an exothermic handle. It has been observed that the average of biosorption increases with increasing temperature; adsorption (rate) is also raised. The hypothesis is confirmed to be exothermic. Wherein the thermodynamics are assessed, these are depicted in Figure (6). Removal of the iron particle (I1I) from walnut husk powder was studied at different temperatures (25-65) at initial pH = 7 with adsorbent dosage (0.5 g), and volume of the solution 20 ml, iron ion (I1I) in solution concentration is 96% [28].

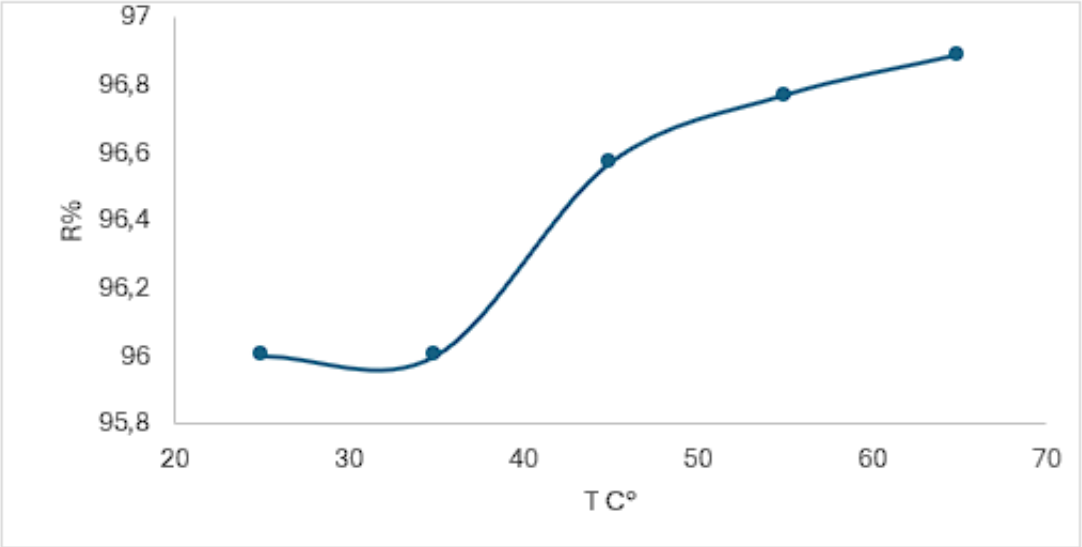


Figure 8. *Relationship between temp and the ratio of removal*

3.6. Isothermal adsorption study:

Several theoretical models describe it as equilibrium biosorption. The most used are Langmuir as well as Freundlich and Temkin equations when monolayer biosorption depends on the monolayer uptake of a solute. According to the outcome of the biosorption in terms of monolayer uptake of solute, the form of the Langmuir isotherm for monolayer biosorption is as follows:

$$Qe = \frac{x}{m} = \frac{KL\,Ce}{(1+aCe)} \ldots\ldots\ldots (3)$$

$$\frac{Ce}{q_e} = \frac{1}{K_L} + \frac{a}{K_L} * Ce \ldots\ldots\ldots (4)$$

Figure 9.

Conditions explain the Freundlich isotherm:

$$Qe = KfCe1/n \ldots\ldots\ldots\ldots\ldots (5)$$

$$\log qe = \log Kf + \frac{1}{n} LogCe. \ldots\ldots\ldots (6)$$

Figure 10.

ISSN 2714-7444 (online), https://acopen.umsida.ac.id, published by Universitas Muhammadiyah Sidoarjo
Copyright © Author(s). This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY).

Academia Open
Vol 10 No 1 (2025): June (In Progress)
DOI: 10.21070/acopen.10.2025.10494 . Article type: (Engineering)

The equilibrium and maximum absorption limits (expressed in mg/g of biosorbent) are represented by Qe and Q-max, respectively. The concentration of the harmony (in the range of mg/l) is denoted as Ce. The equilibrium constant is symbolized as b, while KF and n represent the normal Freudlich constants of the framework. Temkin's model, which focuses on It, studies the adsorption isotherms based on the heat of adsorption and the interaction between adsorbate and adsorbent. Temkin postulated that the absorption of most atoms decreases proportionally with the adsorbate. The next example demonstrated this concept [29].

Qe =B1lnKt + B1lnCe ..... (7)

B1 =RT/b .... (8)

The data adsorption equilibrium for ions onto surface of Walnut husk powder was analyzed using Langmuir equation, Freudlich equation, and Tempkin equation. The constants and other values were calculated by a straight-line plot of the data obtained from these equations and are shown in Table 2. This makes it clear that the highest value obtained is in accordance with the adsorption isotherm of this experiment. Further verification of the R2 value clarifies that the application of the adsorption isotherm of this experiment is more compatible with the equation of Freundlich (R2=0.9324). See Figure 8 for details. [30].

Isotherm	Const.1	Const.2
Freundlich	Kf	n
	62.61812	
	0.449661	
	0.961	
Langmuir	KL	A
	105.2632	
	0.136842	
	0.656	
Temkin	KT	b
	0	
	0.003729	

Table 2. *Isothermal adsorption study*

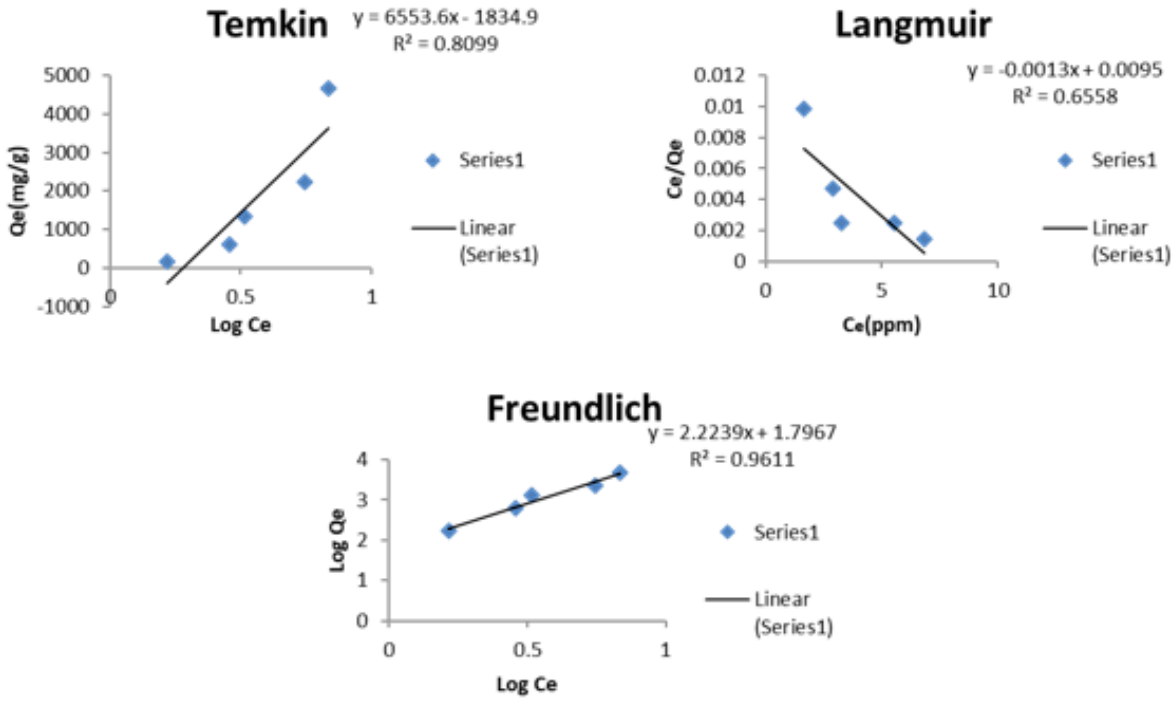


Figure 11. *Show Temkin, Langmuir and Freundlich equation.*

Copyright © Author(s). This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY).

Academia Open
Vol 10 No 1 (2025): June (In Progress)
DOI: 10.21070/acopen.10.2025.10494 . Article type: (Engineering)

3.7Adsorption thermodynamics

The study of thermodynamics of adsorption is one of the best-suited approaches to characterize its thermal nature. The study of these adsorptions is very important from the viewpoint of calculating the thermodynamic parameters of Gibbs free energy (ΔG°), enthalpy change (ΔHo), and entropy change (ΔSo). ΔG° is calculated using equation (9).

ΔG° = -RT ln(Keq) ----------(9)

R (8.314 J. (mol K)-1) is the Outrageous gifs. We are way past the age and check this out now. It is required by simply using the following equation: The attendant value is a function of absolute temperature in kelvin, with the contribution of the universal gas constant given as well.

$$K_{eq} = \frac{mq_e}{VC_e} \qquad \text{--------(10)}$$

Figure 12.

Where qe (mg/g) and Ce (mg/l) stand on the side representing the concentration of metals adsorbed on AC at equilibrium and metal equilibrium concentration in the aqueous phase, respectively also, ΔS° (J/mol. K), the change in entropy and ΔHo (KJ/mol), the change in enthalpy, is expressed as follows:

$$\ln(K_{eq}) = \frac{-\Delta H^0}{RT} + \frac{\Delta S^0}{R} \qquad \text{--------(11)}$$

Figure 13.

By employing the linear regression method, the Vant Hoff plot displayed a linear relationship between ln (Keq) and 1/T. From the intercept and slope of the plot, the values of ΔH and ΔS were determined. These thermodynamic parameters for Fe metal ions are presented in Table (3), as obtained through equation (11) and illustrated in Figure (8).

For ten mg/L concentration, (I1I) exhibited a negative value of ΔG°. The adsorption process is spontaneous and feasible at this concentration. The negative values of ΔHo generally complement that the sorption process is enthalpy-driven and are in agreement with the published reports that adsorption capacities increase with ascending temperatures. Again, the ΔH values for adsorbate are above 65.6 J.mol-1, giving room to assert that it is chemical adsorption that takes the lion's share. The negative ΔSo value also agrees well with this statement, having a value of (-3864.6 Kj. mol -1). [32]

ΔH (J/mol)	ΔS (Kj. mol)	ΔG (Kj. mol)	T
0.065644	-3864.6	-17.2477	318
		-17.319	328
		-17.2185	338
		-21.3568	348
		-18.472	358

Table 3.

ISSN 2714-7444 (online), https://acopen.umsida.ac.id, published by Universitas Muhammadiyah Sidoarjo
Copyright © Author(s). This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY).

Academia Open
Vol 10 No 1 (2025): June (In Progress)
DOI: 10.21070/acopen.10.2025.10494 . Article type: (Engineering)

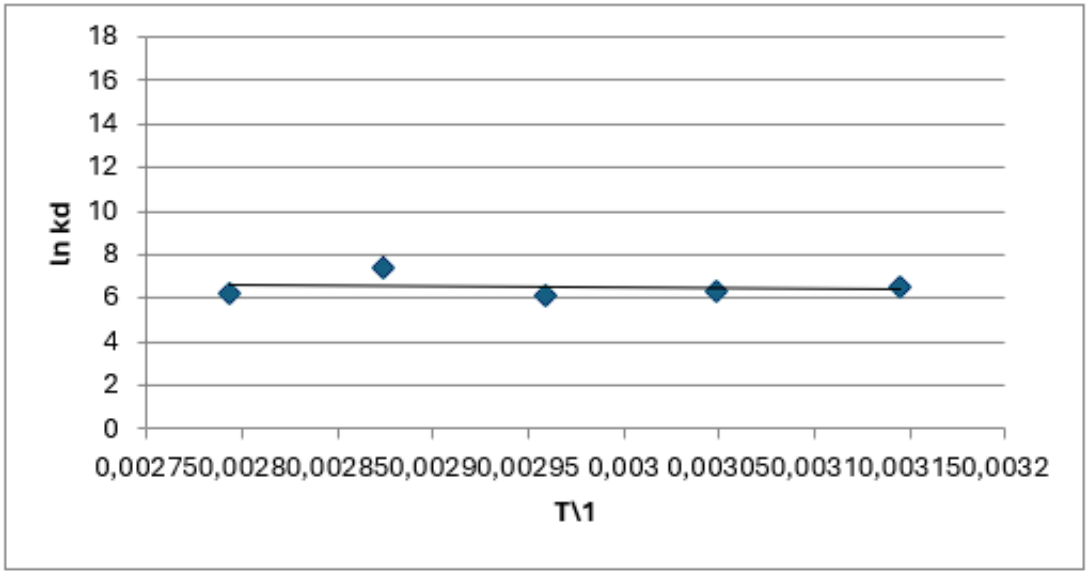


Figure 14. *Vant Hoff plot*

Conclusion

The low-cost bio-adsorbent walnut husk powder used in this study demonstrated the successful removal of Fe (III) ions from wastewater. Walnut husks were selected for this work on account of their availability and low costs. From the results obtained, it is evident that Walnut husks qualify to be a good active adsorbent to remove Fe (III), whereby 93.28% removal efficiency is achieved under optimized conditions. Remarkably high removal efficiencies were obtained in the experiments with the adsorbent. The least, 89.244%, was at 25 °C, at pH=2, the concentration of =100ppm, and the weight of =0.5g. The analysis of the data obtained indicated that good fits were obtained for both the Langmuir isotherm and the Freundlich model. However, the latter was judged better based on its regression coefficients and ΔH value of 0.065644 (J/mol). Equilibrium for this process was further modeled using Langmuir's model, while the thermodynamic parameters ΔS, ΔH, and ΔG were calculated through actual thermodynamic experiments conducted on iron removal.

References

1. . M. Mustaqeem, T. A. Saleh, and M. Khaled, "Water treatment technologies in removing heavy metal ions from wastewater: A review," Environmental Nanotechnology, Monitoring & Management, vol. 17, p. 100617, 2022.
2. . Z. Deng et al., "Modification of coconut shell-based activated carbon and purification of wastewater," Advanced Composites and Hybrid Materials, vol. 4, pp. 65-73, 2021.
3. . D. L. Gómez Aguilar et al., "Removal of Zn (II) in synthetic wastewater using agricultural wastes," Metals, vol. 10, no. 11, p. 1465, 2020.
4. . E. I. Ugwu and J. C. Agunwamba, "A review of the applicability of activated carbon derived from plant biomass in the adsorption of chromium, copper, and zinc from industrial wastewater," Environmental Monitoring and Assessment, vol. 192, no. 4, p. 240, 2020.
5. . R. Mohammadi, A. Azadmehr, and A. Maghsoudi, "Enhancing of competitive adsorptive removal of zinc and manganese from aqueous solution by iron oxide-combusted coal gangue composite," Separation Science and Technology, vol. 55, no. 18, pp. 3343-3361, 2020.
6. . R. Giri et al., "Adsorption of hexavalent chromium from aqueous solution using pomegranate peel as low-cost biosorbent," Environmental Sustainability, vol. 4, no. 2, pp. 401-417, 2021.
7. . T. A. Saleh, "Mercury sorption by silica/carbon nanotubes and silica/activated carbon: A comparison study," Journal of Water Supply: Research and Technology—AQUA, vol. 64, no. 8, pp. 892-903, 2015.
8. . M. H. Rodriguez et al., "Adsorption of Ni (II) on spent coffee and coffee husk-based activated carbon," Journal of Environmental Chemical Engineering, vol. 6, no. 1, pp. 1161-1170, 2018.
9. . T. A. Khan, S. A. Chaudhry, and I. Ali, "Equilibrium uptake, isotherm, and kinetic studies of Cd (II) adsorption onto iron oxide activated red mud from aqueous solution," Journal of Molecular Liquids, vol. 202, pp. 165-175, 2015.
10. . K. Rambabu et al., "Activated carbon from date seeds for chromium removal in aqueous solution,"

ISSN 2714-7444 (online), https://acopen.umsida.ac.id, published by Universitas Muhammadiyah Sidoarjo
Copyright © Author(s). This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY).

Desalination Water Treatment, vol. 156, pp. 267-277, 2019.
11. . B. Babakura et al., "Adsorptive removal of chromium from tannery wastewater by chitosan modified-activated carbon of Hyphaene Thebaica," Journal of Pure and Applied Sciences, Science Forum, 2023.
12. . P. E. Hock and M. A. A. Zaini, "Activated carbons by zinc chloride activation for dye removal–a commentary," Acta Chimica Slovaca, vol. 11, no. 2, pp. 99-106, 2018.
13. . T. H. Liou et al., "Sustainable utilization of rice husk waste for preparation of ordered nanostructured mesoporous silica and mesoporous carbon: Characterization and adsorption performance," Colloids and Surfaces A: Physicochemical and Engineering Aspects, vol. 636, p. 128150, 2022.
14. . U. Yunusa and M. B. Ibrahim, "Equilibrium and thermodynamic studies on adsorption of hexavalent chromium from aqueous solution onto low-cost activated carbon," International Journal of Engineering and Manufacturing, vol. 10, no. 2, p. 52, 2020.
15. . S. Usanmaz, G. Özer, and M. İmamoğlu, "Removal of Cu (II), Ni (II), and Co (II) ions from aqueous solutions by hazelnut husks carbon activated with phosphoric acid," Desalination and Water Treatment, vol. 227, pp. 300-308, 2021.
16. . J. Yang and K. Qiu, "Preparation of activated carbons from walnut husks via vacuum chemical activation and their application for methylene blue removal," Chemical Engineering Journal, vol. 165, no. 1, pp. 209-217, 2010.
17. . M. J. Ahmed and S. K. Theydan, "Physical and chemical characteristics of activated carbon prepared by pyrolysis of chemically treated date stones and its ability to adsorb organics," Powder Technology, vol. 229, pp. 237-245, 2012.
18. . J. Sahu, J. Acharya, and B. Meikap, "Optimization of production conditions for activated carbons from Tamarind wood by zinc chloride using response surface methodology," Bioresource Technology, vol. 101, no. 6, pp. 1974-1982, 2010.
19. . N. Oladoja et al., "Synchronous attenuation of metal ions and color in the aqua stream using tannin–alum synergy," Desalination, vol. 271, no. 1-3, pp. 34-40, 2011.
20. . E. Pehlivan and T. Altun, "Biosorption of chromium (VI) ion from aqueous solutions using walnut, hazelnut, and almond shells," Journal of Hazardous Materials, vol. 155, no. 1-2, pp. 378-384, 2008.
21. . A. Almasi et al., "Lead (II) and cadmium (II) removal from aqueous solution using processed walnut husks: Kinetic and equilibrium study," Toxicological & Environmental Chemistry, vol. 94, no. 4, pp. 660-671, 2012.
22. . Z. T. Abdullah, I. A. Altameemi, and A. M. Sadda, "A new comparison between Ag-nano adsorbent and walnut husks adsorbent," Egyptian Journal of Chemistry, vol. 64, no. 8, pp. 4017-4026, 2021.
23. . J. Ayala and B. Fernandez, "Removal of zinc, cadmium, and nickel from mining waste leachate using walnut husks," Environment Protection Engineering, vol. 45, no. 2, 2019.
24. . A. Ihab, N. Tarikak, and M. Thuraya, "Removal of Pb (II), Cd (II) ions onto dried Conocarpus erectus leaves using batch adsorption and study the adsorption thermodynamics," International Journal of Engineering and Manufacturing, vol. 4, no. 12, pp. 4961-4968, 2012.
25. . O. A. Oba and N. Pasaoglulari Aydinlik, "Preparation of mesoporous activated carbon from novel African walnut husks (AWS) for deltamethrin removal: Kinetics and equilibrium studies," Applied Water Science, vol. 12, no. 7, p. 149, 2022.
26. . H. Aydın, Y. Bulut, and Ç. Yerlikaya, "Removal of copper (II) from aqueous solution by adsorption onto low-cost adsorbents," Journal of Environmental Management, vol. 87, no. 1, pp. 37-45, 2008.
27. . M. Bansal et al., "Removal of Cr (VI) from aqueous solutions using pre-consumer processing agricultural waste: A case study of rice husk," Journal of Hazardous Materials, vol. 162, no. 1, pp. 312-320, 2009.
28. . R. R. Abdul-Rezaq and I. A. Altameemi, "Removal of Cu (II) ions from wastewater by using dried eucalyptus leaves using batch adsorption and study the adsorption thermodynamics," International Journal of Engineering and Manufacturing, vol. 2320-5083, 2018.
29. . I. A. Altameemi and M. Thuraya, "Removal of manganese (Mn^{2+}) from aqueous solution by low-cost adsorbents and study the adsorption thermodynamics and kinetics," Journal of Physics: Conference Series, vol. 1773, p. 012038, 2021.
30. . G. B. Oguntimein and T. Duwane, "The potential use of acid-treated dried sunflower seed hull as a biosorbent for the removal of textile effluent dye from aqueous solution," International Journal of Engineering Science, vol. 4, pp. 21-30, 2014.
31. . V. K. Gupta et al., "Enhanced heavy metals removal and recovery by mesoporous adsorbent prepared from waste rubber tire," Chemical Engineering Journal, vol. 197, pp. 330-342, 2012.
32. . M. Ghasemi et al., "Synthesis of characteristics activated carbon from walnut husks for the removal of Cr (VI) and Fe (II) from aqueous solution: Single and binary solutes adsorption," Iranian Journal of Chemical Engineering (IJChE), vol. 12, no. 4, pp. 28-51, 2015.

ISSN 2714-7444 (online), https://acopen.umsida.ac.id, published by Universitas Muhammadiyah Sidoarjo
Copyright © Author(s). This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY).