Adsorption of Cd (II) into Activated Charcoal from Matoa Fruit Peel

Kustomo1*, Naila Lajja Zulfa Faza1, Andreas Haarstrick2

1Department of Chemistry, Faculty of Science and Technology, Universitas Islam Negeri Walisongo Semarang, Central Java, Indonesia
2Institute for Hydraulic Engineering, Technische Universitat Braunschweig, Niedersachen, Germany

*Corresponding author: kustomo@walisongo.ac.id

Received: 27 May 2022; Accepted: 30 June 2022; Published: 15 July 2022

Abstract

Cadmium (Cd) is one of the heavy metals with a high level of contaminants that is environmentally harmful and can interfere with human health. This study aims to determine the adsorption capacity and adsorption kinetics of Cd (II) from Matoa fruit peel activated by nitric acid. The adsorption method can be used to treat Cd (II) waste in the water. Activated charcoal is used for adsorption. The charcoal produces a relatively 1.17 % ash content, 3.92 % water content, and a 507.64 mg/g iodine absorption test. Based on the results of FTIR characterization, it is known that the O-H and C=O groups play an important role in adsorption. The SEM-EDX characterization produced a carbon content of 99.21 %. At pH 9, activated charcoal adsorbs Cd (II) metal effectively, with a contact time of 40 minutes and a concentration of 20 ppm. The activated charcoal of Matoa fruit peel activated by nitric acid had an adsorption capacity of 59.75 mg/g. It used a pseudo-second-order reaction for the chemical kinetics equation and the Langmuir adsorption isotherm equation for the adsorption isotherm.

Keywords: matoa fruit peel; adsorption; Cd (II); activated charcoal

Introduction

Water is a natural substance found on the earth’s surface. Water has many benefits for the human body, such as controlling metabolism, transporting nutrients, and maintaining body temperature balance, however, there are water problems in some areas due to a lack of clean water supplies for human life. The limitations of clean water are caused by excessive human use of clean water, which is contaminated with heavy metals (Fe, Zn, Cd, Hg) above the threshold level (Adetokun et al., 2019; Nejadshafiee & Islami, 2019; Nugroho, 2013). Heavy metal ions in wastewater have relatively high toxicity, which can cause significant environmental problems (Hajjaoui et al., 2022; Kataria et al., 2022; Pratomo et al., 2017).

Cadmium (Cd) is one of the dangerous heavy metals in the water. Cadmium contamination is typically caused by residual substances in the paint, soft drink, smelting, metal plating industries, and others. It is the second most toxic heavy metal after mercury. Because of its toxicity, this metal in water must be present in small quantities (Sembiring et al., 2010). Government regulation no. 82 of 2001 concerning water quality and water quality standard limits for metal Cd content by

Copyright © 2021 WJC | ISSN 2621-5985 (online) | ISSN 2549-385X (print) | Volume 5, Issue 1, 2022
Minister of Health of the Republic of Indonesia No. 32 of 2017 is a maximum of 0.01 ppm (Khan et al., 2021; Ministry of Health, 2017; Sasonkko et al., 2014).

Heavy metals can cause problems for human health. The toxic impact of Cd (II) metal is that it can cause dangerous diseases in humans, such as lung, kidney, and liver damage, as well as high blood pressure and gastrointestinal problems (Faizal & Fitri, 2014; Rajmohan, 2021). Adsorption is one of the most effective methods for removing hazardous substances from wastewater, and it is commonly used in the treatment of industrial waste liquids. Because the adsorbent used in this process is typically relatively expensive, it is necessary to use an adsorbent that is both inexpensive and environmentally friendly, such as adsorbents made from biomass waste.

Adsorbent derived from waste materials not only reduces environmental pollution caused by solid waste, but it can also increase the adsorbent's selling price (Awokoya et al., 2021; Haura et al., 2017; Xu et al., 2022).

The benefits of matoa are only known to be used as medicinal plants in the North Sulawesi region. Matoa plants are commonly recognized for their fruit, which has a distinctive flavor. This plant has previously been studied as a medicinal plant by observing the secondary metabolism contained in Matoa fruit (Kurniawan et al., 2017; Ngajow et al., 2013; Pakaya et al., 2021). The Matoa fruit is one of the fruits that thrives in eastern Indonesia. Whereas this fruit has numerous benefits, it is still used by a small number of people. As a result, this skin degrades and is discarded. According to (Faustina et al., 2014; Kurniawan et al., 2017), the Matoa fruit peel has a high cellulose content of about 50% and has the potential to be used to make paper. The characterization test on the skin of the Matoa fruit produced a cellulose content of 50.6%, indicating that the Matoa content was higher than that of other materials such as rice straw (27% - 34%) and bagasse (36% - 40%). Because Matoa peel has high antioxidant activity, it has the potential to be an antioxidant source (Faustina et al., 2014; Pakaya et al., 2021).

Activated charcoal is a carbon compound that has been activated so that it has larger pores and surface area. Therefore, it can increase its adsorption power (Alsohaimi et al., 2020; Eze et al., 2022; Popoola, 2019; Suhendarwati et al., 2014). Activation can be accomplished chemically or physically. Chemical activation is typically accomplished through immersion in water-absorbing alkali hydroxide, carbonate compounds, sulfides, ZnCl₂, sulfuric acid, phosphoric acid, and sodium chloride (Setiawati & Suroto, 2010). The sodium hydroxide solution in this activation serves to reduce the lignin compounds present in the Matoa peel, thereby inhibiting the adsorption process. Because lignin can clog the ion transfer process on the active site of the adsorbent, its presence can slow down the adsorption process. According to the study (Safaria et al., 2013), OH-ions in NaOH can break the bonds in the basic structure of lignin. The lignin will then dissolve readily. To decompose the mineral salts in the adsorbent, it must also be activated with nitric acid (Jaouadi et al., 2017; Mentari et al., 2018; Setiaty Pandia & Budi Warman, 2017).

In this study, adsorption of Cd (II) metal was accomplished by using cellulose on activated charcoal from the Matoa fruit peel, which had been activated by nitric acid. This study began with the creation of activated charcoal from the Matoa fruit peel, which was then activated by nitric acid. Following that, the adsorbent will be contacted with a solution of Cd (II) as an adsorbate while taking pH parameters, optimum adsorption contact time, and determining the optimum concentration. It is expected that activated charcoal from the Matoa fruit peel will be able to adsorb Cd (II) metal solution waste during the activation process.

**Research Methodology**

**Materials**

A beaker, 50 ml measuring cup, 1 ml measuring pipette, blender, Erlenmeyer, dropper, porcelain cup, desiccator, magnetic
stirrer, filter paper, 80 mesh sieve, analytical balance, oven, furnace, AAS with Thermo Scientific brand, FTIR with Bruker Alpha 2 brand, and SEM with JEOL JSM-6510LA brand were the tools used in this study. Whereas the materials used in this study were Matoa fruit peel, 1M NaOH solution, CdSO₄·8H₂O, nitric acid, iodine, sodium thiosulfate, and distilled water.

**Activation of activated carbon on Matoa peel**

The matoa fruit peel was weighed as much as 270 grams and placed in a kiln at 400 °C for 60 minutes. The matoa fruit peel, which had become charcoal, was cooled, and then crushed to 80 mesh, then sieved using an 80-mesh sieve. the matoa fruit peel sample was weighed in an erlenmeyer, then 1m nitric acid was added in a ratio of 1:10, after being soaked for 1 hour, rinsed using distilled water, and then filtered and washed with distilled water until the ph was neutral and dried in an oven for 24 hours at 100°C, then cooled and then characterized using FTIR and SEM-EDX.

**Adsorption Test**

The activated charcoal adsorbent was weighed at 0.1 grams and put in an Erlenmeyer. Then a sample solution of 10 ppm was added to 50 mL with various variations, namely variations in pH, contact time, and concentration. The sample was stirred by using a magnetic stirrer for 60 minutes, then allowed to stand for 15 minutes, then filtered using filter paper, and the absorbance was measured by AAS.

**Results and Discussion**

**Cellulose Preparation from Matoa Peel**

The matoa fruit peel used in this study was Matoa that grows in Pati regency. Matoa fruit peel contains lignin of 28.24% (Faustina et al., 2014; Kurniawan et al., 2017). According to (Li et al., 2016), Materials containing cellulose become hard and inhibited cellulose from binding to metal ions. Therefore, a delignification process was carried out to remove lignin content. The delignification process was carried out by using a 6% NaOH solution because NaOH solution could damage lignin. According to (Rambat et al., 2015) the delignification process using NaOH solution can reduce lignin levels by a percentage of 19.11%. NaOH can separate lignin from cellulose and form bonds within the lignin itself. The separate bonds are hydrogen bonds that link lignin to cellulose. There is a reaction to break the bonds of lignin and cellulose as shown in Figure 1.

**Functional Group Analysis by Using FTIR**

Analysis with the FTIR instrument aims to determine what functional groups are present in the Matoa fruit peel adsorbent before and after activation. The results of the characterization of charcoal before activation can be seen in Figure 2.

![Figure 1. Mechanism of breaking the bonds of lignin and cellulose (Zhu et al., 2016)](image-url)
Figure 2 shows that in the presence of an O-H group at a wave number of $3457.43 \text{ cm}^{-1}$, the presence of an O-H bond is usually polar charcoal (Mentari et al., 2018). The presence of C-H groups is indicated by wave numbers $3052.47 \text{ cm}^{-1}$, $2162.27 \text{ cm}^{-1}$, $1447.72 \text{ cm}^{-1}$, and $872.76 \text{ cm}^{-1}$. According to Losev, the C-H functional groups are generally present in materials that contain a lot of cellulose. The C=O groups are at wave number $1682.01 \text{ cm}^{-1}$ and the C-N functional groups are at wave number $1189.85 \text{ cm}^{-1}$. The C=O and C-N functional groups have an important role during the adsorption process (Siregar, 2019). While the results of the characterization of charcoal after activation can be seen in Figure 3.

The FTIR spectra in Figure 3 shows that after activation, a new group appeared, namely C=C at a wave number of $1576.27 \text{ cm}^{-1}$. The C=C group indicates an increase in carbon content (Mentari et al., 2018). The difference in functional groups in activated charcoal of Matoa fruit peel before and after activation is shown in Table 1. Functional groups that have been activated by using nitric acid are hydroxyl groups and carboxyl groups which both affect the adsorption process.

Figure 3. FTIR spectra of Matoa fruit peel charcoal after activation
Charcoal after activation has a more regular pore structure. Meanwhile, before activation, the charcoal has irregular pores and there are still impurities. The activation process by using the HNO₃ activator dissolves impurities that still exist in the charcoal so that it will enlarge the pores by breaking the hydrocarbon bonds.

EDX testing was carried out to identify the constituent elements of carbon material. Figure 4 shows that the constituent elements in charcoal before activation are C 79.70%; Na 11.65%; Mg 1.82%; Al 0.15%; K 0.81%; Ca 4.45%; Cu 1.06%. While the constituent elements in activated charcoal consist of 99.21% carbon, Ca 0.29%, and Cu 0.50%.

A material with a high carbon content can adsorb more than a material with a lower one (Chen et al., 2021; Eze et al., 2022; Popoola, 2019). Figure 5 shows that the activated element consists of 99.21% carbon, Ca 0.29%, and Cu 0.50%. There are differences in the elemental composition before and after activation by using nitric acid on the Matoa fruit peel (Table 3). The elemental composition of carbon (C) dominates the Matoa fruit peel charcoal after activation. This is very influential on the adsorption process carried out because it shows the success of this activated charcoal synthesis process.

### Table 1. Functional Groups of FTIR Spectra Results on Matoa Fruit Peel Charcoal

| Group | Wave Number (cm⁻¹) |
|-------|-------------------|
|       | Charcoal Before Activated | Activated Charcoal |
| O-H   | 3457.43            | 3486.98           |
|       |                    | 2326.26           |
| C-H   | 3052.47            | 2162.27           |
|       | 1447.72            | 812.04            |
|       | 872.76             |                   |
| C=O   | 1682.01            | 1684.11           |
| C=C   | -                  | 1576.27           |
| C-N   | 1189.85            | 1124.50           |

### Analysis of Morphology and Element Composition by using SEM-EDX

The surface shape of the matoa fruit peel charcoal was analyzed by using SEM. It was also analyzed by using EDX to find out the elements in the Matoa fruit peel charcoal. The results of SEM characterization on the charcoal surface before and after activation can be seen in Table 2.

**Figure 4.** Elemental composition of activated charcoal EDX spectra before activation

**Figure 5.** Elemental composition of activated charcoal EDX spectra after activation
Table 2. Comparison of morphological forms of charcoal

| Zoom in | Charcoal before activation | After activation |
|---------|----------------------------|-----------------|
| 1000x   | ![Image](image1.png)       | ![Image](image2.png) |
| 3000x   | ![Image](image3.png)       | ![Image](image4.png) |
| 5000x   | ![Image](image5.png)       | ![Image](image6.png) |
| 10000x  | ![Image](image7.png)       | ![Image](image8.png) |

Table 3: Charcoal mass content percentage (%)

| Adsorbent Types | Element percentage (% mass) |
|-----------------|-----------------------------|
|                 | C  | Na  | Mg  | Al  | K  | Ca  | Cu  |
| before activation | 79.70 | 11.65 | 1.82 | 0.15 | 0.81 | 4.45 | 1.06 |
| after activation | 99.21 | - | - | - | 0.29 | - | 0.50 |

Determination of Optimum pH

At pH < 6, the Cd (II) ion species formed in the solution is Cd\(^{2+}\), which causes competition between protons and the charge of Cd\(^{2+}\) on the carbon surface, which causes small adsorption of Cd (II) ions to occur (Wijaya & Ulfin, 2015).

According to (Wijaya & Ulfin, 2015), at pH ≥ 8, Cd\(^{2+}\) ions will be well adsorbed, but at pH ≥8, there is not only an adsorption process but also a precipitation process in the solution (Table 4).

Figure 6. Graph of the pH Variation Effect on Adsorption Percentage
The effect of solution conditions on alkaline pH is the precipitation of hydroxy species such as Cd(OH)$_2$. In this study, the optimum pH was obtained at pH 9, but the decrease in Cd$^{2+}$ ion levels at pH 9 was not only caused by the adsorption process but also the precipitation process.

Table 4: Variation of pH on adsorption capacity

| pH  | % Adsorption |
|-----|--------------|
| 4   | -89.963      |
| 5   | -33.933      |
| 6   | -8.165       |
| 7   | 18.052       |
| 8   | 31.236       |
| 9   | 46.067       |
| 10  | 43.670       |

**Determination of Optimum Contact Time**

The optimum contact time for Cd adsorption determines to determine the ability of charcoal from matoa fruit peel activated by nitric acid to adsorb Cd metal. In this study, the variations used were 20, 40, 60, 80, and 100 minutes. The results of time contact variations are shown in Figure 7.

Table 5: The effect of contact time on Adsorption Capacity of Cd(II)

| Contact Time (minutes) | % Adsorption |
|------------------------|--------------|
| 20                     | 48.6678      |
| 40                     | 69.4943      |
| 60                     | 69.2768      |
| 80                     | 57.2594      |
| 100                    | 27.7325      |

The contact time between the adsorbent and the adsorbate that exceeds the optimum contact time was caused by the desorption process and the weak interaction between metal ions and the adsorbent bound to the adsorbent surface (Pratomo et al., 2017). Desorption indicated that a dynamic equilibrium condition has been formed in the adsorption process. The desorption phenomenon was caused by the physical adsorption process. This process was reversible, resulting in the release of ions from the surface of the adsorbent into the wastewater solution.

A determination of adsorption kinetics was carried out to determine the rate of metal absorption that occurred. Determination of adsorption kinetics was carried out by making pseudo-first-order and pseudo-second-order adsorption kinetics curves by using a higher result of $R^2$ or close to 1. The adsorption kinetics of using nitric acid-activated Matoa peel as an adsorbent can be seen in Table 6. Based on the table, pseudo-second-order is more suitable than pseudo-first-order.

Table 6: Adsorption kinetics of Cd (II) with Matoa fruit peel adsorbent

| Kinetics Adsorption | Pseudo-first-order | Pseudo-second-order |
|---------------------|--------------------|---------------------|
|                     | $Q_{max}$ (mg/g)   | $K_1$ (min$^{-1}$) | $R^2$     | $Q_{max}$ (mg/g) | $K_1$ (min$^{-1}$) | $R^2$     |
| Value               | 89.2857            | 2.16x10$^{-5}$     | 0.0262    | 0.0255           | -1.7846           | 0.9642    |
This second-order reaction rate model can be used as a reaction rate model for Cd (II) metal adsorption. According to (Huang et al., 2014; Wang et al., 2021) if the kinetic model of adsorption is more suitable than the pseudo-second-order kinetic model, the adsorption that occurs is a chemical adsorption process (chemisorption). It is adsorption involving interaction between the adsorbent and the adsorbate so that the adsorbate cannot move freely to other parts.

**Determination of the adsorption isotherm**

Determination of the optimum concentration was carried out with several variations of the test: at concentrations of 10, 20, 30, 40, and 50 ppm. This test was carried out at an optimum pH of 9 and a contact time of 40 minutes. The results of this concentration variation can be seen in Figure 8.

Figure 8 shows that the optimum concentration condition is at a concentration of 20 ppm because it shows that the Cd (II) metal that can be adsorbed is 95.9557%. The adsorption isotherm is determined by changing the Langmuir and Freundlich isotherms into an equilibrium curve and determining the equilibrium model according to the regression value ($R^2$), which is closer to number 1.

![Figure 8: The graph of concentration variation on adsorption](image)

**Table 7. Cd (II) adsorption isotherm with matoa fruit peel as adsorbent**

| Isotherm Adsorption | Langmuir | Freundlich |
|---------------------|----------|------------|
| Unit                | $Q_{\text{max}}$ (mg/g) | $K_l$ (min$^{-1}$) | $R^2$ | $N$ | $K_f$ (min$^{-1}$) | $R^2$ |
| Value               | -33.445  | -0.01108   | 0.9608 | -22.676 | 0.4177 | 0.0088 |

**Conclusions**

The water content of activated charcoal from Matoa peel was 3.92 % less than the quality standard of SNI 06-3730-1995; the maximum limit was 15%. Iodine absorption was 507.64 mg/g with a minimum limit of 750 mg/g, and ash content was 1.17 % with a maximum limit of 10%. At a concentration of 20 ppm pH 9 as well as an optimum time of 40 minutes, the adsorption capacity of Cd(II) from activated charcoal of 1M nitric acid Matoa peel was 59.75 mg/g. The adsorption kinetics of activated carbon from Matoa fruit peel activated by nitric acid guided pseudo-second-order, and the adsorption isotherm guided the Langmuir adsorption isotherm with $K_l= -0.01108$, $Q_{\text{max}}= -33.4448$, and $R^2=0.9608$. 
References

Adetokun, A. A., Uba, S., & Garba, Z. N. (2019). Optimization of adsorption of metal ions from a ternary aqueous solution with activated carbon from Acacia senegal (L.) Willd pods using Central Composite Design. Journal of King Saud University - Science, 31(4), 1452–1462. https://doi.org/10.1016/j.jksus.2018.12.007

Al-Sahty, I. H., El-Aassar, M. R., Elzain, A. A., Alshammari, M. S., & Ali, A. S. M. (2020). Development of activated carbon-impregnated alginates*β-cyclodextrin/gelatin beads for highly performance sorption of 2,4-dichlorophenol from wastewater. Journal of Materials Research and Technology, 9(3), 5144–5153. https://doi.org/10.1016/j.jmrt.2020.03.031

Awokoya, K. N., Oninla, V. O., & Bello, D. J. (2021). Corrigendum to "Synthesis of oxidized Dioscorea dumortor starch nanoparticles for the adsorption of lead(II) and cadmium(II) ions from wastewater" (Environmental Nanotechnology, Monitoring & Management (2021) 15, 100440), (S2215153221000155), (10.1016/j.enmm.2021.100489. https://doi.org/10.1016/j.enmm.2021.100489

Chen, Q., Zhang, Q., Yang, Y., Wang, Q., He, Y., & Dong, N. (2021). Synergetic effect of methylene blue adsorption to biochar with gentian violet in dyeing and printing wastewater under competitive adsorption mechanism. Case Studies in Thermal Engineering, 26(May), 101099. https://doi.org/10.1016/j.csite.2021.101099

Eze, S. I., Abugu, H. O., Odewole, O. A., Ukwueze, N. N., & Alum, L. O. (2022). Thermal and chemical pretreatment of Terminalia mantaly seed husk biosorbent to enhance the adsorption capacity for Pb2+. Scientific African, 15, e01123. https://doi.org/10.1016/j.sciaf.2022.e01123

Faizal, M., & Fitri, R. M. (2014). Treatment of Wastewater Containing Cd by Using an Adsorbent Composite of Bentonite & Fe3O4. Teknik Kimia, 20(3), 66–72.

Faustina, F. C., Santoso, F., Fransisca, A., Faustina, C., Santoso, F., & Aktivitas, P. (2014). Extraction of Fruit Peels of Pometia Pinnata and Its Antioxidant and Antimicrobial Activities. Pascapanen, 11(2), 80–88.

Hajjaoui, H., Soufi, A., Abdennouri, M., Qourzal, S., Tounsadi, H., & Barka, N. (2022). Removal of cadmium ions by magnesium phosphate: Kinetics, isotherm, and mechanism studies. Applied Surface Science, 9(December 2021), 100263. https://doi.org/10.1016/j.apsadv.2022.100263

Haura, U., Razi, F., & Meilina, D. H. (2017). Adsorbent Characterization from Mangosteen Peel and Its Adsorption Performance on Pb(II) and Cr(VI). Biopropal Industri, 8(1), 47–54.

Huang, W.-Y., Li, D.-Q., Tao, Q., Zhu, Y., Yang, J., and Z. (2014). Kinetics, Isotherm, Thermodynamic, and Adsorption Mechanism studies of La(OH)3-modified exfoliated vermiculites as highly efficient phosphate adsorbents. Chemical Engineering Journal, 236, 191–201.

Jaouadi, M., Hbaieb, S., Guedidi, H., Reinert, L., Amdouni, N., & Duclaux, L. (2017). Preparation and characterization of carbons from β-cyclodextrin dehydration and from olive pomace activation and their application for boron adsorption. Journal of Saudi Chemical Society, 21(7), 822–829. https://doi.org/10.1016/j.jscs.2016.01.001

Kataria, N., Chauhan, A. K., Garg, V. K., & Kumar, P. (2022). Sequestration of heavy metals from contaminated water using magnetic carbon nanocomposites. Journal of Hazardous Materials Advances, 6(March), 100066. https://doi.org/10.1016/j.hazadv.2022.100066

Copyright © 2021 WJC | ISSN 2621-5985 (online) | ISSN 2549-385X (print)
Volume 5, Issue 1, 2022
Khan, N., Malik, A., & Nehra, K. (2021). Groundwater hydro-geochemistry, quality, microbiology and human health risk assessment in semi-arid area of Rajasthan, India: a chemometric approach. In Environmental Monitoring and Assessment (Vol. 193, Issue 4). Springer International Publishing. https://doi.org/10.1007/s10661-021-08979-2

Kurniawan, H., Garchia, C. H., Ayucitra, A., & Antaresti. (2017). Utilization of Matoa Fruit Peel as Mixed Fiber Paper through a Pretreatment Process with the Help of Microwaves and Ultrasonics. Ilmiah Widya Teknik, 16(1), 1–10.

Li, Y., Fu, Q., Yu, S., Yan, M., & Berglund, L. (2016). Optically Transparent Wood from a Nanoporous Cellulosic Template: Combining Functional and Structural Performance. Biomacromolecules, 17(4), 1358–1364. https://doi.org/10.1021/acs.biomac.6b00145

Mentari, A. V., Handika, G., & Maulina, S. (2018). The Comparison of Functional Group and Surface Morphology of Activated Carbon from Oil Palm Frond Using Phosphoric Acid (H3PO4). Jurnal Teknik Kimia USU, 7(1), 16–20.

Ministry of Health, I. (2017). Indonesia Ministry of Health Decree Number 32 Year 2017 Concerning in Water Quality Standard for Hygien Sanitation, Swimming Pool, Solute Per Aqua and Public Bath. In Regulation of Ministry of Health Republic of Indonesia Nb. 32 Year 2017.

Nejadshafiee, V., & Islami, M. R. (2019). Adsorption capacity of heavy metal ions using sulfone-modified magnetic activated carbon as a bio-adsorbent. Materials Science and Engineering C, 101(March), 42–52. https://doi.org/10.1016/j.msec.2019.03.081

Ngajow, M., Abidjulu, J., & Kamu, V. S. (2013). Effect of Antibacterial Bark Extract of Matoa (Pometia pinnata) against Staphylococcus aureus in Vitro. Jurnal MIPA, 2(2), 128. https://doi.org/10.35799/jm.2.2.2013.3121

Nugroho, D. (2013). Utilization of Tofu Industrial Solid Waste and Biosand Filter Reactor to Reduce Fe3+ and Zn2+ Metal Ions Levels in the Galvanized Industry. In Universitas Negeri Semarang.

Pakaya, M. S., Kalangi, N. B. P., Santi, S., Jahja, N., Wijaya, I. M. H., & Agung, F. D. (2021). Utilization of Waste Matoa Husk (Pometia Pinnata) as Herbal Mouthwash Solution to Prevent Dental Caries. Jurnal Sibermas (Sinergi Pemberdayaan Masyarakat), 10(3), 570–580. https://doi.org/10.37905/sibermas.v1i3.11673

Popoola, L. T. (2019). Nano-magnetic walnut shell-rice husk for Cd(II) sorption: design and optimization using artificial intelligence and design expert. Heliyon, 5(8), e02381. https://doi.org/10.1016/j.heliyon.2019.e02381

Pratomo, S. W., Mahatmanti, F. W., & Sulistyawingsih, T. (2017). Utilization of H3PO4 Activated Natural Zeolite as Cd(II) Metal Ion Adsorbent in Solution. Indonesian Journal of Chemical Science, 6(2), 161–167.

Rajmohan, N. (2021). Application of water quality index and chemometric methods on contamination assessment in the shallow aquifer, Ganges River basin, India. Environmental Science and Pollution Research, 28(18), 23243–23257. https://doi.org/10.1007/s11356-020-12270-1

Rambat, Hidayat, N., & Rusdiarso, B. (2015). Application of Cocoa Pod Husk Waste as a Medium for Lactic Acid Fermentation for Raw Materials of Bioplastic. Jurnal Kimia Dan Kemasan, 37(2), 103–110.

Safaria, S., Idiawati, N., & Zaharag, T. A. (2013). The Effectiveness of Cellulase Enzyme Mixture from Aspergillus Niger and Trichoderma Reesei in Hydrolyzing Coconut Coir Substrate. Jurnal Kimia Khatulistiwa, 2(1), 46–51.

Sasongko, E. B., Widyastuti, E., & Priyono, R. E. (2014). Study of Water Quality and
Utility of Dug Well to the People around Kaliyasa Rivers Cilacap. *Jurnal Ilmu Lingkungan*, 12(2), 72. https://doi.org/10.14710/jil.12.2.72-82

Sembiring, Z., Buhani, B., Suharso, S., & Sumadi, S. (2010). The Isothermic Adsorption Of Pb(II), Cu(II) And Cd(II) Ions On Nannochloropsis Sp Encapsulated By Silica Aquagel. *Indonesian Journal of Chemistry*, 9(1), 1-4. https://doi.org/10.22146/ijc.21556

Setiady Pandia, & Budi Warman. (2017). Utilization of Jengkol Husk as an Adsorbent in the Absorption of Cd (II) Metal in the Liquid Waste of the Metal Coating Industry. *Jurnal Teknik Kimia USU*, 5(4), 57-63. https://doi.org/10.32734/jtk.v5i4.1556

Setiawati, E., & Suroto, S. (2010). Effect of Activator Material on Coconut Shell Activated Carbon Production. *Jurnal Riset Industri Hasil Hutan*, 2(1), 21. https://doi.org/10.24111/jrihh.v2i1.91

Siregar, K. N. A. (2019). *Removal of Heavy Metals Pb (II) and Cd (II) with Adsorbent Made from Wood Powder Activated with H3PO4. ii.*

Suhendarwati, L., Bambang, B., & Susanawati, L. D. (2014). Effect of Potassium Hydroxide Concentration on Activated Sugarcane Bagasse Base Ash. *Jurnal Sumberdaya Alam Dan Lingkungan*, 1(1), 19-25. http://jsalub.ac.id/index.php/jsal/article/view/101/97

Wang, P., Ding, F., Huang, Z., Fu, Z., Zhao, P., & Men, S. (2021). Adsorption behavior and mechanism of Cd (II) by modified coal-based humin. *Environmental Technology and Innovation*, 23, 101699. https://doi.org/10.1016/j.eti.2021.101699

Wijaya, V. C., & Ulfin, I. (2015). Effect of pH on Adsorption of Cd2+ Ions in Solution Using Activated Carbon from Trembesi Seeds (Samanea saman). *Jurnal Sains Dan Seni ITS*, 4(2), 4-7. ejurnal.its.ac.id/index.php/sains_seni/article/download/12802/2402

Xu, W., Liu, C., Zhu, J. M., Bu, H., Tong, H., Chen, M., Tan, D., Gao, T., & Liu, Y. (2022). Adsorption of cadmium on clay-organic associations in different pH solutions: The effect of amphoteric organic matter. *Ecotoxicology and Environmental Safety*, 236(March), 113509. https://doi.org/10.1016/j.ecoenv.2022.113509

Zhu, H., Luo, W., Ciesielski, P. N., Fang, Z., Zhu, J. Y., Henriksson, G., Himmel, M. E., & Hu, L. (2016). Wood-Derived Materials for Green Electronics, Biological Devices, and Energy Applications. *Chemical Reviews*, 116(16), 9305-9374. https://doi.org/10.1021/acs.chemrev.6b00225