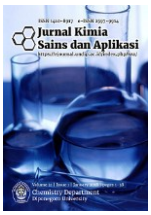
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Synthesis of Reusable Cd(II)-Imprinted Polymers: Impact of Extractant Agents on Selective Cavity Formation and Cadmium Adsorption Performance

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Abstract

Cadmium (Cd) heavy metal pollution from industrial activities poses a serious threat to aquatic ecosystems and human health. This study focuses on creating Cd(II)-imprinted polymers (Cd(II)-IPs) as selective adsorbents for Cd(II) ions and assessing the ability of extractant agents to form specific cavities within the polymer structure. The adsorbent's ability to regenerate was also analyzed to support the development of eco-friendly adsorbents. Cd(II)-IPs were made using 8-hydroxyquinoline, methacrylic acid, ethylene glycol dimethacrylate, and azobisisobutyronitrile. The Cd(II) ions were extracted from the polymer matrix with HNO_3, HCl, and H_2SO_4. The results showed that HNO_3 was the most effective extractant for releasing Cd(II) ions from the polymer, yielding a selective Cd(II) adsorbent with an adsorption capacity of 63.46 mg/g. X-ray diffraction analysis confirmed the successful removal of Cd(II) ions, as indicated by the disappearance of the characteristic peak of $Cd(NO_3)_2{\cdot}4H_2O$ after extraction with HNO_3. Brunauer–Emmett–Teller (BET) analysis showed that Cd(II)-IPs had a larger surface area, pore volume, and pore diameter compared to non-imprinted polymers (NIPs) as a control. Cd(II)-IPs could retain adsorption activity and competitive performance after repeated regeneration, with a regeneration ability of up to five adsorption-desorption cycles and a recovery efficiency of 21.2%. Cd(II)-IPs have the potential to be applied in selective and sustainable industrial wastewater treatment.

1. Introduction

The acceleration of global industrialization and rapid population growth has led to a significant increase in anthropogenic heavy metal emissions, with cadmium (Cd) among the most persistent and hazardous contaminants in aquatic ecosystems. In the environment, Cd contamination comes from natural processes such as rock weathering and volcanic activity but is exacerbated by industrial activities such as mining, metal smelting, electroplating, phosphate fertilizer manufacturing, and nickel-cadmium battery production [1]. As a highly toxic non-essential metal, Cd has a long biological half-life ranging from 25 to 30 years. This characteristic triggers massive bioaccumulation and biomagnification through the food chain, which can ultimately cause damage to vital human organs such as the kidneys, liver, lungs, and bone tissue [2]. This crisis has reached a critical stage in developing countries like Indonesia. Monitoring data on cadmium pollution show that Cd levels in major water bodies, including the Brantas River (0.133 mg/L) and the Ciliwung River (6.3 mg/L), have surpassed the national water quality standard (0.01 mg/L) set by Government Regulation No. 22 of 2021 [3, 4]. Therefore, it is essential to improve remediation by developing efficient, selective,

and cost-effective technologies to remove Cd ions from wastewater before they cause environmental harm.

Various traditional methods, such as ion exchange, chemical precipitation, membrane, and electrodialysis, have been used to reduce cadmium contamination in water. However, these methods often face challenges due to high costs and operational difficulties [5]. Adsorption is a more promising option because it has a simple design, is cost-effective, maintains stability under pH changes, and generates minimal secondary pollutants [6]. However, the use of conventional adsorbents such as activated carbon, zeolites, and iron oxide nanoparticles still faces a significant challenge: low material selectivity [7, 8]. In complex water mixtures, abundant interfering ions such as calcium (Ca), magnesium (Mg), and zinc (Zn) compete for active sites (cavities) on the adsorbent. As a result, the specific adsorption capacity for the target ion (Cd) drops sharply, limiting the effectiveness of traditional adsorbents.

To overcome the selectivity limitations of conventional adsorbents, ion-imprinted polymers (IIPs) are rapidly emerging as functional materials that offer high selectivity through molecular imprinting techniques. The synthesis mechanism of IIPs begins with the formation of a complex between a target metal ion as a template and a specific ligand. This complex is then copolymerized with monomers and crosslinkers using an initiator. The next crucial step is the release of the template metal ion from the polymer, forming a cavity with the appropriate size, charge, geometry, and coordination number for the target ion [9]. The presence of this cavity provides high affinity and selectivity towards target metal ions even in the presence of interfering ions. In addition, IIPs exhibit good thermal and chemical stability, good regeneration capacity, and potential for use in the separation and treatment of wastewater contaminated with heavy metals [10].

Although the synthesis of Cd(II)-imprinted polymers (Cd(II)-IPs) has been extensively investigated, challenges remain, including the use of hazardous organic solvents, prolonged polymerization times, and limited comparative evaluation of extraction agents for adsorbent regeneration [11, 12]. To address these challenges, this study developed Cd(II)-IPs using an ethanol–acetonitrile solvent system, in which ethanol served as a relatively environmentally preferable solvent and acetonitrile acted as a porogenic agent, with polymerization completed within 8 hours at 60°C. The novelty of this study lies in integrating a more environmentally conscious synthesis approach and reduced polymerization time with a systematic comparison of HNO_3, HCl, and H_2SO_4 as extraction agents to improve template removal, restore recognition sites, and support adsorbent regeneration and reuse, thereby reducing adsorbent waste and enhancing the sustainability of Cd(II) adsorption.

The Cd(II)-IPs were synthesized using Cd(II) as the template ion, 8-hydroxyquinoline as the functional ligand, methacrylic acid (MAA) as the functional monomer, and ethylene glycol dimethacrylate (EGDMA) as the crosslinker [11]. This study aims to evaluate the effectiveness of different extraction agents for Cd(II) template removal and subsequent adsorption performance, characterize the structural changes associated with template extraction using X-ray diffraction (XRD) and Brunauer–Emmett–Teller (BET) analyses, and assess the regeneration and reuse performance of the developed Cd(II)-IPs. Ultimately, this work seeks to establish a more sustainable approach to the development of reusable Cd(II)-IP adsorbents for the selective separation of Cd(II) from contaminated water.

2. Experimental

2.1. Tools

The tools used were a set of glassware, a hot plate (Thermo Scientific), a magnetic stirrer, a pH meter, an analytical balance (Ohaus), an oven (Heraeus), a refrigerator, an atomic absorption spectrophotometer (AAS; AA240, Varian), an X-ray diffractometer (XRD; D8 Advance, Bruker), and a surface area analyzer (NOVA Station A, Quantachrome; NovaWin version 11.06) for BET analysis.

2.2. Materials

The materials used in this study included $Cd(NO_3)_2{\cdot}4H_2O$ (Merck), 8-hydroxyquinoline (HiMedia), methacrylic acid (MAA; Sigma-Aldrich), ethylene glycol dimethacrylate (EGDMA; Sigma-Aldrich), azobisisobutyronitrile (AIBN; Sigma-Aldrich), acetonitrile, ethanol, distilled water, N_2 gas, nitric acid (HNO_3), hydrochloric acid (HCl), sulfuric acid (H_2SO_4), filter paper, and aluminum foil. All chemicals were of analytical grade or the highest available purity and were used as received without further purification.

2.3. Synthesis of Cd(II)-IPs

Cd(II)-IPs were synthesized using a precipitation polymerization method. A total of 0.2 mmol of $Cd(NO_3)_2{\cdot}4H_2O$ was reacted with 0.5 mmol of 8-hydroxyquinoline in a mixture of 80 mL of ethanol and 40 mL of acetonitrile, and the mixture was stirred for 30 minutes. The mixture was added with 8 mmol of MAA, 40 mmol of EGDMA, and 8 mmol of AIBN and stirred for 30 minutes. The mixture was cooled in a freezer for 30 minutes, purged with nitrogen gas for 5 minutes, and placed in an oven at 60°C for 8 hours. The polymer was washed with 100 mL of ethanol and dried in an oven at 60°C for 1 hour. Non-imprinted polymers (NIPs) were synthesized using the same procedure without the addition of the Cd(II)-8-hydroxyquinoline complex.

2.4. Effect of Cd(II) Ion Extractant Type

Extraction of Cd(II) ions from Cd(II)-IPs was performed by adding 0.1 g of Cd(II)-IPs to 100 mL of 1 M HNO_3, HCl, and H_2SO_4 solution for 6 hours. The Cd(II)-IPs were washed with deionized water until the pH was neutral and dried in an oven at 60°C for 1 hour. The effect of the extractant type on the adsorption capacity was determined by adding 0.005 g of the extracted Cd(II)-IPs to 150 mL of 2.5 ppm Cd(II) solution at pH 6 for 30 minutes. The mixture was filtered, and the filtrate was

analyzed by AAS at 228.8 nm. The adsorption capacity of Cd(II)-IPs was calculated using Equation 1 [11, 13].

$$Q_e = \frac{(C_o - C_e)V}{m} \quad (1)$$

Where Q_e is the amount of Cd(II) adsorbed by the adsorbent (mg/g), C_o is the initial Cd(II) concentration (mg/L), C_e is the Cd(II) concentration at equilibrium (mg/L), V is the volume of the Cd(II) solution (L), and m is the mass of the adsorbent (g).

2.5. Regeneration of Cd(II)-IPs

The regeneration study of Cd(II)-IPs was conducted through an adsorption–desorption cycle. A total of 0.05 g of Cd(II)-IPs was added to 1.5 L of a 2.5 ppm Cd(II) solution at pH 6 for 30 minutes. The mixture was filtered, and the filtrate was analyzed by AAS at 228.8 nm. The Cd(II) ion was desorbed from Cd(II)-IPs using 50 mL of the best extractant solution for 6 hours, then washed to neutral pH and dried in an oven at 60°C for 1 hour. The adsorption–desorption cycle was repeated five times using the same adsorbent. The recovery percentage (%R) was determined as the ratio of the adsorption capacity in the final cycle to that in the initial cycle, using Equation 2.

$$\%R = \frac{Q_e final\ cycle}{Q_e intial\ cycle} \times 100\% \quad (2)$$

Where $\%R$ is the recovery percentage, Q_e final cycle is the adsorption capacity in cycle 5 (mg/g), and Q_e initial cycle is the adsorption capacity in cycle 1 (mg/g).

3. Results and Discussion

3.1. Synthesis of Cd(II)-IPs

The synthesis of Cd(II)-IPs involves three main stages: complex formation between Cd(II) ions and the 8-HQ ligand, polymerization of the Cd(II)-8-HQ complex with MAA and EGDMA, and release of Cd(II) ions from the polymer matrix, resulting in a selective cavity for Cd(II) ions. The initial stage of synthesis begins with the formation of the Cd(II)-8-HQ complex through coordinate bonds between the Cd(II) ions and oxygen and nitrogen donor atoms on the aromatic ring of the 8-HQ ligand. In this system, ethanol is used as a relatively environmentally friendly solvent, while acetonitrile serves as a porogen, facilitating the formation of a porous polymer structure [11]. They also help maintain the complex's stability during the reaction [14]. Figure 1 shows the synthesis mechanism of Cd(II)-IPs.

During polymerization, MAA was used as the monomer. A three-dimensional crosslinked network was obtained by copolymerizing MAA and EGDMA, thereby ensuring the mechanical strength of the polymer [10]. AIBN was used as an initiator, thereby generating the radicals necessary for the formation of the polymer's three-dimensional structure that fixes the Cd(II)-8-HQ complex [15]. The extraction of Cd(II) ions from the polymer using an acidic solution releases Cd(II) ions from the binding site, and the resulting cavity maintains the charge, geometry, and coordination number characteristic of Cd(II). This ensures the memory effect inherent in Cd(II)-IPs and contributes to their selectivity [16, 17]. The described differences create conditions in which Cd(II)-IPs differ qualitatively from NIPs, a control polymer without a template. While Cd(II)-IPs have specific sites for Cd(II) binding, NIPs lack these sites. Therefore, Cd(II)-IPs can act as selective adsorbents for Cd(II) ions and be used to separate and adsorb these ions [18].

During the imprinting process, 8-hydroxyquinoline (8-HQ) acts as a functional ligand by coordinating with Cd(II) to form a Cd(II)–8-HQ complex that is incorporated into the crosslinked polymer matrix. Acidic extraction disrupts this coordination interaction and removes the Cd(II) template, leaving imprinted cavities with a complementary charge, geometry, and coordination environment to Cd(II), while 8-HQ remains incorporated within the polymer matrix as the functional recognition component. The similar XRD patterns of Cd(II)-IPs before and after extraction indicate that the basic polymer structure is preserved, while the disappearance of diffraction peaks at 2θ = 27.86°, 37.58°, 40.78°, 44.26°, 52.14°, 61.40°, 62.68°, and 66.42°, assigned to $Cd(NO_3)_2{\cdot}4H_2O$, supports the removal of the Cd(II) template. Cd(II) adsorption involves both chemical and physical interactions. However, coordination with 8-HQ functional groups is considered the primary mechanism responsible for Cd(II) recognition and selectivity, while the porous structure facilitates mass transfer and provides additional adsorption sites. Cd(II) adsorption occurs primarily through coordination interactions between Cd(II) and the oxygen and nitrogen donor atoms of 8-HQ, with additional contributions from the oxygen-containing donor groups of MAA.

3.2. Characterization of Cd(II)-IPs

3.2.1. XRD Characterization

The removal of Cd(II) ions was investigated with the help of XRD analysis. The diffraction patterns of Cd(II)-IPs before and after extraction are shown in Figure 2. Cd(II)-IPs before extraction have characteristic peaks of $Cd(NO_3)_2{\cdot}4H_2O$ at 2θ = 27.86°, 37.58°, 40.78°, 44.26°, 52.14°, 61.40°, 62.68°, 66.42°. However, Cd(II)-IPs treated with 1 M HNO_3 do not demonstrate these peaks, which is evidence of the removal of Cd(II) ions from the Cd(II)-IPs matrix, leaving behind specific binding sites. As a result, the peaks typical of $Cd(NO_3)_2{\cdot}4H_2O$ were not detected in Cd(II)-IPs after extraction [19]. The XRD comparison of Cd(II)-IPs before extraction and Cd(II)-IPs after extraction was primarily intended to confirm the removal of the Cd(II) template rather than to demonstrate a major structural transformation of the polymer matrix. The similar diffraction patterns after extraction indicate that the basic polymer structure was maintained, while the disappearance of the $Cd(NO_3)_2{\cdot}4H_2O$ peaks confirms the successful removal of the Cd(II) template and the formation of vacant specific binding sites.

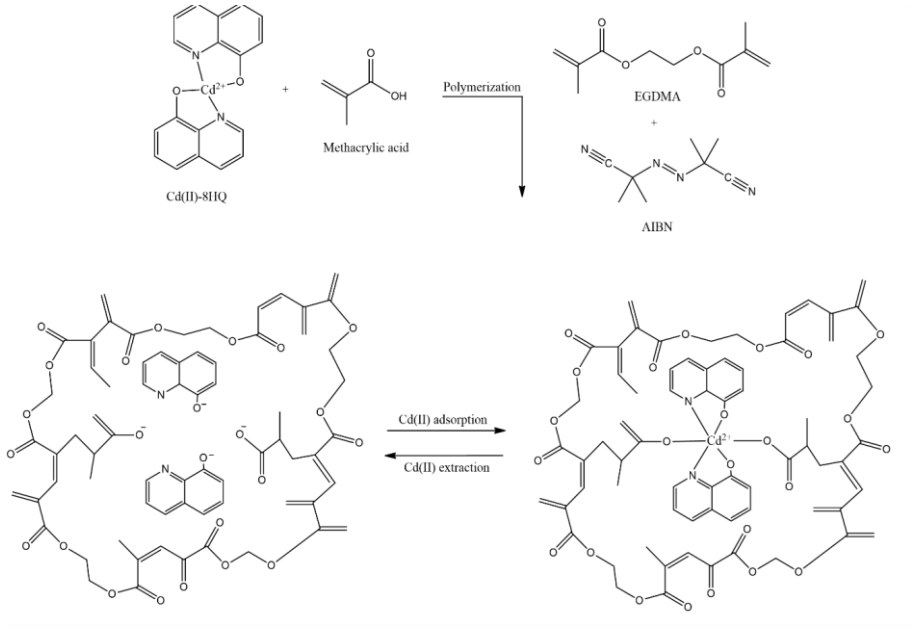


Figure 1. Synthesis mechanism of Cd(II)-IPs

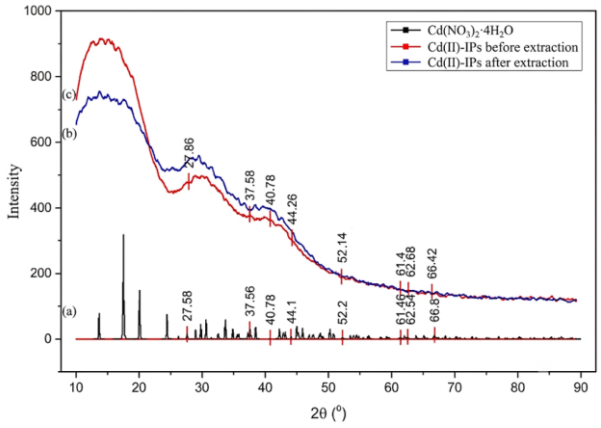


Figure 2. XRD diffractograms of (a) $Cd(NO_3)_2{\cdot}4H_2O$, (b) Cd(II)-IPs after extraction, and (c) Cd(II)-IPs before extraction

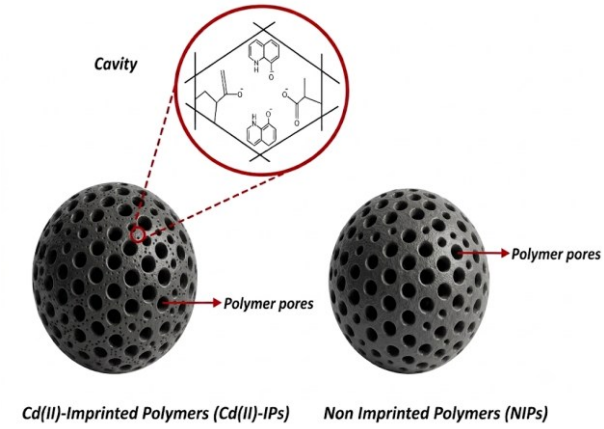


Figure 3. Cd(II)-IPs and NIPs

Table 1. Surface area, pore volume, and pore diameter of Cd(II)-IPs after extraction and NIPs

Adsorbent	Surface area (m^2/g)	Pore volume (cm^3/g)	Pore diameter (nm)
Cd(II)-IPs after extraction	649.968	1.074	1.561
NIPs	346.103	0.517	1.552

3.2.2. BET Characterization

BET analysis was carried out to evaluate the surface area, pore volume, and pore diameter of the materials. As shown in Table 1, Cd(II)-IPs after extraction possess a bigger surface area, pore volume, and pore diameter as compared to NIPs. This implies that removing Cd(II) ions from the polymer matrix created space previously occupied by Cd(II) ions, resulting in an increase in the polymer's surface area, pore volume, and pore diameter. It can be seen from Figure 3 that Cd(II)-IPs after extraction possess a higher number of pores as compared to NIPs, since Cd(II)-IPs after extraction have cavities specific for Cd(II) ions [20]. Cd(II)-IPs contain polymer pores that contribute to physical adsorption and specific recognition cavities that facilitate the selective chemical interaction and recognition of Cd(II) ions. In contrast, NIPs possess polymer pores that primarily contribute to physical adsorption but lack the specific recognition cavities formed through molecular imprinting, resulting in lower selectivity toward Cd(II) ions.

3.2.3. Effect of Cd(II) Ion Extractant Type

Evaluation of the regeneration capability of Cd(II)-IPs by repeated adsorption/desorption cycles. The regeneration capability of Cd(II)-IPs upon repeated adsorption/desorption cycles is an important property that determines their economical use and convenience in industry. A material's regeneration capability defines how stable the polymer's conformation and binding site is after each cycle. The interaction of Cd(II) with the anions of each of the three acids is described by Equations (3), (4), and (5).

$$Cd^{2+} + 2NO_3^- \rightarrow Cd(NO_3)_2 \quad (3)$$

$$Cd^{2+} + 2Cl^{-} \rightarrow CdCl_2 \quad (4)$$

$$Cd^{2+} + SO_4^{2-} \rightarrow CdSO_4 \quad (5)$$

The dependence of the adsorption capacity of Cd(II)-IPs on the type of extractant is shown in Figure 4, which indicates that the adsorption capacity varies slightly among the different extractants tested. The maximum value, achieved with the nitric acid solution, was 66.29 mg/g. Using hydrochloric and sulfuric acids as extractants allowed reaching 61.68 and 56.04 mg/g, respectively. At the same time, the adsorption capacity of NIPs was significantly lower and amounted to only 53.46 mg/g. Cd(II) ions bind to the polymer matrix through coordinate covalent bonds, which are formed between the donor atom in the ligand (8-HQ) and metal ions. Cd(II) ions are removed from the adsorbent by protonation of the ligand and salt formation between Cd(II) and anions of the acid, which is in solution. According to Le Chatelier's principle, the formation of $Cd(NO_3)_2$ salt, which has high solubility, will shift the equilibrium towards desorption of Cd(II) ions, thus facilitating their removal from the polymer matrix. The low solubility of $CdCl_2$ and $CdSO_4$ may explain the inhibition of this process. The solubility of $Cd(NO_3)_2$, $CdCl_2$, and $CdSO_4$ at a temperature of 20–25°C is 150–156, 120–135, and 76.6–76.7 g per 100 g of water, respectively.

3.2.4. Regeneration of Cd(II)-IPs

Evaluating regeneration capability through repeated adsorption-desorption cycles is a crucial parameter for determining the economic feasibility, operational efficiency, and sustainability of Cd(II)-IPs in industrial-scale applications. Regeneration capability indicates the stability of the polymer structure and specific recognition sites after repeated use. During the adsorption stage, Cd(II) ions bind to the polymer matrix through reversible interactions between Cd(II) and donor atoms in the 8-HQ ligand and carboxylate groups in the MAA monomer. During the desorption stage, HNO_3 solution is used to extract Cd(II) ions from the polymer matrix. The HNO_3 solution produces NO_3^- anions, which can bind with Cd(II) ions imprinted on the polymer matrix, forming soluble $Cd(NO_3)_2$ [21]. Once the Cd(II) is released from the polymer matrix, the cavity is empty and can be reused for the next adsorption cycle.

Figure 5 shows that Cd(II)-IPs can be used for up to 5 cycles with a recovery percentage of 21.2%. The adsorption capacity from cycles 1 to 5 gradually decreases due to degradation of the polymer structure and the loss of some active sites during the repeated desorption process [22]. During the HNO_3 desorption process, the ester bonds in EGDMA undergo partial hydrolysis under acidic conditions. This chemical bond damage partially breaks the crosslinking network, reducing the stability and number of cavities in the adsorbent [18]. Despite the decrease in adsorption capacity after five reuse cycles, the comparative results presented in Table 2 demonstrate that the Cd(II)-IPs developed in this study offer competitive performance compared with several other adsorbents. Their relatively high adsorption capacity and short adsorption time highlight their potential for use as selective adsorbents for Cd(II) adsorption and separation.

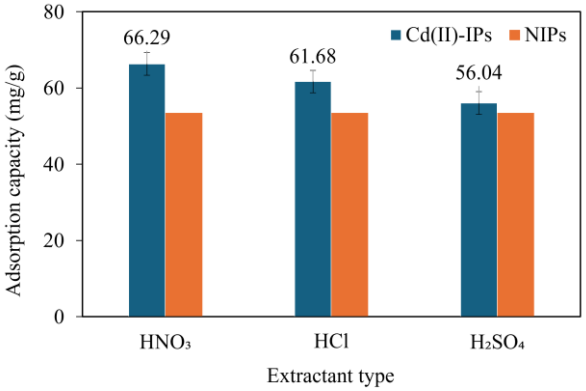


Figure 4. Effect of Cd(II) ion extractant type on the adsorption capacity of Cd(II)-IPs

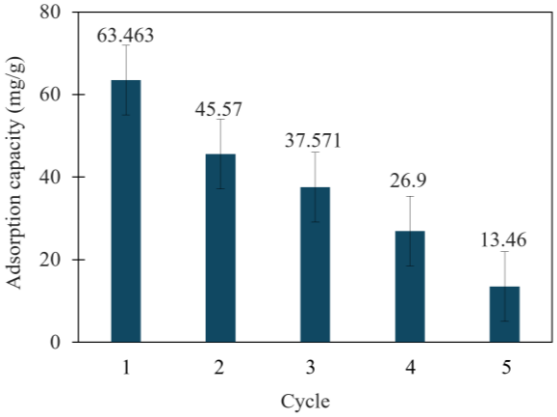


Figure 5. Regeneration of Cd(II)-IPs

Table 2. Adsorption capacity of Cd(II) ions on various adsorbents

Adsorbent	Adsorption capacity (mg/g)	Adsorption time (minutes)	Reference
Sugarcane bagasse cellulose	2.22	120	[23]
Zeolite	1.39	60	[24]
Alginate	6.30	1440	[25]
Activated charcoal (Matoa bark)	6.24	40	[26]
Ketapang leaf biochar	10.40	90	[27]
Coconut fiber waste cellulose	0.52	45	[28]
Bentonite	2.31	80	[29]
Iron oxide nanoparticles	18.32	120	[8]
Magnetite Mercaptosilicate Ion Imprinted Polymer	10.54	30	[30]
Magnetic Ion Imprinted Polymers	46.80	35	[31]
Magnetic Cd(II) Ion-Imprinted Polymer	26.10	60	[32]
Cd(II)-IPs	63.46	30	This study

4. Conclusion

This study successfully synthesized Cd(II)-IPs using ethanol as a green solvent, with a polymerization time of only 8 hours at 60°C, demonstrating an energy-efficient synthesis approach. HNO_3 was identified as the most effective extractant for releasing Cd(II) ions from the polymer matrix, achieving an adsorption capacity of 63.46 mg/g. XRD confirmed the successful extraction of Cd(II) ions by showing the disappearance of the characteristic peak of $Cd(NO_3)_2{\cdot}4H_2O$ after extraction, while BET analysis showed increases in surface area, pore volume, and pore diameter in the Cd(II)-IPs. Notably, the developed Cd(II)-IPs could be regenerated up to 5 cycles, thereby reducing adsorbent waste, although recovery efficiency gradually decreased with successive regeneration cycles. Further optimization of the regeneration conditions, particularly the extraction agent concentration and contact time, is recommended to enhance the durability and reusability of the adsorbent. Despite the decrease in adsorption capacity after five regeneration cycles, the Cd(II)-IPs developed in this study demonstrate competitive performance compared with several previously reported adsorbents, highlighting their potential as reusable, selective adsorbents for Cd(II) removal.

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References

[1] A. E. Charkiewicz, W. J. Omeljaniuk, K. Nowak, M. Garley, J. Nikliński, Cadmium Toxicity and Health Effects—A Brief Summary, *Molecules*, 28, 18, (2023), 6620 https://doi.org/10.3390/molecules28186620

[2] G. Genchi, M. S. Sinicropi, G. Lauria, A. Carocci, A. Catalano, The Effects of Cadmium Toxicity, *International Journal of Environmental Research and Public Health*, 17, 11, (2020), 3782 https://doi.org/10.3390/ijerph17113782

[3] N. Najihah, F. Rachmadiarti, Analisis Kadar Logam Berat Kadmium (Cd) pada Tumbuhan Air di Sungai Brantas Mojokerto, *LenteraBio*, 12, 2, (2023), 239-247

[4] D. Elfidasari, L. N. Ismi, I. Sugoro, Heavy Metal Contamination of Ciliwung River, Indonesia, *Journal of International Scientific Publications*, 13, (2019), 106-111

[5] J. M. Arana Juve, F. M. S. Christensen, Y. Wang, Z. Wei, Electrodialysis for metal removal and recovery: A review, *Chemical Engineering Journal*, 435, (2022), 134857 https://doi.org/10.1016/j.cej.2022.134857

[6] S. Satyam, S. Patra, Innovations and challenges in adsorption-based wastewater remediation: A comprehensive review, *Heliyon*, 10, 9, (2024), e29573 https://doi.org/10.1016/j.heliyon.2024.e29573

[7] L. Darmayanti, L. Indriani, Adsorption of Cadmium (Cd) Metal in Solution Using Pofa-Based Zeolite (Palm Oil Fly Ash), *EduChemia: Jurnal Kimia dan Pendidikan*, 9, 2, (2024), 176-187 https://doi.org/10.30870/educhemia.v9i2.24846

[8] J. Lin, B. Su, M. Sun, B. Chen, Z. Chen, Biosynthesized iron oxide nanoparticles used for optimized removal of cadmium with response surface methodology, *Science of the Total Environment*, 627, (2018), 314-321 https://doi.org/10.1016/j.scitotenv.2018.01.170

[9] S. Jakavula, N. R. Biata, K. M. Dimpe, V. E. Pakade, P. N. Nomngongo, A Critical Review on the Synthesis and Application of Ion-Imprinted Polymers for Selective Preconcentration, Speciation, Removal and Determination of Trace and Essential Metals from Different Matrices, *Critical Reviews in Analytical Chemistry*, 52, 2, (2022), 314-326 https://doi.org/10.1080/10408347.2020.1798210

[10] M. M. Lazar, C. A. Ghiorghita, E. S. Dragan, D. Humelnicu, M. V. Dinu, Ion-Imprinted Polymeric Materials for Selective Adsorption of Heavy Metal Ions from Aqueous Solution, *Molecules*, 28, 6, (2023), 2798 https://doi.org/10.3390/molecules28062798

[11] Rüstem Keçili, Ecevit Yılmaz, Arzu Ersöz, Rıdvan Say, Chapter 12 - Imprinted Materials: From Green Chemistry to Sustainable Engineering, in: G. Szekely, A. Livingston (Eds.) *Sustainable Nanoscale Engineering*, Elsevier, 2020, https://doi.org/10.1016/B978-0-12-814681-1.00012-6

[12] Behisht Ara, Mian Muhammad, Muhammad Salman, Raees Ahmad, Noor Islam, Tanveer ul Haq Zia, Preparation of microspheric Fe(III)-ion imprinted polymer for selective solid phase extraction, *Applied Water Science*, 8, (2018), 41 https://doi.org/10.1007/s13201-018-0680-3

[13] S. E. Kartika, M. B. Amran, Sintesis dan Karakterisasi Poly (Anthranilic Acid-Co-Formaldehyde) untuk Adsorpsi Ion Pb(II), *Alchemy: Journal of Chemistry*, 9, 1, (2021), 15-25 https://doi.org/10.18860/al.v9i1.11476

[14] B. A. Hermawan, Mutakin, A. N. Hasanah, Role of porogenic solvent type on the performance of a monolithic imprinted column, *Chemical Papers*, 75, (2021), 1301-1311 https://doi.org/10.1007/s11696-020-01399-5

[15] Z. Zhou, D. Kong, H. Zhu, N. Wang, Z. Wang, Q. Wang, W. Liu, Q. Li, W. Zhang, Z. Ren, Preparation and adsorption characteristics of an ion-imprinted polymer for fast removal of Ni(II) ions from aqueous solution, *Journal of Hazardous Materials*, 341, (2018), 355-364 https://doi.org/10.1016/j.jhazmat.2017.06.010

[16] S. Ventura, S. Bhamidi, M. Hornbostel, Selective Recovery of Lithium from Brines, *43rd Workshop on Geothermal Reservoir Engineering*, Stanford, California, 2018

[17] S. E. Kartika, P. S. Hariyanto, A. D. R. Madjid, S. A. P. Siboro, R. Sujarwadi, Synthesis and Characterization of Nickel(II) Imprinted Polymers as a Selective Adsorbent for Nickel(II) Ions, *Jurnal Kimia Sains dan Aplikasi*, 28, 6, (2025), 307-315 https://doi.org/10.14710/jksa.28.6.307-315

[18] Muhammad Saqaf Jagirani, Aamna Balouch, Sarfaraz Ahmed Mahesar, Ameet Kumar, Abdul Rehman Baloch, Abdullah Abdullah, Muhammad Iqbal Bhanger, Fabrication of cadmium tagged novel ion imprinted polymer for detoxification of the toxic Cd^{2+} ion from aqueous environment, *Microchemical Journal*, 158, (2020), 105247 https://doi.org/10.1016/j.microc.2020.105247

[19] S. M. Alshuiael, M. A. Al-ghouti, Development of a novel tailored ion-imprinted polymer for recovery of lithium and strontium from reverse osmosis concentrated brine, *Separation and Purification Technology*, 295, (2022), 121320 https://doi.org/10.1016/j.seppur.2022.121320

[20] Hui Cao, Pu Yang, Tai Ye, Min Yuan, Jinsong Yu, Xiuxiu Wu, Fengqin Yin, Yan Li, Fei Xu, Recognizing adsorption of Cd(II) by a novel core-shell mesoporous ion-imprinted polymer: Characterization, binding mechanism and practical application, *Chemosphere*, 278, (2021), 130369 https://doi.org/10.1016/j.chemosphere.2021.130369

[21] V. Yilmaz, H. Yilmaz, Z. Arslan, J. Leszczynski, Novel Imprinted Polymer for the Preconcentration of Cadmium with Determination by Inductively Coupled Plasma Mass Spectrometry, *Analytical Letters*, 50, 3, (2017), 482-499 https://doi.org/10.1080/00032719.2016.1182544

[22] A. K. Zhakina, Y. P. Vassilets, O. V. Arnt, A. M. Zhakin, Synthesis and Study of Sorption Properties of Zinc-Imprinted Polymer, *Polymers*, 16, 24, (2024), 3545 https://doi.org/10.3390/polym16243545

[23] R. Kusumawardani, T. A. Zaharah, L. Destiarti, Adsorpsi kadmium(ii) menggunakan adsorben selulosa ampas tebu teraktivasi asam nitrat, *Jurnal Kimia Khatulistiwa*, 7, 3, (2018), 75-83

[24] S. W. Pratomo, F. W. Mahatmanti, T. Sulistyaningsih, Pemanfaatan Zeolit Alam Teraktivasi H_3PO_4 sebagai Adsorben Ion Logam Cd(II) dalam Larutan, *Indonesian Journal of Chemical Science*, 6, 2, (2017), 161-167

[25] W. Wei, J. K. Bediako, S. Kim, Y. S. Yun, Removal of Cd(II) by poly(styrenesulfonic acid)-impregnated alginate capsule, *Journal of the Taiwan Institute of Chemical Engineers*, 61, (2016), 188-195 https://doi.org/10.1016/j.jtice.2015.12.009

[26] Anita Karunia Zustriani, Naila Lajja Zulfa Faza, Adsorpsi Logam Cd pada Limbah Cair Laboratorium Menggunakan Adsorben Arang Aktif dari Kulit Buah Matoa, *Integrated Lab Journal*, 11, 01, (2023),

[27] Domiruddin, W. Rahmalia, A. Shofiyani, Kapasitas Adsorpsi Ion Logam Cd(II) pada Bioarang Daun Ketapang (*Terminalia catappa* Linn), *Jurnal Kimia Khatulistiwa*, 7, 4, (2018), 83-92

[28] S. K. Saef, V. Amalia, A. M. Supriatna, Adsorpsi Ion Logam Cd(II) oleh Selulosa Limbah Sabut Kelapa sebagai Adsorben Berbiaya Murah, *Gunung Djati Conference Series: Seminar Nasional Kimia 2022*, 2022

[29] Y. Prasetiowati, T. Koestiari, Kapasitas Adsorpsi Bentonit Teknis Sebagai Adsorben Ion Cd^{2+}, *Unesa Journal of Chemistry*, 3, 3, (2014), 194-200

[30] Nabela Viviana, Ngatijo, Restina Bemis, Diah Riski Gusti, Synthesis and Characterization of Adsorbent Materials Magnetite Mercaptosilicate Ion Imprinted Polymer as Cadmium Ion Adsorbent, *Jurnal Riset Kimia*, 14, 2, (2023), 209-218 https://doi.org/10.25077/jrk.v14i2.621

[31] X. Xu, M. Wang, Q. Wu, Z. Xu, X. Tian, Synthesis and Application of Novel Magnetic Ion-Imprinted Polymers for Selective Solid Phase Extraction of Cadmium (II), *Polymers*, 9, 8, (2017), 360 https://doi.org/10.3390/polym9080360

[32] Hongpeng Wang, Yuecheng Lin, Yin Li, Anudari Dolgormaa, Hui Fang, Lin Guo, Jun Huang, Junxing Yang, A Novel Magnetic Cd(II) Ion-Imprinted Polymer as a Selective Sorbent for the Removal of Cadmium Ions from Aqueous Solution, *Journal of Inorganic and Organometallic Polymers and Materials*, 29, (2019), 1874-1885 https://doi.org/10.1007/s10904-019-01148-6