

Application of Bentonite and Modified Bentonite as Green Adsorbent for Cadmium Removal from Aqueous Medium

SACHIN VERMA, SUBHAJIT SIKDAR, ASHOK KUMAR JHA* and PALLAVI KUMARI

University Department of Chemistry, Tilka Manjhi Bhagalpur University, Bhagalpur, Bihar, India.

Abstract

Cadmium in aqueous medium is posing a serious threat to human health and ecosystem. Cd(II) enters the food chain and get biomagnified leading to adverse health effects. Cadmium contamination affects kidneys, bones and lungs due to its persistence and bioaccumulation. The present study deals with the removal of cadmium ion from aqueous medium using bentonite powder and bentonite modified with green saponins such as *Sapindus mukorossi* (reetha) and Aloe vera. The residual concentration was found to be 0.00753 ppm at a wavelength of 228.802 nm when 1g bentonite was treated with 100 mL 1 ppm solution up to 60 minutes. The maximum percent removal is 99.24. A comparative study for removal of Cd(II) showed that adsorption of modified bentonite with Aloe vera was higher than that of the modified bentonite with *Sapindus mukorossi* extract an unmodified bentonite. Bentonite was characterized by XRD, TGA and FTIR. Kinetic investigations were done using pseudo first order and second order kinetic models. The experimental findings revealed that bentonite modified with *Sapindus mukorossi* and Aloe vera could be utilized as an effective adsorbent of Cd(II) from aqueous medium.



Article History

Received: 15 September 2025

Accepted: 01 January 2026

Keywords

Aloe Vera;
Bentonite;
Sapindus Mukorossi;
Saponins.

Abbreviations

BBRC	Barmer bentonite modified with reetha solution
BB2	Barmer bentonite
SB2 to SB7	samples of Rajmahal bentonite

Introduction

Geological weathering, geochemical reactions due to the association of cadmium ores along with zinc ores

contribute to the cadmium contamination in water.^{1,2} Anthropogenic activities such as industrial discharge, solid waste disposals, battery manufacturing, and

CONTACT Ashok Kumar Jha ✉ ashokjha39@gmail.com 📍 University Department of Chemistry, Tilka Manjhi Bhagalpur University, Bhagalpur, Bihar, India.



© 2025 The Author(s). Published by Enviro Research Publishers.

This is an  Open Access article licensed under a Creative Commons license: Attribution 4.0 International (CC-BY).

Doi: <http://dx.doi.org/10.12944/CWE.20.3.14>

metal work industries contribute significantly to the cadmium contamination.^{3,4} Activated carbon, agriculture wastes, cynodon dactyon (perennial grass) are few prominent effective bio-adsorbents used for the remediation of heavy metals, but they face challenges in separation and generate large sludge also.^{5,6} Reverse osmosis, biosorption, electrolysis are the traditional and common methods for removal of heavy metals, but the bentonites exhibit superiority due to high surface area.^{7,8} Bentonites have mesopores and on modification with *Sapindus mukorossi*, saponins present enhance the surface area and several functional groups such as amino and carboxylic get fixed on the surface. Lignins present in the *Sapindus mukorossi*, also contribute to the enhanced adsorption potential of modified bentonites. Lignins and saponins are also present in aloe vera, which get attached to the surface of the bentonites. Thus, modified bentonites contribute to a great extent for removal of heavy metals from aqueous medium. Bentonites are smectite group of minerals having 2:1 structure. Na⁺, K⁺, Ca²⁺, and Mg²⁺ are the exchangeable cations which attribute to the cation exchange.⁹ Major oxides of Si, Al, Fe, Ca, and Mg are present which also contribute to the adsorption of heavy metals. The mesopores present in the bentonite mineral adsorb Cd²⁺ ions from aqueous medium. The bentonite mineral has layered structure as a result of which it possesses intercalation property. Intercalation may be done with Fe³⁺ ions and Cetyl trimethyl ammonium bromide (CTAB) with a view to increase remediation potential of bentonite.¹⁰⁻¹² The present paper has used modification of bentonite with extract of aloe vera which has scientific name *Aloe barbadensis* Miller and *Sapindus mukorossi*.^{13,14} Adsorption of heavy metals such as Cr(VI), Pb(II) in general and Cd(II) to in particular maybe attributed to the presence of mesopores as well as exchangeable cations. Adsorption behaviour was investigated to see the best fit of experimental results with Freundlich and Langmuir adsorption isotherms.^{15,16} Freundlich adsorption isotherm refers to multilayer adsorption whereas, Langmuir refers to monolayer adsorption. In view of high costs, ecological damage in phytoremediation and bioremediation, cadmium immobilization by bentonite as well as bentonite modified with extract of *Sapindus mukorossi* has emerged as a low cost method of remediation.

Materials and Methods

Preparation of Modified Bentonite

The bentonite was procured from Barmer, Rajasthan and the Rajmahal hills of Jharkhand. The collected bentonite was powdered to 300 mesh sieve and dried in oven at 80°C for 2 hours. The suspension of bentonite gives blue colour with benzidine solution indicating the presence of montmorillonite unit in the bentonite. Now 20g of bentonite suspension was prepared in 800 mL of water and 100 mL of *Sapindus mukorossi* extract was added to it followed by stirring for 3 hours on a magnetic stirrer. It was filtered and dried in an oven after washing the bentonite mass several times with deionized water. Thus, modified bentonite was obtained for treatment with 1 ppm Cd (II) solution. Similar experiments were repeated to get bentonite modified with Aloe vera extract. 100 mL 1 ppm Cd(II) solution was taken in a conical flask and treated with 1g modified bentonite up to 30, 60 and 90 minutes.

Instrumental Studies

The residual concentrations were known from UV Double beam spectrophotometer of the model Systronics 2203 and also by Inductively Coupled Plasma – Atomic Emission Spectroscopy (ICP – AES) at ppb level. The modified bentonite was characterized by Fourier Transform Infrared Spectroscopy (FTIR), thermo-gravimetric analysis (TGA), and X-ray diffraction.^{17,18} FTIR indicated the presence of functional groups in the bentonite with Perkin Elmer Spectrum version 10.4.1.

SiO₂ and Al₂O₃ have been determined as alizarin red – S complex from UV Double beam spectrophotometer of Systronics 2203 model. ICP – AES analyzer Perkin Elmer AVIO 560 max (Model ULTIMA – 2, Horiba Jobin, YVON, France) was used to analyze cadmium concentration in the samples.

The diffraction pattern in XRD also indicated the presence of Si and Al as main constituents of bentonite. As specimen length of 10 nm and 0.1000 mm of receiving slit size was used for diffraction in Bruker D8 Advance.

Pyris Diamond TGA/DTA (Perkin – Elmer, STA – 6000) thermal analyzer was used to know the weight loss in TGA and endothermic peak in DTA.

The BET surface area was measured by Micrometrics 3 flex version 4.05 serial H941 Unit/Part 2. The modification of bentonite by natural saponin containing extract of *Sapindus mukorossi* enhanced the surface area of bentonite.

SEM analysis was done to know the surface morphology with the help of ZEISS EVOMA 10, Germany. From

the SEM images, it became clear that structure of bentonite resembled with smectite group.

Results

The samples of BBRC to BB2 starts with 15 minutes but the SB2 to SB7 time starts with 30 minutes to get uniform graphical results.

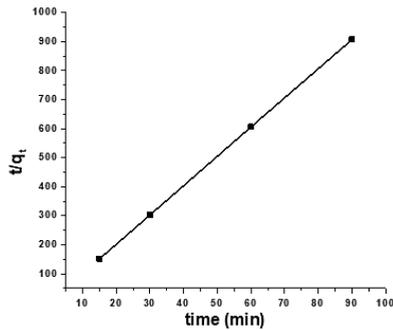
Table 1: Residual Concentrations of Cd(II) at 228.802 nm after treatment with 100 mL 1 ppm Cd(II) solution

Sl. No.	Sample Code	Time (min)	Residual Conc. (ppm)	% Removal
1	BBRC-1	15	0.0282	97.18
2	BBRC-2	30	0.01004	98.99
3	BBRC-3	60	0.0084	99.16
4	BBRC-4	90	0.01006	98.99
5	BB2C1	15	0.01006	98.99
6	BB2C2	30	0.00932	99.068
7	BB2C3	60	0.01038	98.96
8	BB2C4	90	0.0081	99.19
9	BBAC-1	15	0.00863	99.14
10	BBAC-2	30	0.0097	99.03
11	BBAC-3	60	0.00905	99.09
12	BBAC-4	90	0.01067	98.93
13	SB2AV-Cd3	30	0.0088	99.12
14	SB2AV-Cd6	60	0.0089	99.11
15	SB2AV-Cd9	90	0.0077	99.23
16	SB7AV-Cd3	30	0.01007	99.99
17	SB7AV-Cd6	60	0.01046	98.95
18	SB7AV-Cd9	90	0.0886	91.14
19	SB2RS-Cd3	30	0.0087	99.13
20	SB2RS-Cd6	60	0.00787	99.21
21	SB2RS-Cd9	90	0.00775	99.22
22	SB7RS-Cd3	30	0.00829	99.17
23	SB7RS-Cd6	60	0.00753	99.24
24	SB7RS-Cd9	90	0.00804	99.19

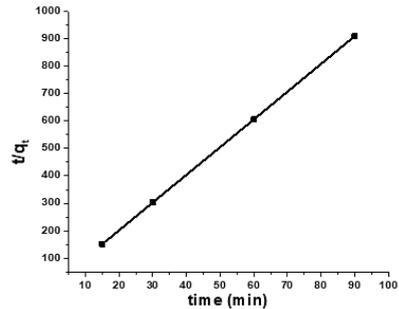
Table 2: Values of qt, Ct/qt, log qt and log Ct

Sample code	Initial Conc. (ppm)	Ct	qt	Ct/qt	log qt	log Ct
BBRC1	1	0.0282	0.09718	0.29018317	-1.01242311	-1.54975089
BBRC2	1	0.01004	0.099	0.10141824	-1.00438235	-1.99826629
BBRC3	1	0.0084	0.09916	0.08471158	-1.00366348	-2.07572071
BBRC4	1	0.01006	0.09899	0.10162232	-1.00439113	-1.99740202

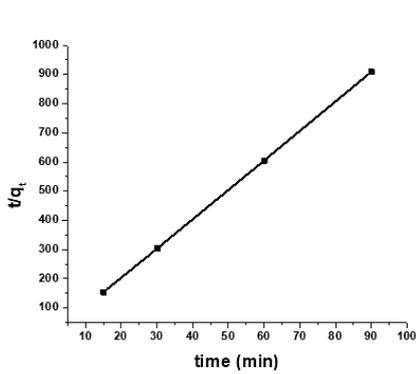
BB2C1	1	0.01006	0.09899	0.10162232	-1.00439113	-1.99740202
BB2C2	1	0.00932	0.09907	0.0940768	-1.0040666	-2.03058409
BB2C3	1	0.01038	0.09896	0.10488875	-1.00453154	-1.98380265
BB2C4	1	0.0081	0.09919	0.08166146	-1.00353211	-2.09151498
BBAC1	1	0.00863	0.09914	0.08705125	-1.00376423	-2.0639892
BBAC2	1	0.0097	0.09903	0.09795012	-1.00423322	-2.01322827
BBAC3	1	0.00905	0.0991	0.0913265	-1.00394826	-2.04335142
BBAC4	1	0.01067	0.09893	0.10785077	-1.00465882	-1.97183558
SB2AV-Cd3	1	0.0088	0.09912	0.08878128	-1.00383871	-2.05551733
SB2AV-Cd6	1	0.0089	0.09911	0.08979921	-1.00388252	-2.05060999
SB2AV-Cd9	1	0.0077	0.09923	0.0775975	-1.00335701	-2.11350927
SB7AV-Cd3	1	0.01007	0.09899	0.10172436	-1.00439551	-1.99697053
SB7AV-Cd6	1	0.01046	0.09895	0.10570568	-1.00456665	-1.98046832
SB7AV-Cd9	1	0.0886	0.09114	0.97213079	-1.04029098	-1.05256628
SB2Rs-Cd3	1	0.0087	0.09913	0.08776354	-1.00379489	-2.06048075
SB2Rs-Cd6	1	0.00787	0.09921	0.07932428	-1.00343142	-2.10402527
SB2Rs-Cd9	1	0.00775	0.09923	0.07810532	-1.00337889	-2.1106983
SB7Rs-Cd3	1	0.00829	0.09917	0.08359299	-1.00361531	-2.08144547
SB7Rs-Cd6	1	0.00753	0.09925	0.07587131	-1.00328261	-2.12320502
SB7Rs-Cd9	1	0.00804	0.0992	0.08105166	-1.00350584	-2.09474395



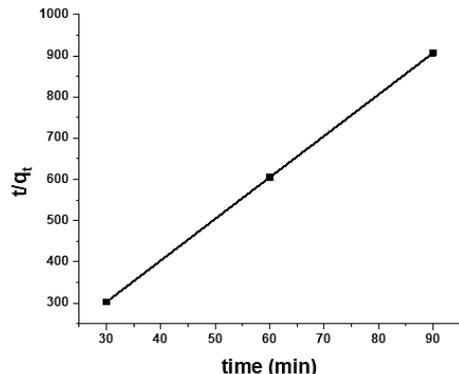
(a)



(b)



(c)



(d)

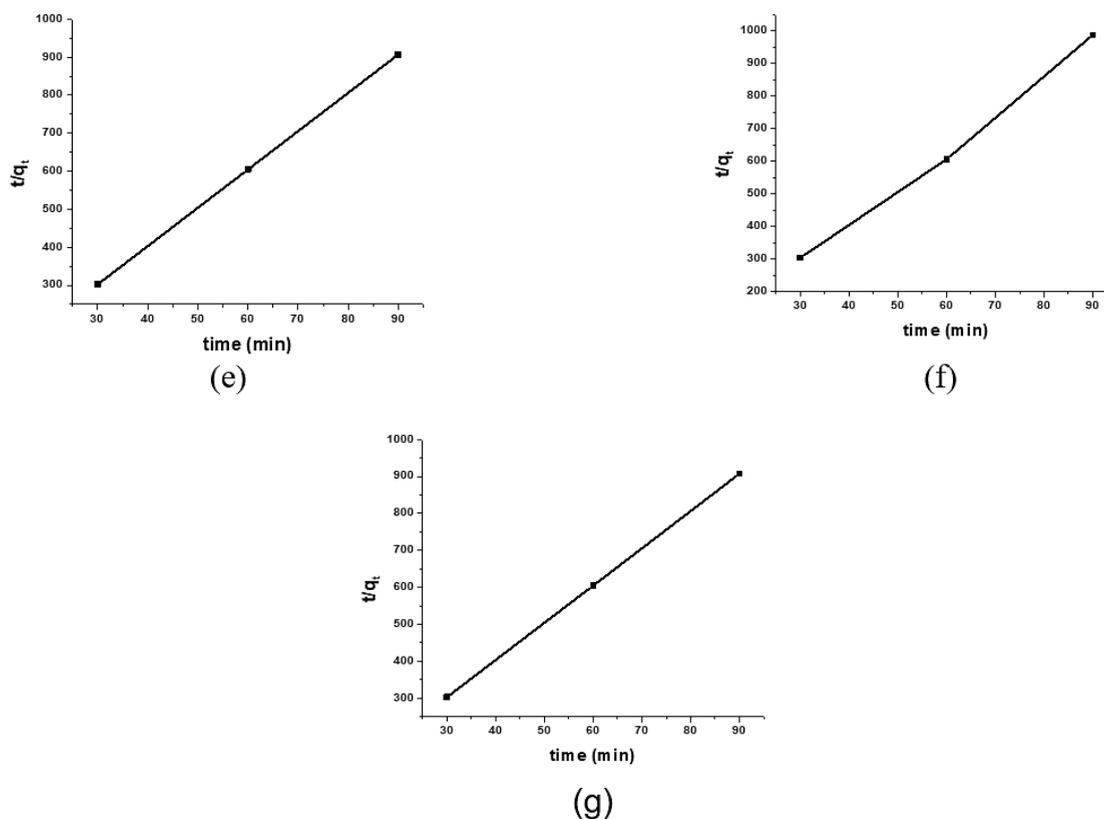


Fig. 1: Pseudo Second Order Kinetics for (a) BB2C1 to BB2C4, (b) BBAC1 to BBAC4, (c) BBRC1 to BBRC4, (d) Sb2AVCd3 to Sb2AVCd9, (e) Sb2RsCd3 to Sb2RsCd9, (f) Sb7AVCd3 to Sb7AVCd9, (g) Sb7RsCd3 to Sb7RsCd9.

Discussion

Kinetic Study

Kinetic studies were done to know the progress of reaction with time. Experimental results were analyzed to see the best fit either for pseudo first order reaction or for pseudo second order reaction. When $\log C_t$ is plotted against t , pseudo first order reaction is obtained. A plot of t/q_t versus t gives pseudo second order reaction. The straight lines obtained [Figure 1(a) to 1(g)] clearly indicated that the experimental results were the best fit for pseudo second order reaction.

Adsorption Isotherms

Freundlich and Langmuir isotherms were evaluated to give an insight into the adsorption mechanism of cadmium. A plot of C_e/q_e versus C_e gives the Langmuir isotherm and a plot of $\log q_t$ versus $\log C_t$ gives

Freundlich isotherm. Linearity in the graph [Figure 2(a) to 2(g)] clearly showed that the experimental data was best fit for Langmuir isotherm. In Langmuir adsorption isotherm, all adsorption isotherm sites on the surface of adsorbent have the same energy. The Freundlich isotherm describes multilayer adsorption in empirical equation form $q_t = k \cdot C_t^{1/n}$. The linearity in graphs for Freundlich adsorption isotherm [Figure 3(a) to 3(g)] was not found satisfactory.

Percent Removal

The percentage removal of Cd (II) ions from aqueous medium varies from 91.14 % to 99.99% depending on the adsorbent quality (Table – 1). The values of percent removal indicate bentonite and modified bentonite as an efficient adsorbent for Cd(II) from aqueous medium [Figure 4(a) to 4(g)]

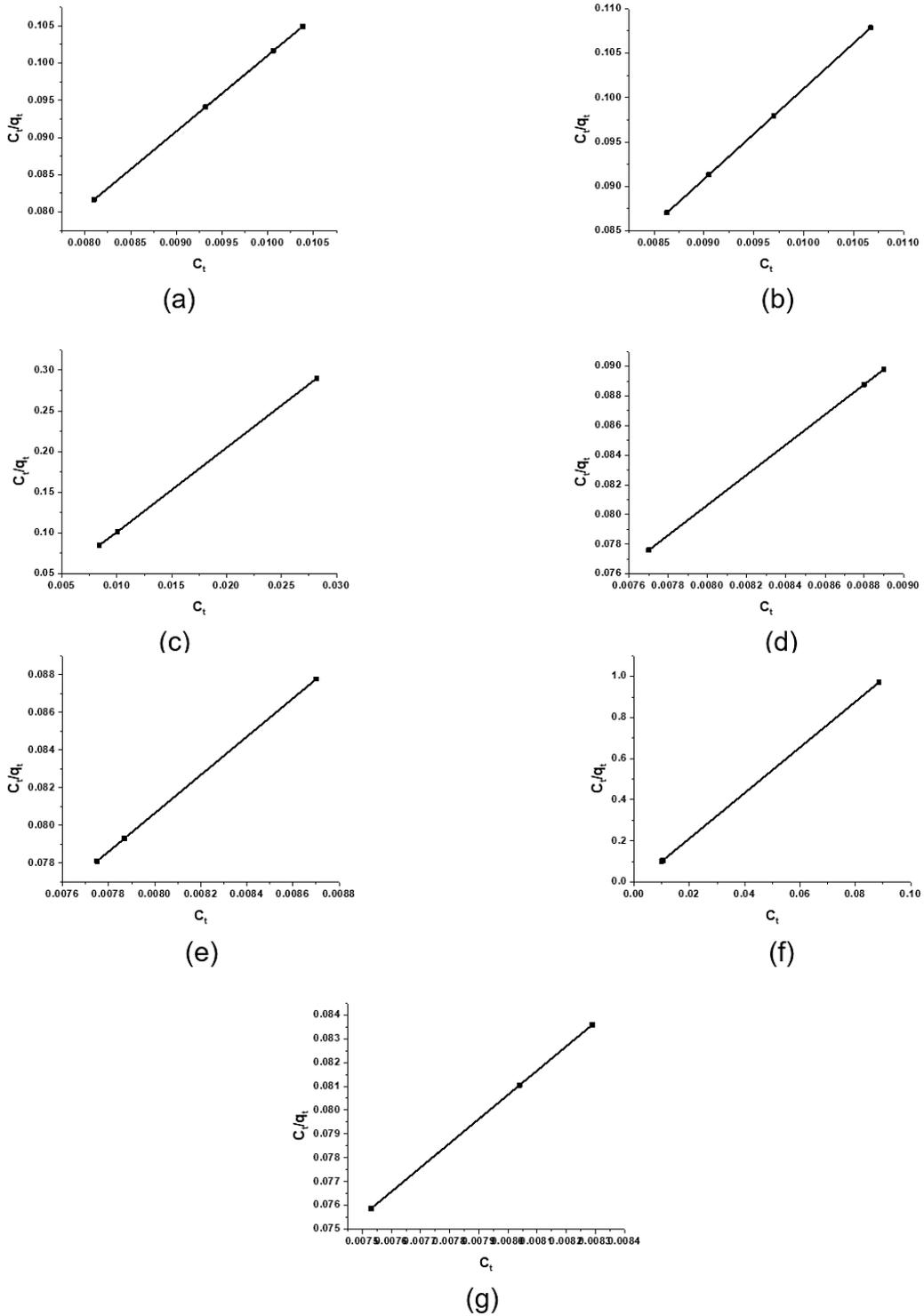


Fig. 2: Langmuir adsorption isotherm for (a) BB2C1 to BB2C4, (b) BBAC1 to BBAC4, (c) BBRC1 to BBRC4, (d) Sb2AVCd3 to Sb2AVCd9, (e) Sb2RsCd3 to Sb2RsCd9, (f) Sb7AVCd3 to Sb7AVCd9, (g) Sb7RsCd3 to Sb7RsCd9

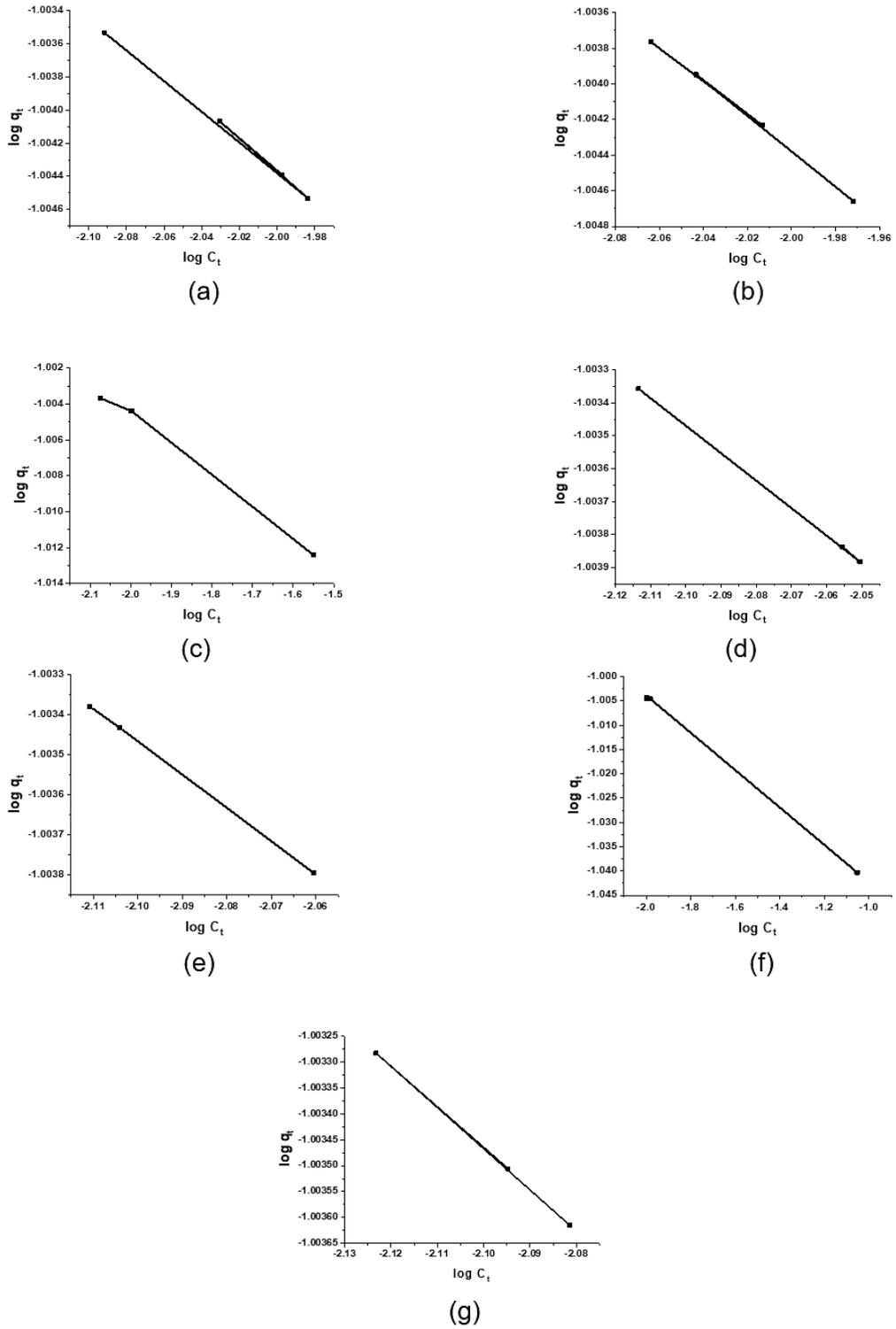


Fig. 3: Freundlich adsorption isotherm for (a) BB2C1 to BB2C4, (b) BBAC1 to BBAC4, (c) BBRC1 to BBRC4, (d) Sb2AVCd3 to Sb2AVCd9, (e) Sb2RsCd3 to Sb2RsCd9, (f) Sb7AVCd3 to Sb7AVCd9, (g) Sb7RsCd3 to Sb7RsCd9.

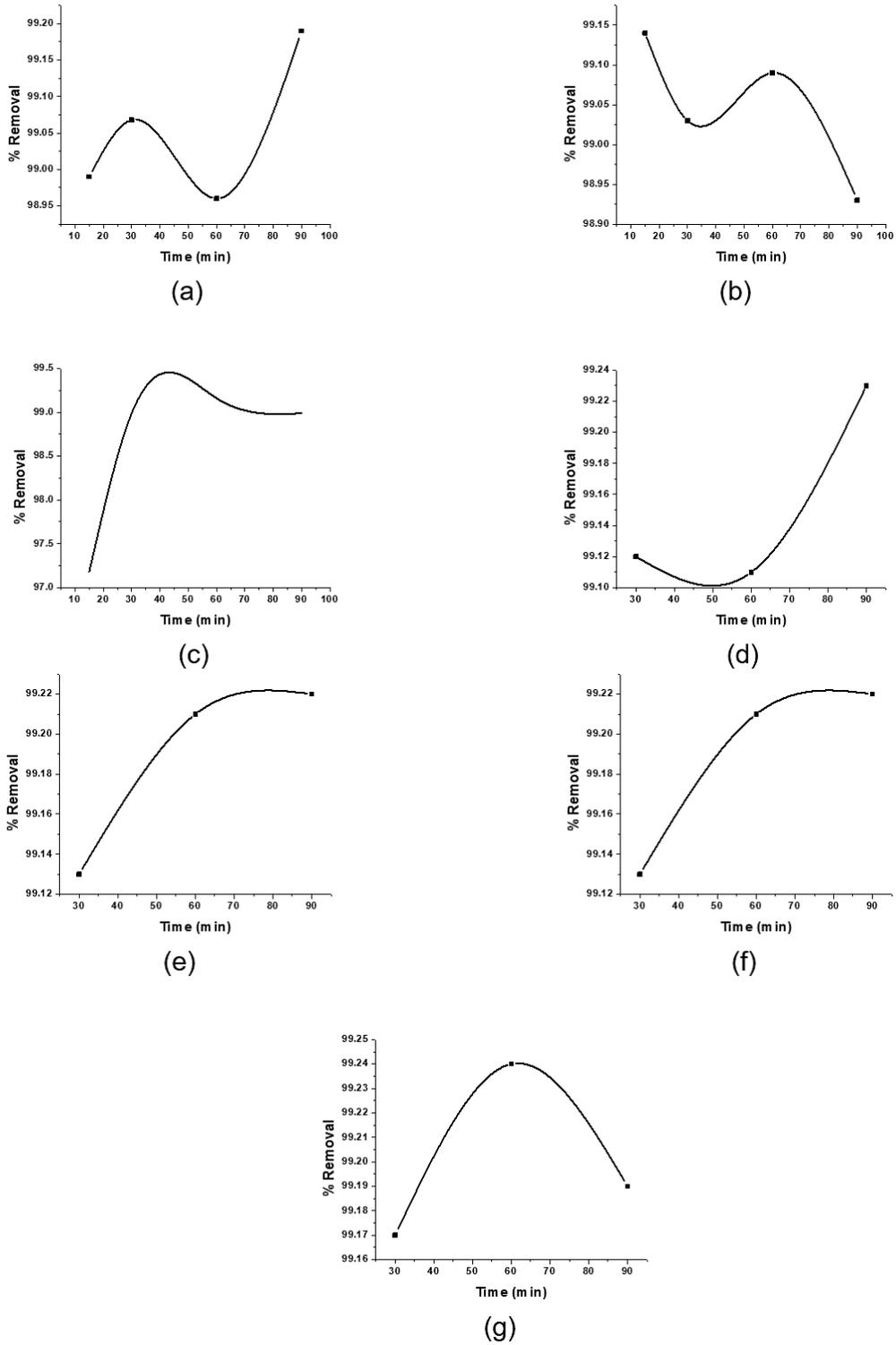


Fig. 4: Percent Removal for (a) BB2C1 to BB2C4, (b) BBAC1 to BBAC4, (c) BBRC1 to BBRC4, (d) Sb2AVCd3 to Sb2AVCd9, (e) Sb2RsCd3 to Sb2RsCd9, (f) Sb7AVCd3 to Sb7AVCd9, (g) Sb7RsCd3 to Sb7RsCd9.

Conclusion

The experimental data showed the best fit for pseudo second order reaction kinetic model and Langmuir adsorption isotherm. Bentonite minerals may be a low cost and eco-friendly alternative for the removal of Cd (II) from aqueous medium. The percentage removal of Cd (II) from aqueous medium by bentonite and modified bentonite is above 90 % and also satisfactory.

Acknowledgement

The authors would like to thank Prof. Chitta Ranjan Sinha, Jadavpur University, Jadavpur and Prof. Alakesh Bisai, IISER Kolkata for providing the instrumentation facilities of FTIR and SEM.

Funding Sources

The author(s) received no financial support for the research, authorship, and/or publication of this article.

Conflict of Interest

The authors do not have any conflict of interest.

Data Availability statement

All the data used in the manuscript are available with the author and will be provided when needed.

Ethics Statement

This research did not involve human participants, animal subjects, or any material that requires ethical approval.

Informed Consent Statement

This study did not involve human participants, and therefore, informed consent was not required.

Permission to Reproduce Material from other Sources

Not Applicable

Author Contributions

Each author mentioned has significantly and directly contributed intellectually to the project and has given their approval for its publication.

- **Sachin Verma:** Laboratory work in the department.
- **Subhajit Sikdar:** Conceptualization, Methodology, writing Original Draft.
- **Ashok Kumar Jha:** Visualization, supervision, project administration.
- **Pallavi Kumari:** Helped in conducting analytical tests outside the laboratory.

References

1. Prakash C. Loni, Biqing L, Ching-Yu C, Yao-Chang L, Jagat R, Ci-Hong C, *et al.*, Enhanced removal of antimony, arsenic and cadmium by bone char in co-contaminated aqueous systems: A lattice level mechanistic understanding. *Journal of Environmental Chemical Engineering*. 2025; 13(4): 117281. <https://doi.org/10.1016/j.jece.2025.117281>.
2. Jha A. K, Kumari K. Cadmium (II) removal by *Cynodon Dactylon* and Orange Peel Powder from aqueous medium by adsorption. *Science Academique*. 2020; 1(1): 21 – 30.
3. Yuxiong H, Arturo A. K. EDTA functionalized magnetic nanoparticle sorbents for cadmium and lead contaminated water treatment. *Water Research*. 2015;80:159-168. <https://doi.org/10.1016/j.watres.2015.05.011>.
4. Abd-Elrahman R, Abd El-Lateef H. M, Abo El-Maali N, Abdel-Mawgoud A. M, Mahmoud E. Highly efficient magnetic iron oxides-polyaniline nanocomposite for electrochemical removal of lead and cadmium ions from contaminated water. *Journal of the Taiwan Institute of Chemical Engineers*. 2025; 173: 106187. <https://doi.org/10.1016/j.jtice.2025.106187>.
5. Hongping C, Zhu T, Peng W, Fang-Jie Z, Geographical variations of cadmium and arsenic concentrations and arsenic speciation in Chinese rice. *Environmental Pollution*. 2018; 238: 482-490, <https://doi.org/10.1016/j.envpol.2018.03.048>.
6. Kumar U, Jha A. K, Kumar N. Cadmium Toxicity in the Environment: Sources, Issues, Remediation, and Challenges. 2024; 10.1007/978-3-031-65611-8_1.
7. Hashim M. A, Mukhopadhyay S, Sahu J. N, Sengupta B. Remediation technologies for heavy metal contaminated groundwater. *Journal of Environmental Management*; 2011;

- 92: 10. 2355-2388. <https://doi.org/10.1016/j.jenvman.2011.06.009>.
8. Xiaomin T, Huaili Z, Houkai T, Yongjun S, Jinsong G, Wanying X, Qingqing Y, Wei C. Chemical coagulation process for the removal of heavy metals from water: a review. *Desalination and Water Treatment*. 2016; 57(4): 1733-1748. <https://doi.org/10.1080/19443994.2014.977959>.
 9. Jha A. K, Mishra B. Removal of fluoride by bentonite minerals of Rajmahal Hills. *Journal of the Indian Chemical Society*. 2012; 89: 519-521.
 10. Yunyan Z, Yuming C, Yiming P, Rui D, Hui C, Yanqing W. Preparation of CTAB intercalated bentonite for ultrafast adsorption of anionic dyes and mechanism study. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*. 2023; 658: 130705. <https://doi.org/10.1016/j.colsurfa.2022.130705>.
 11. Jia-Lin L, Wei-Cong Q, Jian-Zhong G, Yan S, Bing L. Selective removal of anionic and cationic dyes by magnetic Fe₃O₄-loaded amine-modified hydrochar. *Bioresource Technology*. 2021; 320(A): 124374. <https://doi.org/10.1016/j.biortech.2020.124374>.
 12. Zahra J, Maryam K, Pouya M. Application of Modified Bentonite for Efficient Water Purification: A Case of Cr(VI) Adsorption. *Journal of Particle Science and Technology*. 2024; 10(2): 117 – 128. 10.22104/JPST.2025.7462.1273.
 13. Jha A. K, Sharma U, Samanta S. Kinetic and Thermodynamic Studies of Heavy Metal Remediation by Modified Bentonite. *Water, Air, & Soil Pollution*. 2024; 235. 10.1007/s11270-024-07260-9.
 14. Verma S, Jha A. K, Kumari P. Studies on removal of Pb (II) by modified bentonite. *International Journal of Chemical and Biochemical Sciences*. 2024; 25(14): 548 – 552.
 15. Yubo Y, Meng D, Zhiwen S, Qiao L, Muhammad F, Xiaoxin Z, Yuanxin C, Zhijie Z, Zhe Z, Shouyong Z, Exploring the potential of green-synthesized hydroxyapatite for cadmium remediation in paddy soils. *Ecotoxicology and Environmental Safety*. 2025; 297: 118267. <https://doi.org/10.1016/j.ecoenv.2025.118267>.
 16. Majumder S, Jha A. K, Mishra K. K. Powdered X-ray diffraction, FTIR, TGA and DTA studies of montmorillonite derivatives. *Journal of Indian Chemical Society*. 2020; 97(9b): 1604 – 1608.
 17. Houwei J, Hao W, Qingchun Y, Xin X, Dongshuang W, Bin W, Simultaneous removal of Cr(VI), Cd(II) and As(III) in groundwater by ZVI-biochar based composite: Synergy, performance and mechanism. *Process Safety and Environmental Protection*. 2025; 201(A): 107460. <https://doi.org/10.1016/j.psep.2025.107460>.
 18. Elkhatib E, Moharem M, Saad A, Attia F. Novel metal based nanocomposite for rapid and efficient removal of lead from contaminated wastewater sorption kinetics, thermodynamics and mechanisms. *Scientific Reports*. 2022; 12: 8412. 10.1038/s41598-022-12485-x.