

Impact of two Cationic Dyes-Malachite Green and *Methylene Blue* on catalytic Efficiency of *Moringa Oleifera* Leaves as a Sustainable Bio Sorbent



Anu Malhotra¹, Deepika Maan², Karishma Jain², Sushil Kumar Jain² and Balram Tripathi^{3*}

¹Department of Chemistry, SS Jain Subodh PG College, India

²Department of Physics, School of Basic Sciences, Manipal University Jaipur, India

²Department of Physics, SS Jain Subodh PG College, India

³Department of Physics, University of Rajasthan, India

Submitted: May 17, 2025; Published: May 30, 2025

*Corresponding author: Balram Tripathi, Department of Physics, University of Rajasthan, Jaipur, India

Abstract

The present study focuses on the comparative outcomes of the two cationic dyes like malachite green (MG) and methylene blue (MB) on moringa leaves powder as a biosorbent. The factors affecting the adsorption process such as initial dye concentration, biosorbent weight, pH values, and solution temperature have been investigated. The isoelectric point of moringa leaves powder was determined to determine the charge that prevails on its surface under different conditions. The adsorption rate for both dyes is found very high at the initial stages of the process and then decreases until it reaches the equilibrium. On increasing reaction temperature from 20 to 500C, the removal of MB dye decreases from 94.5% to 11.9% respectively. Similarly, for MG dye decrease in adsorption reaches from 11.9% to 8.3% in between 200C to 500C. This behavior can be attributed to the desorption behavior of the adsorbed dye molecules at higher temperature or disintegration of the biosorbents. Both MB and MG dyes show enhanced removal % under acidic conditions. MB dye is adsorbed by the biosorbent at pH value of 4 while MG dye gets removed at pH value of 6 attributes that both the dyes are removed at acidic pH, with MB dye showing slightly higher acidic conditions than MG dye. The differences in adsorption performances between these dyes have been related to the molecular structure of the dyes and the surface chemistry of biosorbent.

Keywords: Cationic dyes; Bio sorbent; Methylene blue; Adsorption; Bio composites; Electrochemical cells; Cosmetics; Carcinogenesis; Methemoglobinemia; Physicochemical

Abbreviations: MB: Methylene Blue; MG: Malachite Green; XRD: X-Ray Diffractometry; FTIR: Fourier Transform Infra-Red Spectroscopy

Introduction

Dyes are an important class of synthetic organic chemicals and are utilized in various sectors. Globally around 450000 tons of dyestuffs are produced, and about 40000 distinct synthetic dyes and pigments are employed in industry. With two thirds of the market, the textile sector is the biggest user of these dyes. In addition to the textile industry, dyes are widely used in leather tanning, paper manufacturing, food, photography, cosmetics, hair coloring, wood staining, agricultural, biological and chemical research, light-harvesting arrays, and photo electrochemical cells [1] Synthetic dye production and usage on a wide scale causes industrial and environmental pollution, which poses a serious

threat to ecological health. Dyes create a significant environmental burden through wastewater [2-5]. Up to 50% of the yearly dye production is made up of azo dyes, the largest and most versatile class of dyes [6].

A small amount of synthetic dye in water (<1ppm) is also very visible and affects the smell, clarity, and gas solubility of water bodies; hence color is typically the first contaminant to be identified in wastewater. Because reactive dyes dissolve in water, 5-10% of them end up in the dye bath, producing highly colored effluent that poses a major threat to the environment. Methylene blue (MB) and malachite green (MG) are two commonly used dyes in the textile industry. Methylene blue is an organic chloride salt

with a formula $C_{16}H_{18}ClN_3S$. It is also called Methylthioninium chloride or Swiss Blue. It is a thiazine dye with antioxidant and cardioprotective properties. Human health problems that may result from MB include methemoglobinemia, cyanosis, jaundice, vomiting, respiratory issues, and eye irritation [7-11]. Malachite green is a triphenyl methane dye, and is also called aniline green, benzaldehyde green, or China green). It is used for its anti-fungal qualities in aquaculture, as a counterstain in histology, as a local antiseptic in diluted solution. Health problems attributed to MG are carcinogenesis, mutagenesis, chromosomal fractures, teratogenicity, and pulmonary toxicity.

Globally, environmental scientists have been concentrating on creating sustainable and effective systems for managing water and wastewater [12,13]. Because of the chemical stability of the dyes, conventional wastewater treatment methods are notably ineffective for treating wastewater containing synthetic textile colors [14]. The main drawbacks of physicochemical approaches include their high cost, low efficiency, limited adaptability, requirement for specialized equipment [15,16] interference from other wastewater constituents, and waste handling. Color can be removed with physical procedures, but the dye molecules do not break down instead, they get concentrated and need to be disposed of properly.

Adsorption is a cost-effective technique among all the wastewater treatment techniques [17-19]. Usage of local biowastes as an adsorbent for removing toxic dyes and metal ions from wastewater [20] is called biosorption. Lignocellulosic biomass is the most abundant renewable bioresource on earth with annual production estimated to be 1×10^{10} million tons. The term "biosorbents" describes a unique class of adsorbents including agricultural waste, and bio composites that have garnered much attention recently due to their environmentally friendly nature and efficiency for adsorbing dyes and heavy metals from textile and industrial wastewater. Physical modifications and chemical modifications like functionalization may be done to improve the effectiveness of biosorbents but it would make them less eco-friendly. A more porous and rougher adsorbent is produced via carbonization and calcination because the high temperature causes volatiles in the particle microstructure to escape, leaving behind voids that eventually become pores. Additionally, it was found that chemical modification may decrease the adsorbent's total surface area but can increase the adsorption capacity because of changes to the functional groups, effects on the pH-controlled solution chemistry, the sorbate-sorbent interphase, and an improvement in the biosorbent's inherent affinity. Activated carbon [21] bio composites [22-24] and CNT [25,26] have been used as biosorbents effectively but their disposal after use is not fully sustainable. Thus, biosorption offers numerous advantages over conventional methods. An inexpensive adsorbent is one that is easily found in nature [27], is a waste product or by-product of industry, and needs little to no processing [28,29]. Numerous biological materials have been studied over the years, and these include fish scales [30,31], plant leaves [32,33], fruit pods, fruit

shells [34] microbes [35] tree barks [36], agricultural wastes [37], eggshells [38,39] chitosan composites [40] and a different type of sand [41] etc. When it comes to removing contaminants from wastewater, these biosorbents can be effective substitutes for synthetic materials. The surface of biosorbents derived from plant leaves is typically quite diverse and uneven, with many voids, cavities, cracks, fissures, and these enhance surface sorption.

Materials and Methods

Biosorbent and dyes

Moringa oleifera traces its origin to Northern India and is locally grown in many regions like Africa, Arabia, Southeast Asia, the Pacific and Caribbean Islands and South America [42]. The leaves are the parts that are mostly used because they are medicinal, nutritional and have positive economic value. *Moringa* leaf powder was sourced from Naveen Kaya Healthcare Ltd. Ahmedabad. It has been abbreviated as MOLP or ML (*Moringa Oleifera* leaf powder). Both the cationic dyes were sourced from Sigma Aldrich.

Preparation of Solutions

1ppm solutions of both MB and Mg dye s were prepared initially. Solutions required for the various experiments later were prepared by successive dilutions with distilled water. A Libman UV-Visible spectrophotometer was used to measure the absorbance values of the experimental solutions. MB shows maximum absorbance at 660nm while MG shows maximum absorbance at 616nm pH of the solutions were varied using 1M HCl and 1M NaOH and pH was measured using Siltronic's pH meter 335 different amounts of MOLP were used for different experiments. The amount of metal sorbed by biomass expressed as % removal (%RE) was calculated from the difference between the initial metal quantity (Co) and the metal ions at equilibrium (Ce) using equation calculated using the equations given below [45]

$$\text{Removal (\%RE)} = (C_o - C_e) / C_o \times 100$$

$$q_i (\text{mg/g}) = (C_o - C_e) V / m$$

where V is the volume of solution used in liters, and m is the mass of adsorbent (g).

Results and Discussion

Various analytical techniques like XRD, SEM and FTIR were used to evaluate different aspects of the biosorbent MOLP for study of biosorption. Fourier transform infra-red spectroscopy (FTIR) is done to determine the functional groups and complexes present in the biosorbent that could be responsible for uptake of dyes. X-ray diffractometry (XRD) is used to investigate the properties of the adsorbent as it relates to the crystalline of the material. SEM analysis is even more important in recent times where the functionalization of adsorbents and biosorbents is a common practice as it can give information of changes on the surface morphology (Figure 1a & 1b).



Figure 1: (a) Structure of Methylene Blue Dye [43].
(b) Methylene Blue Dye (courtesy India Mart).

X-RAY Diffraction

The powder XRD method is used to identify the crystal structure. The X-ray diffraction spectrum of MOLP exhibited four prominent distinguishable diffraction peaks at angle (2θ) values of 15.22° , 21.81° , 22.92° and 22.94° indicating both its amorphous and crystalline nature [46]. In general, crystalline materials show a series of sharp peaks, while amorphous products produce a broad peak. The diffraction patterns of MOLP were found to be

small, which indicates that the crystallite size part of crystalline cellulose and hemicellulose is small (Figure 2a & 2b). Since MOLP contains many proteins about 30% [47], the X-ray patterns could be due to the amorphous nature of native proteins and lipids. MOLP also consists of bioorganic substances, including proteins, carbohydrates, ash, and minerals. Therefore, a few unassigned diffraction peaks observed could be due to these bioorganic compounds in the leaf (Figure 3a & 3b).



Figure 2: (a) Structure of malachite green dye [44].
(b) Malachite Green Dye (courtesy India Mart).

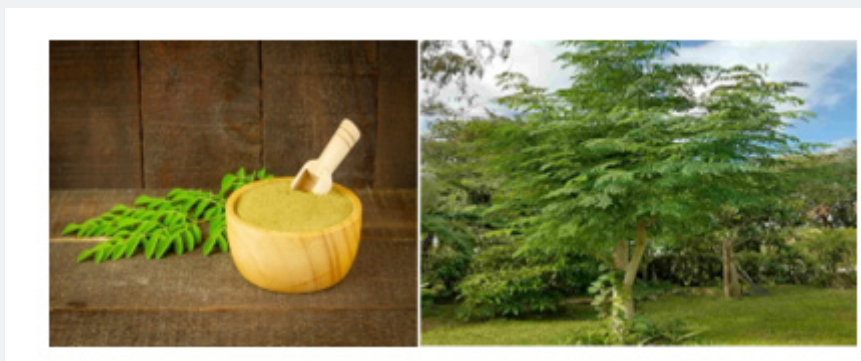


Figure 3: (a) Moringa leaves powder (courtesy India mart).
(b) Moringa Tree (courtesy pang tree).

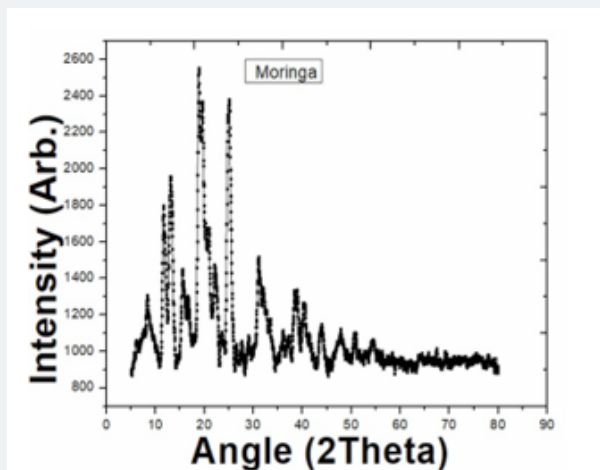


Figure 4: XRD spectra of Moringa leaf powder.

FT-IR Spectrum

The spectra were analyzed in the resolution interval of 400-4000 cm^{-1} . For *Moringa oleifera* leaves powder, the spectrum is shown below Figure 4. The dip at 1062 cm^{-1} corresponds to the C-OH stretching vibration while the dip at approximately 1577 cm^{-1} is attributed to C=C symmetrical stretching [48]. The peak at 1650 cm^{-1} is due to C=O stretching vibrations. The dip at 2913 cm^{-1} represents the C-H stretch and hydroxyl group showing the O-H stretch respectively Figure 5. The dip at 3742 cm^{-1} is due to O-H stretching. Functional groups containing oxygen are essential in

absorbing methylene [49].

Surface Morphology of Moringa Leaves

The surface morphology of MOLP was examined from SEM photographs and it was found that MOLP has heterogeneous and relatively porous morphology. The material exhibited a rough surface with several blocks of pores of different sizes. The image shows a highly microporous structure and extensive surface area which resembles a honeycomb full of cavities having capacity to absorb more dye Figure 6.

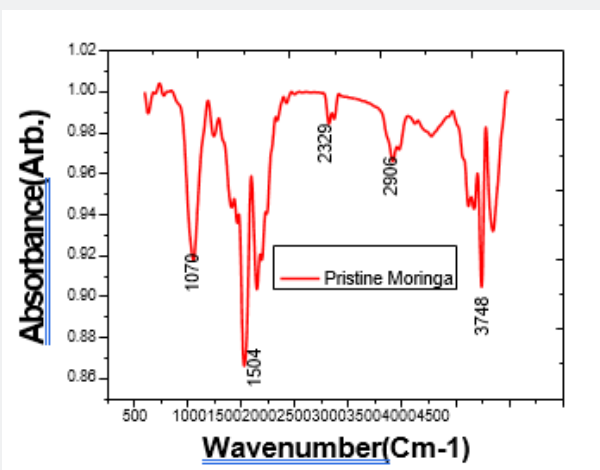


Figure 5: FT-IR spectrum of MOLP.

Photocatalytic Response

Effect of biosorbent dosage

As biosorbent dosage increases, keeping all the other parameters at constant value, the removal capacity of MOLP decreases with respect to both MB and MG dyes as shown in

(Figure 7a & 7b). At lower biosorbent concentration of .0025g as shown in (Figure 7c & 7d) for MG, it is assumed that the number of active sites is higher. With the increase in adsorbent dosage to 030g, the active sites of the dye molecules get exhausted and aggregation of particles of biosorbent take place. The removal capacity falls from 14mg/g to 1 mg/g at the given concentrations.

Same is the case with MB dye. The removal capacity q_i (mg/g) is 0.6mg/g at .05mg of MOLP which falls to 1mg/g at 0.2g of MOLP. As a result, removal efficiency of dye decreases. Also, at high doses

of adsorbent, the available number of dye molecules in solution was not sufficient to combine with all the adsorbent sites leading to a decrease in adsorption capacity [50].

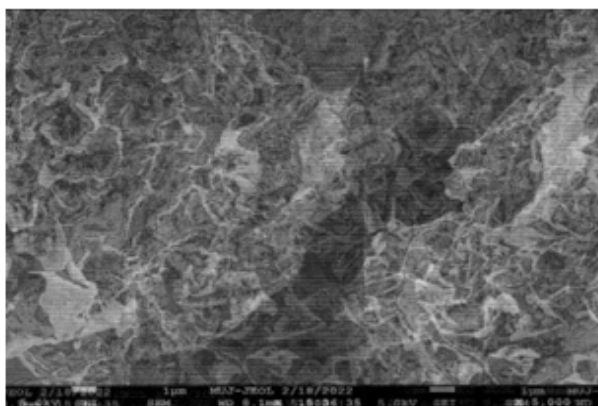


Figure 6: SEM image of moringa oleifera with highly microporous structure.

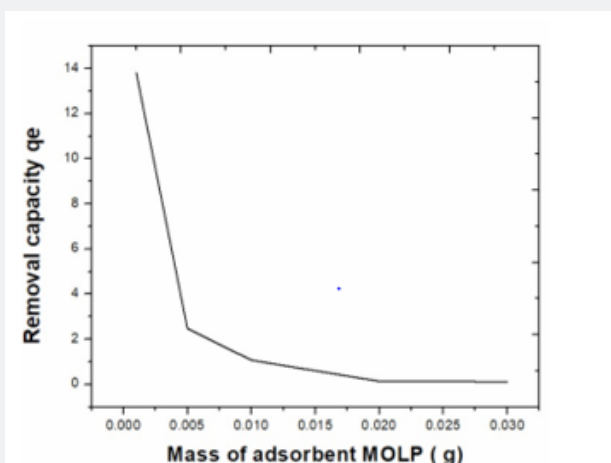


Figure 7(a): Removal capacity vs mass of MOLP for MB dye.

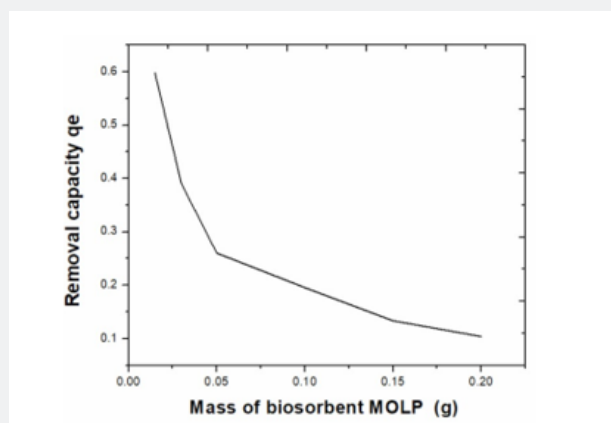


Figure 7(b): Removal capacity vs mass of MOLP for MG dye.

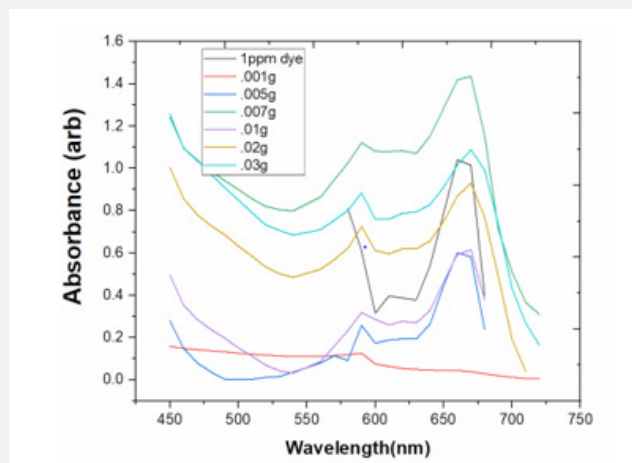


Figure 7(c): Variation of dose of MOLP with 1ppm MB dye.

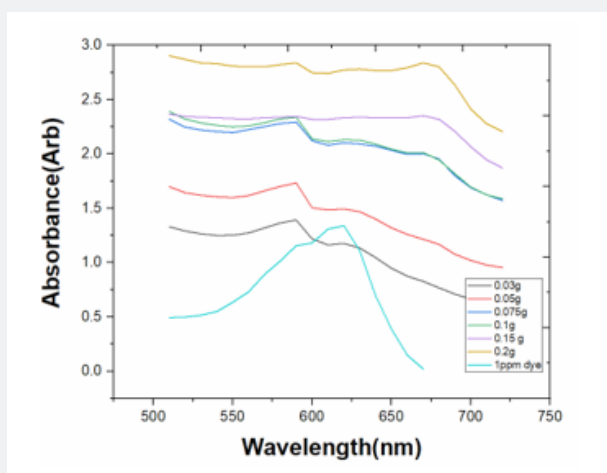


Figure 7(d): Variation of dose of MOLP with 1ppm MG dye.

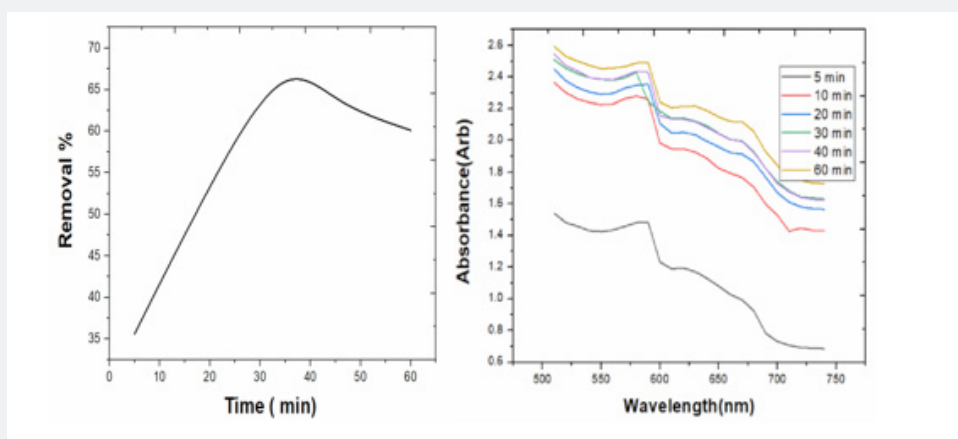


Figure 8: (a) Removal percent of MB dye with MOLP.
(b) Absorbance of MOLP in MG dye at different time intervals.

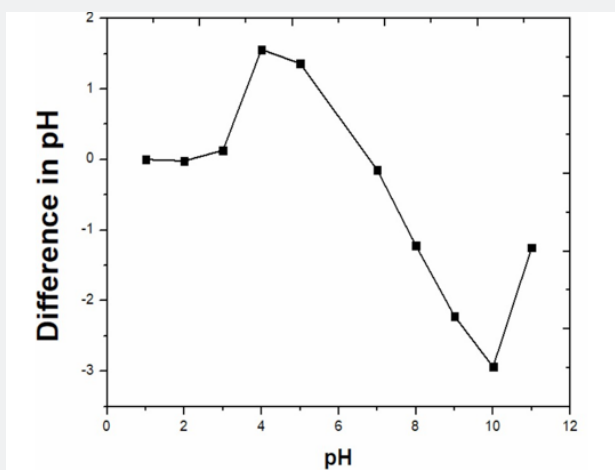


Figure 9(a): Isoelectric point of MOLP.

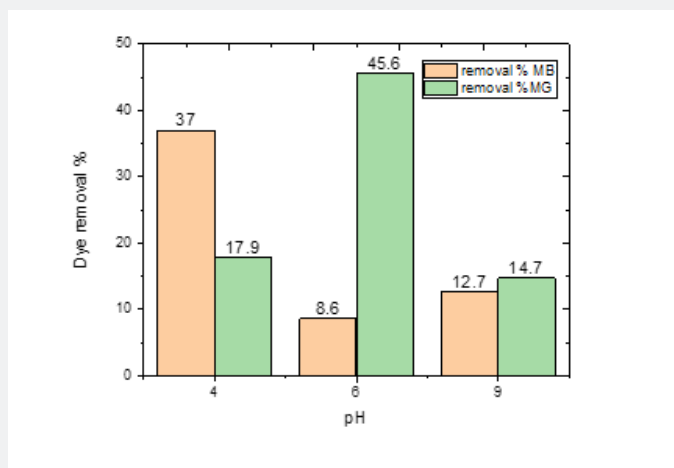


Figure 9(b): Comparison of dye removal percent of MOLP for both MB and MG dye.

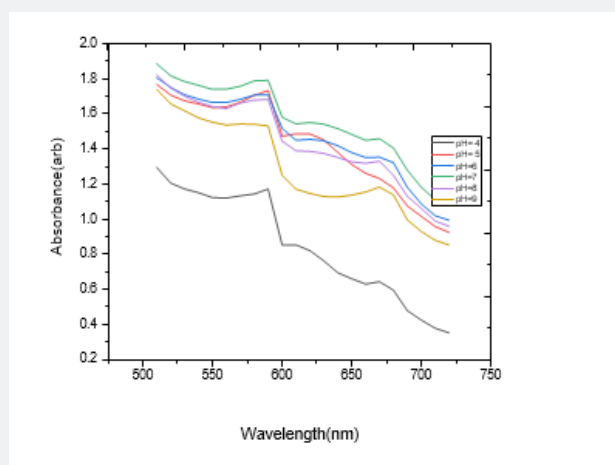


Figure 9(c): Adsorption of MOLP at different pH for MG dye.

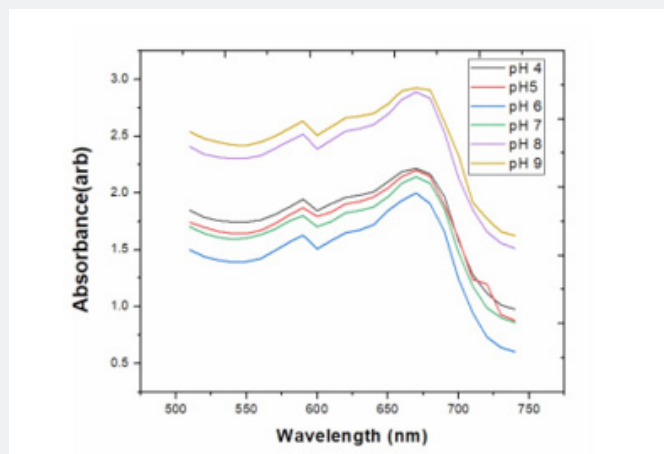


Figure 9(d): Adsorption of MOLP at different pH for MB dye.

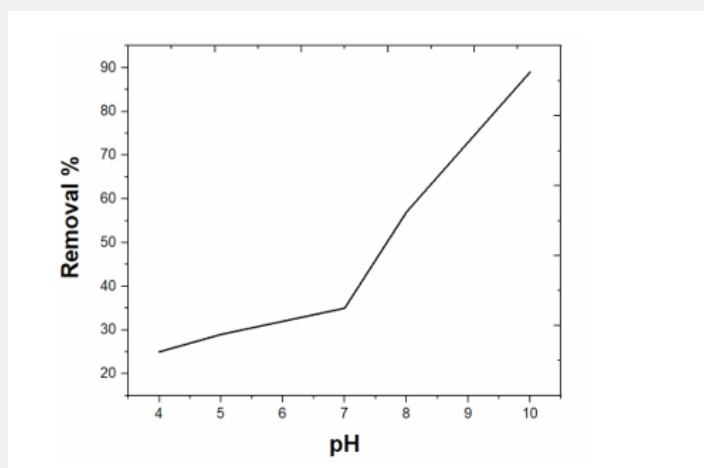


Figure 9(e): Removal percent vs pH for MOLP with MB dye.

Effect of Contact Time

Time of contact is an important factor for biosorption. As time of adsorption changes from 5 min to 60min, efficiency first increased from 35 to 66% and further decreased to 60% and afterwards a fall is observed. As time progresses the surface of the adsorbent gets covered completely and there is no further scope of adsorption due to saturated interface (Figure 8a & 8b). The removal efficiency and adsorption capacity of MOLP initially increase with time of contact time between the adsorbent and adsorbate is now longer than the ideal contact time, shows the relationship between adsorbent contact time and percentage of dyes removed.

Effect of pH

The isoelectric point (P_i) is the pH value at which the molecule carries no electrical charge. The Isoelectric Point has its profound

impact on the molecule's solubility and its interactions with other molecules. For instance, if the pH of a solution is greater than the P_i of a molecule, the molecule carries a negative charge. Conversely, if the pH is below the P_i , the molecule will have a positive charge. At the P_i , the molecule has no net electrical charge and tends to precipitate out of the solution. From the view of the adsorbent, if the pH is below the plc. value, the surface charge of adsorbent would be positive so that the anions can be adsorbed [51] Conversely, if the pH is above the plc. value, the surface charge would be negative so that the cations can be adsorbed. Figure 9a shows us that P_i of MOLP is 2. If the solution is basic, MOLP carries a negative charge and hence facilitates the adsorption of cationic dye molecules. If the pH of the solution is less than 2, MOLP carries a positive charge, and the cationic dye molecules face repulsion and adsorption decreases as is observed here.

It is observed that in case of MB dye maximum removal is seen at pH 4(37%) as per (Figure 9b & 9c) while in case of MG it is pH 6

(45.6%) which is above the isoelectric point of MOLP. As we move towards basic conditions the removal percentage comes down to 12.7% and 14.7% respectively for MB and MG dye (Figure 9d & 9e).

Effect of Initial Dye Concentration

Various dye solutions (1ppm, 2ppm, 3ppm, 4ppm, 5ppm and 8ppm) were used in the biosorption experiment. Initially, the rate of adsorption was found to be quite high i.e. 90% when

the concentration of MB dye was 0.1ppm and later on when MB concentration was increased to 0.5ppm, the removal percent came down to 50%. The removal capacity of MG dye was found to be minimum at 4ppm conc while for MB dye it was found to be minimum at 3ppm as seen in (Figure 10a & 10b). The increase in the number of dye molecules increases the competition between dye molecules for available fixed binding sites [52].

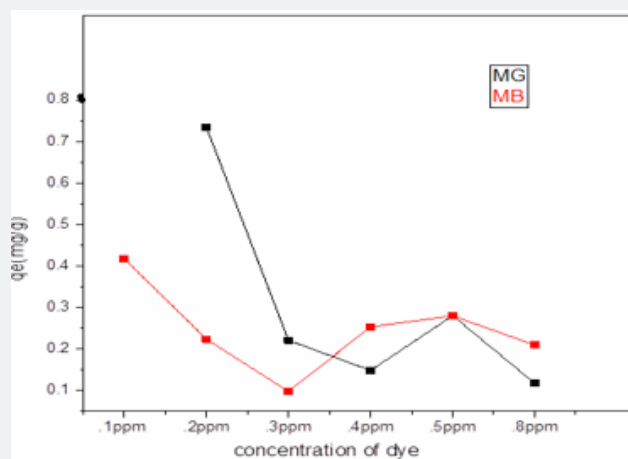


Figure 10(a): Comparison of q_i (mg/g) for both MB and MG dyes.

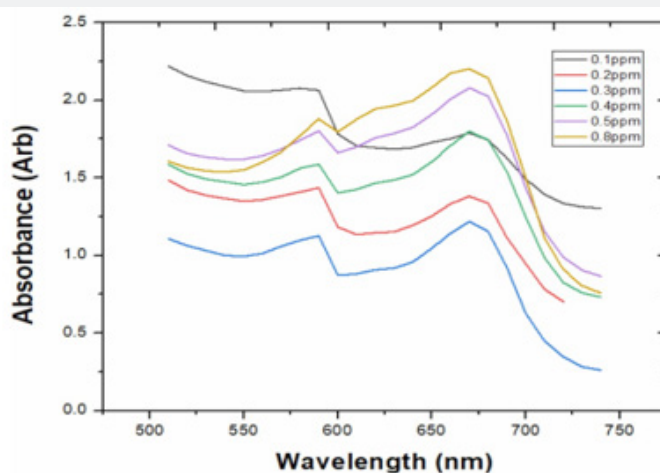


Figure 10(b): Absorbance of MB dye at various concentrations.

Effect of Temperature

The change in temperature is an important factor in the dye removal process. It affects the solid-solute interface and mobility of pollutants during adsorption [53]. In this study, the efficiency of both MB and MG adsorptions decreased with increasing solution temperature (Figure 10c & 10d). This situation may be due to

shrinkage and alteration of active sites on the adsorbent at a higher temperature thus reducing the active adsorbent surface. This may cause dyes to leach into the solution due to a higher separation between the dye molecules and the adsorbent at high temperature in Figure 11a. This demonstrated that both MB and MG adsorption is an exothermic process that favors low- temperature solutions [54, 55].

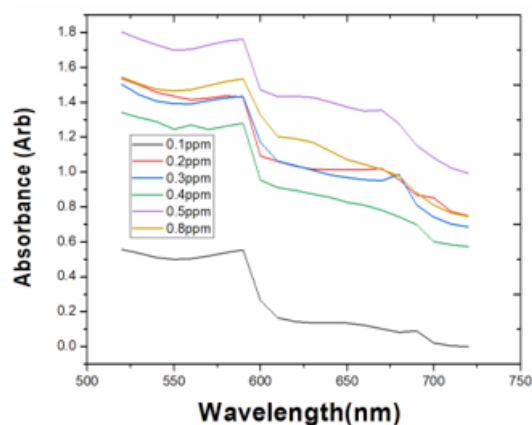


Figure 10(c): Absorbance of MG dye at various concentrations.

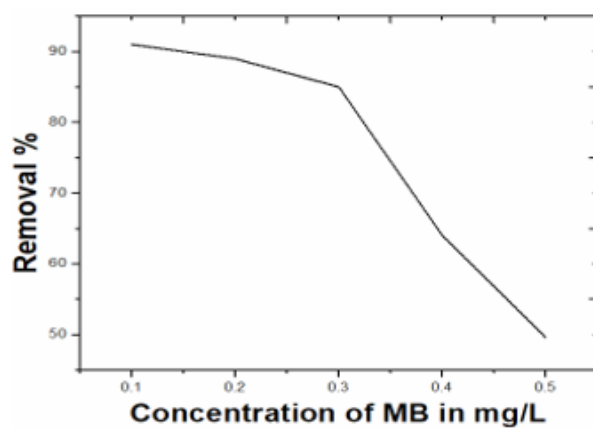


Figure 10(d): Removal percent vs concentration of MB dye.

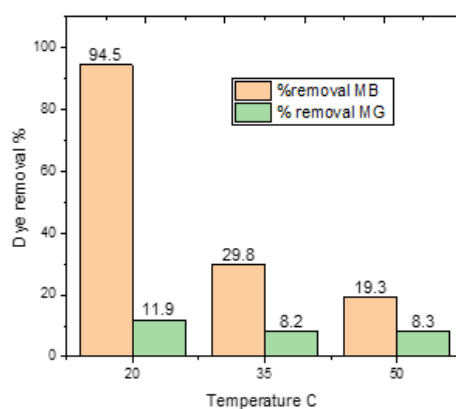


Figure 11(a): Bar graph showing effect of temperature on removal of MB and MG dyes.

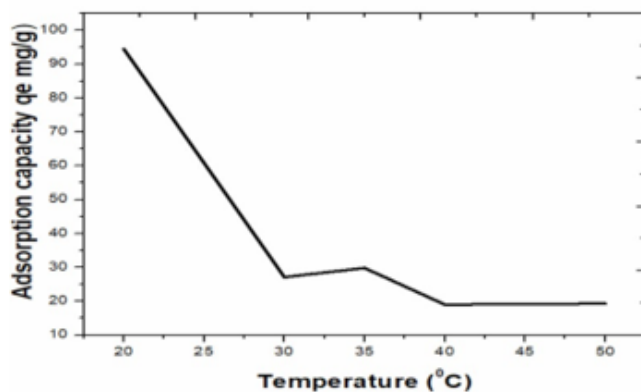


Figure 11(b): Removal capacity with temperature for MB dye.

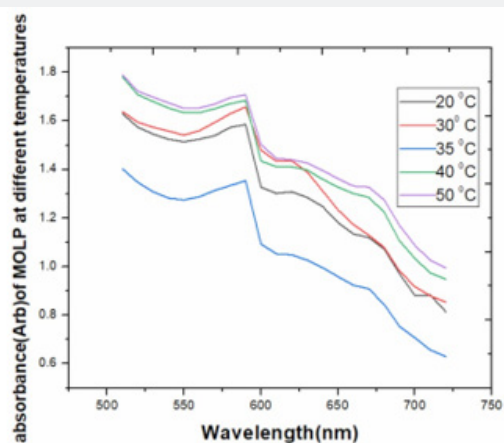


Figure 11(c): Absorbance for MG dye at different temperatures.

The influence of temperature on the adsorption capacity is shown in Figure 11b. The removal percentage of MB dye was found to be 90% at 20°C but fell to 25% at 30°C indicating that the adsorption was exothermic in nature.

The MOLP biosorption is affected by moderate temperatures at medium temperatures (20-35°C) and greatly at higher temperatures, and it is believed that the bio sorbent can be severely denatured at increased temperature [56]. We must consider that the increasing temperature of adsorbate solution may not necessarily increase active sites over the surface of the adsorbent but may create a new pathway that increases the rate of adsorption of the adsorbate on the adsorbents including biosorbents [57]. From the figure, (Figure 11a) we can see that the increase in temperature brings about a decrease in adsorption efficiency and capacity, but maximum removal is in the range 20-25°C which is economically advantageous as both MG and MB

removal can be conducted at environmental temperature without additional costs [58].

Conclusion

In summary, the moringa leaf powder was used as bio sorbent and it has been initially characterized by XRD, FT-IR and SEM. The photocatalytic response has been executed using two dyes MB and MG. It has been observed that both the dyes were removed efficiently at low pH and low temperature. The high yield of adsorption has been obtained for MB dye in Figure 11c. The need for recovery and regeneration of the biosorbent depends on the cost of adsorbent recovery and the effect of solute on the environment and methods of disposal. In industrial usage, the ability of a biosorbent to be reused is important for the removal of dyes from wastewater. The cost of adsorption gets reduced by the adsorbent's capacity to regenerate and reuse itself without causing any major changes to its adsorption efficiency and capacity.

References

- Couto SR (2009) Dye removal by immobilized fungi. *Biotechnol Adv* 27(3): 227-235.
- Ayed L, Mahdhi A, Cheref A, Bakhrouf A (2011) Decolorization and degradation of azo dye Methyl Red by an isolated *Sphingomonas paucimobilis*: biotoxicity and metabolites characterization. *Desalination* 274(1-3): 272-277.
- Vinoda B, Vinuth M, Bodke Y, Manjanna J (2015) Photocatalytic degradation of toxic methyl red dye using silica nanoparticles synthesized from rice husk ash. *J Environ Anal Toxicol* 5(6).
- Ahmad MA, Ahmad N, Bello OS (2015) Modified durian seed as adsorbent for the removal of methyl red dye from aqueous solutions. *Appl Water Sci* 5: 407-423.
- Dadfarnia S, Shabani AH, Moradi S, Emami S (2015) Methyl red removal from water by iron-based organic metal frameworks loaded onto iron oxide nanoparticle adsorbent. *Appl Surf Sci* 330: 85-93.
- Zollinger H (1987) *Color Chemistry: Syntheses Properties and Applications of Organic Dyes and Pigments*. (1st edn), Weinheim, New York, USA.
- Liu T, Li Y, Du Q, Sun J, Jiao Y, et al. (2012) Adsorption of methylene blue from aqueous solution by graphene. *Colloids Surf B Biointerfaces* 90: 197-203.
- Mokhtar N, Aziz EA, Aris A, Ishak WFW, Ali NSM (2017) Biosorption of azo dye using marine macro-alga of *Euchema Spinosum*. *J Environ Chem Eng* 5(6): 5721-5731.
- Reddy PMK, Verma P, Subrahmanyam C (2016) Bio-waste derived adsorbent material for methylene blue adsorption. *J Taiwan Inst Chem Eng* 58: 500-508.
- Shakoor S, Nasar A (2016) Removal of methylene blue dye from artificially contaminated water using citrus limetta peel waste as a very low-cost adsorbent. *J Taiwan Inst Chem Eng* 66: 154-163.
- Spagnoli AA, Giannakoudakis DA, Bashkova S (2017) Adsorption of methylene blue on cashew nutshell-based carbons activated with zinc chloride: The role of surface and structural parameters. *J Mol Liq* 229: 465-471.
- Ashraf MA, Balkhair KS, Chowdhury AJK, Hanafiah MM (2019) Treatment of Taman Beringin landfill leachate using the column technique. *Desalin Water Treat* 149: 370-387.
- Ashraf MA, Hanafiah MM (2019) Sustaining life on earth system through clean air, pure water, and fertile soil. *Environ Sci Pollut Res* 26: 13679-13680.
- Forgacs E, Cserhati T, Oros G (2004) Removal of synthetic dyes from wastewater: a review. *Environ Int* 30(7): 953-971.
- Kaushik P, Malik A (2009) Fungal dye decolorization: recent advances and future potential. *Environ Int* 35(1): 127-141.
- Vander Zee FP, Villaverde SC (2005) combined anaerobic-aerobic treatment of azo dyes- a short review of bioreactors studies. *Water Res* 39(8): 1425- 1440.
- Kimbrough DE, Cohen Y, Winer AM, Creelman L, Mabuni CA (1999) Critical assessment of chromium in the environment *Crit Rev Environ Sci Technol* 29(1): 1-46.
- Lin SH, Juang RS (2002) Heavy metal removal from water by sorption using surfactant-modified montmorillonite. *J Hazard Mater* 92(3): 315-326.
- Bhattacharya AK, Mandal SN, Das SK (2006) Adsorption of Zn (II) from aqueous solution by using different adsorbents. *Chem Eng J* 123(1-2): 43-51.
- Hanafiah MM, Hashim NA, Ahmed ST, Ashraf MA (2018) Removal of chromium from aqueous solutions using a palm kernel shell adsorbent. *Desal in Water Treat* 118: 172-180.
- Abbas A, Murtaza S, Munir M, Zahid T, Abbas N (2011) Removal of Congo Red from Aqueous Solutions with Raphanus sativus peels and activated carbon: a comparative study. *Am-Eur J Agric Environ Sci* 10(5): 802-809.
- Akram M, Bhatti HN, Iqbal M, Noreen S, Sadaf S (2017) Bio composite efficiency for Cr (VI) adsorption: kinetic, equilibrium and thermodynamic studies. *J Environ Chem Eng* 5(1): 400-411.
- Mahmoud DK, Salleh MAM, Karim WAWA, Idris A, Abidin ZZ (2012) Batch adsorption of basic dye using acid treated kenaf fiber char: Equilibrium, kinetic and thermodynamic studies. *Chem Eng J* 181-182: 449-457.
- Bhatti HN, Jabeen A, Iqbal M, Noreen S, Naseem Z (2017) Adsorptive behavior of rice bran-based composites for malachite green dye: isotherm, kinetic and thermodynamic studies. *J Mol Liq* 237: 322-333.
- Sajid M, Asif M, Baig N, Kabeer M, Ihsanullah I, et al. (2022) Carbon nanotubes-based adsorbents: Properties, functionalization, interaction mechanisms, and applications in water purification. *Journal of Water Process Engineering* 47: 102815.
- Rezazade M, Ketabi S, Qomi M (2024) Effect of functionalization on the adsorption performance of carbon nanotube as a drug delivery system for imatinib: molecular simulation study. *BMC Chemistry* 18.
- Raval NP, Shah PU, Shah NK (2016) Adsorptive amputation of hazardous azo dye Congo red from wastewater: a critical review. *Environ Sci Pollut Res* 23(15): 14810-14853.
- Abdur Rahman FB, Akter M, Abedin MZ (2013) Dyes removal from textile wastewater using orange peels. *Int J Sci Technol Res* 2(9): 47-50.
- Noreen S, Bhatti HN, Zuber M, Zahid M, Asgher M (2017) Removal of act acid orange-RL dye using biocomposites: modeling studies. *Pol J Environ Stud* 26(5): 2125-2134.
- Ahmadifar Z, Koohi AD (2018) Characterization, preparation, and uses of nanomagnetic Fe₃O₄ impregnated onto fish scale as more efficient adsorbent for Cu²⁺ ion adsorption. *Environ Sci Pollut Res* 25: 19687-19700.
- Eletta OAA, Ighalo JO (2019) A review of fish scales as a source of biosorbent for the removal of pollutants from industrial effluents. *J Res Inf Civ Eng* 16(1): 2479-2510.
- Adeniyi AG, Ighalo JO (2019) Biosorption of pollutants by plant leaves: an empirical review. *J Environ Chem Eng* 7(3): 103100.
- Anastopoulos I, Robalds A, Tran HN, Mitrogiannis D, Giannakoudakis DA, et al. (2018) Removal of heavy metals by leaves- derived biosorbents. *Environ Chem Lett* 17: 755-766.
- Osakwe CE, Sa'id S, Sanni I, Zubairu A (2014) Adsorption of heavy metals from wastewater using adonosa digitata Fruit shells and Theobroma cacao Pods as adsorbents: a comparative study. *AU J Technol* 18(1): 11-18.
- Solis M, Solis A, Pérez HI, Manjarrez N, Flores M (2012) Microbial decolouration of azo dyes: a review. *Process Biochem* 47(12): 1723-1748.
- Sebastian A, Nangia A, Prasad M (2019) Cadmium and sodium adsorption properties of magnetite nanoparticles synthesized from *Hevea brasiliensis* Muell. Arg. bark: relevance in amelioration of metal stress in rice. *J Hazard Mater* 371: 261-272.
- Sud D, Mahajan G, Kaur M (2008) Agricultural waste material as potential adsorbent for sequestering heavy metal ions from aqueous solutions-a review. *Biores Technol* 99(14): 6017-6027.

38. Mutavdžić Pavlović D, Ćurković L, Macan J, Žižek K (2017) Eggshell as a new biosorbent for the removal of pharmaceuticals from aqueous solutions. *Clean Soil Air Water* 45(12): 1700082.
39. Bamukyaye S, Wanasolo W (2017) Performance of eggshell and fish-scale as adsorbent materials for chromium (VI) removal from effluents of tannery industries in Eastern Uganda. *Open Access Library J* 4(8).
40. Wan Ngah WS, Teong LC, Hanafiah MAKM (2011) Adsorption of dyes and heavy metal ions by chitosan composites: a review. *Carbo hydr Polym* 83(4): 1446-1456.
41. Bello OS, Bello IA, Adegoke KA (2013) Adsorption of dyes using different types of sand: a review. *South Afr J Chem* 66: 117-129.
42. Reddy DHK, Seshaiha K, Reddy AVR, Rao MM, Wang MC (2010) Biosorption of Pb²⁺ from aqueous solutions by *Moringa oleifera* Bark: Equilibrium and Kinetic Studies. *Journal of Hazardous Materials* 174(1-3): 831-838.
43. Archin S, Sharifi HS, Asadpour G (2018) Optimization of Process Parameters by Response Surface Methodology for Methylene Blue Removal Using Cellulose Dusts. *Civil Engineering Journal* 4(3).
44. Cheraghi E, Ameri E, Moheb A (2015) Adsorption of Cadmium Ions from Aqueous Solutions Using Sesame as a Low-Cost Biosorbent: Kinetics and Equilibrium Studies. *International Journal of Environmental Science and Technology* 12: 2579-2592.
45. Huang X, Liang KH, Liu Q, Qiu J, Wang J, et al. (2020) Super fine grinding affects physicochemical, thermal and structural properties of *Moringa Oleifera* leaf powders. *Ind Crops Prod* 151: 112472.
46. Gopalakrishnan L, Doriya K, Santhosh D (2016) *Moringa oleifera*: A review on nutritive importance and its medicinal application. *Food Sci Hum Wellness* 5(2): 49-56.
47. Bello O, Adegoke K, Akinyunni O (2017) Preparation and characterization of a novel adsorbent from *Moringa oleifera* leaf. *Appl Water Sci* 7: 1295-1305.
48. Amalina F, Razak ASA, Zularisam AW, Nasrullah M, Krishnan S (2022) Dyes removal from textile wastewater by agricultural waste as an absorbent- A review. *Cleaner Waste Systems* 3: 100051
49. Kuang Y, Zhang X, Zhou S (2020) Adsorption of Methylene Blue in water onto Activated Carbon by Surfactant Modification. *Water* 12(2): 587.
50. Goudie KJ, McCreath SJ, Parkinson JA, Davidson CM, Liggat JJ (2023) Investigation of the influence of pH on the properties and morphology of gelatin hydrogels. *Journal of Polymer Science* 61(19): 2316-2332.
51. Mordhiya B, Daga K, Chandra S, Aggarwal S (2012) Adsorptive Treatment of Methylene Blue Dye from Aqueous Solution Using *Moringa Oleifera* as an Adsorbent. *Nature Environment and Pollution Technology* 11(1): 113-116.
52. Han X, Wang W, Ma X (2011) Adsorption characteristics of methylene blue onto low-cost biomass material lotus leaf. *Chem Eng J* 171(1): 1-8.
53. Kulkarni S, Kaware J (2014) Regeneration and Recovery in Adsorption- a Review. *IJSET-International Journal of Innovative Science Engineering & Technology* 1(8).
54. Esvandi Z, Foroutan R, Peighambaroust SJ, Akbari A, Ramavandi B (2020) Uptake of anionic and cationic dyes from water using natural clay and clay/starch/MnFe₂O₄ magnetic nanocomposite. *Surfac Interfac* 21: 100754.
55. Foroutan R, Peighambaroust SJ, Esvandi Z, Khatooni H, Ramavandi B (2020) Evaluation of two cationic dyes removal from aqueous environments using CNT/MgO/CuFe₂O₄ magnetic composite powder: A comparative study. *J Environ Chem Eng* 9(2): 104752.
56. Adeniyi AG, Ighalo JO (2019) Biosorption of pollutants by plant leaves: an empirical review. *J Environ Chem Eng* 7(3): 103100.
57. Unuabonah EI, Adebawale KO, Olu-Owolabi BI (2007) Kinetic and thermodynamic studies of the adsorption of lead (II) ions onto phosphate-modified kaolinite clay. *J Hazard Mater* 144(1-2): 386-395.
58. Paska OM, Pacurariu C, Muntean SG (2014) Kinetic and thermodynamic studies on MB biosorption using cornhusk. *RSC Adv* 107.



This work is licensed under Creative Commons Attribution 4.0 License
DOI: [10.19080/JOJMS.2025.09.555769](https://doi.org/10.19080/JOJMS.2025.09.555769)

**Your next submission with JuniperPublishers
will reach you the below assets**

- Quality Editorial service
- Swift Peer Review
- Reprints availability
- E-prints Service
- Manuscript Podcast for convenient understanding
- Global attainment for your research
- Manuscript accessibility in different formats
(Pdf, E-pub, Full Text, Audio)
- Unceasing customer service

Track the below URL for one-step submission

<https://juniperpublishers.com/submit-manuscript.php>