Methylene blue removal using Eucalyptus Leaves: A Low Cost Protocol towards Environmental Sustainability

Soumen Dey, Priyanka Bhagat, Jhilirani Mohanta, and Banashree Dey

ABSTRACT

Indiscriminate use of dyes pollutes water bodies and poses a serious threat to mankind. Hence there is a need to address the problem. Eucalyptus leaves, being abundantly available were tested for the removal of methylene blue dye from water by both batch and column experiments. The material was characterized by Scanning electron microscopy, proximate analysis, and FT-IR spectroscopy. SEM Images show a fractured surface with heterogeneous morphology. Batch experiments were conducted with respect to various physico-chemical parameters such as pH, agitation speed, concentration, etc. The maximum adsorption capacity was found to be 66 mg/g. Over a pH range of 4-8, high adsorption was seen. Adsorption follows a pseudo-second-order kinetic model ($R^2$=0.999). Regeneration was achieved with dilute hydrochloric acid and the material can be reused. Column studies show the possibility of field application. In a nutshell, a low-cost methodology was established with eucalyptus leaves for a safer environment.

Keywords: Methylene blue, Eucalyptus leaves, adsorption, regeneration.

I. INTRODUCTION

In past few decades, a rapid increase in the number of textile and other dyes based industries have grown up. To add up, use of various dyes are increasing day by day. Dyes are used to color diverse products and large quantities of wastewater are discharge into streams and rivers which is a major source of water pollution. Azo dyes are non-biodegradable, highly toxic and proven carcinogens [1]. Dyes are mainly used in textile, paint, plastic industries; effluent from this industries are toxic in nature [2]-[4]. Dyes imposes serious threat to biological processes inside water bodies as the color of dyes prevent penetration of sunlight [5]-[6]. The presence of dyes in water bodies inhibits the growth of aquatic biota and decreases the oxygen solubility [7]. Wastewater containing dyes represents a threat to aquatic life so it’s necessary to remove from wastewater [8].

But if methylene blue dose is higher than 0.09 mL per pound of body weight it cause dangerous side effects like chest pain, vomiting and confusion. Kidney and diabetics patient never takes it because it permanently destroyed the eyes. [9] Many methods are developed for removal of dyes in wastewater such as: coagulation and flocculation, sonochemical degradation, micellar enhanced ultrafiltration, cation exchange membranes, electrochemical degradation, membrane separation, oxidation and adsorption/precipitation [10]. Among all these, adsorption is easier and economically inexpensive process. In adsorption process adsorbents are used which are readily available and have very low cost. Activated carbon was used for the removal of color effluents in polluted wastewater [11]-[12]. Also different types of bio-adsorbents are reported from many years, such as carpobrotus edulis plant, sugarcane bagasse, agrobiomass, coconut husk, peat, straw, orange and uvaia seed. Recently neem leaf and orange peel powder has been reported. The adsorption of cationic dye on CTAB modified multi-component biosorbent is reported to be feasible [13]-[20].

Among all the purification process adsorption is easy, low cost, high efficiency, and recyclable process. An extensive variety of adsorbents like biomass, Zeolitic imidazolate frameworks-67 (ZIF-67), chitosan and its nanoparticles, carboxymethyl cellulose, acrylicamide and graphene oxide, corn stalk polyethyleneimine-modified graphene oxide hydrogel, saw dust, clay based materials, rice husk, graphene,
silica-sand/starch composite, magnetic porous organic Polymers, activated carbon, bio-char, graphitic magnetic nanocomposite, polyoxometalate@UiO-66, Fe@graphitecore–shell magnetic nanocomposite, porous diatomite microsphere, CMC-g-P(PSMA) superadsorbent hydrogel, bioconjugated graphene oxide hydrogel, reduced graphene oxide, graphene oxide intercalated montmorillonite nanocomposite, cement kiln dust, aminated calcium lignosulfonate, palygorskite, manganese oxide, zinc oxide, ZnO/NiO hollow microspheres, ZnO-Al₂O₃ microspheres, MeSrCuO (Me = Mg and Ce) metal Oxides, CeO₂–Fe₂O₃–Al₂O₃, Ag/ZnO/3D, CuMgAl layered double hydroxide, binary oxides, polyaniline-alumina composite material, amberlite Ira-938 etc were tested [21]-[70]. With this line, we have demonstrated previously the application of various phytosorbents and chemisorbents for dye removal from contaminated water [71]-[82].

II. MATERIALS AND METHODS

A. Biosorbent Preparation and Characterization

Eucalyptus leaves are collected from the university campus and washed thoroughly to remove all the dirt. It was then refluxed with distilled water to completely remove any natural color present within, and dried it to 70 °C overnight. Dried leaves were crushed, sieved in different mesh sizes and used as such. Methylene blue is cationic dye. Molecular weight (MW) is 319.65 gmol⁻¹. Structure is given in Fig 1.

100 mg/L stock solution was prepared by dissolving 0.05gm of MB in 500 mL distilled water. LR grade hydrochloric acid and sodium hydroxide was used to adjust solution pH.

Analytical balance (Denver instrument corp.) was used for weighing of samples. Systronic digital pH meter 802 was used for pH measurements. Sohag orbital shaker incubator was used for shaking in the shaking range 100-150 rpm. Muffle furnace (Thermo Scientific) was used for drying of samples. ZIESS SEM Analyzer was used for SEM study. Hita chi double beam spectrophotometer (model U-2900) equipped with UV solutions program NSJ was used for all UV measurements. Perkin Elmer (spectrum-II) and Remi-bench top centrifuge (R-8 M) were used for centrifugation.

The different concentration was measured using an UV-Visible spectrophotometer at a wavelength of 664nm. Calibration curve was obtained by using standard MB solution at pH 7 and was fitted by a straight line with high coefficient value (R²=0.987) as shown in Fig. 2.

Batch studies were carried out by varying the initial dye concentration, contact time, agitation speed, adsorbent dose, particle size, pH and time. In this experiment 100mL bottle was used in which appropriate amount of adsorbent is used in 50mL dye solution with a known concentration. After equilibration is reached, bottles were withdrawn from the shaker, centrifuged and absorbance was measured using UV-visible spectrophotometer. Concentration of dye was calculated using above calibration curves. The amount of dye adsorbed and the percentage removal was calculated using equation (1) and (2).
where $q_t$ (mg/gm) is the amount of dye adsorbed at equilibrium, $C_e$ (mg/L) is the initial and $C_i$ is concentration of dye after shaking at any time (min). $V$ is the volume (mL) of dye, $m$ (g) is the mass of adsorbent. $R\%$ is the percentage of dye removal.

III. RESULTS AND DISCUSSION

Proximate Analysis was done for determination of ash, moisture, fixed carbon and volatile matter contents. It was carried out on eucalyptus leaves with 0.05μm mesh size.

TABLE I. PROXIMATE ANALYSES OF THE SAMPLES

| Sl. No | Parameter            | Content (%) |
|-------|----------------------|-------------|
| 1.    | Moisture content     | 9.8         |
| 2.    | Ash content          | 73.10       |
| 3.    | Volatile content     | 2.21        |
| 4.    | Fixed carbon content | 14.89       |

A. FT-IR Analysis

This technique is used for the prediction of functional groups present in the sample. In this experiment FT-IR shows the difference before adsorption and when adsorption takes place. The FTIR analysis indicated broad band at 3467 cm$^{-1}$, representing bonded O–H groups which gets shifted to 3363 cm$^{-1}$ after adsorption (Fig. 3). The shift is attributed by interaction of dye with eucalyptus leaves.

B. SEM Analysis

Scanning electron microscopy helps in determining the nature of the surface. Fig.4 (a) and (b) show the SEM images of prepared eucalyptus leaves and adsorption with MB solution. It was observed that pore size reduces after adsorption. This indicates that EU is effective in adsorbing methylene blue. Fig 4 represents SEM images of EU before and after adsorption.
C. Effect of Contact Time

The effect of contact time on the adsorption of MB onto EU ranges from 10 to 60 min. 5 mg/L MB solution was prepared by diluting 100 mg/L stock solution. 0.1g EU was taken and kept in shaker at room temperature in different time interval. Fig. 5 shows percentage removal of MB dye versus time. It was seen that the 88% adsorption occur in 10 min, after that there is no sharp increase in adsorption (Fig. 5). This suggests that equilibrium sets at 10 min.

![Fig. 5. Effect of contact time on MB adsorption.](image)

D. Effect of Initial Dye Concentration

To demonstrate the effect of initial concentration, 5-30 mg/L concentration was taken. 0.1gm EU was added in different MB solution and shakes for 10min. Fig 6 shows the percentage removal vs concentration. There is a decrease in adsorption efficiency with increases of dye concentration. It was observed that at lower concentration there are sufficiently available active sites, due to this adsorption is fast. This is might be due to increase the competition for active site and adsorption process will decreases slowly.

![Fig. 6. Effect of initial dye concentration.](image)

E. Effect of Agitation Speed

To evaluate the effect of agitation speed, 5 mg/L dye solution was taken in four bottles. The speed was ranges from 80 to 140 rpm and shaken it for equilibrium time one by one. Fig. 7 shows the effect of agitation speed. It was observed that increase in agitation speed decreases the adsorption insignificantly. This may be due to slight occurrence of desorption.

![Fig. 7. Effect of agitation speed on adsorption of MB.](image)
F. Effect of Adsorbent Dose

Fig. 8 shows the effect of adsorbent dose which was carried out by using different amount of EU (0.05 to 0.25 g), added to fixed initial dye concentration of MB. Initially concentration increases rapidly with increase in dose. This is due to availability of greater surface area. But after certain dosage efficiency becomes constant. This is due to fast superficial adsorption onto the adsorbent surface. Thus when adsorbent doses increases, amount of dye adsorbed per unit mass decreases.

![Image of Fig. 8: Effect of adsorbent dose on adsorption of MB onto EU.](image)

G. Effect of Particle Size

Fig. 9 shows the adsorption of MB of different particle sizes. Here initial dye concentration was taken and agitated for equilibrium time. It was observed that there is slow decrease in adsorption removal with increase in mesh size. Size is inversely proportional to surface area. Larger the size, lower was the adsorption. Hence small size was used which leads to greater adsorption.

![Image of Fig. 9: Effect of particle size on adsorption of MB onto EU.](image)

H. Effect of pH

The effect of pH was shown in Fig. 10. pH of initial dye solution is adjusted by adding small amount of 0.1M NaOH or HCl. Adsorption capacity increases with increasing pH. EU has larger number of active sites. In pH 2 there is large number of H⁺ ions present which compete with active sites of EU for MB adsorption. When pH is gradually increased, number of H⁺ ion deceases and electrostatic interaction between MB and EU gets better and efficiency increases. Fig. 10 represents the effect of pH on adsorption of dye.

![Image of Fig. 10: Effect of pH on adsorption of MB onto EU.](image)
I. Adsorption Kinetics

For knowing the mechanism of dye adsorption and designing the adsorption system, kinetics is one of the important parameter. For this pseudo-first-order, pseudo-second-order and intra-particle diffusion models were evaluated to fit the kinetics experiments data.

1) Pseudo first order kinetics model

In 1898 Lagergren developed the pseudo-first-order kinetic model is shown in (3).

\[ \frac{dq}{dt} = k_1(q_e - q_t) \]  \hspace{1cm} (3)

where \( q_e \) and \( q_t \) are the amounts of dyes adsorbed at equilibrium and at time \( t \) (mg/g), respectively, and \( k_1 \) is the pseudo-first-order rate constant (min\(^{-1}\)). The integrated form of (3) with the initial condition, \( q_t = 0 \) at \( t = 0 \) is shown in (4). The rate constant can be determined from linear plot of \( \log(q_e - q_t) \) versus time.

\[ \log(q_e - q_t) = \log(q_e) - \frac{k_1 t}{2.303} \]  \hspace{1cm} (4)

2) Pseudo second order kinetics model

Linearized form of the Pseudo second-order kinetic model is shown in below (5):

\[ \frac{t}{q_t} = \frac{1}{K_2(q_e)^2} + \frac{t}{q_e} \]  \hspace{1cm} (5)

where \( K_2 \) is the equilibrium rate constant of pseudo-second-order adsorption [g/(mg.min)]. A plot between \( t/q_t \) vs. \( t \) gives the value of rate constant \( K_2 \) (g/mg.min).

3) Intra particle diffusion model

Weber-Morris developed the intra-particle diffusion model which is shown in (6):

\[ q_t = k_3t^{1/2} + c \]  \hspace{1cm} (6)

where \( k_3 \) is the inter particle diffusion rate constant (mg.g\(^{-1}\).min\(^{0.5}\)) and \( C \) is intercept (mg.g\(^{-1}\)), which is the thickness of boundary layer.

The kinetics of MB adsorption was analyzed with respect to pseudo-first order, pseudo-second order and intra-particle diffusion model. By using relevant equations all the graphs was plotted and shown below. The 1\(^{st}\) and 2\(^{nd}\) order rate constants were determined. The kinetic data of Pseudo2\(^{nd}\) order model are fitted with highest correlation coefficient (\( R^2=0.999 \)) which is better than pseudo-first (\( R^2=0.982 \)) intra particle model (\( R^2=0.933 \)). These result shows that adsorption of MB onto EU might be best described by pseudo2\(^{nd}\) order kinetic model. Fig. 11 shows all the kinetic models. From the observations, it seems that there is a combining effect of physi-sorption and chemi-sorption.

IV. COLUMN STUDY

Only batch experiment may not be conducive whether a material will work on pilot scale. Column study was carried out to check whether EU can be used in industrial wastewater treatment. In this experiment adsorbent bed of knowing amount was prepared and 5mg/L methylene blue solution was passed through dropwise. A constant flow rate is maintained. Fixed bed glass column was used and experiments were performed at pH 7. Results are summarized in Table 2.
V. REGENERATION AND REUSE

Regeneration study helps to understand the mechanism of adsorption. The scope of recovery of adsorbate as well as adsorbent is also called regeneration. If the adsorbent can be successfully regenerated, then it will make the treatment process more economically advantageous. To achieve that, 0.5 g MB treated EU was taken in three 50 mL of conical flask. In these flasks, one acidic (25 mL, 1N HCl), one basic (25 mL, 1N NaOH) and one neutral (25 mL, 1N NaCl) solution was taken and shaken for overnight. The final readings of concentration were noted down. A graph between percentage desorption and 0.1 N solution was plotted.

In case of hydrochloric acid, the percentage desorption was very high. EU was then thoroughly washed with distilled water and adjusted to pH 7. A continuous cycle experiments were conducted for three cycles. It was found that after each cycle efficiency is retained by almost 95%. Fig. 12 shows desorption with HCl and NaOH solution. This is in accordance to our previous works where we have demonstrated highly efficient regeneration and reuse of various materials for diverse dye removal from contaminated water [71]-[82].

VI. CONCLUSION

Present study shows that Eucalyptus leaves, a cheap and easily available material, that can be effectively used to remove methylene blue from solution. Proximate analysis showed good carbon content which favors adsorption. Percentage carbon was found to be. The moisture content (9.8%), volatile content (2.21%) and ash content (76.10%) were also found to be quite reasonable. FTIR spectra show little change in the surface properties of adsorbent after adsorption as compared to that of before adsorption. Scanning Electron micrographs exhibited that EU had a considerable number of pores where there is a good possibility of methylene blue dye to be trapped and adsorbed into these pores and also there is no significantly change in the surface topography of EU before and after adsorption of dye due to lack of dye and adsorbent ratio.

Adsorption tends to increase with contact time. At first the increase in adsorption is very rapid as there are lots of free sites for the adsorption to take place. Rate of adsorption decreases at later stages till saturation is reached due to saturation of active sites. The optimum contact time for equilibrium was found to be ten minutes. The removal efficiency of adsorbent is maximum at higher pH range. As adsorbent dose increases, adsorption increases due to the availability of free sites. Concentration of adsorbent is taken as the optimum adsorbate dose. As we increase adsorbate dose more than the optimum, the subsequent increase in adsorption is very less and it becomes cost ineffective. There is decrease in adsorption with the increase in initial dye concentrations due to the high driving force for mass transfer at a high initial dye concentration. The adsorption process follows pseudo second order kinetics.

CONFLICT OF INTEREST STATEMENT

All the authors declare that there is no conflict of interest.
ACKNOWLEDGEMENT

Authors thank Central University of Jharkhand for infrastructural facilities.

REFERENCES

[1] Saleh VM, Abudabuss M. Removal of Methylene Blue Dye Using Roselle Petals from Aqueous Solutions. Int J Chem Mol Nucl Mat and Metal Engg 2013;7:340-343. doi.org/10.5281/zenodo.133411.

[2] Afroze S, Sen TK, Ang HM. Adsorption performance of continuous fixed bed column for the removal of methylene blue (MB) dye using Eucalyptus sheathiana bark biomass. Res Chem Intermed. 2016; 42:2343–2364. doi.org/10.1007/s11164-015-2153-8.

[3] Li JW, Li J. Removal of methylene blue from aqueous solution by Adsorption onto crofton weed stalk. Bio Resources. 2013; 8:2521–2533. doi.org/10.15376/biores.8.2.2521–2533.

[4] Kangkli GB, Metin AU. Phragmites Australis/Phrh as a new cellulose source: Extraction, characterization and adsorption of methylene blue. J Mol Liq. 2020; 312:113313-113323. doi.org/10.1016/j.molliq.2020.113313.

[5] Shooito ND, Nkutha CG, Guilandre NR, Naidoo EB. Pristine and modified mucuna beans adsorptive studies of toxic lead ions and methylene blue dye from aqueous solution. South Afr J Chem Enng. 2020; 31:33–43. doi.org/10.1016/sajce.2019.12.001.

[6] Lopez–Vasquez A, Suarez A, Gomez C. Assessment of Dye Adsorption by Luffa Cylindrica fibers Using Experimental Design Methodology. Proceedings of the World Congress on Engineering/WCE. pp. 3-8, vol. I, London, U.K., 2012.

[7] Pathania V, Sharma S, Singh P. Removal of methylene blue by adsorption onto activated carbon developed from ficuscaricabast. Arb J Chem. 2017; 10:1445-1541. doi.org/10.1016/j.arabjc.2013.04.021.

[8] Mane VS, Vijay Babu PV. Studies on the adsorption of Brilliant Green dye from aqueous solution onto low-cost NaOH treated saw dust. Desalination.2011; 273:321–329. doi.org/10.1016/j.desal.2011.01.049.

[9] Murat O, Dietrich EL, Mohammed H, George AP. Celluluar and Molecular Actions of Methylene Blue in the Nervous System. Medici Res Reviews.2010;31:93-117. doi.org/10.1002/med.20177.

[10] Mesquita B, Botrel C, Magriots ZM, Saczk AA, Coelho SM, Sales PF. Removal of methylene blue by orange and uvaia seeds. J Adv Agr. 2015; 3:236-251. doi: https://doi.org/10.4491/eeer.2018.107.

[11] Khatod I. Removal of Methylene Blue Dye from Aqueous Solutions by Neem Leaf and Orange Peel Powder.Proceedings of the International Conference on Global Scenario in Environment and Energy, Int J Chem Tech Research, pp. 572-577, vol. 5, Bhopal, Madhya Pradesh, India, 2013.

[12] Eden MK, Celaeitett O. Removal of Methylene Blue Dye from Aqueous Solution Using Natural Boron Ore and Leach Waste Material: Adsorption Optimization Criteria.Inter J Current Res Acad Review. 2014; 1:66–71. ISSN: 2347-3215.

[13] Patil S, Das SR, Patel N. Removal of methylene blue, a basic dye from aqueous solutions by adsorption using teak tree (Tectona grandis) bark powder. Int J Environ Sci. 2011; 1:71–76. ISSN. 0976 – 0002.

[14] Dabagh A, Bagui A, Abali M, Aziam R, ChibanM, SinanM, et al. Adsorption of Crystal Violet from aqueous solution onto eco-friendly native Carpoprotus edulis plant.Materials Today: Proceedings. 2021; 37(3):3980-3986. doi.org/10.1016/j.matpr.2020.10.349.

[15] Nandi BK, Goswami A, Purkait MK. Adsorption characteristics of brilliant green dye on kaolin. J Hazard Mater. 2009; 161:387–395. doi.org/10.1016/j.jhazmat.2008.03.110.

[16] Ayad MM, El-Nasr AA. Adsorption of Cationic Dye (Methylene Blue) from Water Using Polyaniiline Nanotubes Base J Phys Chem C.2010;114:14377–14383. doi.org/10.1021/p1010378w.

[17] Aruna, Bagotia N, Sharma AK, Kumar S. A review on modified sugarcane bagasse biosorbent for removal of dyes. J Chem Eng. 2021;268:129309-129324. doi.org/10.1016/j.chemosphere.2020.129309.

[18] Gottipati R, Mishra S. Application of Biowaste (waste generated in biodiesel plant) as adsorbent for the removal of hazardous dye-methylene blue from aqueous phase. Brazilian J Chem Eng. 2010;27:357-367. doi.org/10.1590/S0103-64222010000200014.

[19] Mishra S, Cheng L, Maiti A. The utilization of agro-biomass/byproducts for effective bio-removal of dyes from dyeing wastewater: A comprehensive review.J Environ Chem Eng. 2021; 9:104901-1049923. doi.org/10.1016/j.jece.2020.104901.

[20] Esan OS, Abiola ON, Owoyomi O, Christopher OA, Osunyita MO. Adsorption of Brilliant Green onto Luffa Cylindical Sponge: Equilibrium, Kinetics, and Thermodynamic Studies. ISRn Phy Chem. 2014; 2014:1–12. doi.org/10.1155/2014/743532.

[21] Bhusan Tiwah, Hanim S, Fahzrowah, Rosidah H, Rama M. Adsorption of Acetic acid from aqueous solution by crosslinked chitosan/bentonite composite. J Disper Sci Tech.2015;36:61–67. doi.org/10.1080/01932691.2014.888004.

[22] Asfaram A, Ghadzi M, Yousef F, Dustkhoon M. Experimental design and modeling of ultrasound assisted simultaneous adsorption of cationic dyes onto ZnS: Mn -NP-AC from binary mixture. Ultrasonics Sonochemistry. 2016; 33:77-89. doi.org/10.1016/j.ultsonch.2016.04.016.

[23] Yasemin B, Haluk A. A kinetics and thermodynamics study of methylene blue adsorption on wheat shells. Desalination. 2006; 194:259–267. doi.org/10.1016/j.desal.2005.10.032.

[24] Alhaz H, Khalil TE, Abubakr R. The effect of dye chemical structure on adsorption on activated carbon: a comparative study. Color Tech. 2014; 130:205–214. doi.org/10.1111/cote.12086.

[25] Leite LS, Maselli BS, Unibuziero GA, Nogueira RFP. Monitoring ecotoxicity of dispersion red 1 dye during photo-fenton degradation. Chemosphere. 2016; 148:511–517. doi.org/10.1016/j.chemosphere.2016.01.053.

[26] Al-Rashdi BAM, Johnson DI, Hilal N. Removal of heavy metal ions by nanofiltration. Desalination. 2013;315:2–17. doi.org/10.1016/j.desal.2012.05.022.

[27] Peterskova M, Valderrama C, Gibert O, Cortina JL, Extraction of valuable metal ions (Cs, Rb, Li, U)from reverse osmosis concentrate using selective sorbents. Desalination. 2012;286:316–323. doi.org/10.1016/j.desal.2011.11.042.

[28] Lin Q, Gao M, Chang J, Ma H. Adsorption properties of crosslinking carboxymethyl cellulosegrafting dimethyldialkyiammonium chloride for cationic and anionic dyes. Carbohydrate Polymers. 2016; 151:283-294. doi.org/10.1016/j.carbpol.2016.05.064.doi.org/10.3390/molecules25163624.

[29] Khan MA, Siddique M, Wahid F, Khan R. Removal of reactive blue 19 dye by sono, photo and sonophotocatalytic oxidation using visible light. Ultrason Sonochem. 2015; 26:370-377. doi.org/10.1016/j.ultsonch.2015.04.012.

[30] Ainscough TJ, Alagappan P, Oakley-Radcliffe DL, Barron AR. A hybrid super hydrophilic ceramic membrane and carbon nanotube adsorption process for clean water production and heavy metal removal and recovery in remote locations. J Water Process Eng. 2017; 19:220–230. doi.org/10.1016/j.jwpe.2017.08.006.

[31] Natarajan S, Bajaj HC, Tayade RJ. Recent advances based on the synergetic effect of adsorption for removal of dyes from waste water using photocatalytic process. J Environ Sci.2017; 65:201–222.doi.org/10.1016/j.jes.2017.03.011.
Selective adsorption and separation of organic dyes from aqueous solution on polyaniline microspheres. J Colloid Inter Sci. 2016; 461:292−304. doi: 10.1016/j.jcis.2015.09.017.

Javidian H. Application of kinetic, isotherm and thermodynamic models for the adsorption of Co(II) ions on polyamine/polypropylene copolymer nanofibers from aqueous solution. J Ind Eng Chem. 2014; 20(6):4233−4241. doi: 10.1016/j.jiec.2014.01.026.

Hajighahrami S, Kamparananwot P, Supaphol P. Metal adsorption behavior of 2,4-dinitrophenyl hydrazinomodified polyaniline nanofibers. Express Polymer Letters. 2013; 7:832−841. doi: 10.3341/expresspolymlett.2014.1.026.

Ren X, Xiao W, Zhang R, Yang H, Han R. Adsorption of crystal violet from aqueous solution by chemically modified phoenix tree leaves in batch mode. Desalination Water Treat. 2015; 53:1324−1334. doi: 10.1080/19443994.2013.859105.

Du X, Wang C, Liu J, Zhao X, Zhong J, Li Y, et al. Extensive and selective adsorption of ZIF-67 towards organic dyes: Performance and mechanism. J Mater Chem A. 2017; 5:4637−4441. doi: 10.1039/c7ta04777j.

Shajahan A, Shankar S, Sathiyaseelan A, Narayan KS, Narayanan V, Kaviyarasan V, et al. Comparative studies of chitosan and its nanopersorption efficiency of various dyes. International J. Biol. Macromol. 2017; 104:1449−1458. doi.org/10.3390/ijbm.2017.01045.

Baraprasad K, Jayaramdu T, Sudikur EK. Facile green synthesis of magnetic porous mesoporous nanocomposite and its application in dye adsorption. J Mol Liq. 2018; 256:395−407. doi: 10.1016/j.molliq.2018.02.034.

Agrawal JS, Cecilia VA, Tavares PAS, Azvedo DCS, Castellung ER, Lucena SMP, et al. Adsorption study of reactive dyes on porous clay heterostructures. Appl Clay Sci. 2017; 135:35−44. doi: 10.1016/j.clay.2016.09.001.

Sawadse S, Jankerd H, Watcharabundit P. Adsorption of dye effluent in house hold-scale dyeing on rice husk. Energy Procedia. 2017; 138:1159−1164. doi.org/10.24944/ace.v112.624.

Essawy NA, Ali SM, Farag HA, Konsowa AH, Elnoouby M, Hamad HA. Green synthesis of graphene from recycled PET bottle waste for use in the adsorption of dyes in aqueous solution. Ecotox Environ Safety. 2017; 145:57−68. doi: 10.1016/j.ecoenv.2017.07.014.

Li P, Gao B, Li A, Yang H. Highly selective adsorption of dyes and arsenate from their aqueous mixtures using a silica-sand/cationized-starch composite Micropor Mesopor Mater. 2018; 263:210−219. doi: 10.1016/j.micromeso.2017.12.025.

Huang L, He M, Chen B, Cheng Q, Hu B. Facile Green Synthesis of Magnetic Porous Organic Polymers for Rapid Removal and Separation of Methylene Blue. ACS Sustainable Chem Eng. 2017; 5:4630−4635. doi: 10.1021/acssuschemeng.7b00031.

Gowamun M, Phukan P. Enhanced Adsorption of cationic dyes using surfactant activated carbon. J Environ Eng. 2017; 5(4):3508−3517. doi: 10.1016/j.ejene.2017.07.016.

Menya E, Olupot PW, Storz H, Lubwama M, Kiros Y. Production and performance of activated carbon from rice husks for removal of natural organic matter from water: A review. Chem Eng Res Des. 2018; 129:271−296. doi: 10.1016/j.cherd.2017.11.008.

Dawood S, Sen TK, Khan C. Adsorption removal of Methylene Blue (MB) dye from aqueous solution by bio-char prepared from Eucalyptus sheathiana bark: kinetic, equilibrium, mechanism, thermodynamic and process design. Desalination Water Treat. 2016; 57(59):28964−28980. doi: 10.1016/j.desal.2014.09.094.

Dai H, Peng X, Yang W, Hu F, Qiu Z, Zou Y. Synthesis and characterization of graphitic magnetic mesoporous nanocomposite and its application in dye adsorption. J Mol Liq. 2018; 253:197−204. doi: 10.1016/j.molliq.2018.01.030.

Zeng L, Xiao L, Long Y, Shi X. Trichloroacetic acid-modulated synthesis of polyoxometalate@UO2-66 for selective adsorption of cationic dyes. J Colloid Inter Sci. 2018; 516:274−283. doi: 10.1016/j.jcis.2018.01.070.

Konicka W, Helminia A, Arabczyk W, Mijowsk E. Adsorption of cationic dyes onto Fe@graphitecore−shell magnetic nanocomposite: Equilibrium,kinetics and thermodynamics. Chem Eng Res Design. 2018; 129:259−270. doi: 10.1016/j.chemar.2017.11.008.

Yan S, Hao W, J Zhang, Y Wang, Q Wang, L et al. Green synthesis and influence of calcined temperature on the formation of novel porous diatome microspheres for efficient adsorption of dyes. Powder Tech. 2018; 329:260−269. doi: 10.1016/j.solid.2018.04.046.

Salama A. Preparation of CMC-g-P(SPM) super adsorbent hydrogels: Exploring their capacity for MB removal from wastewater. Inter J Bio Macromol. 2018; 106:940−946. doi: 10.1016/j.ijbiomac.2017.08.097.

Li D, Li A, Yang H. Facile Green Synthesis and Modulated synthesis of polyoxometalate@UO2-66 for Adsorption of cationic dyes. J Colloid Inter Sci. 2017; 516:274−283. doi: 10.1016/j.jcis.2018.04.046.

Hao J, Li L, Li C, Hu C, Wu K. Rapid, efficient and economic removal of organic dyes and heavy metals from wastewater by zinc-induced in-situ reduction and precipitation of graphene oxide. J Taiwan Inst Chem Eng. 2017; 64:186−194. doi:10.1016/j.tice.2017.03.045.

Puri C, Sumana G. Highly effective adsorption of cationic dyes from contaminated water using graphene oxide intercalated montmorillonite nanocomposite. Appl Clay Sci. 2018; 166:102−112. doi: 10.1016/j.claysci.2018.09.012.

Magdya YH, Althae H. Kinetic analysis of the adsorption of dyes from high strength wastewater on cement kiln dust. J Environ Chem Eng. 2016; 8:634−641. doi: 10.1016/j.jece.2018.01.009.

Wang Y, Zha L, Wang X, Zheng W, Hao C, Jiang C, et al. Synthesis of aminoated calcium lignosulfonate and its adsorption properties for azo dyes. J Ind Eng Chem. 2016; 61:321−330. doi: 10.3388/jiec.2016.61.91528.

Brenot E, Li D, Li A, Yang H. Adsorption properties and mechanism of polyglyksite for removal of various ionic dyes from water. Appl Clay Sci. 2018; 151:20−28. doi: 10.1016/j.clay.2017.10.016.

Islam MA, Mortown DW, Johnson BB, Mainali B, Angove MJ. Manganese oxides and their application to metal ion and contaminants removal from wastewater. J Water Process Eng. 2018; 26:264−280. doi: 10.1016/j.jwpe.2018.10.018.

Lei C, Pi M, Jiang C, Cheng B, Yu J. Synthesis of hierarchical porous zinc oxide (ZnO) microspheres with highly efficient adsorption performance on Congo red dye. J Hazard Mater. 2017; 490:242−251. doi: 10.1016/j.jhazmat.2016.11.049.

Lei C, Pi M, Cheng B, Jiang C. Fabrication of hierarchical porous ZnO/NiO hollow microspheres for adsorptive removal of Congo red. Appl Surf Sci. 2018; 435:1002−1010. doi: 10.1016/j.apsusc.2017.11.201.

Lei C, Pi M, Xu D, Jiang C, Cheng B. Fabrication of hierarchical porous ZnO-Al2O3 microspheres with enhanced adsorption performance. Appl Surf Sci. 2017; 426:360−368. doi: 10.1016/j.apsusc.2017.07.095.

Chen H, Motocai J, Martens W, Diniz da Costa JC. Degradation of Orange II Dye Under Dark Ambient Conditions by MesS(C)CuO (Me = Mg and Ce) Metal Oxides Sep Purification Tech. 2020; 293−301. doi: 10.1016/j.seppur.2018.05.029.
Ms. Priyanka Bhagat was born in Chittaranjan, the rail city in eastern India in 1994. She completed her integrated M.Sc. in 2017 from Central University of Jharkhand and did masters research under Dr. Soumen Dey. Currently, she is working as a school teacher in Crescent Public School since January 2021.

Dr. Jhilirani Mohanta was born in Mayurbhanj district, Odisha, India. She received her M.Sc. from North Orissa University Baripada and M.Phil from Sambalpur University. She then qualified CUCET and admitted to Ph.D. under Dr. Soumen Dey. She received her Ph.D. in September, 2021. She has published 10 research papers and one book chapter.

Dr. Soumen Dey was born in Kolkata, India on 16th February 1977. He received his B.Sc., M.Sc. (Chemistry), and B.Ed. degrees from Visva Bharati University, Santiniketan (established by the great Rabindranath Tagore, the first Asian Nobel laureate). Thereafter he moved to Presidency University in 2001 and joined as JRF in a project on Arsenic poisoning. He then joined the group of Prof. Babasachar Sarkar at I.I.T. Kanpur, India and received a Ph.D. in the year 2009. He joined as an Assistant Professor in the Department of Chemistry, S.K.M. University Dumka, India in 2008. In 2011, he moved to the Central University of Jharkhand where he is working as a senior Assistant Professor. So far, he has published 26 research papers in reputed journals and 3 book chapters. He has successfully guided 6 students for their Ph.D. and 35 students for their Master's dissertations. He received major research grant under DST Young Scientist Scheme in 2013. His current research area is to develop environmentally benign techniques for wastewater treatment towards safer health. Various plant-derived materials have been demonstrated as photocatalysts. Magnetic metal oxide nanoparticles have been recently synthesized and used as potential sustainable materials for wastewater treatment.

Some representative publications are as follows:

1. Mohanta, J.; Dey, B.; Dey S* (2020) Magnetic Cobalt Oxide Nanoparticles: Sucrose-Assisted Self-Sustained Combustion Synthesis, Characterization, and Efficient Removal of Malachite Green from Water. J. Chem. Eng. Data, 65: 2819–2829.

2. Kumari, R.; Khan, M.D.; Mahto, M.; Qaiyum, M.A. Mohanta, J.; Dey, B.; Dey S* (2020) Dwaxed Honeycomb as a Promising Scavenger for Malachite Green from Water. ACS Omega, 5: 19548–19556.

3. Kumari, R., & Dey, S* (2019). A breakthrough column study for removal of malachite green using coco-peat. International Journal of Phytoremediation, 21(12), 1263–1271.

Dr. Dey is the twice recipient of ‘YOUNG SCIENTIST AWARD’ conferred by the Indian Chemical Society in the year 2002 and 2008. He has delivered about 10 invited lectures at various scientific meetings. He is currently a reviewer of many prestigious journals such as Journal of Chemical & Engineering Data (ACs), Environmental Progress (Wiley), Journal of Chemical & Environmental Engineering (Elsevier), and International Journal of Phytoremediation (Taylor and Francis). Dr. Dey is a member of various coveted societies such as the American Chemical Society, Chemical Research Society of India, Indian Council of Chemists, and I.I.T. Kanpur Alumni Association. Apart from academics he also actively takes part in Institutional Management committees; the Academic Council (2015-2020), Board of Studies, Research Advisory Council, and Board of Research. He held the position of ‘Coordinator’ of the Department of Education (2014-17).
Dr. Banashree Dey was born in steel city Bokaro, Jharkhand, India. She received her M.Sc. from Visva Bharati University Santiniketan, India in 2004 and Ph.D. from Indian Institute of Technology (Indian School of Mines, Dhanbad) in 2014. She has expertise in utilization of fly-ash in various applications. She is currently working as an Assistant Professor and Head in the the Department of Chemistry, The Graduate School College for Women, Jamshedpur, India. She has published over 10 papers in various reputed journals.