Volume 11, Issue 3, March – 2026 International Journal of Innovative Science and Research Technology
ISSN No: -2456-2165 https://doi.org/10.38124/ijisrt/26mar070

A Study on Adsorptive Dyes Using Nano-Materials

Pabitra Chakrabortty[1]

[1]Department of Chemistry, Nabagram Hiralal Paul College, West Bengal, India

Publication Date: 2026/03/10

Abstract: Dyes are major water contaminants due to their extensive industrial use. Colors can be constructively taken out from contaminated water via adsorption. The pace of industrialization is accelerating in the twenty-first century. More noble hues and dyes are employed at this point. These colors are responsible for a variety of pollutants, such as air, soil, and water contamination. This report's sole goal is to go over the chemical adsorbents that are utilized to get rid of different kinds of industrial dyes. Numerous mathematical formulations and adsorption isotherm assumptions were examined. Numerous factors' effects on adsorptive phenomena are discussed.

Keywords: *Dye Adsorption, Adsorption Isotherms, Effect of pH, Temperature, Adsorbent Concentration.*

How to Cite: Pabitra Chakrabortty (2026) A Study on Adsorptive Dyes Using Nano-Materials. *International Journal of Innovative Science and Research Technology*, 11(3), 158-162. https://doi.org/10.38124/ijisrt/26mar070

I. INTRODUCTION

Pigments and dyes are widely used in many sectors to colour their materials. Some dyes are benign and hypoallergenic at the concentrations let out into water, but they give the water user an undesirable tint [1].

Due to the challenges of treating textile effluents using traditional physicochemical and biological treatment techniques, colour removal is a significant environmental issue. Wood, fly ash, coal, silica gel, clay materials (including bentonite and montmorillonite), cotton wastes, and farm wastes (such pith, corncob, coconut shell, and rice hull) have all been tried for colour removal [1].

To determine the adsorption rate, the batch contact time approach was employed. After assessment, solution pH, dye concentration is associated with kinetic characteristics [1].

An estimated two million tonnes of dyes are generated per year to fulfill industrial demand, with ten to fifteen percent of this amount being wasted as polluted water. Maximum water pollution is occurred due to these discharged dyes. In addition to causing respiratory problems and skin pain, excessive dye exposure increases the risk of cancer in people [2].

Researchers have focused a lot of emphasis on low-priced adsorbents made from farm wastes over the past ten years. It has been demonstrated that the majority of these wastes may efficiently remove heavy metalsas well. For instance, harmful dyes, zinc, and scopper are eliminated utilising an adsorbent produced from leftover palm oil. Particles size range from one to hundred nanometer are known as nanomaterials or nanoparticles [2, 8].

Familiar nanoparticles are generally prized for their lightweight, strength, and hyperactive sites. Current research focuses on advanced nonmaterial for sensors, optical data storage and lightweight, long-lasting building materials in insertion to polluted water treatment. Even though both nano-particles and activated C(carbon) have a lot of surface area, some nano-particles are better adsorbents than activated carbon for two primary reasons: they are easier to make and less expensive, and they require less to remove pollutants effectively. Therefore, it is anticipated that for adsorption applications, nanomaterials would become more cost-effective than activated carbon [3].

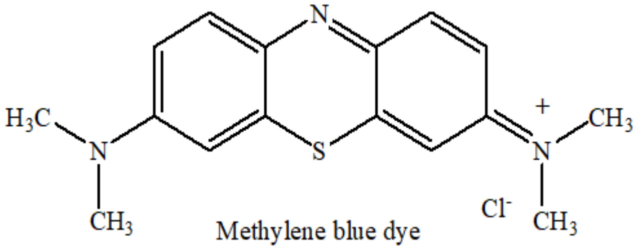
To eradicate coloration from industrial effluents, coagulation, flotation, adsorption, oxidation, biological treatment, and hyperfiltration are the methods used. Adsorption has come out as one of the most systematic and cost-effective treatment techniques for decolorising wastewater from textiles. Dye, metal ions, and other organic compounds like silica gels perlite, lignite, fly ash, peat, and bentonite have all been removed from aqueous solutions using a variety of adsorbents. Textile and pulp mills are known to discharge brightly coloured industrial effluent that comprises significant amounts of suspended particles (SS) and materials with high oxygen demand (BOD) [4].

Industrial operations have made considerable use of adsorption for different types of rupture and distillation objectives. One significant use of adsorption methods with the right adsorbent is the eradication of both coloured and non-coloured organic contaminants from industrial polluted water.

Since organic dyes are a common component of industrial effluents, proper disposal techniques are required. Biodegradation, photo-catalysis, photolysis, and enhanced oxidative degradation of these solutions are frequently recommended techniques. The use of the adsorption approach to take away undeniable colorant from liquid phase on a variety of adsorbent surfaces, including mud, coal ash, peat, polymers, alumina and activated carbon, has garnered a deal of attention lately. This method is reported to be easy to use and effective for treating intense dyes [5].

One of the most researched adsorptive materials is activated carbon. One efficient method for removing color from wastewater is adsorption. It has been discovered that the adsorbents' textural characteristics (porosity, surface area) affect how well they work. The bit of the structure that a patch of a specific size and shape may access is determined by the severance size distribution. In order to illuminate some of the findings of this type analysis, some authors have lately begun to examine the surface chemistry of activated carbons. It was demonstrated that the actuated carbon's surface chemistry may be pivotal to the effectiveness of color adsorption [3, 5].

With transmit of mass the solute to its surface; a solid material can selectively take out dissolved materials from solution. In consequence, it brings about the material concentration accumulation at a side or at the interkinesis. Coagulation, adsorption on activated carbons, reverse osmosis, activated alluvium, bacterial action, ozonation, chemical oxidation, and physical techniques like filtration with membrane, electrochemical methods and ion exchange methods are some of the other conventional methods of dye elemination from polluted water that are either costly or inefficient [6-8].



II. MATERIALS AND METHODS

- *Adsorption Studies*

Adsorption process takes place through two categories such as physical sorption and Chemical sorption. Interaction between adsorbate ions and the surface of the adsorbent are symptomatic of chemical adsorption, alternatively known as chemisorption. By electron exchange method this type of bonds are set up, making chemisorption frequently irreversible process. Weak Vander Waals force of intraparticle connections between the adsorbate and the adsorbent are what define physical adsorption, also known as physisorption, and they are typically reversible. Physical forces govern adsorption on the majority of adsorbents, including agricultural byproducts, with the exception of chemisorption. Vander Waals forces, H-bonding, polarity, ∏–∏ interaction, dipole–dipole interaction and some physical forces are basic points governing the process of adsorption. This method offers a compelling substitute to treat toxic waters, specifically if low cost adsorbent is used and doesn't need to undergo an extra pretreatment stage before being used [7].

SHALE OIL ASH (SOA) was used for this type of study. This material's samples were burned for one hour at 8008C. After cooling, the leftover ash was ground and sieved into a number of different fractions. Three diameter fractions—53-15, 150-250, and 250-355 mm—were employed. The ash particles have a porosity of around 0.42 and a powder density of 1450 kg/m^3 [4].

To dissolve the soluble part of the ash, the SOA was first combined with warm water and swirled for fifteen minutes. The viscosity and voidage of the ash are also determined after it had been filtered and dried. The PV 8700 visible spectrophotometer was used for the spectroscopic analysis. A one centimeter light path glass cell was used to test the concentration after filtration of the solution of dye, totalling roughly 1 ml, making diluted with deionized water as needed [4].

Since gypsum is used by numerous cloth directors and emits sweet amines (similar as benzidine and methylene) and may be carcinogenic, attention is being paid to its operation as an indispensable inexpensive adsorbent for the junking of methylene blue(MB) from waterless results. A series of 250 mL conical flasks containing 100 mL diluted solutions (5–25 mg L–1) of methylene blue dye were filled with a predetermined amount of gypsum (0.25 g) in order to perform adsorption investigations. The conical flasks were then sealed, placed in a waterbath shaker, and shaken at 100 rpm for the proper duration at 298 K. After the flasks were removed from the shaker at predetermined intervals, the dye concentration in the solution was measured at its maximum wavelength (668 nm) using a CARY 50 UV/VIS spectrophotometer equipped with a 1-cm quartz cell. To determine the equilibrium period for maximal adsorption, the MB adsorption on gypsum was also investigated as a function of contact time. The findings demonstrated that 20 to 40 minutes was the equilibrium period needed for MB to adsorb on gypsum [5, 7].

To guarantee total equilibrium, the samples were left for forty minutes. Methylene blue's equilibrium adsorption period on wheat shells was reported to be 135 minutes, whereas methylene blue's adsorption on fallen phoenix tree leaves was reported to be 100 and 150 minutes.

Methyl orange (MO) and methylene blue adsorption tests employed commercial activated carbon and activated carbon generated from apricot stones as the adsorbents. For the batch investigations, a set of 250 ml stoppered flasks (Erlenmeyer flasks) with a specified volume (100 ml in each flask) of dye solution at a fixed starting concentration (10 mg/L) and a constant solution pH were utilised, along with a known amount of adsorbent (0.010 g). The flasks were then placed in a shaker set at 25°C and 200 rpm. The samples were analysed at predefined intervals to determine the equilibrium concentrations, and the solutions were filtered at equilibrium using 0.45-µm filter paper. Using a Shimadzu UV-1700 spectrophotometer, the starting and equilibrium concentrations of MB and MO were determined at wavelengths of 665 and 465 nm, respectively [8].

- *Time Optimization*

Experiments were conducted using a 25 ml aqueous solution and shaken together for varying durations ranging from 5 to 60 minutes in order to determine the ideal shaking time. The spectrophotometer recorded the filtrate's absorbance at each dye's λ_{max}. As the shaking time increased after equilibrium was attained, the quantity of dye absorbed increased and eventually stabilized [4 - 8].

- *Chemisorption*

Chemisorption occurs when a substrate and an adsorbate form a covalent connection by electron transfer or sharing. The breadth of the connections in chemisorption is significantly larger than in physisorption, indeed though chemisorption is less frequent. The chemical forces that exist between the solute's molecules and the liquid surface are the foundation of chemisorption [9 - 11].

When chemisorption occurs, the heat of adsorption (ΔHads) may increase by tens or even hundreds of times. At room temperature, it is most evident. It needs to be reversed by raising the temperature significantly [11].

- *Physisorption*

Physisorption is a cycle that is caused by the intermolecular attraction between adsorbents and adsorbates. It includes dipole-dipole powers and Van Der Waals collaboration, among other weak electrostatic connections. On any strong substrate, real adsorption can take place since any two particles have Van Der Waals power. Adsorption is caused by interactions between molecules and leads to low adsorption heat, fast adsorption and desorption rates, and a limiting power that is not excessively high. The adsorbed substance is also easier to desorb and partially reversible. Physical adsorption occurs from a pure fluid phase when the force between the solute molecules is smaller than the intermolecular interactions between the adsorbent and solute molecules. The physisorption process is hence exothermic. Because activation energy is not required, the process progresses quickly and is facilitated by heat dissipation. At equilibrium pressure, the quantity adsorbed should decrease as the temperature increases pH affects physical adsorption [7, 9].

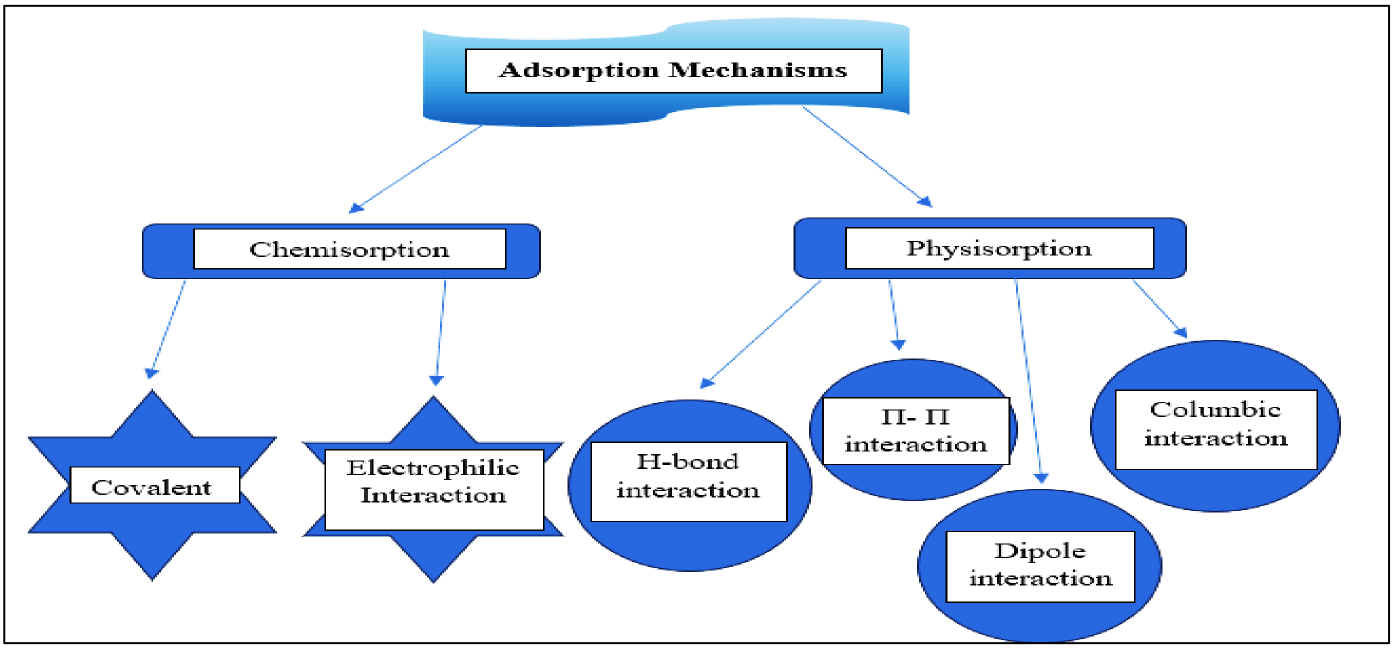


Fig 1 Diagrammatic Representation of Adsorption Mechanisms

- *Adsorption Isotherms*

Adsorption equations are essential for boosting the use of adsorbents since they explain the interaction between the pollutant and the sorbent. The hyperlink between the amount of the contaminated mixture and the material's removal capacity can be demonstrated as a consequence of the adsorption isotherms method. Perhaps The Langmuir isotherm is the most applied model for physisorption regulating data. Numerous research have made extensive use of the model to explain adsorption processes [12, 1]. The linear format of this isotherm is represented by Equation (1):

$$\left(\frac{1}{q_e}\right) = \left(\frac{1}{q_m}K_LC_e\right) + \left(\frac{1}{q_m}\right) \quad (1)$$

The main model recommended for sorption measurements was the Freundlich isotherm condition, which Freundlich first developed in 1906. It could be applied to multi-facet sorption and non-ideal sorption on heterogeneous surfaces [14]. The Freundlich isotherm's mathematical expression is provided by Equation (2):

$$\ln(q_e) = \ln(K_F) + \frac{1}{n}\ln(C_e) \quad (2)$$

The adsorption system with Gaussian energy distribution onto miscellaneous shells is symbolised by the Dubinin-Radushkevich adsorption isotherm model. The adsorption cycle that occurs on both homogeneous and miscellaneous shells is appertained to by this general expression. The previous Eq. (3) was used to construct the D-R model:

$$\ln(q_e) = q_s - K\varepsilon^2 \qquad (3)$$

The Temkin model considers the impact of aberrant adsorbate/ adsorbate communications during the adsorption period. In addition, it predicts that the warmth of adsorption (ΔH_{ads}) of every atom in the topmost layer will fall gradually due to increased surface inclusion. The Temkin model's numerical articulation is displayed in Equation (4):

$$q_e = \left(\frac{RT}{b}\right)\ln(A) + \left(\frac{RT}{b}\right)\ln(C_e) \qquad (4)$$

$$B = \frac{RT}{b} \qquad (5)$$

Where b indicate constant (mg L^{-1}) for the Temkin isotherm, A indicate the equilibrium constant for Temkin isotherm, and B represent the constant associated with heat of adsorption (J mol^{-1}) [1 - 14].

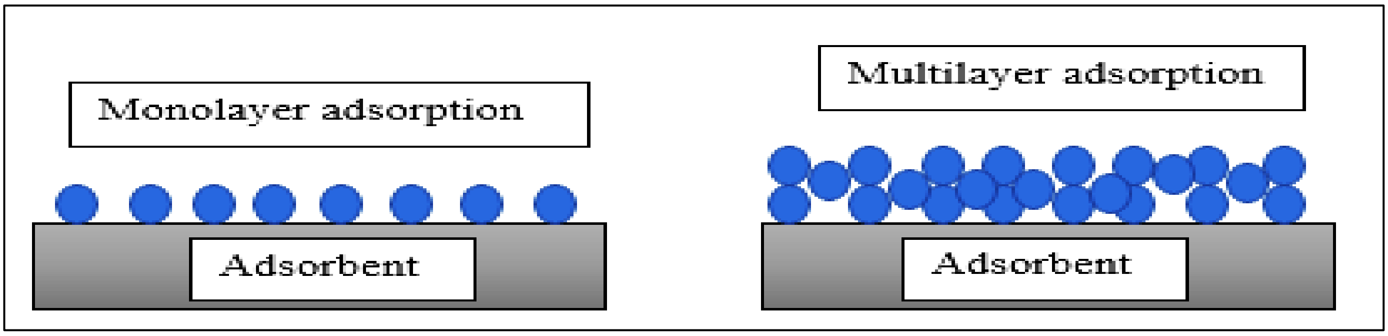


Fig 2 Diagrammatic Portrayal of Adsorption in Monolayer and Multilayer

III. RESULTS AND DISCUSSION

- *Effect of pH*

The adsorption geste of colorings on gypsum samples was observed by varying the pH of the result, which has a significant impact on color junking. The color result's pH has a crucial impact on adsorption process, videlicet on its adsorption capability. At natural pH (pH = 7.5), the quantum of color adsorption at equilibrium, or q_e(in mg g $^{-1}$), was set up to be at its loftiest.In introductory circumstances, the quantum of adsorption was nearly constant, but it was lower in acidic media.At pH lower than 7.5, the face becomes appreciatively charged, which makes(H+) ions efficiently contend with color cations, reducing the quantum of color adsorbed.This could clarify the spoted low rate adsorption of MB on the gypsum.With the exception of methylene blue and malachite green, the adsorption of the chosen colors on actuated watercolor declined with pH. The development of a appreciatively charged face on actuated housekeeper coal provides one explanation for this.The adsorption of the negatively charged adsorbate is bettered by a low pH value because it lowers the negative charge on the watercolor's face and increases the positive charge.The capability of the adsorbent for colorings with negative charges is likewise reduced as the pH value rises because the attention of hydroxyl ions rises along with the negative charge on the watercolor's face. 13.40 was fixed up to be the optimum pH for adsorption of methylene blue [5, 7, 14].

- *Effect of Temperature*

Because of adsorption is an exothermic process, it reduces as temperature rises. This can also be explained by the fact that higher temperatures increase dye solubility and decrease adsorbate-adsorbent interactions, which in turn reduce adsorption. The experiment uses a temperature range of 25 to 45 degrees Celsius [1 - 14].

- *Effect of Adsorbent Concentration*

The adsorbent concentration is a crucial component of the adsorption test because it affects the removal effectiveness.

$$q_e = \left(\frac{C_i - Ce}{m}\right)V$$

Percentage of removal = $\left(\frac{C_i - Ce}{C_i}\right) \times 100$

Where C_i is the initial adsorbate concentration (mgL^{-1}), Ce is the ultimate equilibrium concentration of adsorbate (mg.L^{-1}), V is the volume of the dye solution (mL), and m is the mass of the adsorbent (mg). It was demonstrated that boosting the adsorbent material (from twenty-five to hundred mg) enhanced evacuation viability [4, 8, 14].

IV. CONCLUSION

This review study offered a range of adsorbents for the adsorption of industrial colours. Along with other factors that influence adsorption, the adsorption isotherms have also been covered. While knowledge of this can aid in the development of industrial-scale processes, further research is necessary to determine whether low-cost biosorbents are feasible. Furthermore, the extensive research conducted for particular colours do not account for the combination of contaminants present in the actual environment.

REFERENCES

[1] Annadurai, G., Juang, R. S., & Lee, D. J. (2002). Use of cellulose-based wastes for adsorption of dyes from aqueous solutions. *Journal of hazardous materials*, *92*(3), 263-274.
[2] Tan, K. B., Vakili, M., Horri, B. A., Poh, P. E., Abdullah, A. Z., &Salamatinia, B. (2015). Adsorption of dyes by nanomaterials: recent developments and adsorption mechanisms. *Separation and purification technology*, *150*, 229-242.
[3] Iqbal, M. J., & Ashiq, M. N. (2007). Adsorption of dyes from aqueous solutions on activated charcoal. *Journal of hazardous materials*, *139*(1), 57-66.
[4] Al-Qodah, Z. (2000). Adsorption of dyes using shale oil ash. *Water research*, *34*(17), 4295-4303.
[5] Bello, O. S., Bello, I. A., & Adegoke, K. A. (2013). Adsorption of dyes using different types of sand: A review. *South African Journal of Chemistry*, *66*, 117-129.
[6] Ngah, W. W., Teong, L. C., &Hanafiah, M. M. (2011). Adsorption of dyes and heavy metal ions by chitosan composites: A review. *Carbohydrate polymers*, *83*(4), 1446-1456.
[7] Yagub, M. T., Sen, T. K., Afroze, S., & Ang, H. M. (2014). Dye and its removal from aqueous solution by adsorption: a review. *Advances in colloid and interface science*, *209*, 172-184.
[8] Djilani, C., Zaghdoudi, R., Djazi, F., Bouchekima, B., Lallam, A., Modarressi, A., & Rogalski, M. (2015). Adsorption of dyes on activated carbon prepared from apricot stones and commercial activated carbon. *Journal of the Taiwan Institute of Chemical Engineers*, *53*, 112-121.
[9] Kumar, P. S., Joshiba, G. J., Femina, C. C., Varshini, P., Priyadharshini, S., Karthick, M. A., &Jothirani, R. (2019). A critical review on recent developments in the low-cost adsorption of dyes from wastewater. *Desalination and Water Treatment*, *172*, 395-416.
[10] Krysztafkiewicz, A., Binkowski, S., & Jesionowski, T. (2002). Adsorption of dyes on a silica surface. *Applied surface science*, *199*(1-4), 31-39.
[11] Adeyemo, A. A., Adeoye, I. O., & Bello, O. S. (2017). Adsorption of dyes using different types of clay: a review. *Applied Water Science*, *7*(2), 543-568.
[12] Visa, M., Bogatu, C., & Duta, A. (2010). Simultaneous adsorption of dyes and heavy metals from multicomponent solutions using fly ash. *Applied Surface Science*, *256*(17), 5486-5491.
[13] Crini, G. (2003). Studies on adsorption of dyes on beta-cyclodextrin polymer. *Bioresource technology*, *90*(2), 193-198.
[14] Foo, K. Y., & Hameed, B. H. (2010). An overview of dye removal via activated carbon adsorption process. *Desalination and Water Treatment*, *19*(1-3), 255-274.