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# Recent Trends and Advances in the Removal of Dyes from Industrial Wastewater Using Low Cost Adsorbents

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***Author's contribution***

*The sole author designed, analyzed, interpreted and prepared the manuscript.*

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## ABSTRACT

Dyes are complex class of organic compound having wide range of applications in textile and food industries and a large amount of dyes are wasted, which get mixed in natural water resources, and pollute environment. Mixing of dyes in water resources must be prohibited for the safety of natural ecosystem. Dyes are used for coloring textiles, wool, leather, paper and fibers. Natural dyes like indigo have been in use for over 5000 years. Natural dyes are replaced by synthetic dyes because of their low cost and vast range of new colors. Today, there are more than 10,000 dyes with different chemical structures available commercially. The natural and modified adsorbents are being successfully used for the adsorption of dyes from wastewater. Importance of several adsorbents like industrial waste, agricultural waste and clay adsorbents of both raw and modified for adsorption of dyes from textile wastewater has been highlighted in this review article. In this review we cover the regeneration capacity and adsorption efficiency of different adsorbents for the treatment of industrial dyes to control water pollution. We also reviewed wide variety of techniques

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and materials that have been used to remove organic pollutants from water. some adsorption techniques are cost-effective, ecofriendly, clay-supported adsorbents are widely because if their simplicity and good efficiency.

**Graphical Abstract:**


*Keywords: Wastewater treatment; dye removal; adsorbents; cost effective adsorbents; pollution control.*

## 1. INTRODUCTION

Water pollution has become a serious issue worldwide, due to rapid growth of industrialization, and urbanization. Release of several substances in to the surface groundwater or into lakes, rivers and oceans that interferes with benificial use of water or natural functioning of ecosystems is the main cause of water pollution. These pollutants include toxic chemicals, pathogenic microorganisms, petrolium products, domestic sewage, sediment, agricultural wastes, waste from manufacturing or indutrial processes like dirt, garbage, scrap metlas, solvents, weed grass, trees wood, dyes etc.

Water pollution due to dyes is one of the different reasons of water pollutions.Dyes are mainly used in producing consumer products, like paints, textiles, plastic, paper and printing inks. Dyes are used to add colors and patterns to materials.Textile industry contributes to several environmental impacts [1]. Often waste water from textile industries are released untreated into the environement. Wastewater carries a host of different chemicals from the processesing of dyes. Textile dyeing industry is the most chemical intensive industry on the earth. More then 3600 different types of textile dyes are being manufactured by textile industries these days. More than 8000 chemicals are being used at various steps of dyeing process in the textile manufacturing industry. A texile mill of an average size which produces 8000kg of fabric per day consumes about 1.6 million liters of water [2]. Depending on the dye being used 30 to 50 litres of water one kg of fabric is used. Gloablly, 280k tons of dyes which accounts for 10 to 15% of total are being released into environment from textile industry, which contaminates water,and in turn affects human health and animal health [3,4]. In most developing countries, drinking water is still a serious challenge. Many water purification methods exist, but they are costly and out of reach for many people [5].

A dye is a substance that imparts colour to clothes, leather, paper, food so that color cannot be altered by heat, wash, ligh or any other factors. To be used as dye, it should have properties like color, it should be water soluable, ability to be absorbed and retained by fibre, and should be able upstand washing, drying, light exposure and cleaning. Dyes are very toxic and carcenogenic. Dyes are classified in multiple ways, based on source of material, based on chromophores nature, based on method of application.

## 2. CLASSIFICATION OF DYES BASED ON SOURCE OF MATERIAL

Dyes are organic compounds which means they contian carbon. Based on the maerial from which dye has been made, dyes are classified into natural dyes and synthetic dyes as shown in Fig. 1. Until 1850s dyes were mostly taken from natural sources like plants, vegetables,trees and lichens and insects. Two dyes indigo and alizarin have major importance and significance. Blue dye indigo is the oldest dye that was obtained from the leaves of dyerswoad herb in Europe, as well as indogo plant from asia.

Even though we have been using dyes from several centuries the start of manufacturing synthetic dyes have started causing cancers [6]. Some chemicals found in synthetic dyes are copper, mercury, lead, chromium toulene, benzene. Getting exposed to large amounts of these chemicals cause severe health issues in human body[7,8].

## 3. AGRICULTURAL WASTE

Peanut husk or peanut shells are the cover of seeds that are grown underground. Peanut husks are mainly used for abiomass, animal feeeds and as industrial adsorbants. Peanut husks are used to removal different types of dyes from polluted water. Removal of light green anionic dye was analyzed and the adsorption capacity obtained was 146.2 mg/g, methylene blue with the maximum adsorption capacity of 43.5 mg/g, 32.5 mg/g [9]. Peanut husk treated with polyethyleneimine (PEI) has shown an adsorption capacity of 141mg/g for Indosol Black NF and the percentage of adsorption was noted as 51.58%, and it was 98.2 mg/g with a percentage of removal noted as 76.6% [10].

Tea waste has beeen investigated as potential adsorbant to removed congo red from dye pollutied water and the adsorption capacity that was obtained is 32.26 mg/g [11]. Tea dust is researched as potential lo cost adsorbent for the removal of crystal violet by batch adsorption technique and the adsorption capacity found was 175.4 mg/g [12].

Banana stem are part of musa genus botanically , and are actually flower stalk of banana plant. Banana stems are capable of removing dyes from textile wastewater. Study was performed on analyzing capability of banana stem as a potentail adsorbant of Methylene blue. Initial concentration of Methylene blue taken was taken as 200 g/ml and the oadsorption capacity obtained was 101.01 mg/g which is 99.76% [25].

Rapanea ferruginea is plant that belongs to Myrsine Family which can be used for dye removal from waste water. Study was perfomed to analyze the capability of Rapanea ferruginea for the removal of dyes Mythelene blue, and crystal violet. Rapanea ferruginea is treated with ethanol and is used as adsorbant. The initial dye concentration taken was in between 20- 120 mg/l and an adsorption capacity of 69 mg/g was observed within 120 mins at a temerature 25°C [13].

Bengal gram seeds are a type of chipea seeds family which are high in proteing. They can be used as potential adsorbetns for dye removal. Adsorption studies were conducted for the rmeoval of Congo red dye from waste water using bengal gram seed husk. 89% of dye was adsobed from the water for an initial dye concentration of 2 mg/l. Using Langmuir model the maximum adsorption capacity obtained was 41.66 mg/g [14].

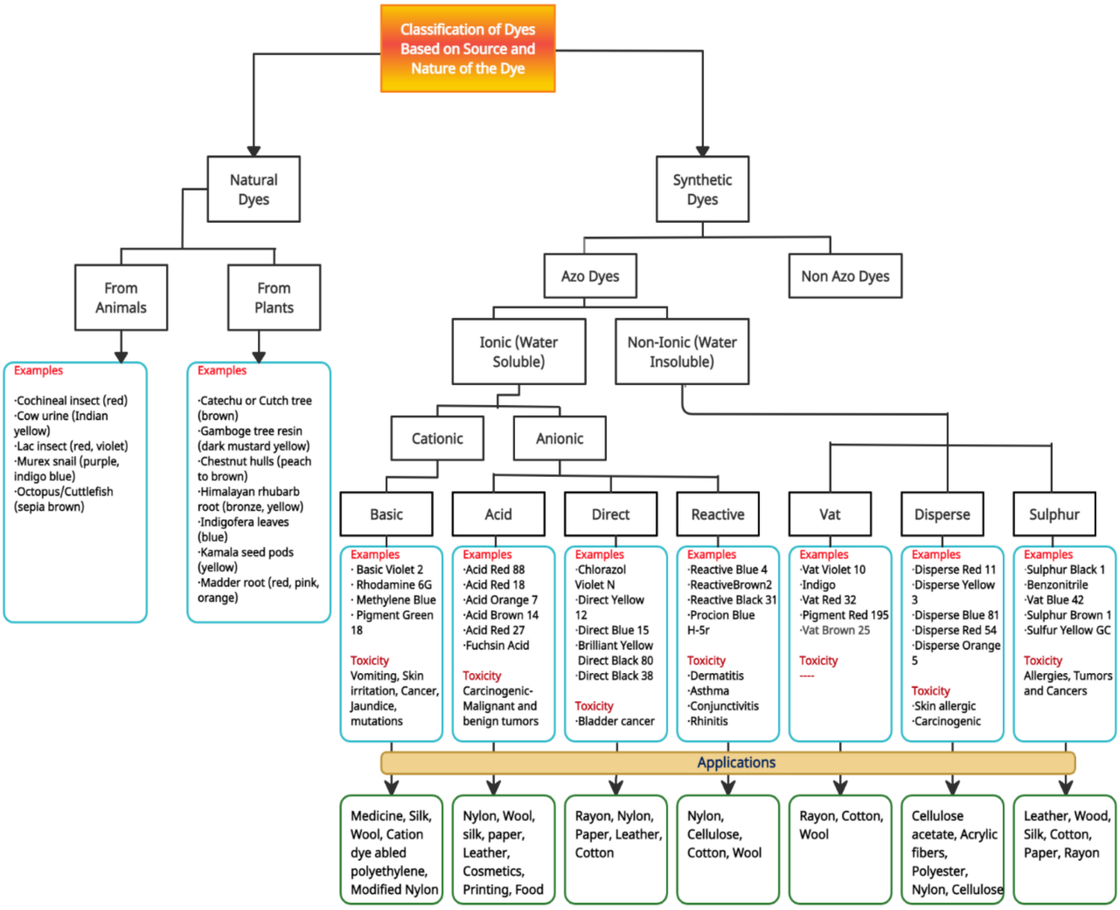


**Fig. 1. Classification of dyes based on source of material**

*Natural materials: wood , coal,peat, Chitin and chitosan, Biomass ,clays, sea weed , algae, zeolites, ore minerals ,zeolites*

Almond shells are the protective layer hard layer between hull and the almonds meat, is classifeid as agricultural waste of the food industry. Almond shells are studied as potential adsorbents for the removal of crystal voilet dye. The maximum adsorption capacity obtained was 1.075mg/g at a ph of 6, and within the ocntact time of 180 min [15].

Coffee husk which is also called as coffe chaff, is the dried skin of bean, which falls off during the roasting process and is classified as agricultural waste. Coffee husk was treated with SCH and NAOH to form low cost adsorbent for the removal of methylene blue. The maximum adsorption capacity obtained using Freundlich model was 129 mg/g and 200 mg/g for SCH and NCH at a pH of 7.637, initial dye concentration of 37.78 mg/L and adsorbent dosage of 0.740 g/L [16,17].

Table 1 represents several agricultural waste materials as low cost adsorbants used in removing several dyes from wastewater, and sevral techniques used to remove dyes and their efficienceies were compared.

## 4. INDUSTRIAL WASTE

Industrial waste which can be either solid, liquid or gases held in containers can be classified into two categories hazardous waste and non hazardous waste. Accordiing to EPA 8 billion tons of industrial waste is being generated every year, by manufacturing, mining, along with commerical and domestic sources [53]. This waste which is inert and harmless can be recycled as non conventional adsorbents that are cheap to reduce waste water treatmetns costs. Several industrial wastes are analyzed with or without modification chmically or physically, to remove pollutants from waste water. Fly ash wastes from leather industry, steel industry, aluminium industry and paper industry, blast furnace slag, sludge from steeel industry, redmud, spent rubber tyres, are utilized by several researchers to remove dye from wastewater.

Lignocellulosic material which is a waste material from sugarcane industry is collected and analyzed as a potential adsorbent by [43]. Sugarcane bagasse is soaked with alkali and then treated with sulfuric acid. This chemically treated bagasse was targeted as adsorbent to remove procion Blue dye from water. The highest percentage of dye removal achieved was 98.5% [43].

Sawdust is a by product or waste product generated from woodworking operations like sanding, planning, milling, and routing. Saw dust contain different functional groups like phenolic, carboxyl, hydroxyl groups in its structure, and so sawdust play a crucial role in the adsorbing pollutants from waste water. In a research conducted by [44] char is generated from sawdust through pyrolysis at 800°C. This low cost adsorbent was analyzed as potential adsorbent to remove orange 30 dye, and an adsorption efficiency of 83.4% was achieved at pH 2 and temperature of 67°C. The adsorption mechanism Redlich–Peterson isotherm was a better fit to this experiment [44].

Djilali et al. [45] analyzed two potential low cost adsorbents timber sawdust (TS-OH) and alkaline treated analog (TS-ONa) for the removal of Methyl Green and Methylene Blue. There is an increase in dye removal efficiency seen with TS-ONa due to the increase of surface polarity and density of adsorption cites. The adsorption capacity obtained for 500 mg/L dye concentration of Methylene Blue are 694.44 and 1928.31 mg/g with TS-OH and TS-ONa respectively for Methyl Green are 892.86 and 1821.33 mg/g using TS-OH and TS-ONa respectively [45].

Tectona grandis is a tropical hardwood tree species. The sawdust generated from this tree is analyzed as potential low cost adsorbent for the removal of crystal violet from waste water. The initial dye concentration take was 50 mg/L and adsorbent dose of 2 g/L. At a pH of 7.5, the adsorption capacity obtained within 180 mins was 31.58 mg/g [46].

Fly ash is the fine residue that was formed from combustion of pulverized coal and is transported from the combustion chamber by exhaust gases. Million tons of fly ash were produced every year by coal fired electric and steam generating plants, steel mills. Fly ash concists of oxides and carbon of silica, iron and heavy metals. The adsorption capacity increases with increase in the carbon content. Fly ash might contain trace amounts of radioactive elements and heavy metals, and there can be possibility of leaching during the process of adsorption, and this is the disadvantage of using fly ash as adsorbant. Fly ash can be used as potential adsorbent for dye removal from wastewater generated from textile industries and [47] researched the capability of fly ash to remove direct black eye from wastewater. They obtained the fly ash from thermal power plant Yamuna nagar, India and at a temperature of 44.8°C.

Polyethylene terephthalate also called PET, is a chemical name for polyster. Pet is lightweight but strong, and clear plastic used for food packaging and beverage packaging. The adsorption of orange dye using PET was studied. The adsorption capacity obtained was 6.99 mg/g at room temperatures. Langmuir isotherm model and pseudo-second order kinetic model were best fitted models [48].

Residue generated from aluminum cold lamination (TTR) was burnt directly and calcinated at 500°C. TTR obtained from this process was applied as adsorbant for the removal of Drimaren Blue (DB), Drimaren Red (DR) and Drimaren Gold (DG) from dye polluted water. The maximum adsorption capacity obtained were 6.27, 0.42 and 1.23 mg $g^{-1}$ for DB, DR and DG, respectively. pseudo-second-order model was the better fitted model [49].

Blat furnace slag is a calcium silicate-based product removed from the top of molten iron during its extraction from ore in a blast furnace. Silica nanoparticles synthesized from commercial blast furnace slag (NSBFS) and desilicated blast furnace slag (DBFS) were investigated as potential adsorbents. AT pH of 10, the maximum adsorption capacity obtained were 80.8 and 109.8 mg/g using DBFS and NSBFS respectively [50,51].

**Table 1. Agricultural waste as adsorbant to remove several dyes from waste water**

| Adsorbent | Dye | adsorbent dose | Adsorption capacity mg/g | Concentration range | pH | Temperature($^{o}$c) | Contact Time | Best Adsorption isotherm model(IM) and/or Kinetic model (KM) | % Removal | Reference |
|---|---|---|---|---|---|---|---|---|---|---|
| cucumis sativus peel | Methylene blue | 10 g/L | 320 mg/g | 250 MG/L | 10 | 25°C | 60 mins | Freundlich IM, pseudo-second-order KM | 47% | [18] |
| coconut shell waste | Methylene blue | - | 200.01 mg/g | 25–250 mg/L | 3–11 | 30 °C. | - | Langmuir IM, pseudo-second-order KM | - | [19] |
| Sugarcane Waste Ash | acid orange 8 | 1g/L | 146 mg/g | 150 mg/L | 4 | 25°C | 240min | Liu IM, Pseudo second-order KM | 90% | [20] |
| coconut coir dust | Methylene blue | 0.2 g/L | 29.50 mg/g | 50 mg /L | 6 | 30 °C | 20min | Langmuir, Freundlich and Temkin IM, Pseudo second-order KM | 99.5% | [21] |
| saw dust | tartrazine | 5 g/L | 4.71 mg/g | 1 mg/L | 3 | 44.85°C | 70 min | Dubinin-Radushkevich (D-R) IM, Pseudo second-order KM | 97% | [22] |
| Ageratum conyzoides leaf powder | Methylene blue | 0.06 g | 192.4 mg/g. | | 4 | | 20 min | Langmuir and Freundlich isotherm | 90% | [22,23] |
| garlic straw | Methylene blue | 0.04 g | 256.41 mg/g | 100 mg/ mL | 7 | 30 °C | 200 min | Pseudo second-order | 85% | [24,25] |
| chia-seed-oil-extraction | reactive yellow B2R | | 70.95 mg/g | | 2 | 29.85 °C | 60 min | Pseudo second-order | 92% | [26] |
| Untreated Peanut Husk | Malachite Green | 100mg | | 25 mg/L | | 60 °C | | | 84.85 % | [27] |
| black acacia bark wastes | crystal violet dye | | 280 mg/g | 750 mg/L | 10 | | 120 mins | Freundlich | 95% | [28] |
| Tea Waste | Eriochrome Black-T | 11 g/L | 97.08 mg/g | 100 mg/L | 2 | 20 °C | 60 mins | pseudo-second order model | 95% | [29] |
| Untreated Fava bean peels | Methylene blue | 5 g/L | 140 mg/g | 50 mg/L | 5.8 | 27 °C | 30 mins | pseudo-second order model | 90% | [30] |
| Lawsonia inermis Seeds powder | Brilliant green dye | 0.2g | 34.96 mg/g | 50 mg/L | 6 | 50 °C | 180 mins | Langmuir, pseudo-second | 93% | [31] |

| Adsorbent | Dye | adsorbent dose | Adsorption capacity mg/g | Concentration range | pH | Temperature($^o$c) | Contact Time | Best Adsorption isotherm model(IM) and/or Kinetic model (KM) | % Removal | Reference |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | order model | | |
| mango leaf powder | methylene blue | 0.25 g | 156 mg/g | 50 mg/L | 5.6 ± 0.2 | 25 ± 2 | 120min | **Langmuir** ,Pseudo second-order kinetics | 85% | [32] |
| Aleurites Moluccana | rhodamine B | 50mg | 117 mg/g | 100 mL | 9 | 55 °C | 60 min | pseudo-second order adsorption | | [33] |
| Tectona grandis Sawdust | Crystal Violet | 2 g/L | 22 mg/g | 50 mg/L, | 7.5 | 25 °C | 180 min | Langmuir IM, pseudo-second-order KM | 95% | [34] |
| olive leaves powder | crystal violet | 0.2 g/L | 181.1 mg/g | 50 mg/L, | 7.5 | 25 °C | 20 min | Langmuir, Freundlich, Temkin IM, pseudo-second-order KM | 99.2% | [35] |
| Raw pomegranate peel | Basic Red 46 | 2 g/L | 86.13 $mg.g^{-1}$ | 200 $mg.L^{-1}$ | - | 25 °C | 60 min | Temkin IM , pseudo-second-order KM | 86% | [36] |
| Teucrium polium L-leaf powder | Cong red | 0.03 g | 526.32 mg/g | 60 mg/L | 7 | 27°C | 22h | Langmuir IM, pseudo-second-order KM | 80% | [37] |
| AC from empty fruit bunches (EFB) and mesocarp fibers (MF) of oil palm | Acid orange 10 | 5 g/L | 18.76 mg/g | 50 mg/L | 3 | 10°C | 90 min | Langmuir IM, pseudo-second-order KM | - | [38] |
| groundnut shell | Methylene Blue | 0.4 gm/ L | | 500mg/l | 2 | 30°C | 100 minutes. | | 94% | [39] |
| cashew nut shell | Crystal Violet | - | 35 mg/g | $50mg/dm^3$ | 6.0 | 39.85°C | 100 minutes | Langmuir and Freundlich IM | 74% | [40] |
| Banana stem | Methylene Blue | 0.2 g/L | 101.01 mg/g | 200 g/mL | 7 | 25 °C | 90 min | Freundlich IM, pseudo-second-order KM | 99.762% | [41] |
| Sago Waste | Synthetic Dye | 20 g/L | | 4 mg/L | 7 | 34°C | 50 min | Langmuir IM, pseudo-second-order KM | 78.3% | [42] |

**Table 2. Industrial waste as adsorbant to remove several dyes from waste water**

| Adsorbent | Dye | adsorbent dose | Adsorption capacity mg/g | Concentration range | pH | Temperature | Contact Time | Best Adsorption isotherm model(IM) and/or Kinetic model (KM) | % Removal | Reference |
|---|---|---|---|---|---|---|---|---|---|---|
| carpet waste | methyl orange | 10 g/L | 0.76 mg/g | 10 mg/L | 8-9 | 20 °C | 3 h | - | 69.13 % | [54] |
| cow leather powder | Reactive Blue 222 | 0.3 g/ 50 mL | 129.6 mg/g | 50 mg·L−1 | 3 | 30 °C | 100 min | Langmuir IM, pseudo-second-order KM | 99.9 % | [55] |
| leather shavings | Congo Red | - | - | 60 mg/L | 5 | 30 °C | 240 mins | Langmuir, Freundlich IM, pseudo-second-order KM | 30% | [55] |
| coal fly ash | scarlet 4BS | 0.05 g | - | 100 mg/L | | 300℃ | | Langmuir, Freundlich IM, pseudo-first-order KM | 96.03% | [56] |
| coal fly ash | Remazol Blue | 250 g/mL | - | 50 mg/L | 2 | 30 °C | 240 mins | - | 94% | [57] |
| moroccan fly ash | indigo carmine | 1 g/L | 13.51 mg/g | 14 mg/L | 6 | 25 °C | 60 mins | Langmuir, Freundlich IM, pseudo-second-order KM | 100% | [58] |
| fly ash | methyl orange | 5 g | 0.16 mg/g | 1000 mg/L | 7 | 22 °C | 65 mins | Freundlich IM, pseudo-second-order KM | 99.95% | [59] |
| activated red mud-200 | methylene blue | 1 g/L | 232.2 mg/g | 200 mg/L | 7 | 23-27 °C | 40 minutes | Freundlich IM, pseudo-second-order KM | 85% | [60] |
| Blast Furnace Slag | methyl orange | 0.1 g in 50 mL | 0.422 mg/g | 25 mg/L | 11 | 25 °C | 60 min | Langmuir IM | 52.6 | [61] |
| Blast Furnace Slag | methyl orange | - | 167 mg/g | 25 mg/L | 3.0–13.0 | 25°C | 25 min | Langmuir IM, pseudo-second-order KM | 99.97% | [62] |
| steel converter slag | methylene blue | - | 1.15 mg/g | - | 7.0 | 19.85°C | 25 min | Langmuir IM, pseudo-second-order KM | - | [63] |
| Algerian Red Slag | Cibacet Blue | 1 g/L | 33 mg/g | 40 mg/L | 6.5 | 25 ° C | 60 min | Langmuir, Freundlich IM, pseudo-first-order KM | 75% | [64] |

| Adsorbent | Dye | adsorbent dose | Adsorption capacity mg/g | Concentration range | pH | Temperature | Contact Time | Best Adsorption isotherm model(IM) and/or Kinetic model (KM) | % Removal | Reference |
|---|---|---|---|---|---|---|---|---|---|---|
| cement industry electro-filter recycle powder | Astrazon Blue FGRL | 1 g/L | 72 mg/g | 200 mg/L | 6 | 20 ° C | 40 min | Langmuir IM, pseudo-second-order KM | 90% | [65] |
| LD slag | Direct Red 23 | 5 g/L | 12.68 mg/g | 40 mg/L | 5 | 50 ° C | 150 min | Langmuir IM, pseudo-first-order KM | - | [66] |
| solid waste from paper industry | Rhodamine B | 2.0 g | 6.711 mg/g | 50 mg/L | -- | 30 ° C | 60 mi | Langmuir IM, pseudo-second-order KM | 99% | [67] |
| waste active sludge | crystal violet | 1.0 g/L | 44.97 mg/g | 60 mg/L | 6 | 25 °C | 150 min | Freundlich IM, pseudo-second-order KM | 96.2% | [68] |
| activated red mud | methylene blue | 1 g/L | 232.2 mg/g | 300 mg/L | 7 | 25 °C | 120 min | Langmuir, Freunlich, and Temkin IM, pseudo-second-order KM | 87% | [69] |
| oil sludge waste | Direct Blue 6 | 10.0 mg/50mL | 124.24 mg/g | 475 mg/L | 7 | 45 °C | 30 min | Langmuir IM, pseudo-second-order KM | - | [70] |
| modified red mud | safranin-O | 0.25 g | 89.4 mg/g | 50 mg/L | 4 | 34.8 ° C | 45 min | Langmuir IM, pseudo-second-order KM | 93.2% | [71] |
| metal hydroxide sludge | brilliant blue | 5 g/L | 2.76 mg/g | - | 4 | - | 60 min | Freundlich IM, pseudo-second-order KM | 78% | [72] |
| wastewater sludge modified with zinc oxide | Methylene Blue | 0.5 g /100 cc | 6.6 mg/g | 50 mg/l | 9 | 25 ± 1˚C | 120 min | Langmuir IM | 80% | [73] |
| paper industry waste | Rhodamine B | 2.0 g/100 mL | 6.711 mg/g | 75 mg/L | 4.4 | 34.8 ° C | 60 min | Langmuir IM, pseudo-second-order KM | 99.35% | [74] |
| hydrothermally modified fly ash | Methylene Blue | 10 g/L | - | - | 10 | 40 °C | 90 min | Langmuir IM | 94.3% | [75] |
| waste active sludge char | reactive blue 49 | 0.05 g/L | 18 mg/g | 60 mg/L | 1 | 25 °C | 1,620 min | Freundlich IM, pseudo-second-order KM | 25% | [76] |

| Adsorbent | Dye | adsorbent dose | Adsorption capacity mg/g | Concentration range | pH | Temperature | Contact Time | Best Adsorption isotherm model(IM) and/or Kinetic model (KM) | % Removal | Reference |
|---|---|---|---|---|---|---|---|---|---|---|
| sewage sludge | malachite green | 2.0 g/L | 388.65 mg/g | 500 mg/L | 7.0 | 20 ° C | 40 min | Langmuir IM, pseudo-second-order KM | 77.73% | [77] |
| AC from waste tires | methylene blue | 2 g/L | 1.6 mg/g | 20 mg/L | 6.5 | 20°C | 30 min | Freundlich and Temkin IM, pseudo-second-order KM | 83% | [78] |
| spent tire rubber | Remazol Yellow | 4 g/L | 11.9 mg/g | 20 mg/L | 6 | 25°C | 150 min. | Langmuir IM, pseudo-first-order KM | 95% | [79] |

**Table 3. Clay as adsorbant to remove several dyes from waste water**

| Adsorbent | Dye | Surface area of adsorbent | Adsorption capacity mg/g | Concentration range | pH | Temperatue | Contact time | Adsorption Isotherm model | % Removal | Reference |
|---|---|---|---|---|---|---|---|---|---|---|
| organo modified bentonite clay | methylene blue | | 399.74 μmol/g | | 9.0 | 30 °C | 240 min | Freundlich | 99.99% | [80] |
| organo modified bentonite clay | crystal violet | | 365.11 μmol/g | | 9.0 | 30 °C | 240 min | Freundlich | 95.0% | [81] |
| organo modified bentonite clay | Rhodamine B | | 324.36 μmol/g | | 9.0 | 30 °C | 240 min | Freundlich | 83.0% | [81] |
| mesoporous synthetic hectorite clay | methylene blue | 468 m2/g | 196.00 mg/g | | | | | Langmuir | | [82] |
| modified clay by cetyltrimethylammonium bromide | Reactive Red 198 | 0.1 g/L | 25.84 mg/g | 20 mg/L | 3 | 20 °C. | 60 min | Langmuir Freundlich | 99.61% | [83] |
| montmorillonite–alginate nanobiocomposite | basic red 46 | | 35 mg g−1 | | | 25 °C. | 60 min | | 85.07% | [84] |
| bentonite clay modified by Fe3O4 NPs | Congo Red | | | 16 mg/L | 4 | 20 °C. | 105 min | Freundlich & Langmuir | 94.9% | [85] |
| Kaolin clay | annatto dye | | 59.88 mgg−1 | | | 25°C | | pseudo-second-order | | [86] |
| Sejnane Clay | Methyl Green | | 100 mg/g | 500 mg/L | 5.2 | 25°C | 350 min | Langmuir and Freundlich | 73.3% | [87] |
| Natural clay | (Methylene Blue) | | 8 mg/g | 50 mg L–1 | 6.8 | 24°C | 120 min | Langmuir | | [88] |
| Fe(III)–montmorillonite | methylene blue | | | | 7 | 30 °C. | 7 min | | 100% | [89] |

| Adsorbent | Dye | Surface area of adsorbent | Adsorption capacity mg/g | Concentration range | pH | Temperatue | Contact time | Adsorption Isotherm model | % Removal | Reference |
|---|---|---|---|---|---|---|---|---|---|---|
| natural clay modified by cocamidopropyl betaine | reactive yellow 160 | | 38 mg/g | 20 mg/L | 2 | 60 °C. | 60 min | Langmuir | 85% | [90] |
| Didodecyldimethylammonium Bromide-Modified Brown Clay | Methylene Blue | | 164 mg/g | 100 mg/L | 7 | 55 °C | 45 min | Langmuir isotherm and pseudo-second-order kinetics | 98% | [91] |
| Brazilian kaolin | Malachite Green | | 128 mg/g | 175 mg/L | 6.3 | 25 °C | 240 min | Elovich | | [92] |
| bentonite clay | Reactive Black 5 | | 35 mg/g | 170 mg/L | 10 | 50 °C | 40 min | Harkin-Jura, Freundlich and Halsey, Langmuir, Temkin, Dubinin–Radushkevich. | 57% | [93] |
| natural clay | Methylene Blue | | 96.38 mg/g | 100 mg/L | 8.5 | 22 °C | 25 min | pseudo-second-order kinetic, Langmuir | 96% | [94] |
| raw kaolin | Methylene blue | | 13 mg/g | 10 mg/L | 5.64 | 20 °C | 80 Min | Pseudo-second-order kinetic model | | [95] |
| Kaolin | Methylene Blue | 1.5 g | 83 mg/g | 100 mg/l | 6 | $25^{o}$C | 60 min | -- | 88% | [95] |
| Natural Clay- bentonite | Basic Red 46 | 10 mg /100 mL | 594 mg $g^{-1}$ | 60 mg $L^{-1}$ | 7 | $25^{o}$C | 10 min | Langmuir isotherm and pseudo-second order kinetic model | 94% ± 4 | [96] |

Waste products obtained during the olive oil production process were studied as bio sorbents for the removal of dyes [9] from wastewater. Another researcher has investigated effectiveness of solid waste obtained from paper industry as adsorbent to remove Rhodamine B dye from its aqueous solution. This paper waste is chemically modified and applied as adsorbent and maximum adsorption capacity obtained was 6.7 mg/g at 34.8°C [52].

Table 2 represents several industrial waste materials as low cost adsorbants used in removing several dyes from wastewater, and sevral techniques used to remove dyes and their efficienceies were compared.

## 5. CLAY ADSORBANTS

Clays are different from other fine-grained soils by variation in size and mineralogy. Silts, which are fine-grained soils that do not include clay minerals, tend to have larger particle sizes than clays, but there is some degree of overlap in both particle size and other physical properties and there are many naturally occurring deposits which include silts and also clay. As clay has the eco friendly nature it has gained quite popularity in the the effective use of the sorption properties of different clays as sorbents for the removal of dyes from wastewater.

Table 3 represents several clay waste materials as low cost adsorbants used in removing several dyes from wastewater, and sevral techniques used to remove dyes and their efficienceies were compared.

## 6. CONCLUSION

The current exhaustive review on the natural and adsorbants has a major influence on water quality, targeting to enlighten multi-sector decision making towards achieving cleaner manufacturing environment. Some of the developing countries are still in early stages due to lack of funds, not capable of adopting suitable methodologies, poor systems coordination and high-operational costs of conventional wastewater treatment plants. With the implementation of proper strategies along with modern technologies have the potential to bridge these challenges and deliver a viable sustainable route towards localization, implementation, and monitoring of water systems on real time basis.

## COMPETING INTERESTS

Author has declared that no competing interests exist.

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