

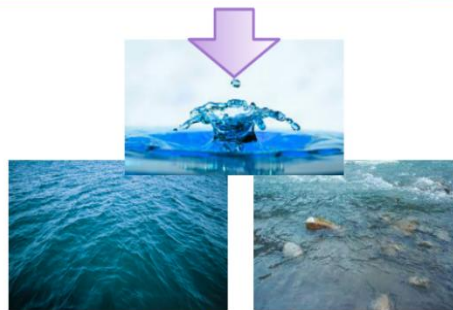
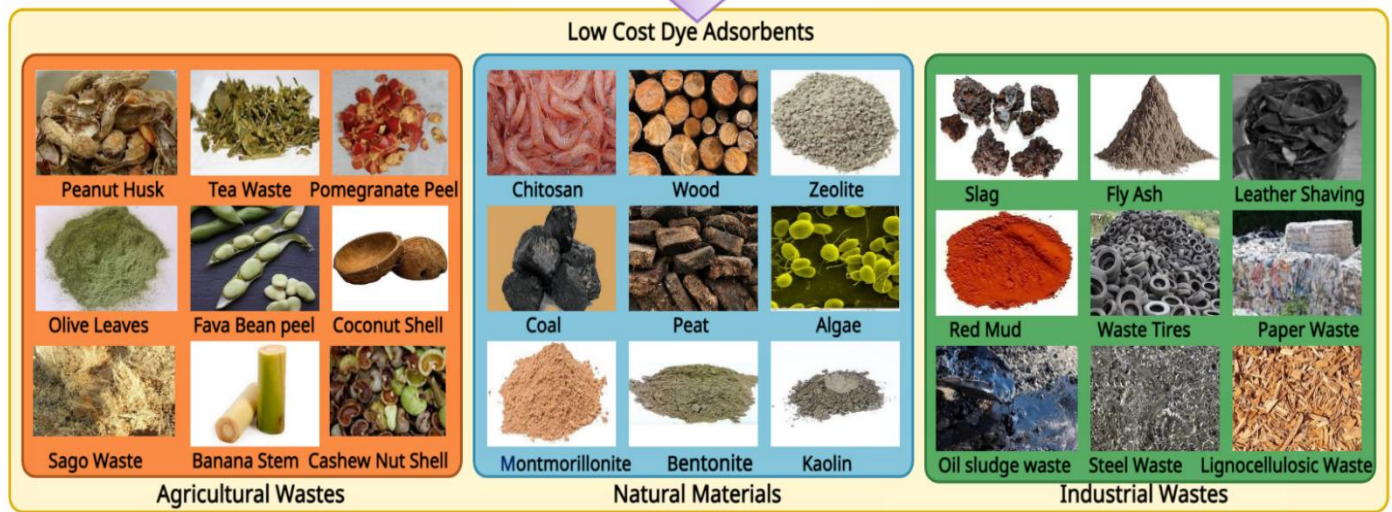
Recent trends and advances in the removal of dyes from industrial waste water using low cost adsorbents (2015-2021)

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 also used for colouring textiles, wool, leather, paper and fibres. 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 colours. 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 and materials that have been used to remove organic pollutants from water. Some adsorption techniques are cost-effective, ecofriendly, clay-supported adsorbents are widely used because of their simplicity and good efficiency.

KeyWords: Wastewater treatment, Dye removal, adsorbents, cost effective adsorbents, Pollution control

Graphical Abstract:



Dye free water

Introduction:

Water pollution has become a serious issue worldwide, due to rapid growth of industrialization, and urbanization. Release of several substances into the surface groundwater or into lakes, rivers and oceans that interferes with beneficial use of water or natural functioning of ecosystems is the main cause of water pollution. These pollutants include toxic chemicals, pathogenic microorganisms, petroleum products, domestic sewage, sediment, agricultural wastes, waste from manufacturing or industrial processes like dirt, garbage, scrap metals, 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 environment. Wastewater carries a host of different chemicals from the processing of dyes. Textile dyeing industry is the most chemical intensive industry on the earth. More than 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 textile 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. Globally, 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].

A dye is a substance that imparts colour to clothes, leather, paper, food so that color cannot be altered by heat, wash, light or any other factors. To be used as dye, it should have properties like color, it should be water soluble, ability to be absorbed and retained by fibre, and should be able to withstand washing, drying, light exposure and cleaning. Dyes are very toxic and carcinogenic [5]. Dyes are classified in multiple ways, based on source of material, based on chromophore nature, based on method of application.

Classification of dyes based on source of material:

Dyes are organic compounds which means they contain carbon. Based on the material from which dye has been made, dyes are classified into natural dyes and synthetic dyes as shown in Figure 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 dyer's woad herb in Europe, as well as indigo 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, toluene, benzene. Getting exposed to large amounts of these chemicals cause severe health issues in human body.

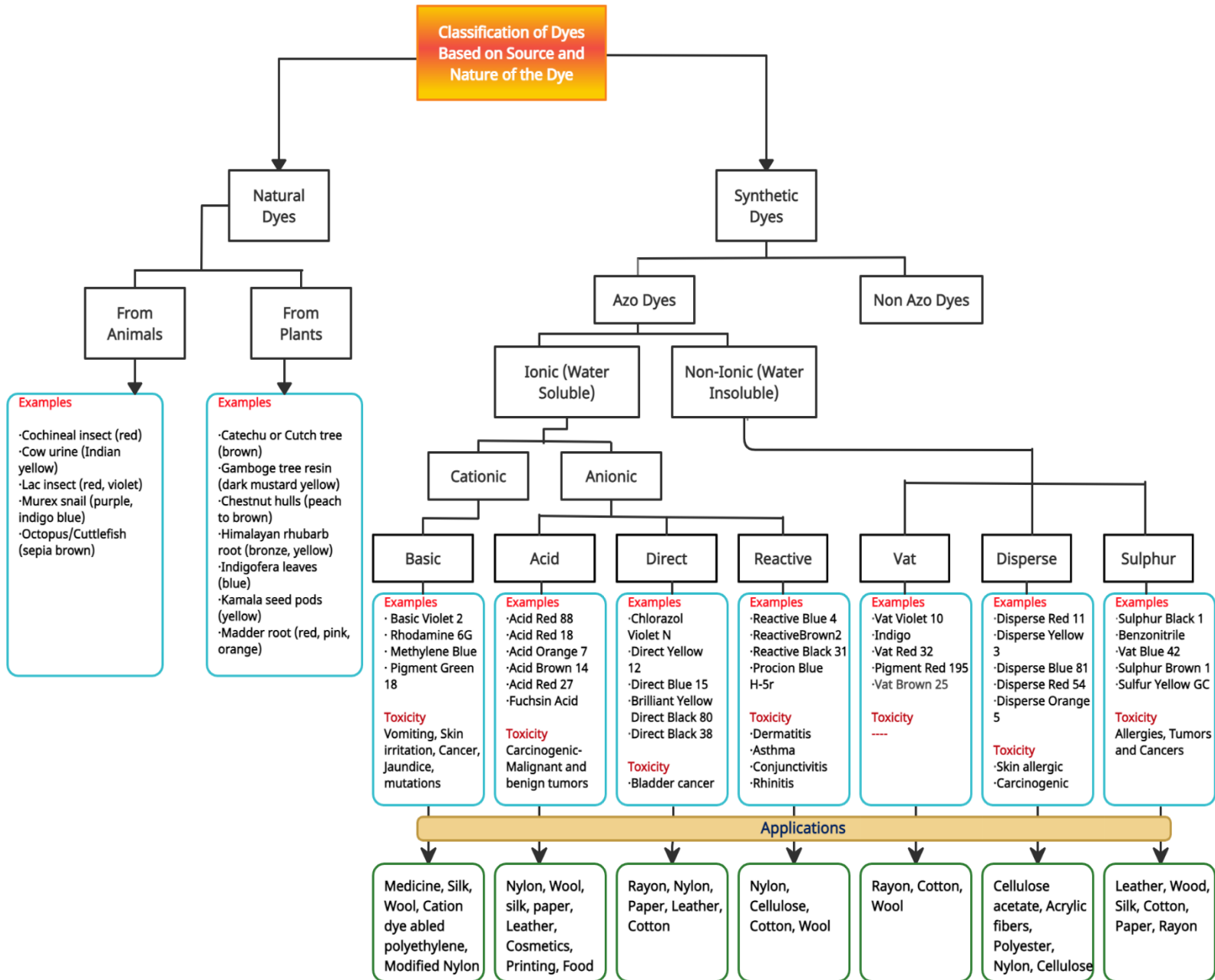


Figure 1: Classification of dyes based on source of material

Agricultural waste

Peanut husk or peanut shells are the cover of seeds that are grown underground. Peanut husks are mainly used for abiomass, animal feeds 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 [7], methylene blue with the maximum adsorption capacity of 43.5 mg/g [8], 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 been investigated as potential adsorbant to removed congo red from dye polluted water and the adsorption capacity that was obtained is 32.26 mg/g[11]. Tea dust is researched as potential low 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 potential adsorbant of Methylene blue. Initial concentration of Methylene blue taken was taken as 200 g/ml and the adsorption 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 performed to analyze the capability of Rapanea ferruginea for the removal of dyes Methylene 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 temperature 25°C [13].

Bengal gram seeds are a type of chipea seeds family which are high in proteing. They can be used as potential adsorbents for dye removal. Adsorption studies were conducted for the removal of Congo red dye from waste water using bengal gram seed husk. 89% of dye was adsorbed 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].

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

Coffee husk which is also called as coffee 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].

Adsorbent	Dye	adsorbent dose	Adsorption capacity mg/g	Concentration range	pH	Temperature (°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	44.8 5°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	29.8 5 °C	60 min	Pseudo second-order	92%	26
Untreated Peanut Husk	Malachite Green	100mg		25 mg/L		60 °C			84.8 5 %	27
black acacia bark wastes	crystal violet dye		280 mg/g	750 mg/L	10		120 mins	Freundlich	95%	28
Tea Waste	Eriochrome	11 g/L	97.08	100 mg/L	2	20 °C	60 mins	pseudo-second order model	95%	29

	Black-T		mg/g							
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 order model	93%	31
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 Saw dust	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 m g.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 (EF B) and mesocarp fibers (MF) of oil palm	Acid orange 10	5 g/L	18.76 m g/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/d m ³	6.0	39.8 5°C	100 minutes	Langmuir and Freundlich IM	74%	40
Banana stem	Methylene Blue	0.2 g/L	101.01 mg/g	200 g/m L	7	25 °C	90 min	Freundlich IM, pseudo-second-order KM	99.7 62%	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 1: Agricultural waste as adsorbant to remove several dyes from waste water

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. According to EPA 8 billion tons of industrial waste is being generated every year, by manufacturing, mining, along with commercial 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 treatment costs. Several industrial wastes are analyzed with or without modification chemically 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 steel 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, planing, 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].

[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 sites. 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 taken 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 consists 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 adsorbent. 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 dye 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 polyester. 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 adsorbent 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].

Blast 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].

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].

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°C		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	methylen 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	methylen blue	-	1.15 mg/g	-	7.0	19.85 °C	25 min	Langmuir IM, pseudo-second-order KM	-	63
Algerian	Cibacet	1 g/L	33 mg/g	40	6.5	25 °	60 min	Langmuir,	75%	64

Red Slag	Blue			mg/L		C		Freundlich IM, pseudo-first-order KM		
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 min	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, Freundlich, 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

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 2: Industrial waste as adsorbant to remove several dyes from waste water

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.

Adsorbent	Dye	Surface area of adsorbent	Adsorption capacity mg/g	Concentration range	pH	Temperature	Contact time	Adsorption Isotherm model	% Removal	Reference
organo modified bentonite clay	methylene blue		399.74 $\mu\text{mol/g}$		9.0	30 °C	240 min	Freundlich	99.99 %	80
organo modified bentonite clay	crystal violet		365.11 $\mu\text{mol/g}$		9.0	30 °C	240 min	Freundlich	95.0 %	81
organo modified bentonite clay	Rhodamine B		324.36 $\mu\text{mol/g}$		9.0	30 °C	240 min	Freundlich	83.0 %	81
mesoporous synthetic hectorite clay	methylene blue	468 m^2/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-	basic red		35 mg			25 °C	60 min		85.07	84

alginate nanobiocomposite	46		g-1						%	
bentonite clay modified by Fe ₃ O ₄ 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
natural clay modified by cocamidopropyl betaine	reactive yellow 160		38 mg/g	20 mg/L	2	60 °C	60 min	Langmuir	85%	90
Didodecyldimethyl ammonium 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	5.6 4	20 °C	80 Min	Pseudo-second-order kinetic model		95
Kaolin	Methylene	1.5 g	83 mg/g	100 mg/l	6	25°C	60 min	--	88%	95

	Blue									
Natural Clay-bentonite	Basic Red 46	10 mg /100 mL	594 mg g ⁻¹	60 mg L ⁻¹	7	25° C	10 min	Langmuir isotherm and pseudo-second order kinetic model	94% ± 4	96

Table 3: clay as adsorbant to remove several dyes from waste water

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.

REFERENCES:

1. Lellis, B., Fávaro-Polonio, C. Z., Pamphile, J. A., & Polonio, J. C. (2019). Effects of textile dyes on health and the environment and bioremediation potential of living organisms. *Biotechnology Research and Innovation*, 3(2), 275-290.
2. Kant, R. (2011). Textile dyeing industry an environmental hazard.
3. Gonawala KH, Mehta MJ (2014) Removal of colour from dif-ferent dye wastewater using ferric oxide as an adsorbent. *Int JEng Res Appl* 4(5):102–1094.
4. Errais E, Duplay J, Darragi F (2010) Textile dye removal bynatural clay—case study of Fouchana Tunisian clay. *EnvironTechnol* 31:373–38
5. Sharma, B., Dangi, A. K., & Shukla, P. (2018). Contemporary enzyme based technologies for bioremediation: a review. *Journal of environmental management*, 210, 10-22.
6. R.M. Christie Environmental aspects of textile dyeing Elsevier (2007).

7. Zhao, B., Xiao, W., Shang, Y., Zhu, H., & Han, R. (2017). Adsorption of light green anionic dye using cationic surfactant-modified peanut husk in batch mode. *Arabian Journal of Chemistry*, 10, S3595-S3602.
8. Aryee, A. A., Mpatani, F. M., Kani, A. N., Dovi, E., Han, R., Li, Z., & Qu, L. (2020). Iminodiacetic acid functionalized magnetic peanut husk for the removal of methylene blue from solution: characterization and equilibrium studies. *Environmental Science and Pollution Research*, 27(32), 40316-40330.
9. Aryee, A. A., Zhang, R. Z., Liu, H. F., Han, R. P., Li, Z. H., & Qu, L. B. (2020). Application of magnetic peanut husk for methylene blue adsorption in batch mode. *Desalin Water Treat*, 194, 269-279.
10. Sadaf, S., Bhatti, H. N., Arif, M., Amin, M., & Nazar, F. (2015). Adsorptive removal of direct dyes by PEI-treated peanut husk biomass: Box-Behnken experimental design. *Chemistry and Ecology*, 31(3), 252-264.
11. Foroughi-Dahr, M., Abolghasemi, H., Esmaili, M., Shojamoradi, A., & Fatoorehchi, H. (2015). Adsorption characteristics of Congo red from aqueous solution onto tea waste. *Chemical Engineering Communications*, 202(2), 181-193.
12. Khan, M. M. R., Rahman, M. W., Ong, H. R., Ismail, A. B., & Cheng, C. K. (2016). Tea dust as a potential low-cost adsorbent for the removal of crystal violet from aqueous solution. *Desalination and Water Treatment*, 57(31), 14728-14738.
13. Chahm, T., Martins, B. A., & Rodrigues, C. A. (2018). Adsorption of methylene blue and crystal violet on low-cost adsorbent: waste fruits of *Rapanea ferruginea* (ethanol-treated and H₂SO₄-treated). *Environmental Earth Sciences*, 77(13), 1-15.
14. Reddy, M. S., Nirmala, V., & Ashwini, C. (2017). Bengal Gram Seed Husk as an adsorbent for the removal of dye from aqueous solutions—Batch studies. *Arabian Journal of Chemistry*, 10, S2554-S2566.
15. Goksu, A., & Tanaydin, M. K. (2017). Adsorption of hazardous crystal violet dye by almond shells and determination of optimum process conditions by Taguchi method. *Desalination and Water Treatment*, 88, 189-199.
16. Murthy, T. K., & Gowrishankar, B. S. (2020). Process optimisation of methylene blue sequestration onto physical and chemical treated coffee husk based adsorbent. *SN Applied Sciences*, 2(5), 1-18.
17. Ooi, Jecksin, et al. "Assessment of fish scales waste as a low cost and eco-friendly adsorbent for removal of an azo dye: Equilibrium, kinetic and thermodynamic studies." *Bioresource technology* 245 (2017): 656-664.
18. Shakoor, Sadia, and Abu Nasar. "Adsorptive treatment of hazardous methylene blue dye from artificially contaminated water using cucumis sativus peel waste as a low-cost adsorbent." *Groundwater for Sustainable Development* 5 (2017): 152-159
19. Islam, Md Azharul, et al. "Mesoporous activated coconut shell-derived hydrochar prepared via hydrothermal carbonization-NaOH activation for methylene blue adsorption." *Journal of environmental management* 203 (2017): 237-244.
20. Rovani, Suzimara, et al. "Highly pure silica nanoparticles with high adsorption capacity obtained from sugarcane waste ash." *ACS omega* 3.3 (2018): 2618-2627.

21. Etim, U. J., S. A. Umoren, and U. M. Eduok. "Coconut coir dust as a low cost adsorbent for the removal of cationic dye from aqueous solution." *Journal of Saudi Chemical Society* 20 (2016): S67-S76.
22. Banerjee, Sushmita, and M. C. Chattopadhyaya. "Adsorption characteristics for the removal of a toxic dye, tartrazine from aqueous solutions by a low cost agricultural by-product." *Arabian Journal of Chemistry* 10 (2017): S1629-S1638.
23. Ezechi, Ezerie Henry, et al. "Characterization and optimization of effluent dye removal using a new low cost adsorbent: equilibrium, kinetics and thermodynamic study." *Process Safety and Environmental Protection* 98 (2015): 16-32.
24. Ezechi, Ezerie Henry, et al. "Characterization and optimization of effluent dye removal using a new low cost adsorbent: equilibrium, kinetics and thermodynamic study." *Process Safety and Environmental Protection* 98 (2015): 16-32.
25. Kallel, Fatma, et al. "Sorption and desorption characteristics for the removal of a toxic dye, methylene blue from aqueous solution by a low cost agricultural by-product." *Journal of Molecular Liquids* 219 (2016): 279-288.
26. da Silva, Deborah Cristina Crominski, and Juliana Martins Teixeira de Abreu Pietrobelli. "Residual biomass of chia seeds (*Salvia hispanica*) oil extraction as low cost and eco-friendly biosorbent for effective reactive yellow B2R textile dye removal: characterization, kinetic, thermodynamic and isotherm studies." *Journal of Environmental Chemical Engineering* 7.2 (2019): 103008.
27. Ali, Asmadi, et al. "Preparation of high-performance adsorbent from low-cost agricultural waste (Peanut husk) using full factorial design: Application to dye removal." *Biointerface Res. Appl. Chem* 10 (2020): 6619-6628.
28. da Silva, Jéssica Silveira, et al. "Preparation of an alternative adsorbent from Acacia Mearnsii wastes through acetosolv method and its application for dye removal." *Journal of cleaner production* 180 (2018): 386-394.
29. Bansal, Megha, Prem Kishore Patnala, and Tom Dugmore. "Adsorption of Eriochrome Black-T (EBT) using tea waste as a low cost adsorbent by batch studies: A green approach for dye effluent treatments." *Current Research in Green and Sustainable Chemistry* 3 (2020): 100036.
30. Bayomie, Omar S., et al. "Novel approach for effective removal of methylene blue dye from water using fava bean peel waste." *Scientific reports* 10.1 (2020): 1-10.
31. Ahmad, Rais, and Khalid Ansari. "Chemically treated Lawsonia inermis seeds powder (CTLISP): An eco-friendly adsorbent for the removal of brilliant green dye from aqueous solution." *Groundwater for Sustainable Development* 11 (2020): 100417.
32. Uddin, Md Tamez, et al. "A potential low cost adsorbent for the removal of cationic dyes from aqueous solutions." *Applied Water Science* 7.6 (2017): 2831-2842.
33. Postai, Debora Luiza, et al. "Adsorption of rhodamine B and methylene blue dyes using waste of seeds of *Aleurites Moluccana*, a low cost adsorbent." *Alexandria Engineering Journal* 55.2 (2016): 1713-1723.
34. Mashkoo, Fouzia, Abu Nasar, and Abdullah M. Asiri. "Exploring the reusability of synthetically contaminated wastewater containing crystal violet dye using *tectona grandis* sawdust as a very low-cost adsorbent." *Scientific reports* 8.1 (2018): 1-16.

35. Elsherif, Khaled Muftah, et al. "Adsorption of crystal violet dye onto olive leaves powder: Equilibrium and kinetic studies." *Chemistry International* 7.2 (2021): 79-89.
36. Akkari, Imane, et al. "Raw pomegranate peel as promise efficient biosorbent for the removal of Basic Red 46 dye: equilibrium, kinetic, and thermodynamic studies." *Biomass Conversion and Biorefinery* (2021): 1-14.
37. Alamrani, Nasser A., and Hatem A. AL-Aoh. "Elimination of Congo Red Dye from Industrial Wastewater Using Teucrium polium L. as a Low-Cost Local Adsorbent." *Adsorption Science & Technology* 2021 (2021).
38. Baloo, Lavania, et al. "Adsorptive removal of methylene blue and acid orange 10 dyes from aqueous solutions using oil palm wastes-derived activated carbons." *Alexandria Engineering Journal* 60.6 (2021): 5611-5629.
39. Kowsalya, E., Sharmila, S., Jeyanthi Rebecca, L., & Yogasri, K. (2015). Ground nut shell and spent tea: an eco-friendly low cost adsorbent. *International Journal of Pharmaceutical Sciences Review and Research*, 31(1).
40. Borhade, S. (2017). REMOVAL OF DYE CRYSTAL VIOLET FROM WASTE WATER BY LOW COST NATURAL ADSORBENT (CCNS). Vol 6, Issue 9, pp. 837-844.
41. Misran, E., Bani, O., Situmeang, E. M., & Purba, A. S. (2021). Banana stem based activated carbon as a low-cost adsorbent for methylene blue removal: Isotherm, kinetics, and reusability. *Alexandria Engineering Journal*.
42. Karthika, M., & Vasuki, M. (2018). Adsorptive Removal of Synthetic Dye Effluent Using Sago Waste as LowCost Adsorbent. *Int J Waste Resour*, 8(3), 1000344.
43. Tony, M. A. (2021). An industrial ecology approach: green cellulose-based bio-adsorbent from sugar industry residue for treating textile industry wastewater effluent. *International Journal of Environmental Analytical Chemistry*, 101(2), 167-183.
44. Un, U. T., & Ates, F. (2019). Low-cost adsorbent prepared from poplar sawdust for removal of disperse orange 30 dye from aqueous solutions. *International Journal of Environmental Science and Technology*, 16(2), 899-908.
45. Djilali, Y., Elandaloussi, E. H., Aziz, A., & De Ménorval, L. C. (2016). Alkaline treatment of timber sawdust: A straightforward route toward effective low-cost adsorbent for the enhanced removal of basic dyes from aqueous solutions. *Journal of Saudi Chemical Society*, 20, S241-S249.
46. Mashkooor, F., Nasar, A., & Asiri, A. M. (2018). Exploring the reusability of synthetically contaminated wastewater containing crystal violet dye using tectona grandis sawdust as a very low-cost adsorbent. *Scientific reports*, 8(1), 1-16.
47. Singh, K., Gupta, A. B., & Sharma, A. K. (2016). Fly ash as low cost adsorbent for treatment of effluent of handmade paper industry-Kinetic and modelling studies for direct black dye. *Journal of cleaner production*, 112, 1227-1240.
48. Cojocariu, B., Mocanu, A. M., Nacu, G., & Bulgariu, L. (2018). Possible utilization of PET waste as adsorbent for Orange G dye removal from aqueous media. *Desalination and Water Treatment*, 104, 338-345.
49. Fraga, T. J. M., Carvalho, M. N., Fraga, D. M. D. S. M., da Silva, M. D. C. L., Ferreira, J. M., & da Motta Sobrinho, M. A. (2020). Treated residue from aluminium lamination as

adsorbent of toxic reactive dyes—a kinetic, equilibrium and thermodynamic study. *Environmental technology*, 41(6), 669-681.

50. Dhmees, A. S., Khaleel, N. M., & Mahmoud, S. A. (2018). Synthesis of silica nanoparticles from blast furnace slag as cost-effective adsorbent for efficient azo-dye removal. *Egyptian journal of petroleum*, 27(4), 1113-1121.
51. Anastopoulos, I., Massas, I., & Ehaliotis, C. (2015). Use of residues and by-products of the olive-oil production chain for the removal of pollutants from environmental media: A review of batch biosorption approaches. *Journal of Environmental Science and Health, Part A*, 50(7), 677-718.
52. Thakur, A., & Kaur, H. (2017). Response surface optimization of Rhodamine B dye removal using paper industry waste as adsorbent. *Int J Ind Chem*, 8(2), 175-186.
53. World Resources Institute, The 1994 Information Please Environmental Almanac (Boston: Houghton Mifflin Company, 1994), 10
54. Janbooranapini, Kasidit, et al. "Conversion of industrial carpet waste into adsorbent materials for organic dye removal from water." *Cleaner Engineering and Technology* (2021): 100150.
55. Xia, L., Li, C., Zhou, S., Fu, Z., Wang, Y., Lyu, P., ... & Xu, W. (2019). Utilization of waste leather powders for highly effective removal of dyes from water. *Polymers*, 11(11), 1786.
56. Hussain, Z., Chang, N., Sun, J., Xiang, S., Ayaz, T., Zhang, H., & Wang, H. (2021). Modification of coal fly ash and its use as low-cost adsorbent for the removal of directive, acid and reactive dyes. *Journal of Hazardous Materials*, 126778.
57. Taufiq, A., Hidayat, P., & Hidayat, A. (2018). Modified coal fly ash as low cost adsorbent for removal reactive dyes from batik industry. In *MATEC Web of Conferences* (Vol. 154, p. 01037). EDP Sciences.
58. El Alouani, M., Alehyen, S., Achouri, M. E., & Taibi, M. (2017). Potential use of moroccan fly ash as low cost adsorbent for the removal of two anionic dyes (indigo carmine and acid orange). *Journal of Materials and Environmental Sciences*, 8, 3397-3409.
59. Potgieter, J. H., Pardesi, C., & Pearson, S. (2021). A kinetic and thermodynamic investigation into the removal of methyl orange from wastewater utilizing fly ash in different process configurations. *Environmental geochemistry and health*, 43(7), 2539.
60. Hu, Z. P., Gao, Z. M., Liu, X., & Yuan, Z. Y. (2018). High-surface-area activated red mud for efficient removal of methylene blue from wastewater. *Adsorption Science & Technology*, 36(1-2), 62-79.
61. Yasipourtehrani, S., Strezov, V., Kan, T., & Evans, T. (2021). Investigation of Dye Removal Capability of Blast Furnace Slag in Wastewater Treatment. *Sustainability* 2021, 13, 1970.
62. Gao, H., Song, Z., Zhang, W., Yang, X., Wang, X., & Wang, D. (2017). Synthesis of highly effective absorbents with waste quenching blast furnace slag to remove Methyl Orange from aqueous solution. *Journal of environmental sciences*, 53, 68-77.

63. Cheng, M., Zeng, G., Huang, D., Lai, C., Liu, Y., Zhang, C., ... & Yi, H. (2018). High adsorption of methylene blue by salicylic acid–methanol modified steel converter slag and evaluation of its mechanism. *Journal of colloid and interface science*, 515, 232-239.
64. Teboul, F., Naceur, M. W., Cheknane, B., & Maazouzi, A. (2020). REMOVAL OF CIBACET BLUE (CB) BY ADSORPTION ONTO AN ALGERIAN RED SLAG. *Lebanese Science Journal*, 21(1), 24.
65. Nalbant, I., Kumbur, H., Bilgen, H. D., & Turkey, G. K. (2017). Electro-filter recycle powder of cement industry as a low-cost adsorbent for removal of textile dye Astrazon Blue FGRL. *FEB-FRESENIUS ENVIRONMENTAL BULLETIN*, 4790.
66. Sarkar, C., Basu, J. K., & Samanta, A. N. ADSORPTION OF DIRECT RED 23 BY MICROWAVE ACTIVATED LD SLAG. *Chemical Engineering: An International Journal (CEIJ)*, Vol. 1, No.1, 2017.
67. Thakur, A., & Kaur, H. (2017). Response surface optimization of Rhodamine B dye removal using paper industry waste as adsorbent. *Int J Ind Chem*, 8(2), 175-186.
68. Sahbaz, D. A., Dandil, S., & Acikgoz, C. (2019). Removal of crystal violet dye by a novel adsorbent derived from waste active sludge used in wastewater treatment. *Water Quality Research Journal*, 54(4), 299-308.
69. Hu, Z. P., Gao, Z. M., Liu, X., & Yuan, Z. Y. (2018). High-surface-area activated red mud for efficient removal of methylene blue from wastewater. *Adsorption Science & Technology*, 36(1-2), 62-79.
70. Li, X., Han, D., Zhang, M., Li, B., Wang, Z., Gong, Z., ... & Yang, X. (2019). Removal of toxic dyes from aqueous solution using new activated carbon materials developed from oil sludge waste. *Colloids and surfaces A: physicochemical and engineering aspects*, 578, 123505.
71. Sahu, M. K., & Patel, R. K. (2015). Removal of safranin-O dye from aqueous solution using modified red mud: kinetics and equilibrium studies. *RSC Advances*, 5(96), 78491-78501.
72. Baptisttella, A. M. S., Araújo, A. A. D., Barreto, M. C., Madeira, V. S., & da Motta Sobrinho, M. A. (2018). The use of metal hydroxide sludge (in natura and calcined) for the adsorption of brilliant blue dye in aqueous solution. *Environmental technology*.
73. Noorimotlagh, Z., Darvishi Cheshmeh Soltani, R., Shams Khorramabadi, G., Godini, H., & Almasian, M. (2016). Performance of wastewater sludge modified with zinc oxide nanoparticles in the removal of methylene blue from aqueous solutions. *Desalination and Water Treatment*, 57(4), 1684-1692.
74. Thakur, A., & Kaur, H. (2017). Response surface optimization of Rhodamine B dye removal using paper industry waste as adsorbent. *Int J Ind Chem*, 8(2), 175-186.
75. Mor, S., Chhavi, M. K., Sushil, K. K., & Ravindra, K. (2018). Assessment of hydrothermally modified fly ash for the treatment of methylene blue dye in the textile industry wastewater. *Environment, development and sustainability*, 20(2), 625-639.
76. Akin Sahbaz, D., Dandil, S., & Acikgoz, C. (2021). Adsorption of reactive blue 49 onto cross-linked chitosan-based composites containing waste mussel shell and waste active sludge char. *Water Science and Technology*, 83(3), 715-726.

77. Zhang, J., Liu, M., Yang, T., Yang, K., & Wang, H. (2016). A novel magnetic biochar from sewage sludge: synthesis and its application for the removal of malachite green from wastewater. *Water Science and Technology*, 74(8), 1971-1979.
78. Özbaşa, E. E., Balçık, B., & Özcan, H. K. (2019). Preparation of activated carbon from waste tires, and its use for dye removal. *Desalin Water Treat*, 172, 78-85.
79. Nogueira, M., Matos, I., Bernardo, M., Pinto, F., Lapa, N., Surra, E., & Fonseca, I. (2019). Char from Spent Tire Rubber: A Potential Adsorbent of Remazol Yellow Dye. *C*, 5(4), 76.
80. Anirudhan, T. S., and M. Ramachandran. "Adsorptive removal of basic dyes from aqueous solutions by surfactant modified bentonite clay (organoclay): kinetic and competitive adsorption isotherm." *Process Safety and Environmental Protection* 95 (2015): 215-225.
81. Pawar, Radheshyam R., et al. "Porous synthetic hectorite clay-alginate composite beads for effective adsorption of methylene blue dye from aqueous solution." *International journal of biological macromolecules* 114 (2018): 1315-1324.
82. Ashna, Parisa, and Rouhollah Heydari. "REMOVAL OF REACTIVE RED 198 FROM AQUEOUS SOLUTIONS USING MODIFIED CLAY: OPTIMIZATION, KINETIC AND ISOTHERM." *Journal of the Chilean Chemical Society* 65.4 (2020): 4958-4961..
83. Hassani, Aydin, et al. "Preparation of montmorillonite-alginate nanobiocomposite for adsorption of a textile dye in aqueous phase: isotherm, kinetic and experimental design approaches." *Journal of Industrial and Engineering Chemistry* 21 (2015): 1197-1207.
84. Belachew, Neway, and Getahun Bekele. "Synergy of magnetite intercalated bentonite for enhanced adsorption of congo red dye." *Silicon* 12.3 (2020): 603-612.
85. Dias, Munique, et al. "Adsorption of natural annatto dye by kaolin: kinetic and equilibrium." *Environmental technology* (2019).
86. Satlaoui, Yosra, et al. "Removal properties, mechanisms, and performance of methyl green from aqueous solution using raw and purified Sejnane clay type." *Journal of Chemistry* 2019 (2019).
87. Behilil, Asma, et al. "Natural and Modified Clays for the Removal of Cationic Dye from Water." *Scientific Journal of Riga Technical University. Environmental and Climate Technologies* 24.1 (2020): 562-579.
88. Vinuth, M., et al. "Enhanced removal of methylene blue dye in aqueous solution using eco-friendly Fe (III)-montmorillonite." *Materials Today: Proceedings* 4.2 (2017): 424-433.
89. Abdel Ghafar, Hany H., Emad K. Radwan, and Shaimaa T. El-Wakeel. "Removal of hazardous contaminants from water by natural and zwitterionic surfactant-modified clay." *ACS omega* 5.12 (2020): 6834-6845.
90. Munir, Muhammad, et al. "Effective adsorptive removal of methylene blue from water by didodecyldimethylammonium bromide-modified Brown clay." *ACS omega* 5.27 (2020): 16711-16721.
91. Caponi, Natiela, et al. "Use of Brazilian kaolin as a potential low-cost adsorbent for the removal of malachite green from colored effluents." *Materials Research* 20 (2017): 14-22.

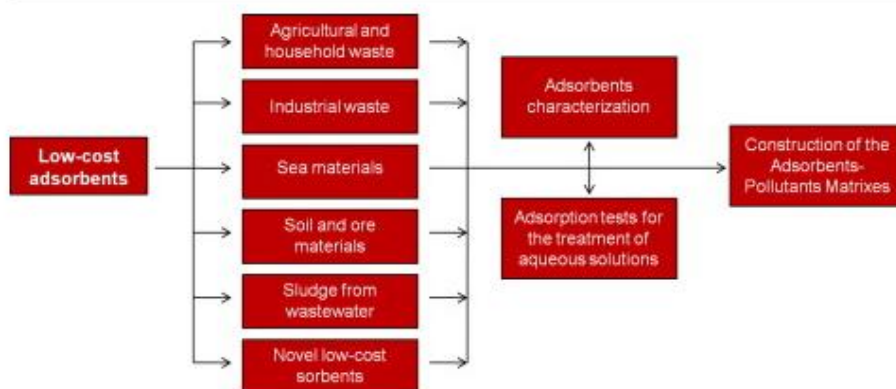
92. Amin, Muhammad Tahir, Abdulrahman Ali Alazba, and Muhammad Shafiq. "Adsorptive removal of reactive black 5 from wastewater using bentonite clay: isotherms, kinetics and thermodynamics." *Sustainability* 7.11 (2015): 15302-15318.
93. Bentahar, Safae, et al. "Removal of a cationic dye from aqueous solution by natural clay." *Groundwater for Sustainable Development* 6 (2018): 255-262.
94. Harrou, Achraf, et al. "Thermodynamics and kinetics of the removal of methylene blue from aqueous solution by raw kaolin." *SN Applied Sciences* 2.2 (2020): 1-11.
95. Ethaib, Saleem, and Salah L. Zubaidi. "Removal of Methylene Blue Dye from Aqueous Solution Using Kaolin." *IOP Conference Series: Materials Science and Engineering*. Vol. 928. No. 2. IOP Publishing, 2020.
96. Paredes-Quevedo, Laura C., et al. "Removal of a textile azo-dye (Basic Red 46) in water by efficient adsorption on a natural clay." *Water, Air, & Soil Pollution* 232.1 (2021): 1-19.

UNDER PEER REVIEW

Table 1
Waste products used for generating low cost adsorbents.

<p>A. House hold wastes</p> <ul style="list-style-type: none"> a. Fruit waste b. Coconut shell c. Scrap tyres 	<p>D. Sea materials</p> <ul style="list-style-type: none"> a. Chitosan and seafood processing wastes. b. Sea weed and algae c. Peat moss d. Miscellaneous waste
<p>B. Agricultural products</p> <ul style="list-style-type: none"> a. Bark and other tannin-rich materials. b. Saw dust and other wood type materials. c. Rice husk d. Other agricultural waste. 	<p>E. Soil and ore materials</p> <ul style="list-style-type: none"> a. Clays b. Red mud c. Zeolites d. Sediment and soil e. Ore minerals
<p>C. Industrial waste</p> <ul style="list-style-type: none"> a. Petroleum wastes. b. Fertilizer wastes c. Fly ash d. Sugar industry wastes e. Blast furnace slag 	<p>F. Metal oxides and hydroxides</p>

(Pollard et al., 1992).



Agricultural waste:

Industrial waste: slag, fly ash, sludge, leather, red mud, carbon slurry, Black liquor, Roll Mill Scale, fertilizer waste, petroleum wastes

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

UNDER PEER REVIEW