Journal of
Bioremediation & Biodegradation

ISSN: 2155-6199

Vital et al., J Bioremediat Biodegrad 2016, 7:6
DOI: 10.4172/2155-6199.1000371

Review Article

Open Access

Dye Removal by Adsorption: A Review

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Abstract

This review discusses the methods for the removal of dyes from the wastewater effluents. Wastewater effluents contain synthetic dyes which cause a potential hazard to the environment hence these dyes need to remove from the water bodies. The various dye removal techniques are classified into Chemical, Physical, and Biological methods. Physical methods includes adsorption, ion exchange, and filtration/coagulation methods etc. while chemical methods includes ozonisation, Fenton reagent, photo catalytic reactions and biological methods include aerobic degradation, anaerobic degradation, biosorption etc. Adsorption found to be very effective and cheap method among the all available dye removal methods. Dyes from the industrial waste water effluents are effectively separated by using adsorbent such as activated carbon however its cost restricts the use in large scale applications. Experimental studies proved that the effective removal of dyes is obtained using several cheaply available non-conventional adsorbents also. Therefore, studies related to searching for efficient and low cost adsorbents derived from existing resources are gaining importance for the removal of dyes.

Keywords: Dye; Adsorbent; Ozonisation; Anaerobic degradation

Introduction

Dyes are colored compounds which are widely used in textiles, printing, rubber, cosmetics, plastics, leather industries to color their products results in generating a large amount of colored wastewater. Mainly dyes are classified into anionic, cationic, and non-ionic dyes. Among all the dyes using in industries, textile industries placed in the first position in using of dyes for coloration of fiber [1]. Dyes are chemical compounds which attach themselves to fabrics or surface shells to impart color. Depolarization of waste water from textile and manufacturing industries is a major challenge for environmental managers [2] as dyes are water soluble and produce very bright colors in water with acidic properties. It has been projected that textile and manufacturing industries are using more than 10,000 commercially available (worldwide) dyes and the consumption of dyes in textile industry is more than 1000 tones/year and about 10-15% of these dyes are discharged into waste streams as effluents during the dyeing processes [1].

Sources of dyes and its classification

Dyes are mainly derived from natural sources without any chemical treatment [3] such as plants, insects, animals and minerals. Dyes derived from plant sources are indigo and saffron, insects are cochineal beetles and lac scale insects, animal sources are derived from some species of mollusks or shellfish, and minerals are ferrous sulfate, ochre. Industries such as textile, printing, paper, carpet, plastic, and leather use dyes to provide colour to their products. These dyes are always left in industrial waste and consequently discharged into the water body [4-7].

Dyes release into waste water from various industrial outlets, such as paper, food colouring, cosmetics, leather, pharmaceutical, dyeing, printing, carpet industries etc. The textile manufacturing and dyeing industries utilize more quantities of a large number of dyes and release these dye pollutants into environment as waste water effluents. These dyes are highly toxic and even carcinogenic to microbial populations and mammalian animals hence these are needed to remove from the water effluents before they are released into water bodies. Dyes are stable to light and not biologically degradable; they are resistant to aerobic digestion and signify one of the difficult groups to be removed from the industrial wastewater [8].

Dye removal/separation techniques

Wastewater effluents contain synthetic dyes which may cause a potential hazard to the environment. Due to the environmental and health concerns associated with the wastewater effluents, different separation techniques have been used in the removal of dyes from aqueous solutions. The dye removal techniques are Physical, Chemical and Biological methods.

Adsorption: Adsorption is used as top quality treatment procedures for the removal of dissolved organic pollutants like dyes from industrial waste water. Adsorption is defined as concentration of materials on the surface of solid bodies. Adsorption is a surface phenomenon which deals primarily with the utilization of surface forces. When a solution having absorbable solute, also called as adsorbate, comes into contact with a solid, called as adsorbent, with highly porous surface structure liquid-solid intermolecular forces of attraction causes the solute to be concentrated at the solid surface. Adsorption is one of the unit operations in the chemical engineering processes used for the separation of industrial wastewater pollutants.

Adsorbents are mainly derived from sources such as zeolites, charcoal, clays, ores, and other waste resources. Adsorbents prepared from waste resources used include coconut shell, rice husk, petroleum wastes, tannin-rich materials, sawdust, fertilizer wastes, fly ash, sugar industry wastes, blast furnace slag, chitosan and seafood processing wastes, seaweed and algae, peat moss, scrap tyres, fruit wastes, etc. [9].

Dye removal by adsorption: While searching for cheap and existed low cost adsorbents used for the removal of dyes from waste water. Activated rice husk used as cheap adsorbent for dye removal from

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Received October 05, 2016; **Accepted** October 17, 2016; **Published** October 18, 2016

Citation: Vital RK, Saibaba KVN, Shaik KB, R Gopinath (2016) Dye Removal by Adsorption: A Review. J Bioremediat Biodegrad 7: 371. doi: 10.4172/2155-6199.1000371

waste water [10]. Hamdaoui [11] stated that maximum adsorption of methylene blue, basic dye, onto cedar sawdust and crushed brick was 60 and 40 mg L^{-1}, respectively.

Wood-shaving bottom (WBA) ash used for the separation of azo reactive and red reactive 141 dyes. Wood-shaving bottom ash / H_2SO_4 and Wood-shaving bottom ash/H_2O adsorbents were made by treating Wood-shaving bottom ash with 0.1 M H_2SO_4 and water respectively; to increase the adsorption capacity. The effects of various parameters on adsorption such as initial pH of solution, contact time, dissolved metals and elution studied. The maximum dye adsorption capability of WBA/H_2SO_4 and WBA/H_2O achieved from a Langmuir model at 30°C were 24.3, 29.9, and 41.5 mg l^{-1} correspondingly. By counting of, WBA/H_2SO_4 and WBA/H_2O able to decrease colour and high chemical oxygen demand (COD) of actual textile waste water [12].

Activated carbon adsorbent prepared by applying of sewage sludge applied for the preparation of activated carbon is a possibly attractive material for wastewater. Even research studies conducted and that could be proved the uses of treated sewage sludge for separation of dyes from polluted water and waste water [13-18]. Otero et al. [18] used pyrolysis of sewage sludge and chemically activation to produce activated carbon. The main advantages of such type of materials were studied mainly by liquid-phase adsorption by using indigo carmine, phenol and crystal violet as adsorbents. Three prepared activated carbon of various particle sizes, were used ASS-g1 (particle diameter<0.12 mm), ASS-g2 (0.12 mm<particle diameter<0.5 mm) and PSS-g2 (0.12<particle diameter<0.5 mm). Indigo carmine dye adsorption has shown lesser (Qmax 60.04 mg/g using AAS, 54.8 mg/g using ASS and 30.8 mg/g using PPS) than Crystal violet dye adsorption higher (Qmax 263.2 mg/g using AAS, 270 mg/g using ASS and 184 mg/g using PPS). They suggested and proposed that separation of organic pollutants from aqueous streams by using activated carbons from sewage sludge.

It was studied that, dyes from textile waste water can be separated by using adsorbent as fly ash. Congo red dyes can be removed by using the Calcium-rich fly ash under various conditions. Experimental studies proved that the maximum adsorption obtained and it was between 93%-98% [19]. Wang et al. [20] reported that methylene blue and basic dye from waste water can be removed by using treated and non-treated fly ash. The adsorption capability for non-treated fly ash presented an adsorption capacity of 1.4×10^{-5} mol/g, while treated fly ash was found to be 2.4×10^{-5} mol/g. Wang et al. [21-24] also investigated and found that porous unburned carbon in the fly ash can be responsible for the adsorption of dye, not the fly ash itself (Tables 1-3).

Metal hydroxide sludge used for the separation of azo dyes from industrial waste water. Hydroxide sludge comprises of metal hydroxides and salts. It was studied that using hydroxide sludge (electroplating industry) reactive dyes can be removed. Researchers observed that pH plays a significant role on the adsorption process which helps in development of dye-metal complexes.

Red mud is another industrial by-product [25-27]. This was studied by various researchers with different industrial wastewater. While production of Alumina, Waste red mud discharged as bauxite processing residue. Namasivayam et al. [28] observed the capacity of waste red mud which can be used effectively for the removal of dye from wastewater. They also studied Freundlich isotherm and found maximum adsorption of dye removal occurred at pH 2. Namasivayam and Arasi [27] observed waste red mud plays a key role for the removal of Congo red from aqueous solution. They also found that the maximum adsorption capacity of the red mud is 4.05 mg/g. Wang et al. [29] studied red mud plays an important role as an adsorbent for the removal of methylene blue, basic dye, and from its aqueous solution. They also observed that the maximum adsorption capacity of red mud was 7.8×10^{-6} mol/g. Tor and Cengeloglu [30] observed the removal of Congo red dye from industrial waste water using red med by using Langmuir isotherm model. Gupta et al. [31] studied both Langmuir and the Freundlich models for the removal of rhodamine B, methylene blue, and fast green dyes from waste water. The percentage of removals for rhodamine B is 92.5, methylene blue is 94.0, and fast green is 75.0.

Clays defined as minerals which are helpful in making up the colloid fraction of rocks, soils and sediments, water. In the earlier days and in the present days, it has been studied that normal clay minerals well known to mankind because of clays properties like high sorption, potential for ion exchange and, abundant in nature. Clays are cheaply available and clay mineral works as effective adsorbents, because of layered structure it was called as hosting materials for adsorbates and counter ions. It has been studied that clays surface area filled with exchangeable ions which plays an important role in the environment to take up both cations and anions through adsorption [32]. Clays are having strong affinity towards both cations and anions and helps in removal of dyes from waste water. Many researchers proved that based on varies in pH adsorption capacity also varies and adsorption process mainly dominated by ion-exchange process.

It has been studied that more than 40 different types of Zeolites are available in the nature. However, researchers observed that linoptilolite is easily available and commonly used Zeolite, which is a heulandite mineral group. Because of its low cost, high surface area, and high ion-exchange capability zeolites become adsorbents (attractive adsorbents). Zeolites are having different cavity structures since they are highly porous this is the reason sorption mechanism in Zeolites is complex [33-35], researchers studied and observed that Zeolites removing trace elements also such as phenols, heavy metals, etc.

Conclusion

This review article presented about various methods available for wastewater treatment using low cost adsorbents which are easily available. Different techniques available for removal of toxic organic compounds from waste water such as filtration, coagulation/ flocculation, ion exchange, adsorption, fenton reagent technique, ozonisation, photocatalytic methods, aerobic degradation and

Physical methods	Chemical methods	Biological methods
Adsorption	Fenton reagent Technique	Aerobic degradation
Ion exchange	Ozonisation	Anaerobic degradation
Filtration	Photocatalytic methods	
Coagulation/flocculation		

Table 1: Various dye removal methods from wastewater.

Researchers	Dye	Adsorption capacity	pH	References
Santos et al.	Remazol Brilliant Blue	91.0 mg/g	7	[24]
Netpradit et al.	Reactive Red 120	45.87 mg/g	8	[22]
Netpradit et al.	Reactive Red 2	61.73 mg/g	9	[22]
Golder et al.	Congo red	513 mg/g	3	[23]
Burcu Uçar et al.	Reactive Red 2	7.99 mg/g	7	[41]
Burcu Uçar et al.	Reactive Blue 4	4.48 mg/g	7	[41]
A. AZIZI et al.	Reactive Dyes	85.81 mg/g	7	[42]
Selvam PP et al.	Rhodamine B	42.19 mg/g	7	[43]
Santos et al.	Direct Blue 85 dye	600 mg/g	4	[44]

Table 2: Shows various researchers observations about the differences in adsorption capacity with Metal hydroxide sludge at different pH.

Researchers	Dye	Adsorption capacity	References
Namasivayam and Arasi	Congo red	4.05 mg/g	[27]
Wang et al.	Methylene Blue	7.8 × 10-6 mol/g	[29]
Gupta et al.	Rhodamine B	1.16 × 10-5 mol/g	[31]
Shivkumar S. Prajapati et al.	Phosphate	205.13 mg/g	[36]
G. M. Ratnamala et al.	Remazol Brilliant Blue	27.8 mg/ g	[37]
Manoj Kumar Sahu et al.	Safranin-O	89.4 mg/g	[38]
Shirzad-Siboni, Mehdi, et al	Acid Blue 113	83.33 mg/g	[39]
Shirzad-Siboni, Mehdi, et al	Reactive Black 5	35.58 mg/g	[39]
Kong, Chun-yan	Lead (Pb)	38.2 mg/g	[40]

Table 3: Shows the adsorption capacity of various dyes by researchers using waste red mud as adsorbent.

anaerobic degradation methods have been used. Chemical and biological methods found to be limited as they are often involve high investment and functional costs. On the other hand physical methods like ion exchange and reverse osmosis are interesting methods because of their effective removal process of pollutants from industrial waste water but these ion exchange and reverse osmosis methods restricts the use in large scale industries due to their high capital and operational costs. Among all the methods available for separation of pollutants from waste waters, the adsorption shows possible method for treatment and removal of organic pollutants in waste water treatment. Adsorption follows surface phenomenon and more advantageous over the other available methods because of its low capital, operation costs and simple design. As per the researchers the adsorption is most commonly used method for the removal of both organic and inorganic pollutants from industrial waste water. Adsorption material available from various sources such as natural sources, agricultural, and industrial wastes. Dye removal from wastewater using activated carbon is effective method but in industrial processes it was restricted due to its high operational and investment costs. In the adsorption method various other natural sources are available for removal of dyes from industrial wastewater.

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