Decolourisation of Synthetic Dyes by Agricultural Waste- A Review

Neetu Sharma, D.P. Tiwari, S. K. Singh

Abstract— Decolourisation of waste water has now become a major problem for the treatment plants in various industries. Many industries use synthetic dyes to colour their products such as textiles, rubber, paper, plastics, leather, cosmetic, food etc. Nearly 10-15% of synthetic textile dyes, used yearly are lost to waste streams and about 20% of these losses enter the environment through effluent from waste water treatment plant. Numerous techniques were used in the recent past for decolourisation of dyes. Among them adsorption technique has got maximum potential for the removal of dyes. Adsorption being a physical process, in-expensive and less time consuming, is widely accepted. It is evident from last 20-25 years that many researchers have studied the feasibility of low cost adsorbents derived from natural material, industrial material, agricultural waste and bio-adsorbents and resulted in innovative approach in this area. The current research is focussed on the need to develop an efficient adsorbent with cost effectiveness and high potentiality. From the survey of about 80-85 research papers, it was concluded that low cost adsorbents obtained from agricultural waste products were found to be having outstanding removal capabilities. This paper reviews the suitability of both raw and chemically modified agricultural products in the decolourisation of synthetic dyes.

Index Terms— Activated carbon, Agricultural waste, bio-adsorbents, chemically treated adsorbents, decolourisation, low-cost adsorbents, Synthetic Dyes.

1 INTRODUCTION

Waste water from the textile industries mainly contain moderate concentration (10-200 mg.ml-1) of dyestuffs which contribute significant contamination of aquatic ecosystem (Neill et al, 1999). The demand of synthetic dyes has experienced the significant growth in the past decades and it was reported that more than 7×105 metric tons of various dyes are produced worldwide annually (Pearce et al,2003). Effluent discharged from dyeing industries is highly coloured and prove toxic to the aquatic ecosystem. Dyes are persistent in nature and strongly absorb sunlight which decreases the intensity of light absorbed by the water plants and phytoplankton, reducing photosynthesis and dissolve oxygen of the aquatic ecosystem and results in increase of COD. Further, dye effluents are highly dispersible, hard to treat, high in volume, hazardous in nature and made of harmful organic and inorganic chemicals that exhibit toxic and carcinogenic effects towards microbial population, human beings and animals (Reife et al, 1993).

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During the last few decades, a no. of physical, chemical and biological methods were studied as coagulation, ultra-filtration, electrochemical adsorption, photo-oxidation and ion exchange method. Among them adsorption technique is generally considered to be an effective method for quickly lowering the concentration of dissolved dyes in waste water (Reife et al, 1996). Activated carbon is the most widely used adsorbent for dye molecules and dissolves compounds due to its high porosity and good surface area for sorption of organic compounds but high capital problem with handling of spent carbon, limits its widespread application. (Silva et al, 2006). In order to overcome this problem, the researchers are trying to develop low cost adsorbents as viable substitute for activated carbon. Over the years numerous low cost adsorbents were exploited as possible alternatives to activated carbon for the removal of hazardous chemicals. Some of the reported adsorbents include clay material, siliceous materials, zeolites, agricultural wastes, industrial waste products, bio sorbents etc. (G.Crini, 2006).

In this article, the feasibility of various non-conventional low cost adsorbents prepared from agricultural waste has been reviewed. The main goal of this review is to provide a summary of recent information concerning the agricultural material as sorbents. Agricultural wastes are of low economic value, so inexpensive and abundantly available, mainly composed of cellulose, hemicelluloses and lignin which make them effective adsorbents for a wide range of pollutants due to the presence of functional groups such as hydroxyl, carboxyl, methoxy, phenols, etc., that participates in binding with the pollutants (Hassanein & Koumanova, 2010).

For this recently published papers were compiled. This review presents (a) variety of low cost adsorbents used in the recent past. (b) Describes the adsorption efficiency of treated and raw agricultural waste adsorbents (c) Adsorption isotherm models and thermodynamic parameters used to define the mechanism and process of adsorption.

SYNTHETIC DYES

A dye is a coloured substance that has an affinity to bind with the substrate to which it is being applied. The dye is generally applied in an aqueous solution, and may require a mordant to improve the fastness of the dye on the fibers. Both dyes and pigments appear to be coloured because they absorb some light. In contrast with a dye, a pigment generally is insoluble, and has no affinity for the substrate. Synthetic dyes quickly replaced the traditional natural dyes. They are comparatively inexpensive and offered a wide range of new colours, which imparted better properties to the dyed materials (Simon Garfield, 2000). Acid dyes are water-soluble anionic dyes that are applied to fibers such as silk, wool, nylon. Basic dyes are water-soluble cationic dyes that are mainly applied to acrylic fibers, but find some use for wool and silk. Direct dyes are used on cotton, paper, leather, wool, silk and nylon. Direct dyeing is normally carried out in a neutral or slightly alkaline dye bath, at or near boiling point, with the addition of either sodium chloride (NaCl) or sodium sulfate (Na2SO4). Mordant dyes require a mordant, which improves the fastness of the dye against water, light and perspiration. The choice of mordant is very important as different mordant can change the final colour significantly. Vat dyes are essentially insoluble in water and incapable of dyeing fibres directly. However, reduction in alkaline liquor produces the water soluble alkali metal salt of the dye, which, in this leuco form, has an affinity for the textile fibre. Reactive dyes utilize a chromophores attached to a substituent that is capable of directly reacting with the fibre substrate. A chromophore is a radical configuration consisting of conjugated double bonds containing delocalised electrons such as azo (-N=N-), Carbonyl(=C=O),Carbon(=C=C=), Carbon – Nitrogen (>C=NH or –CH=N-); nitoso (-NO or N-OH); nitro (-NO2 or =NO-OH); and sulphur (C=S) (S.J. Allen& B. Koumanova, 2005) The presence of ionising groups known as auxochromes results in maximum adsorption of the compound and provides a strong bonding affinity. Some common auxochromes groups include –NH3,-COOH, -HSO3, -OH (Al-Ghouti, 2004).

ADSORPTION ISOTHERM MODELS

The process of adsorption is achieved by various pathways. Some adsorbents are held loosely by vander waals forces indicates the physical adsorption, while those held firmly indicates the chemical adsorption. The state of adsorbed molecule and the nature of bonding can be known by photoelectron spectroscopy. However the nature of adsorbed species can be very effectively studied by Infrared and Raman spectra under high pressure.The mechanism of adsorption can be studied by various adsorption isotherms. In order to understand the design of adsorption process, various equilibrium curves have been described by the scientists.

Langmuir isotherm model

Langmuir proposed the monolayer adsorption of sorbet on homogenous adsorbent. The linear form of Langmuir (1918) isotherm model is represented by the Eqn.

$$C_e/q_e = 1/Q_{max}K_L + C_e/Q_{max} \quad (1)$$

Where C_e (mg/dm3) is the dye concentration in the solution at equilibrium, q_e (mg/g) is the amount of dye adsorbed per unit mass of adsorbent. Qmax (mg/g) and KL (dm3 /g) are the Langmuir constants related to the theoretical maximum adsorption capacity and the energy of adsorption corresponds to a monolayer adsorption. The essential characteristics of Langmuir isotherm can be expressed by a dimensionless separation factor, RL. It indicates the nature of adsorption and expressed as below:

$$RL=1/1+K_LC_0 \quad (2)$$

Where C0 is the initial concentration (mg/dm3) and KL is the Langmuir constant. Four possible conditions can be obtained:
RL > 1 - Unfavourable, RL = 1 - Linear, RL = 0 - Irreversible,
0< RL < 1 - favourable

Freundlich isotherm model

Freundlich (1906) describe the equilibrium on heterogeneous surfaces and does not assume monolayer capacity and relates the adsorption with bulk. The linear form of Freundlich can be expressed by Eqn.

$$\log q_e = \log KF + 1/n \log C_e \quad (3)$$

Where KF is the Freundlich constant, representing the adsorption capacity (dm3/g) and n is the Freundlich exponent that depicting the adsorption intensity (dimensionless). C_e and q_e stands for the same as described in Langmuir equation. The plot of q_e versus log C_e yields a straight line, with a slope of 1/n and intercept of lnKF . Greater will be the value of n more will be the adsorption.

Temkin isotherm model

Temkin isotherm provides the relation between the amount adsorbed and the heat of adsorption. In chemisorptions, adsorption is accomplished by intake of energy or by release of energy showing the endothermic or exothermic processes. The linear form of Temkin isotherm model can be expressed by Eqn.

$$q_e = B\ln A + B\ln C_e \quad (4)$$

Where A (dm3/gm) is the equilibrium binding constant and B

is related to the heat of adsorption.

Thermodynamic parameters

The values of thermodynamic parameters, confirms the nature and type of adsorption. The various thermodynamic parameters such as Gibbs free energy (ΔG), enthalpy (ΔH), and entropy (ΔS) can be evaluated by following equations:

C_F=Csolid/Cliquid (5)

$\Delta G = -RT\ln C_F$ (6)

$\Delta H = -R(T_2T_1/T_2 - T_1)\ln C_{F2}/C_{F1}$ (7)

$\Delta S = \Delta H - \Delta G/T$ (8)

$\Delta G = \Delta H - T\Delta S$ (9)

$\ln C_F = -\Delta G/RT = \Delta S/R - \Delta H/RT$ (10)

$\log C_F = \Delta S/(2.303)R - \Delta H/(2.303)RT$ (11)

C_F, C_{F1}, C_{F2} are the equilibrium constants. Csolid and Cliquid (mg/l) are the concentration of solid and liquid phase respectively at equilibrium. T is the temperature in Kelvin and R is the gas constant. As the adsorption progresses the residual forces acting along the surface decreases. This in turn decreases the surface energy which appears as heat. This implies that adsorption accompanied by decrease in enthalpy of the system. The negative value of ΔG shows that adsorption is highly favourable and spontaneous. The positive value of ΔS shows increased disorder during the adsorption at the solid interface because of replacement of water molecule by dye molecule.

LOW COST ADSORBENTS USED FOR THE REMOVAL OF DYES

Low cost materials in their natural and modified forms have been extensively used as alternative adsorbents for dye removal (Ahmad et al, 2007; Gurses et al, 2006; Aksu and Tezer,2000; Acemioglu,2004). According to Bailey et al, 1999, a sorbent can be considered as low cost if it require less processing, abundant in nature or is a by-product of some process and obtained as waste materials from another industries. Clay material such as bentonite (Espantaleon et al, 2003), kaolinite (Ghosh and Bhattacharyya, 2002), montmorillonite, saponite (Alkan et al, 2004), diatomite (Al-Ghouti et al, 2003), and fuller's earth (Atune et al, 2003), activated bleaching earth(W.T. Tsai et al 2004), were studied as low cost adsorbents in their natural form for the removal of synthetic dyes. The adsorption capacities of clay results from a net negative charge present on the surface of minerals. This negative charge facilitates clay the capability to absorb positively charge species. Their sorption properties also come from their highly porous structure. The use of zeolite and silicaceous material as silica beads, glasses, alunite, perlite and dolomite has also been observed for dye removal in recent past. Phan et al (2000) also showed that modified silica beads have better potential for the removal of acid dyes from coloured effluents. Use of modified alunite for the removal of acid dyes from waste water was conducted by özacar and Sengil, 2002. Other silicaceous material such as dolmite has also been proposed by Walker et al, 2003 for the removal of reactive dyes. The use of perlite as low cost adsorbent for the removal of dyes has been investigated for the first time by Alkan & co-workers, 2004. Several studies have also been conducted on the sorbent behaviours of natural zeolites for azo reactive dyes (Ozdemir et al, 2004; Armagan et al, 2004; Meshko et al 2001).

Industrial waste products have been also used extensively by researchers because of its free or limited cost of availability. The thermal power plant produce large amount of fly ash annually. The high percentage of silica and alumina in fly ash make it a good material for utilization. Fly ash has been used for the removal of phenol and chlorophenols (Haribabu et al, 1993), Heavy metals (pandey et al, 1985), dyes (Janos et al, 2003; Dizge et al, 2008; Kara et al, 2007; Tabrez et al, 2009).Various type of industrial waste such as blast furnace slag, dust and sludge obtained from steel industries has been investigated as adsorbents (Yamada et al, 1986 Dimitrova, 1996) for the removal of heavy metals. The adsorbents developed from industrial waste have the tendency to remove inorganic contaminants (metal ions) more efficiently than organic constituents (dyes and phenols).

The carbon containing adsorbents were made from biochemical and surplus sludge obtained from different plants by physical and chemical activation for the treatment of wastewater. The adsorption capacities of the sludge derived adsorbents were observed better than the activated carbon by Lanlan Yu & Qin Zhong, 2006.

Naturally occurring material with great abundance and their low cost characteristics make them attractive adsorbents for the dye removal. Among naturally occurring adsorbents chitin is abundant. It is found in exoskeleton of shell fish and crustacean animals and various researchers investigated it for dye removal (Yoshida et al, 1997; Chiou et al, 2002; Chiou et al, 2004). Peat is another naturally occurring material containing lignin and cellulose. Maria investigated adsorption characteristics of peat along with fly ash and bentonite and found that it was having maximum adsorption capacities than the rest two. Wood(Poots et al, 1976), natural coal (Mittal et al, 1993) water hyacinth (Varghese et al, 2004) were also studied by the researchers as low cost adsorbents for the decolourisation of dyes.

AGRICULTURAL WASTE USED IN THE DECOLOURISATION OF SYNTHETIC DYES

Large amount of agricultural waste is produced by most of the countries every year and major part of this waste is utilized as domestic fuel. The abundance and widespread availability of agricultural by-products make them good source of raw mate-

rials for dye removal. Several agricultural waste products like rice husks, corncob, coir-pith, plum kernels, bagasse pith, nut shells, fruit peels, leaf powders, used tea leaves, fruit shells, seed husk, saw dust, hyacinth root etc were tried as alternative low cost adsorbent by various researchers in recent past decades.

ACTIVATED CARBON PREPARED FROM AGRICULTURAL WASTE

Plentiful agricultural waste and various unused plant parts offer an inexpensive and renewable additional source of activated carbon (AC). These waste materials have little or no economic value and often pose a great disposal problem. So these waste materials are used in treated and untreated form for the removal of dyes. Porter demonstrated that adsorption of AC is an effective and complete treatment for the textile waste water. Preparation of ACs from a wide range of agro waste for treatment of waste water has been reported earlier by Pollard et al, 1992. A wide variety of activated carbon prepared from agro- waste such as pine- wood (Tseng et al, 2003), Corn cob (Robinson et al, 2002), fruit stones and nut shells (Aygün et al, 2003 and Sumanjit et al, 2007), Cassava peel (Rajeshwarisivraj et al, 2001), Tapioca peel (Parvathi et al, 2010) Bamboo(Wu et al, 1999), bagasse (Tsai et al, 2001 and Raghuvanshi et al, 2004), rice husk (Jyoti Sharma and Beena Janvi, 2008; Chandrasekhar and Pramada, 2006; Y.C. Sharma et al 2009), bark (Shanmugam Arivoli et al, 2009; L.S. Tan et al, 2010), leaves (Hema & Arivoli, 2008 and M.C. Ncibi et al.,2007) and Used tea leaves(Sumanjit et al., 2007).

Kaushik et al 2004 demonstrated that dye removal is more effective with chemically activated bagasse in comparison to raw bagasse. The activated rice husk carbon prepared simply by steam was proved as a favourable low cost adsorbent for the removal of congo red dye was investigated by Jyoti Sharma and Beena Janvi, 2008. It was observed that an amount of 0.08g/l of RHCAS could remove 10-99% of dye from an aqueous solution of 25 ppm. Application of activated carbon prepared from rice husk, was estimated as a potential adsorbent for the removal of Malachite green and found to be having good adsorption capacity comparative to the activated carbon prepared from banana peel (Annadurai et al,2002), date pits(Banat et al, 2003), rice husk (Kannan and Sundaram et al, 2001), wood saw dust (Namasivayam et al 2001), orange peel (Annadurai et al,2002), sugarcane dust (Khattri and Singh et al, 2000), activated carbon (Sharma et al,2007) except the coconut husk(Sharma et al,2009). Kaushik et al (2004) reported that adsorption on activated bagasse increases from 78.09% to 86.35% with rise in temperature from 30-50 ċ with 4 gm/l dose from 100 ppm of dye solution. Garg et al (2003) demonstrated that adsorption efficiency of sulphuric acid treated saw dust was higher than formaldehyde treated saw dust for the removal of malachite green. It was concluded that ACR adsorption efficiency was unaffected by pH, while 6-9 pH was optimum for dye removal by SDC and SD. The adsorption of ash prepared from rice husk was found to be an effective adsorbent because of their high surface area and the volume. The maximum monolayer capacity estimated was 690mg/g. Moreover the adsorption was maximum on the ash compared to the activated carbon prepared from the rice husk after calcinations because of the presence of both silica and carbon (Chandrasekhar and Pramada, 2006).

The adsorption characteristics of direct red-23 on to mangrove bark (Rhizopus apiculata) that has been previously treated with formaldehyde in acid medium was investigated and observed that dye sorption decreases at high pH values in accordance with the ion exchange mechanism of the adsorption and maximum removal was at 2. The monolayer sorption capacity of modified bark for DR-3 sorption was found to be 21.55 mg/g. (Tan et al 2010) A carbonaceous adsorbent prepared from banana peel was investigated as considerable adsorbent in the removal of rhodamine B with the adsorption capacity of 40.161 mg/g at 30ċ and 7 pH by Shanmugam et al, 2009. The positive value of ΔH indicates the physiosorption and the endothermic nature of adsorption. The adsorption of Malachite green on the carbonaceous material prepared by dried leaves of pandanus was observed by Hema et al, 2008. The maximum adsorption capacity was found to be 9.73 mg/g at 6 pH and 30ċ. Activated carbon prepared by impregnation of H_3PO_4 followed by activation at 800ċ of Euphorbia antiquorum L wood was used as adsorbent by Sivakumar and Palanisamy, 2010, for the removal of Acid Blue 92, Basic Red 29, Reactive Red 4 and Direct Blue 53. It was demonstrated that the selected adsorbent was mesoporous and can accommodate multilayer dye adsorption due to its high pore width and pore diffusion plays a significant role in the adsorption than film diffusion.

The removal efficiency of activated carbon prepared from agricultural adsorbents depends on various factors such as surface area, nature of charge present, pore structure, chemical composition and mechanism of adsorption. The removal efficiency also depends upon the characteristics of sorbet which is to be adsorbed. The characteristics of sorbet vary with significant variation in concentration, contact time and pH. Adsorption is a complicated process and not accomplished by a specific mechanism. So much work is still required to identify the mechanism of adsorption.

RAW AGRICULTURAL WASTE USED AS ADSORBENTS

Literature from past decades reports several studies on the effective adsorption of dyes by raw adsorbents prepared from agricultural waste and unused plant parts. Several agricultural solid wastes from cheap and readily available sources were tried in the natural form in the recent past for the removal of dyes to avoid the cost of chemicals and complicated processes of modification. Such as tamarind fruit shell (M.C Somasekhara Reddy., 2006), Jack fruit peel, a nanoporous adsorbent (M. Jayarajan et al., 2011), grapefruit peel (Abassi & Razzaghi., 2009), rice husk (Ola Abdelwahab et al., 2005), yellow passion fruit peel (Flavio Andre Pavan et al., 2008) have also been successfully employed in raw form for the removal of dyes from aqueous solution.

Bark is an abundant forest residue which has been found to be effective in removing dyes from aqueous solution (McKay

et al., 1999). Bark is an effective adsorbent because of its tannin content (Bailey et al., 1999; Morais et al., 1999). Teak tree bark powder was used as attractive adsorbent for the adsorption of methylene blue by Satish Patil et al., 2011. The uptake by raw TTBP adsorbent was found to be 333.3 mg/g and increased with increasing pH.

The adsorption of congo red, a direct azo dye on hazelnut shell was estimated by Riccardo A. Carletto et al., 2008. Hazlenut shells were employed as organic support for the culture of phanerochaete chrysosporium to take macronutrients as carbon and nitrogen from hazelnut shells and biodegradation of adsorbed dyes was studied. The maximum amount of congo red adsorbed on hazelnut shell was 13.75 mg/g. Saw dust is an abundant by-product of the industry that is either used as cooking fuel and packing material. The role of saw dust materials in the removal of pollutants from aqueous solutions has been reviewed recently (Shukla et al., 2002). Chemical pre-treatment of sawdust has been shown to improve the sorption capacity and enhance the efficiency of saw dust adsorption (Garg et al., 2003, 2004a,; Batzias and Sidiras, 2004). Batch adsorption of methylene blue and acid blue onto ground nut hazelnut shell was studied in comparison with saw dust of various species of wood by F. Ferrero, 2006. The author observed the higher adsorption capacity of hazelnut shell than wood sawdust obtained from various species of wood, towards both dyes.

The sorption characteristics of sunflower seed husk was investigated by Siew-Teng Ong et al, 2010, to remove methylene blue under batch condition and maximum sorption capacity was found to be 45.25 mg/g also the sorption was found to be pH, concentration and agitation dependent. The granular bio adsorbent prepared from the fruit peel of Cucumis sativa could effectively remove methylene blue, methyl red and malachite green from aqueous solution at the pH 6 and the maximum adsorption capacity was 140.84 mg/g for methyl red (T.Santhi et al., 2009).

Naturally available agricultural waste, wheat straw was evaluated for the treatment of basic yellow 21 with maximum adsorption capacity of 71.43 mg/g by Taha F. Hassanein & B. Koumanova, 2010. The adsorption mechanism was suggested to be complex, consisting of both surface adsorption and pore diffusion. A nanoporous adsorbent prepared from jackfruit peel waste was found to be an attractive adsorbent for the removal of rhodamine B at low pH of 4.3 with maximum removal efficiency of 4.361 to 1.98 mg/g (M.Jayarajan et al, 2011). The rate of adsorption increases with increase in temperature indicating that the sorption is an endothermic process and rising temperature enhance the mobility of dye which facilitates the adsorption process. Increase in temperature enhance the sorptive interaction between the active sites of sorbent and sorbate ions. It is also said that increasing temperature may also produce a swelling effect in the internal structure of the carbons enhancing more dye adsorption on the sorbents (S. Senthilkumaar et al., 2006). The rate of adsorption of malachite green on neem bark powder and mango bark powder increases with increase in temperature was demonstrated by Srivastva & Rupainwar, 2010. Also mango bark powder was suggested better adsorbent than neem bark powder.

The sorption efficiencies of corncob and barley husk with different particle size and weight for various dyes were demonstrated by T.Robinson et al. It was observed by the author that 2gm of barley husk and corn cob was more efficient than 5gm resulted in 92% of dye removal while the paricle size of ≤600 µm, for both substrates, had the higher rate of removal than 1×4mm particle size in the first five hours, and further removal occurred at much slower rate. It may be expected because smaller particle have large specific surface

CONCLUSION

This review presents the efficiency of low cost agricultural adsorbents for dye removal. The comparison between the raw and treated adsorbents is summarised briefly. From the recent literature reviewed it is demonstrated that chemically treated agricultural waste showed comparatively significant removal efficiency than the raw agricultural waste. Decolourisation process is not specific and depends upon many factors. Although there are lots of agricultural adsorbents which can act as a substitute for the expensive commercial activated carbon but complete replacement is not possible. The factors which favour the selection of agricultural adsorbents are its low cost, widespread presence and organic composition which shows strong affinity for some selected dyes.

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Nomenclature

C_e = concentration of dye at equilibrium
q_e = amount of dye adsorbed
Q_{max} = maximum adsorption capacity
K_L = energy of adsorption
R_L = Separation factor
$C_{0=}$ Initial dye concentration
K_F = Freundlich constant related to adsorption capacity
n= Freundlich exponent depicting the adsorption capacity
ΔG= Gibbs free energy
ΔS= Entropy change
ΔH= Enthalpy
R= Gas Constant
T= Temperature in Kelvin
RHCAS= Rice husk carbon
SDC= Saw dust carbon
SD= Saw dust
ACR= activated carbon
DR= Direct red
TTBP= Teak tree bark powder
A= Equilibrium binding constant
B= Heat of adsorption

TABLE 1

ADSORPTION CAPACITIES OF TREATED AGRICULTURAL WASTE

Dyes	Activation Process	Equillibrium time	qε(mg/g)	References
Rhodamine B	Carbonized by Conc. H2SO4 & activated by heating at 600ċ	40 min	40.161	Shanmugam Arivoli et al(2009)
Direct F. Scarlet	activated by 0.6M citric acid for 20ċ	90 min	4.35	Ola Abdelwahab et al(2005)
Direct red-23	Chemically treated with a mixture of 37% HCHO+0.2N H2SO4	4 hrs	21.55	L.S. Tan et al(2010)
Malchite Green	Carbonized by Conc. H2SO4 & activated by heating at 400ċ for 12hrs	40 min	9.737	Hema&Arivoli(2008)
Reactive red 23	Chemically treated with a mixture of 0.2 HNO3	10 hrs	0.31	M.C. Ncibi et al(2007)
Methylene blue	Ash is formed by heating at 500ċ for 2 hrs	30 min	690	Chandrasekhar&Pramada(2006)
Red Brown C4R	Activated by conc. H2SO4 and carbonized at 200ċ	45 min	121.47	C. Parvathi et a(2010)
Acid violet 17	Charcoal prepared by burning in open air	4 hrs	38.32	Sumanjit et al (2007)
Acid violet 17	do		100.57	Sumanjit et al (2007)
Acid Red 119	do	4 hrs	44.48	Sumanjit et al (2007)
Acid Blue15	do	4 hrs	126.53	Sumanjit et al (2007)
Acid Red 119	do		72.81	Sumanjit et al (2007)
Malachite green	Carbonized in quartz tube in muffle furnace at 450ċ for 1 hrs & activated at 650ċ for 2 hrs.	40 min	63.85	Y.C.Sharma et al(2009)

TABLE 2

ADSORPTION CAPACITIES OF RAW AGRICULTURAL WASTE

Adsorbents	Dye	equilibrium time	Temperature(ċ)	qε(mg/g)	References
Neem Bark	Malchite Green	7 hrs	25ċ	0.36	Srivastava&Rupainwar(2010)
Mango Bark	Malchite Green	7 hrs	25ċ	0.53	Srivastava&Rupainwar(2010)
Tamarind shell	Congo red	4 hrs	30±1ċ	10.48	Somasekhara Reddy(2006)
Neem leaf powder	Congo red	5 hrs	27ċ	72	Bhattacharya&Arunima(2004)
Grape fruit peel	Reactive blue 19	45 min	25ċ	12.53	Abassi& Razzaghi Asl(2009)
Teak tree bark	Methylene blue	30 min	30ċ	333.3	Patil et al(2011)
Wheat straw	Basic Yellow 21	48 hrs	20±2ċ	71.43	Hassanein&Koumanova(2010)
sunflower seed husk	Methylene blue	4 hrs	25±2ċ	45.25	Siew-Teng Ong et al(2010)
Hazlenut shell	Methylene blue	60 min	20ċ	76.9	F.Ferrero(2007)
Hazlenut shell	Acid Blue	60 min	20ċ	60.2	F.Ferrero(2007)
Cherry saw dust	Methylene blue	2 hrs	20ċ	39	F.Ferrero(2007)
Walnut saw dust	Methylene blue	60 min	20ċ	59.17	F.Ferrero(2007)
Oak saw dust	Acid Blue	60 min	20ċ	29.5	F.Ferrero(2007)
Pitch Pine saw dust	Acid Blue	60 min	20ċ	27.5	F.Ferrero(2007)

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