

# Malachite green “a cationic dye” and its removal from aqueous solution by adsorption

Nirav P. Raval<sup>1</sup> · Prapti U. Shah<sup>1</sup> · Nisha K. Shah<sup>2</sup>

Received: 12 October 2016 / Accepted: 28 November 2016  
© The Author(s) 2016. This article is published with open access at Springerlink.com

**Abstract** Adsorption can be efficiently employed for the removal of various toxic dyes from water and wastewater. In this article, the authors reviewed variety of adsorbents used by various researchers for the removal of malachite green (MG) dye from an aqueous environment. The main motto of this review article was to assemble the scattered available information of adsorbents used for the removal of MG to enlighten their wide potential. In addition to this, various optimal experimental conditions (solution pH, equilibrium contact time, amount of adsorbent and temperature) as well as adsorption isotherms, kinetics and thermodynamics data of different adsorbents towards MG were also analyzed and tabulated. Finally, it was concluded that the agricultural solid wastes and biosorbents such as biopolymers and biomass adsorbents have demonstrated outstanding adsorption capabilities for removal of MG dye.

**Keywords** Malachite green · Wastewater · Biosorbents · Biopolymers · Nanomaterials

**Electronic supplementary material** The online version of this article (doi:10.1007/s13201-016-0512-2) contains supplementary material, which is available to authorized users.

✉ Nirav P. Raval  
nirav.raval90@gmail.com  
Prapti U. Shah  
prapti.shah1126@gmail.com  
Nisha K. Shah  
nish\_chem2004@yahoo.com

<sup>1</sup> Department of Environmental Science, School of Sciences, Gujarat University, Ahmedabad 380 009, Gujarat, India

<sup>2</sup> Department of Chemistry, School of Sciences, Gujarat University, Ahmedabad 380 009, Gujarat, India

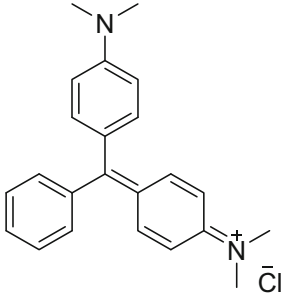
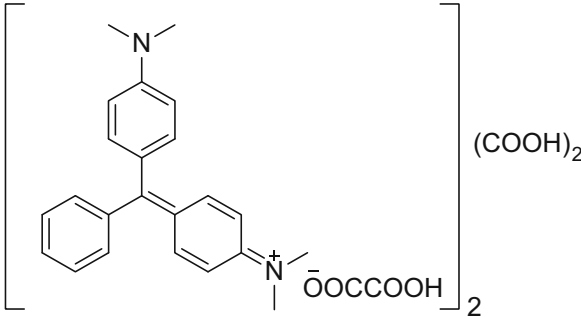
## Introduction

Till the late nineteenth century, all the colorants were extracted from shells, flowers, roots, insects and molluscs. But, with the historic discovery of first synthetic dye, Mauveine, most of the uses of natural dyes have been replaced with synthetic ones as they can be manufactured on a large scale (Gordon and Gregory 1987). At present, more than 1,00,000 synthetic dyes exist with an annual production of over  $7 \times 10^5$  tonnes/year and are mostly associated with water pollution (Mittal et al. 2009; Gupta et al. 2011; Saravanan et al. 2016).

Malachite green (MG) is water soluble cationic dye that appears as green crystalline powder and belongs to triphenylmethane category (Raval et al. 2016b). The important physicochemical characteristics of MG were presented in Tables 1 and Table 2 narrated its applications and toxic effects. It was revealed from the Table 2 that the extensive usage of MG dye has caused several health hazards and hence, proper treatment of effluent containing MG dye is extremely necessary.

Many treatment technologies have been applied to decolorize MG from aqueous medium, such as biodegradation and decolorization (An et al. 2002; Levin et al. 2004; Ren et al. 2006; Eichlerová et al. 2006; Daneshvar et al. 2007a, b; Ayed et al. 2008; Ali et al. 2009; Wu et al. 2009; Cheriaa and Bakhrouf 2009; Ayed et al. 2010; Du et al. 2011; Khataee et al. 2011a, b; Shedbalkar and Jadhav 2011; Hu et al. 2011; Abd-El-Kareem and Taha 2012); photocatalytic degradation (Hasnat et al. 2003; Kominami et al. 2003; Lv et al. 2005; Yang et al. 2005; Chen et al. 2007; Sayilkan et al. 2007a, b, 2008; Tayade et al. 2007; Wang et al. 2008a; Ju et al. 2008; Asiltürk et al. 2009; Prado and Costa 2009; Bansal et al. 2009; Kaneva et al. 2010; Liu et al. 2010; Bojinova and Dushkin 2011; Chen

**Table 1** Physicochemical properties of malachite green dye

Parameters	Value	
Common name	Malachite green chloride	Malachite green oxalate
Molecular formula	$C_{23}H_{25}ClN_2$	$C_{52}H_{54}N_4O_{12}$
Molecular weight	364.911 g/mol	927.00 g/mol
IUPAC name	[4-[[4-(Dimethylamino)phenyl]-phenylmethylidene]cyclohexa-2,5-dien-1-ylidene]-dimethylazanium; chloride	[4-[[4-(Dimethylamino)phenyl]-phenylmethylidene]cyclohexa-2,5-dien-1-ylidene]-dimethylazanium;2-hydroxy-2-oxoacetate;oxalic acid
Molecular Structure		
Other names	Aniline green; Basic green 4; Diamond green B; Victoria green B	
Color index number	42000	
CAS number	123333-61-9	
Maximum wavelength	618 nm	

**Table 2** Applications and toxicity of Malachite green dye**Applications**

It is used for the dyeing of cotton, paper, jute, silk, wool, leather products and acrylic industries  
 Antiseptic and fungicidal for humans  
 Antiparasitical, antibacterial and antifungal in aquaculture and commercial fish hatchery industries  
 It is also used as a food coloring agent, food additive, a medical disinfectant, and anthelmintic

**Toxicity**

Environmentally persistent  
 Damage to nervous system, brain and liver when ingested  
 Eye burns, fast breathing, profuse sweating and cancer of different parts of the body  
 Acutely toxic to a wide range of aquatic and terrestrial animals  
 Decreases food intake, growth and fertility rates  
 Causes damage to the liver, spleen, kidney and heart  
 Inflicts lesions on the skin, eyes, lungs and bones  
 Produces teratogenic effects  
 Cytotoxic to mammalian cells  
 Acts as a respiratory enzyme poison  
 Decreasing RBC count (Dyscrasia), Hb (Anemia), and HTC (%)  
 Increasing WBC count (Leukocytosis) and delay in blood coagulation  
 Its presence in the hydrosphere reduces photosynthesis by obstructing light penetration and adversely affects aquatic life

et al. 2011; Tolia et al. 2012; Saha et al. 2012; Aliyan et al. 2013); photooxidative degradation (Modirshahla and Behnajady 2006); Solar degradation (Pirsaheb et al. 2015); coagulation–floculation (Oladoja and Aliu 2009; Man et al. 2012); ozonation (Zhou et al. 2013); fenton reagent (Chen et al. 2002; Karimi et al. 2012; Bai et al. 2013; Nidheesh et al. 2013); Solvent extraction (Pandit and Basu 2004); sonochemical and sonophotocatalytic degradation (Berberidou et al. 2007; Bejarano-Pérez and Suárez-Herrera 2008; Moumeni and Hamdaoui 2012). However, all these techniques have certain limitations in terms of design, dye separation efficiency, cost and effectiveness. Advantages and disadvantages of various techniques used for the removal of MG dye have been summarized in Table 3 (Dawood and Sen 2014; Yang et al. 2014). More than 250 research articles have been published related to the adsorption of MG which confirmed that amongst all the available treatment techniques, adsorption has more frequently used one.

In addition, though there was a number of review articles such as Microbial decolorization of textile-dye containing effluents: a review by Banat et al. (1996); Fungal decolorization of dye wastewaters: a review by Fu and Viraraghavan (2001); Remediation of dyes in textile effluent: a critical review on current treatment technologies with a proposed alternative Robinson et al. (2001); The removal of color from textile wastewater using whole bacterial cells: a review by Pearce et al. (2003); Removal of synthetic dyes from wastewaters: a review by Forgacs et al. (2004); Decolourization of industrial effluents—available methods and emerging

technologies—a review by Anjaneyulu et al. (2005); Adsorption–desorption characteristics of phenol and reactive dyes from aqueous solution on mesoporous activated carbon prepared from waste tires by Tanthapanichakoon et al. (2005); Non-conventional low-cost adsorbents for dye removal: a review by Crini (2006); Methods of dye removal from dye house effluent—an overview by Mondal (2008); Agricultural based activated carbons for the removal of dyes from aqueous solutions: a review by Demirbas (2009); Application of low-cost adsorbents for dye removal—a review by Gupta and Suhas (2009); Biodegradation of synthetic dyes—a review by Ali (2010); Decolorization of dye wastewaters by biosorbents: A review by Srinivasan and Viraraghavan (2010); Cationic and anionic dye adsorption by agricultural solid wastes: a comprehensive review by Salleh et al. (2011); A review on applicability of naturally available adsorbents for the removal of hazardous dyes from aqueous waste by Sharma et al. (2011); Adsorption of dyes and heavy metal ions by chitosan composites: a review by Wan Ngah et al. (2011); Microbial decolouration of azo dyes: A review by Solís et al. (2012); Adsorption of dyes using different types of sand: a review by Bello et al. (2013); Adsorptive removal of dyes from aqueous solution onto carbon nanotubes: a review by Gupta et al. (2013); Agricultural peels for dye adsorption: a review of recent literature by Anastopoulos and Kyzas (2014); Magnetic composite an environmental super adsorbent for dye sequestration—a review by Sivashankar et al. (2014); Dye and its removal from aqueous solution by adsorption: a review by Yagub et al.

**Table 3** Advantages and disadvantages of various methods used for the removal of malachite green dye (Dawood and Sen 2014; Yagub et al. 2014)

Techniques	Advantages	Disadvantages
<b>Chemical methods</b>		
Coagulation–floculation	Simple and economically feasible. Short detention time and low capital costs. Good removal efficiencies	High sludge production. Handling and disposal problems. High cost of chemicals for pH adjustment. Dewatering and sludge handling problems
Ozonation	Ozone can be applied in its gaseous state and does not increase the volume of wastewater and sludge	Short half-life (20 min)
Fenton's reagent	Capable of decolorizing wide variety of wastes. No attention in volume. Effective decolorization of both soluble and insoluble dyes	Prohibitively expensive. Sludge generation
<b>Biological methods</b>		
Biodegradation	Economically attractive. Publicly acceptable treatment	Slow process. Necessary to create an optimal favorable environment. Maintenance and nutrition requirements
<b>Emerging technologies</b>		
Photocatalysis	Process carried out at ambient conditions. Inputs are atoxic and inexpensive. Complete mineralization with shorter detention times. No sludge production	Effective for small amount of colorants. Expensive process. Formation of by-products
Sonication	Simplicity in use. Very effective in integrated systems	Relatively new method and awaiting full scale application

(2014), none of them has given comprehensive knowledge on the adsorptive removal of MG from aqueous media.

Therefore, in this review article we tried to congregate the available information on various adsorbents used for the removal of MG, a cationic dye, from water and wastewater. The main objective of this review article was to compile an extensive list of adsorbents which will help the future generation to furnish comprehensive up-to-date research summary on adsorbents used for removal of MG dye. Also the reported optimal experimental conditions (solution pH, contact time and amount of adsorbent) as well as adsorption isotherms, kinetics and thermodynamics data of different adsorbents towards MG were also mentioned. The authors embolden the readers to refer to the original research articles for information regarding the experimental conditions.

## Dyes and their classification

Dyes (a natural or synthetic substance) are mainly chemical compounds that can affix themselves on the surface of fabrics to impart color (Yagub et al. 2014). It refers as a substance, usually organic, which is designed to be absorbed or adsorbed by, made to react with, or deposited within a substrate to impart color to that substrate with some degree of permanence (Burkinshaw 2016). Dyes may be classified in several ways (Adegoke and Bello 2015). Figure 1 summarizes the complete classification of dyes.

### Based on the source of materials: Dyes can be classified mainly into two types based on their origin

#### Natural dyes

Natural dyes can be derived from the three primary sources—plants, animals and minerals. They are mostly negatively charged. Positively charged natural dyes can also exist, but they are not very common. Irrespective of the source of origin, natural dyes can be categorized as:

1. Substantive dyes: Those dyes which become chemically fixed to the fiber without the aid of any other chemicals or additives are referred to as substantive dyes or direct dyes.
2. Adjective dyes: Those natural dyes which require an added substance or mordant to make the dyes colorfast are known as adjective dyes or mordant dyes. Most of the natural dyes belong to this category (Cardon 2007).

#### Synthetic dyes

Dyes derived from organic or inorganic compounds are known as synthetic dyes. Because of their easy use, cost

effectiveness and wide range of colors these dyes became popular.

### Based on their method of application to the substrate

#### Acid dyes

Acid dyes are highly water soluble anionic dyes which contain one or more sulfonic groups/substituents and other acidic groups. They have better light fastness compare to basic dyes. The existence of sulfonic acid groups upsurge their solubility in water and give the dye molecules a negative charge. Acid dyes can be further divided into two sub-groups:

1. Acid-leveling dyes: These dyes are smaller or medium sized, and show a moderate affinity for wool fibers. Hence, due to average affinity these dyes are not very resistant to washing.
2. Acid-milling dyes: These dyes are larger than acid-leveling dyes, and show a much stronger inter-molecular attractions for wool fibers. Due to this strong affinity these dyes are very resistant to washing.

#### Basic dyes

These water soluble dyes possess cationic functional groups such as  $-NR^{3+}$  or  $=NR^{2+}$ . They are generally amino and substituted amino compounds soluble in acid. They become attached to the fibers by formation of ionic bonds with fiber's anionic groups.

#### Direct dyes

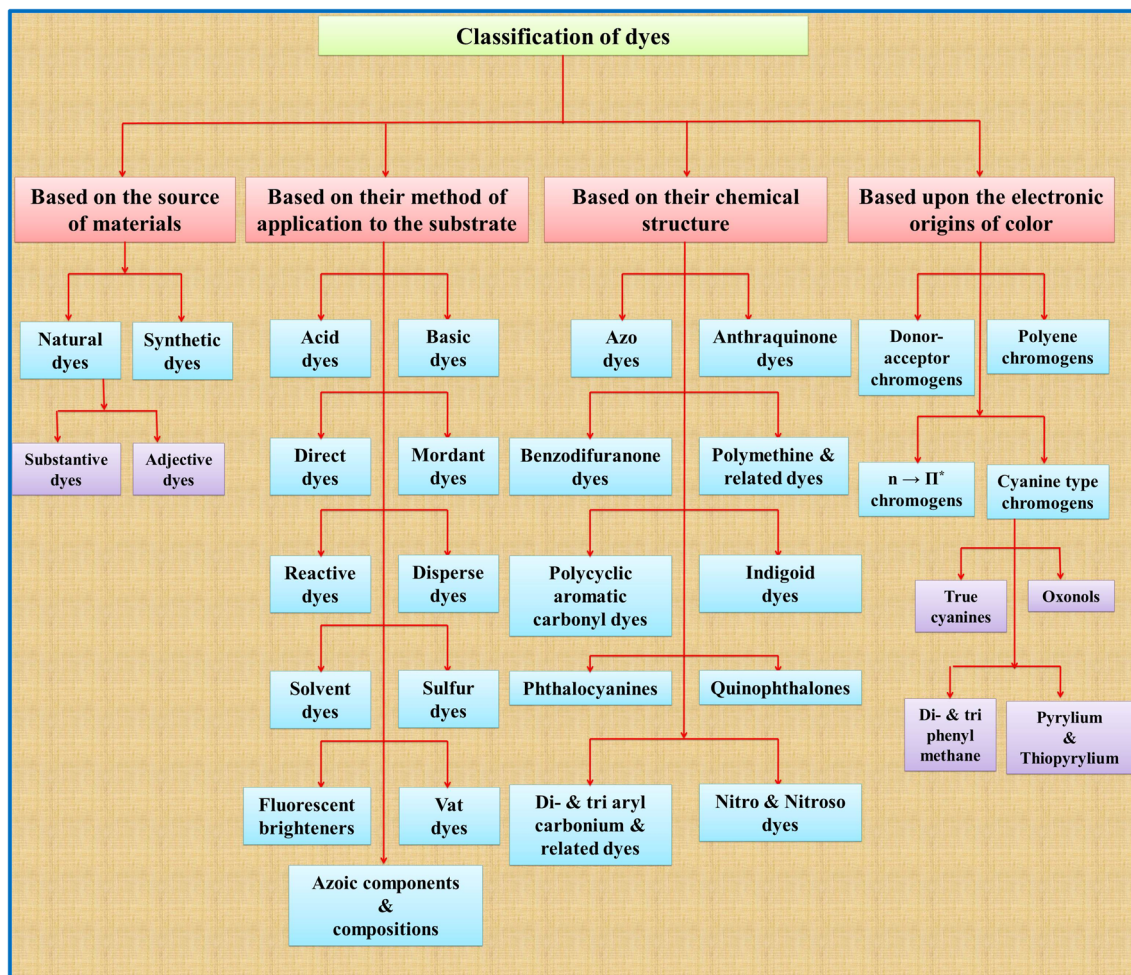
Although these dyes are water soluble anionic dyes, they cannot be classified as acid dyes because the acid groups are not the means of attachment to the fiber. Since, these dyes do not require any kind of fixing, they are called direct dyes.

#### Mordant dyes

A latin word mordant means 'to bite'. It acts as 'fixing agent' to improve the color fastness of some acid dyes, because they have the ability to form insoluble colored complexes with metal ions. They are usually metal salts. Besides, alum there is a large range of other metallic salt mordants available. Aluminum, chromium and iron salts are frequently used for synthetic mordant dyes.

#### Reactive dyes

Fiber reactive dyes will form a covalent bond while they react with the cellulosic fiber. As a result they are very



**Fig. 1** Broad classification of dyes

difficult to remove, once attached with the fiber. Initially, these dyes were designed for cellulose fibers but now some fiber-reactive dyes for protein and polyamide fibers are also commercially available.

#### *Disperse dyes*

These dyes have substantially low solubility in water. Their structure is small, planar and non-ionic with attached polar functional groups, such as  $-\text{NO}_2$  and  $-\text{CN}$ . They are mainly used for the dyeing of polyesters because they can interact with the polyester chains by forming dispersed particles.

#### *Solvent dyes*

These dyes are insoluble in water but soluble in alcohols, chlorinated hydrocarbons and liquid ammonia. They are mainly used for coloring plastics, synthetic fibers, gasoline, oils and waxes.

#### *Sulfur dyes*

Sulfur dyes are applied to cotton from an alkaline reducing bath with sodium sulfide as the reducing agent. These dyes are water insoluble but they are soluble in their reduced form and exhibit affinity for cellulose. They are low cost and have good fastness to light, washings and acids. The actual structures of sulfur dyes are largely unknown although it is considered that they possess sulfur-containing heterocyclic rings.

#### **Based on their chemical structure: (Gordon and Gregory 1987; Waring and Hallas 1990)**

#### *Azo dyes*

Approximately half of all dyes are azo dyes, making them the largest group of synthetic colorants used in textile industries. This type of dyes contain minimum one azo group but can also contain two or three, but very rarely,

four azo groups. Azo dyes are complex aromatic compounds with significant structural diversity and are of great environmental concern because the reductive cleavage of azo linkages is responsible for the formation of amines, which are classified as toxic and carcinogenic (Raval et al. 2016a).

#### *Anthraquinone dyes*

Anthraquinone dyes are the second most important class after azo dyes. They are also one of the oldest types of dyes since they have been found in the covering of mummies dating back over 4000 years. In contrast to the azo dyes, which have no natural counterparts, all the natural red dyes were anthraquinones. The lower tinctorial strength and reduced flexibility increase the production cost of anthraquinone dyes and hence, they are not as widely used as azo dyes.

#### *Benzodifuranone dyes*

Benzodifuranone (BDF) dyes are one such type which attacking anthraquinone dyes. The BDF chromogen is one of the very few novel chromogens to have been accidentally discovered this century

#### *Polymethine and related dyes*

Dyes containing a conjugated chain of carbon atoms terminated by an ammonium group and, in addition, a nitrogen, sulfur, or oxygen atom, or an equivalent unsaturated group is termed as polymethine dyes. This type of dyes may be neutral, cationic or anionic. The best known cationic polymethine dyes are the cyanine dyes. Cyanine dyes cannot be used as textile dyes because they have poor light fastness. They are used in photography.

#### *Polycyclic aromatic carbonyl dyes*

Polycyclic aromatic carbonyl dyes have one or more carbonyl groups. These carbonyl groups are linked by a quinonoid system. These dyes are relatively very large molecules which are made up from smaller units of anthraquinones. These dyes are often termed as anthraquinonoid vat dyes because they are applied to the substrate by a vatting process.

#### *Indigoid dyes*

Indigoid dyes also contain carbonyl groups, similar to the anthraquinone, benzodifuranone and polycyclic aromatic carbonyl dyes. They are vat dyes and represent one of the oldest known classes of dyes.

#### *Phthalocyanines*

Phthalocyanines are one of the novel chromophores which have been discovered since the nineteenth century. They are structurally similar to the natural porphyrin pigments haemin and chlorophyll. These natural pigments have poor stability, but phthalocyanines have exceptional stability and tinctorially stronger. All the phthalocyanine compounds are blue to green in color because substituents in their fused benzene rings exert only a minor sway on the color of phthalocyanines. They are widely used in printing inks and paints.

#### *Di- and tri-aryl carbonium and related dyes*

Di- and triarylcarbonium dyes and their heterocyclic derivatives comprise the oldest class of synthetic dyes—the majority of which were discovered in the 19th and early 20th century. Diphenylmethane and Triphenylmethane dyes are the most important aryl carbonium dyes. Structurally and property wise they are similar to the cyanine dyes i.e. exceptional brightness, high tinctorial strength and low light fastness.

#### *Nitro and nitroso dyes*

Nitro and nitroso dyes are minor commercial importance and constitute only a fraction of the total dyes market. Nitro dyes have simple chemical structures. They are small aromatic molecules which contain minimum one nitro group and one or more amino or hydroxy groups. Initially, the nitro dyes were acid dyes which were used for dyeing the natural animal fibers i.e. wool and silk. Picric acid was the first synthetic nitro dye which imparted a greenish-yellow color to silk but could not be used for longer period of time because of its toxicity and poor fastness properties.

Nitroso dyes are prepared by nitrosation of the appropriate phenol or naphthol. They are generally metal complex derivatives of *o*-nitrosophenols or naphthols. Nitroso dyes are polygenetic because they form differently colored complexes with different metals. They have good light fastness.

#### **Based upon the electronic origins of color**

Griffith (1976, 1981) has classified dyes based on the electronic mechanism by which color is generated. According to this, purely on theoretical basis, dyes can be arranged into four classes.

- (II) Donor–acceptor chromogens
- (III) Polyene chromogens
- (III)  $n \rightarrow \pi^2$  chromogens

(IV) Cyanine type chromogens

## Literature on various adsorbents used for the removal of MG

See (Fig. 2)

### Activated carbon adsorbents

Activated carbons (AC) are known as very efficacious adsorbents due to their large surface area, a micro-porous structure and a high degree of surface reactivity. However, due to their high production costs, these materials tend to be more expensive than other adsorbents. Four classes of AC include: powder (PAC), granular (GAC), fibrous (ACF) and cloth (ACC). Also two more frequently used ACs are: (1) commercial activated carbons and (2) activated carbons prepared from agricultural waste materials (Raval et al. 2016c).

#### Commercial activated carbons

A number of commercially available activated carbons such as powdered activated carbon (Kumar 2006); coal-based activated carbon (Aitcheson et al. 2000); commercially available powdered activated carbon (CPAC) (Malik et al. 2007); activated carbon prepared from lignite (Önal et al. 2007); activated Charcoal (Iqbal and Ashiq 2007); activated carbon prepared from Tuncbileklignite (Önal et al. 2006); oxyhumolite (Young brown coal) (Janos et al. 2005); Ordered mesoporous carbons (OMCs) (Tian et al.

2011); etc. have been extensively studied for the adsorption of MG.

Mesoporous carbon was synthesized by Anbia and Ghaffari (2012) for the removal of a cationic dye malachite green (MG) from aqueous solution. They carried out study under various experimental conditions and concluded that the equilibrium was attained within 30 min of contact with adsorbent and more than 99% removal of MG was reached at the optimum pH value of 8.5.

Aitcheson et al. (2000) used coal-based activated carbon 207EA (Sutcliffe Speakman) for the removal of aquaculture therapeutants (Malachite Green, formalin, Chloramine-T and Oxytetracycline) which were widely used in aquaculture to control fish parasites and disease. The adsorption process was well fitted to the Freundlich isotherm and confirmed that adsorption was heterogeneous in nature.

Adsorption of MG was studied by Mall et al. (2005) using commercial grade (ACC) and laboratory grade (ACL) activated carbons. Authors conducted batch adsorption studies to evaluate the effect of various parameters such as pH, adsorbent dose, contact time and initial MG concentration on the removal of MG and concluded that the effective pH was 7.0 for adsorption of MG. Equilibrium reached in about 4 h contact time and optimum ACC and ACL dosages were 20 and 4.0 g/L, respectively.

To overcome deficiencies of CACs the use of activated carbon adsorbents derived from various agricultural waste and industrial solid waste materials have received increasing consideration in the purification of wastewater over the last several years because they are generated in excess, inexpensive, locally available and their use will

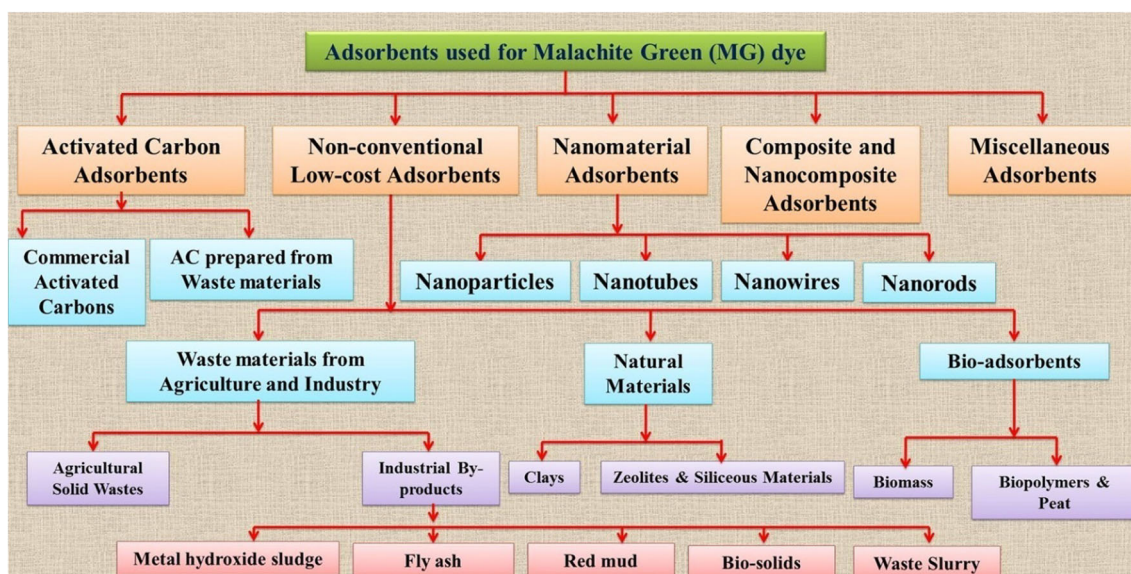


Fig. 2 Classification of adsorbents used for the removal of MG

further solve the problem of their disposal (Pehlivan and Arslan 2007).

#### *Activated carbons prepared from agricultural and industrial solid wastes*

As biomass and other waste materials have little or no economic value and often present a disposal problem, they offer an inexpensive and additional renewable source of activated carbon. Thus, conversion of these low cost by products into activated carbon would provide an inexpensive substitute to the existing CACs, add monetary value and help in dropping the expenditure of waste disposal (Raval et al. 2016c).

*Polygonum orientale* Linn is an annual plant of the genus *Polygonum* in the family Polygonaceae, which is native to eastern Asia and widely distributed in China. This plant has a developed caudex system and generally produces large and continuous caudex masses. Therefore, this plant offers a good basis for the development of adsorbent materials. Looking upon this property of plant (Wang et al. 2010) prepared *P. orientale* Linn activated carbon (PLAC) from waste *P. orientale* Linn by chemical activation with  $H_3PO_4$  and used as an adsorbent to remove malachite green (MG) and rhodamine B (RB) from aqueous solution.

Durian (*Durio zibethinus* Murray) is the most popular seasonal fruit in Southeast Asia, particularly Malaysia, Indonesia, Thailand, and the Philippines, and belongs to the family Bombacaceae. A significant percentage of the planted durian fruit crop is wasted each year. Only one third of durian fruit is edible, whereas the seeds (20–25%) and the shells are usually discarded. The wasted durian seed represents a significant potential for the development of value-added products. Thus, Ahmad et al. (2014) studied the removal of Malachite green dye using durian seed-based activated carbon.

Rambutan (*Nephelium lappaceum* L.) is a popular tropical fruit which belongs to Sapindaceae family. However, due to the high consumption of rambutan's edible part, massive amount of the peel is disposed, causing a severe problem in the community as they gradually ferment and release off odors. Therefore, Ahmad and Alrozi (2011) converted rambutan peel into activated carbon by physiochemical activation for its potential to remove MG dye from wastewater.

Akar et al. (2013) produced active carbon from spent tea leaves (STAC) by activation with 4% NaOH solution for the removal of malachite green dye because tea is basically dried and processed leaves of plant called *Camellia sinensis*. It is consumed by the most of people in the world and is the second most popular beverage in the world. It is estimated that between 18 and 20 billion cups of tea are

drunk daily in world and disposal of spent leaves become a major problem.

Banana (*Musa paradisiaca*) is native to Southeast Asia, most of the bananas produced are consumed locally and ~10% are exported. Massive amounts of stalk (as waste products) are disposed, resulting in a serious environmental problem through the emission of foul odors when it is left to decompose. Hence, Bello et al. (2012) attempted to use banana stalk, an abundantly available lignocellulosic agricultural waste, as a cheap and renewable precursor for activated carbon preparation for MG dye removal and helped in placing value on this agricultural waste and provide a potentially cheap alternative to existing commercial activated carbons.

In addition to above described materials, a wide variety of other agricultural and industrial waste materials have also been used for the preparation of activated carbon and applied for the adsorptive removal of MG dye from aqueous solution. It includes Tamarind fruit shells carbon (Vasu 2008); *Juglans regia* shells carbon (Nethaji et al. 2012); *Annona squamosa* seed (Santhi et al. 2010a); Groundnut shell carbon (Malik et al. 2007); Pine sawdust (Akmil-Başar et al. 2005); Tea leaves (Singh and Rastogi 2004); Bamboo (Hameed and El-Khaiary 2008a); Jute fiber (Porkodi and Vasanth Kumar 2007) and waste printed circuit boards (Kan et al. 2015), etc.

In addition, Table 4 presented various commercially available and agricultural waste based activated carbon adsorbents used for the removal of MG and their optimum conditions.

#### **Non-conventional low-cost adsorbents**

Activated carbon adsorption has been cited by the US Environmental Protection Agency as one of the best available control technologies. However, although activated carbon is a preferred sorbent, its widespread use is restricted due to high cost. To decrease the cost of treatment, attempts have been made to find inexpensive alternative adsorbents. Recently, numerous approaches have been studied for the development of cheaper and effective adsorbents. Thus, there is a need to search for new and economical adsorbent that could remove metal. In this context, agricultural by-products and industrial waste can be seen as having a great potential to be developed as a low cost sorbent. A low-cost adsorbent is defined as the one which is plentiful in nature, or is a by-product or waste from industry and requires little or no processing (Raval et al. 2016c). Literature survey reveals that multifarious materials have been utilized as adsorbents under this category.



**Table 4** The maximum adsorption capacities and other optimal conditions of commercially available and agricultural waste based activated carbon adsorbents for adsorption of MG from water and wastewater

Sr. No.	Adsorbents	$Q_{max}$ (mg/g)	Isotherm study	Kinetics study	Thermodynamic study	pH	Equilibrium time	Dosage of adsorbent	References
1.	Powdered activated carbon	509.00	Langmuir and Redlich–Peterson	–	Exothermic	–	–	–	(Kumar 2006)
2.	Activated carbon	490.77	Langmuir and Redlich–Peterson	Pseudo 2nd order	–	–	–	–	(Kumar and Sivanesan 2006)
3.	Mesoporous Carbon	476.10	Langmuir	Pseudo 1st order	–	8.5	30	0.005 g/25 mL	(Anbia and Ghaffari 2012)
4.	Coal-based activated carbon	325.00	Freundlich	–	–	–	–	–	(Aitcheson et al. 2000)
5.	Commercially available powdered activated carbon (CPAC)	222.22	Freundlich	–	–	–	15	0.7 g/L	(Malik et al. 2007)
6.	Activated carbon prepared from lignite	200.00	Langmuir	Pseudo 2nd order	Endothermic	7.0	60 min	0.1 g/50 mL	(Önal et al. 2007)
7.	Activated Carbon	75.08 (batch capacity) 94.00 (column capacity)	Langmuir and Freundlich	Pseudo 1st order	Endothermic	10.0	6–8 h	1.0 g/L	(Gupta et al. 1997)
9.	Laboratory grade activated carbon (ACL)	42.18	Redlich–Peterson	Pseudo 2nd order	–	7.0	240	4 g/L	(Mall et al. 2005)
10.	Acid-activated carbon	9.78	Langmuir	–	Endothermic	6.0	40 min	–	(Hema and Arivoli 2007)
11.	Commercial grade activated carbon (ACC)	8.27	Freundlich	Pseudo 2nd order	–	7.0	240	20 g/L	(Mall et al. 2005)
12.	Activated Charcoal	0.180	Langmuir	–	Exothermic	7.0	30 min	0.1 g	(Iqbal and Ashiq 2007)
13.	Activated carbon prepared from Tuncbileklignite	$9.92 \times 10^{-4}$ (mol/g)	Freundlich	Pseudo 2nd order	Endothermic	5.0	120 min	0.1 g/25 mL	(Önal et al. 2006)
14.	Oxyhumolite (Young brown coal)	0.278 mmol/g	Langmuir	–	–	5.0	–	–	(Janos et al. 2005)
15.	Activated carbon	26.19	Langmuir	Pseudo 2nd order	Endothermic	7.0	60 min	0.5 g/50 mL	(Arivoli et al. 2008)
16.	Oxyhumolite (Young brown coal)	0.278 mmol/g	Langmuir	–	–	–	–	–	(Janoš et al. 2007)
17.	Ordered mesoporous carbons (OMCs)	–	Freundlich	Pseudo 2nd order	Exothermic	–	–	0.07 g/25 mL	(Tian et al. 2011)
18.	<i>Polygonum orientale</i> Linn activated carbon (PLAC)	556.00	Langmuir	Pseudo 2nd order	Endothermic	10.0	150 min	0.45 g/L	(Wang et al. 2010)
19.	Durian seed activated carbon (DSAC)	476.19	Freundlich	Pseudo 2nd order	Endothermic	8.0	24 h	0.1 g	(Ahmad et al. 2014)
20.	Pine sawdust by chemical activation with $ZnCl_2$	370.37	Langmuir	Pseudo 1st order	–	10.0	120 min	0.1 g/25 mL	(Aknil-Başar et al. 2005)

Table 4 continued

Sr. No.	Adsorbents	$Q_{\max}$ (mg/g)	Isotherm study	Kinetics study	Thermodynamic study	pH	Equilibrium time	Dosage of adsorbent	References
21.	Rambutan peel-based activated carbon (RPAC)	329.49	Freundlich	Pseudo 2nd order	Endothermic	8.0	24 h	0.2 g	(Ahmad and Alrozi 2011)
22.	Tea leaves based activated carbon	275.00	Langmuir and Freundlich			8.0–10.0		1.2 g/L	(Singh and Rastogi 2004)
23.	Bamboo-based activated carbon	263.58	Langmuir	Pseudo 2nd order	–	4.0	170 min	0.2 g	(Hameed and El-Khaiary 2008a)
24.	Spent tea leaves active carbon (STAC)	256.40	Langmuir	Pseudo 2nd order	Endothermic	4.0		0.8 g/L	(Akar et al. 2013)
25.	Groundnut shell based powdered activated carbon (GSPAC)	222.22	Freundlich	–	–	–	30	0.7 g/L	(Malik et al. 2007)
26.	Cattail carbon	196.08	–	–	–	–	–	–	(Shi et al. 2010)
27.	Activated carbon prepared waste apricot	163.93	Langmuir and Frumkin	–	Endothermic	–	60 min	0.1 g/50 mL	(Başar 2006)
28.	Banana ( <i>Musa paradisiaca</i> ) stalk-based activated carbon	141.76	Langmuir	Pseudo 2nd order	Endothermic	8.0	120 min	0.2 g	(Bello et al. 2012)
29.	Jute fiber carbon (JFC)	136.58	Freundlich	Pseudo 2nd order	–	8.0	220 min	0.05 g	(Porkodi and Vasanth Kumar 2007)
30.	Activated carbon prepared waste apricot	111.60	–	Pseudo 2nd order	Endothermic	–	60 min	0.1 g/50 mL	(Onal 2006)
31.	Tamarind fruit shells activated carbon	83.41	Langmuir	Pseudo 2nd order	Endothermic	8.0			(Vasu 2008)
32.	Rubber seed coat based activated carbon (RSCAC)	72.73	Langmuir	–	Endothermic	6.0	3 h		(Idris et al. 2011)
33.	Rice husk activated carbon	63.85	Langmuir	Pseudo 2nd order	Exothermic		40 min		(Sharma et al. 2009)
34.	Activated carbon derived from <i>Borassus aethiopicum</i> flower biomass (PFAC)	48.48	Langmuir	Pseudo 2nd order	Endothermic	6.0–8.0	24 h	0.1 g/10 mL	(Nethaji et al. 2010)
35.	Rice husk activated carbon (RHAC)	49.62	Langmuir	Pseudo 2nd order	Endothermic	8.0	40 min		(Sharma 2011)
36.	Water nut modified carbon (WNMC)	46.27	Langmuir	Pseudo 2nd order	Endothermic	8.0		10 mg/50 mL	(Ahmad and Mondal 2010)
37.	<i>Cucumis sativ</i> a fruit peel based activated carbon	36.230	Langmuir	Pseudo 2nd order	–	6.0	50 min	1 g/50 mL	(Santhi and Manonmani 2011)
38.	<i>Juglans regia</i> shells-based activated carbon	29.74	Freundlich	Intraparticle diffusion and Boyd models	Endothermic	6.0–7.0	–	3.0 g/L	(Nethaji et al. 2012)
39.	Activated carbon prepared from the epicarp of <i>Ricinus communis</i>	27.78	Langmuir	Pseudo 2nd order	–	7.0	50 min	1 g/50 mL	(Santhi et al. 2010b)
40.	Coconut coir activated carbon	27.44	Langmuir	Pseudo 2nd order	Endothermic	–	–	–	(Uma et al. 2013)
41.	<i>Annona squamosa</i> seed based activated carbon	25.91	Temkin	Pseudo 2nd order	–	7.0	–	–	(Santhi et al. 2010a)
42.	Arundo donax root carbon (ADRC)	9.35	Langmuir	Pseudo 2nd order	Endothermic	5.0	180 min	0.6 g/100 mL	(Zhang et al. 2008)



Table 4 continued

Sr. No.	Adsorbents	$Q_{\max}$ (mg/g)	Isotherm study	Kinetics study	Thermodynamic study	pH	Equilibrium time	Dosage of adsorbent	References
43.	Cassava ( <i>Manihot esculenta</i> ) peels based carbon	-	-	-	-	-	-	-	(Rajeshwarisivaraj et al. 2001)
44.	Rubber wood ( <i>Hevea brasiliensis</i> ) sawdust carbon	-	Langmuir	Pseudo 2nd order	Endothermic	-	3.0 h	100 mg	(Rajgopal et al. 2006)
45.	Rice husk-based porous carbon	-	Freundlich	-	-	-	-	-	(Guo et al. 2003b)
46.	<i>Ulva lactuca</i> and <i>Systocera stricta</i> algae-based activated carbons	-	Langmuir	Pseudo 2nd order	Endothermic	4.0	90 min	10 g/L	(Sallima et al. 2013)
47.	Rice husk-based porous carbons (RHCs)	-	Freundlich	-	Endothermic	6.59	90 min	0.8 g/L	(Guo et al. 2003a)
48.	Activated <i>Enteromorpha</i> carbon	-	Langmuir	Pseudo 2nd order	-	4.0	3 h	250 mg	(Jayaraj et al. 2011)
49.	Activated carbons prepared from the agricultural solid wastes	-	-	-	-	-	-	-	(Kadirvelu et al. 2003)
50.	Activated parthenium carbon	-	-	-	-	6.35	30 min	-	(Rajeshwarisivaraj and Subburam 2002)

### Waste materials from agriculture and industry

**Agricultural solid wastes** Agricultural solid wastes are relatively cheap and are available in huge quantities. They can be used as an adsorbent due to their physic-chemical properties. The utilization of these wastes can play a significant role in national economy (Crini 2006).

Orange peel is discarded in the orange-juice and soft-drink industries all over the world. It has been used as an adsorbent for the removal of MG from wastewater by Kumar and Porkodi (2007). The results revealed that the adsorption process followed both Langmuir and Redlich–Peterson isotherms, the adsorption capacity was 483.63 mg/g.

A study of Rahman et al. (2005) reported the removal of MG from aqueous solutions onto Phosphoric acid ( $H_3PO_4$ ) and sodium hydroxide (NaOH) treated rice husks.

Rice straw is a lignocellulosic agricultural stalk containing cellulose (37.4%), hemi-cellulose (44.9%), lignin (4.9%) and silica ash (13.1%). Gong et al. (2006) compared MG adsorption efficiency of native and thermos chemically modified rice straw and found their adsorption efficiency 94.34 and 256.41 mg/g, respectively.

Chieng et al. (2015) investigated the use of breadnut (*Artocarpus camansi*) as a low-cost adsorbent for the removal of MG toxic dye. In Brunei Darussalam, breadnut was locally known as ‘*Kemangsi*’, whose seeds were consumed either cooked or roasted. The skin and core of *Artocarpus* fruits, the major parts of the fruits, were inedible and have no economical value, and discarded as waste. Authors concluded that the adsorption characteristics of breadnut skin towards MG can be significantly enhanced by modification through treatment with dilute NaOH solution.

Other solid wastes from cheap and readily available resources have also been successfully employed for the removal of MG from aqueous solution and were given in Table 5.

**Industrial by-products/industrial solid wastes** Industrial by products, such as metal hydroxide sludge, fly ash, red mud and bio-solids, can be used as low-cost adsorbents for MG removal. Table 6 represented the maximum adsorption capacities together with the isotherm, kinetics and thermodynamic results of various industrial solid wastes adsorbents for MG.

Fly ash: Witek-Krowiak et al. (2012) investigated the use of fly ash for the adsorption MG from solution with different contact times, initial dye concentrations, pHs and temperatures. The adsorption equilibrium has been described in terms of Langmuir model. The enthalpy values obtained in the experiment were not high, which suggested

that physical sorption dominates in the process of cationic dyes bonding on microspheres of fly ash.

Bagasse fly ash (BFA) is a waste collected from the particulate separation equipment attached to the flue gas line of the sugarcane bagasse-fired boilers and has been used as an effective adsorbent for the removal of dyes. This is available in plenty, and almost free of cost from the sugar mills. In addition, bagasse fly ash generated in the sugar industry does not contain large amounts of toxic metals and hence, Mall et al. (2005) used bagasse fly ash (BFA) as adsorbent for the removal of MG from aqueous solutions. Maximum adsorption capacity for MG was reported as 170.33 mg/g (at pH 7.0 and adsorbent dosage of 1.0 g/L) and within 240 min of contact time.

Waste red mud: Zhang et al. (2014b) used the acid activated (Acid treatment neutralize the alkalinity of red mud, which could also be recognized as a method for activating the material) sintering process red mud (ASRM) for the adsorption of MG. The optimum process variables were found to be pH > 3.2, 180 min of contact time and 0.25 g/250 mL of adsorbent dosage. The adsorption process followed the Langmuir isotherm with 336.40 mg/g of adsorption capacity.

Activated slag: Steel plants produce granular blast furnace slag as a byproduct, and this material also causes a disposal problem. Hence, Gupta et al. (1997) utilized this waste product for the adsorption of MG from aqueous medium both in batch and column modes. Further, they concluded that the column capacity was found to be higher than the batch capacity. The removal takes place through a film diffusion mechanism at lower concentrations and by particle diffusion at higher concentrations.

#### Natural materials

**Clays** Clay is mineral comprised of alumina and silica that usually includes bound water. Clays have a sheet-like structure and are composed of tetrahedrally arranged silicates and octahedrally arranged aluminates. Due to their low-cost, abundance in nature, high sorption capacity, chemical and mechanical stability, layered structure and high cation-exchange capacity (CEC), clay minerals are frequently used as an adsorbent (Krauskopf 1956; da Fonseca et al. 2006). The clays always contain exchangeable ions on their surface and play vital role in the environment by acting as a natural scavengers of contaminants by taking up cations and/or anions through either ion exchange or adsorption (Babel and Kurniawan 2003).

A low-cost inorganic powder (Persian Kaolin) was used as adsorbent for the sequestration of cationic dye from aqueous solution by Tehrani-Bagha et al. (2011). The sorption of the dye malachite green on kaolin confirmed to linear form of Langmuir adsorption equation. The

maximum adsorption capacity was 52.91 mg/g. In addition, kinetic and thermodynamic parameters, such as enthalpy ( $\Delta H$ ) and free energy ( $\Delta G$ ) were calculated. The negative values of  $\Delta G$  and positive values of  $\Delta H$  indicated that the dye adsorption process was spontaneous and endothermic in nature

The efficacy of montmorillonite clay had been investigated by Tahir et al. (2010) for the adsorptive removal of malachite green dye from aqueous solution. Authors concluded that the MG dye was homogeneously adsorbed on the surface of montmorillonite clay adsorbent.

Bulut et al. (2008) investigated the sorption of MG from aqueous solution onto bentonite as a function of contact time, pH and initial dye concentration. The adsorption equilibriums have been described in terms of Langmuir, Freundlich, Temkin and Dubinin–Radushkevich models. Authors reported that the adsorption process obeyed the Langmuir isotherm and pseudo-second-order kinetic model. The results of the thermodynamic study indicated that the sorption process was endothermic and spontaneous.

Tahir and Rauf (2006) utilized the natural bentonite clay for the adsorption of MG dye from aqueous solution. The authors finally concluded that the values of sorption free energy ( $E_a$ ) of 1.00–1.12 kJ/mol indicated physical adsorption of dye on clay mineral.

**Siliceous materials** Siliceous rocks are sedimentary rocks that have silica ( $\text{SiO}_2$ ) as the principal constituent. The most common siliceous rock is chert other types include diatomite. They commonly form silica-secreting organisms, such as radiolarians, diatoms, or some types of sponges. The natural siliceous materials used for MG adsorption were perlite, silica, glass fibers and alunite because of their high abundance, easy availability and low cost.

Govindasamy et al. (2009) studied the removal of MG from aqueous solution by perlite. Authors reported 40 min of contact time, 0.1 g/50 mL of adsorbent dosage and 8.0–9.0 pH value were optimum conditions for the removal of dye. It was suggested that the adsorption of MG onto perlite was spontaneous, chemical and exothermic in nature and followed Freundlich isotherm as well as pseudo-first-order kinetic rate model.

Silica gel is a hydrophilic porous adsorbent. Aromatic compounds are found to involve the pi-cloud in hydrogen bonding with silanol ( $\text{SiOH}$ ) group during adsorption. Cationic and nonionic surfactants adsorb on silica surface involving hydrogen bonding (Parida et al. 2006).

Kannan et al. (2008) utilized tetrahedral silica for the adsorption of MG. The adsorbent was characterized by Fourier transformed infrared spectroscopy (FT-IR) to confirm the tetrahedral framework of silica. The

**Table 5** The maximum adsorption capacities and other optimal conditions of agricultural solid wastes for adsorption of MG from water and wastewater

Sr. No.	Adsorbents	$Q_{max}$ (mg/g)	Isotherm study	Kinetics study	Thermodynamic study	pH	Equilibrium time	Dosage of adsorbent	References
1.	Orange Peel	483.63	Langmuir and Redlich-Peterson	-	-	-	-	-	(Kumar and Porkodi 2007)
2.	Pyromellitic dianhydride modified sugarcane bagasse	377.40	Langmuir	Pseudo 2nd order	-	6.0	13 h	-	(Yu et al. 2011)
3.	NaOH-modified breadnut peel	353.00	Sips	Pseudo 2nd order	Exothermic	8.02	240 min	-	(Chieng et al. 2015)
4.	NaOH-modified grapefruit peel (MGP)	314.90	Koble-Corrigan and Dubinin-Radushkevich models	Elovich model	Endothermic	-	-	-	(Zou et al. 2013)
5.	Oxalic acid modified <i>Cinnamomum camphora</i> sawdust (OACS)	282.50	Langmuir	Pseudo 2nd order	Endothermic	8.0	3 h	1.0 g/L	(Wang et al. 2014a)
6.	Modified rice straw (MRS) [rice straw was modified with citric acid (CA)]	256.41	Langmuir and Freundlich	Pseudo 1st order	-	6.0	10 h	2.0 g/L	(Gong et al. 2006)
7.	Citric acid modified <i>Cinnamomum camphora</i> sawdust (CACS)	260.40	Langmuir	Pseudo 2nd order	Endothermic	8.0	3 h	1.0 g/L	(Wang et al. 2014a)
9.	Eggshells	243.20	Freundlich	-	-	6.0	-	1.0 g/L	(Podstawczyk et al. 2014)
10.	Functionalized sawdust (FS)	196.08	Langmuir	-	Exothermic	6.0	4.5 h	2.0 g/L	(Gong et al. 2009)
11.	Treated ginger waste (TGW)	188.60	Langmuir	Pseudo 2nd order	Endothermic	9.0	150 min	0.5 g	(Ahmad and Kumar 2010)
12.	Breadnut peel	180.00	Freundlich	Pseudo 2nd order	Endothermic	8.02	240 min (2 h)	-	(Chieng et al. 2015)
13.	Phosphoric acid esterifying soybean hull	178.57	Langmuir	Pseudo 2nd order	Exothermic	6.0	-	2.0 g/L	(Gong et al. 2008)
14.	Pomelo ( <i>Citrus grandis</i> ) peels	178.43	Langmuir	Pseudo 2nd order	Endothermic	8.0	240 min	0.2 g	(Bello et al. 2014)
15.	Treated jack fruit peel	166.37	-	-	-	-	-	-	(Inbaraj and Sulochana 2002)
16.	Ethylendiaminetetraacetic dianhydride (EDTAD) modified sugarcane bagasse (SB)	157.20	Langmuir	Pseudo 2nd order	Endothermic	6.0	3 h	10 mg	(Xing and Deng 2009)
17.	Tartaric acid modified <i>Cinnamomum camphora</i> sawdust (TACS)	156.70	Langmuir	Pseudo 2nd order	Endothermic	8.0	3 h	1.0 g/L	(Wang et al. 2014a)
18.	Oil palm trunk fiber (OPTF)	149.35	Langmuir	Pseudo 1st order	-	8.0	195 min	0.30 g	(Hameed and El-Khatary 2008b)
19.	Rice straw-derived char (RSC)	148.74	Langmuir	Pseudo 1st order	-	3.0-7.0	-	1.5 g/L	(Hameed and El-Khatary 2008c)
20.	Effective Microorganisms based compost (EMKC)	136.60	Sips	Pseudo 2nd order	-	8.0	-	4.0 g/L	(Bhagavathi Pushpa et al. 2015)

Table 5 continued

Sr. No.	Adsorbents	$Q_{max}$ (mg/g)	Isotherm study	Kinetics study	Thermodynamic study	pH	Equilibrium time	Dosage of adsorbent	References
21.	Neem leaf powder	133.6	Langmuir	Pseudo 1st order	Endothermic	–	300 min	0.63 g/L	(Bhattacharyya and Sarma 2003)
22.	Formaldehyde-treated <i>Simarouba glauca</i> seed shell powder	125.00	Langmuir	Pseudo 2nd order	–	8.0	60 min	0.15 g	(Jeyagowri and Yamuna 2015)
23.	Cellulose modified with phthalic (P) anhydride (CPA)	111.00	Langmuir	Pseudo 2nd order	Endothermic	–	–	–	(Zhou et al. 2015)
24.	Poly(methacrylic acid)-modified sugarcane bagasse	103.20	Langmuir	Pseudo 2nd order	–	6.0	3 h	–	(Xing and Wang 2009)
25.	Brinjal plant root powder (cellulose)	100.29	Freundlich	Pseudo 2nd order	Endothermic	6.0	25 min	250 mg/50 mL	(Buvanewari and Kannan 2011)
26.	Oxidized-activated form HTC-APN	97.08	Langmuir	Pseudo 2nd order	Endothermic	7.0	–	2.0 g/L	(Hammud et al. 2015)
27.	Native rice straw	94.34	Langmuir and Freundlich	Pseudo 1st order	–	6.0	10 h	5.0 g/L	(Gong et al. 2006)
28.	Conch shell powder (CSP)	92.25	Langmuir	Pseudo 2nd order	Endothermic	8.0	120 min	3.0 g/L	(Chowdhury and Saha 2011)
29.	20% Phosphoric acid ( $H_3PO_4$ ) treated + carbonized rice husks [PCP 20]	92.592	Langmuir and Freundlich	–	Endothermic	5.0–6.0	30 min	0.6 g/100 mL	(Rahman et al. 2005)
30.	Walnut shell (WS)	90.80	Langmuir	Pseudo 2nd order	Endothermic	5.0	90	0.03 g/20 mL	(Dahri et al. 2014)
31.	10% Phosphoric acid ( $H_3PO_4$ ) treated + carbonized rice husks [PCP 10]	83.33	Langmuir and Freundlich	–	Endothermic	5.0–6.0	30 min	0.8 g/100 mL	(Rahman et al. 2005)
32.	White rice husk ash (WRHA)	85.56	Langmuir	Pseudo 2nd order	Exothermic	7.0	120 min	0.45 g/100 mL	(Tavlieva et al. 2013)
33.	Crude sawdust (CS)	85.47	Langmuir	–	Exothermic	8.0	23 h	5.0 g/L	(Gong et al. 2009)
34.	Bivalve shell-treated <i>Zea mays</i> L. (maize) husk leaf [BS-ZHL]	81.5	Langmuir	Pseudo 1st order	Endothermic	6.0	0.5 h	2.5 g/L	(Jalil et al. 2012)
35.	Maize cob (Zea maize)	80.64	Langmuir and Freundlich	Pseudo 2nd order	–	8.0	25 min	4.0 g/L	(Sonawane and Shrivastava 2009)
36.	Scots Pine ( <i>Pinus silvestris</i> ) sawdust	71.67	Langmuir	Pseudo 2nd order	–	5.0	–	2.0 g/L	(Witek-Krowiak 2013)
37.	<i>Luffa acutangula</i> peel	69.64	Langmuir	Pseudo 2nd order	Endothermic	4.0	–	8.0 g/L	(Ng et al. 2015)
38.	Rice bran	68.97	Freundlich	Pseudo 2nd order	Spontaneous and physical	6.0	60–90 min	5.0 g/L	(Wang et al. 2008b)
39.	Formaldehyde-treated sawdust (PCSD)	65.80	–	Pseudo 1st order	–	6.0–10.0	30–45 min	1.0 g/100 mL	(Garg et al. 2004)



Table 5 continued

Sr. No.	Adsorbents	$Q_{\max}$ (mg/g)	Isotherm study	Kinetics study	Thermodynamic study	pH	Equilibrium time	Dosage of adsorbent	References
40.	Sulphuric acid-treated sawdust (PCSDC)	65.8	–	Pseudo 1st order	–	6.0–10.0	30–45 min	1.0 g/100 mL	(Garg et al. 2004)
41.	Wheat bran	66.57	Freundlich	Pseudo 2nd order	Spontaneous and physical	6.0	60 – 90 min	5.0 g/L	(Wang et al. 2008b)
42.	Lignocellulosic material (TA modified oil palm tree sawdust)	65.79	Langmuir	Pseudo 2nd order	Endothermic	9.0			(Low et al. 2013)
43.	Rattan sawdust (RSD)	62.71	Langmuir	Pseudo 1st order	–	4.0–9.0	210 min	0.30 g	(Hameed and El-Khaiary 2008d)
44.	Eucalyptus bark	59.88	Langmuir	Pseudo 2nd order	Endothermic	5.0	270 min	1.0 g/200 mL	(Boutemedjet and Hamdaoui 2009)
45.	NaOH treated saw dust	58.4795	R–P and Temkin	Pseudo 2nd order	Exothermic	2.9	3 h	4 g/L	(Mane and Babu 2011)
46.	Sodium hydroxide (NaOH) treated + carbonized rice husks [NCP]	57.143	Langmuir	–	Exothermic	5.0 – 6.0	30 min	0.6 g/100 mL	(Rahman et al. 2005)
47.	Eggshell	56.76	Langmuir and Freundlich	Pseudo 2nd order	Endothermic	9.0	90 min	2.0 g/L	(Chowdhury and Das 2012)
48.	Degreased coffee bean	55.3	Langmuir and Freundlich	Pseudo 2nd order	Endothermic	4.0	120 min (2 h)	2.0 g/L	(Baek et al. 2010)
49.	Tamarind seed	54.95	Langmuir	Pseudo 1st order	–	7.0	202 min	2.85 g/L	(Rajeshkannan et al. 2011)
50.	Aerobic granules	56.80	Langmuir	Pseudo 2nd order	Endothermic	Alkaline pH	60 min (50–60 mg/L)	0.09 g	(Sun et al. 2008)
51.	<i>Ananas comosus</i> (pineapple) leaf powder	54.64	Langmuir	Pseudo 2nd order	Exothermic	9.0	150 min	5.0 g/L	(Chowdhury et al. 2011a)
52.	Hydrothermal carbonization of pine needles (HTC-PN)	52.91	Langmuir	Pseudo 2nd order	Endothermic	7.0	–	2.0 g/L	(Hammud et al. 2015)
53.	Lemon peel	51.73	Langmuir and Redlich–Peterson	–	–	–	24 h	0.5 g/L	(Kumar 2007)
54.	Pine tree root decayed by brown-rot fungi (BRW)	42.63	Langmuir	Pseudo 2nd order	Endothermic	4.0	24 h	3.95 g/L	(Zhang et al. 2011)
55.	Sea shell powder	42.33	Langmuir	Pseudo 2nd order	Exothermic	8.0	120 min	2.0 g/L	(Chowdhury and Saha 2010a)
56.	<i>Limonia acidissima</i> (wood apple) shell	34.56	Langmuir	Pseudo 1st order	Endothermic	7.5–8.0	210 min (3.30 h)	0.4 g	(Sartape et al. 2015)

Table 5 continued

Sr. No.	Adsorbents	$Q_{\max}$ (mg/g)	Isotherm study	Kinetics study	Thermodynamic study	pH	Equilibrium time	Dosage of adsorbent	References
57.	Jalshakti® (JS), a super absorbent polymer	34.2	Langmuir	Intraparticle Diffusion	–	–	60–90 min	0.8 g/L	(Dhodapkar et al. 2007)
58.	Potato leaves powder, PLP	33.30	Freundlich	Pseudo 2nd order	Exothermic	7.0	–	2.0 g/L	(Gupta et al. 2014)
59.	Fish ( <i>Labeo rohita</i> ) Scales	38.461	Langmuir	Pseudo 2nd order	Endothermic	8.0	60 min	2.0 g/L	(Chowdhury et al. 2012)
60.	Rubber wood( <i>Hevea brasiliensis</i> ) sawdust	36.45	Langmuir and Redlich–Peterson	–	–	–	–	–	(Vasanth Kumar and Sivanesan 2007)
61.	Luffa cylindrica	29.40	Langmuir	Pseudo 2nd order	Endothermic	5.0	5 h	0.05 g	(Altınışık et al. 2010)
62.	Potato stem powder (PSP)	27.0	Freundlich	Pseudo 2nd order	Exothermic	7.0	–	2.0 g/L	(Gupta et al. 2014)
63.	Peroxide treated rice husk (PRH)	26.60	Langmuir	Pseudo 2nd order	Endothermic	8.0	90 min	200 mg/100 mL	(Ramaraju et al. 2014)
64.	Hen feathers	26.10	Langmuir	Pseudo 1st order	Endothermic	5.0	150 min	0.1 g	(Mittal 2006)
65.	Marine alga <i>Caulerpa Racemosa</i> var. <i>cylindracea</i> (CRC)	25.67	Freundlich	Pseudo 2nd order	Endothermic	6.0	300 min	0.1 g/25 mL	(Bekçi et al. 2009)
66.	Mesoporous aluminophosphate (AIPO <sub>4</sub> ) molecular sieve	24.51	Langmuir	Pseudo 2nd order	Endothermic	10.0	20 min	0.5 g	(Kannan et al. 2013)
67.	Wheat bran	24.0	Freundlich	–	–	7.0–9.0	40 min	–	(Papinutti et al. 2006)
68.	Sugarcane Bagasse (SB)	23.41	Langmuir	Pseudo 2nd order	Endothermic	6.0	3 h	10 mg	(Xing and Deng 2009)
69.	Nitric acid treated rice husk (NRH)	18.10	Langmuir	Pseudo 2nd order	Endothermic	8.0	90 min	200 mg/100 mL	(Ramaraju et al. 2014)
70.	Chemically modified rice husk	17.98	Freundlich	Pseudo 2nd order	Endothermic	7.0	60 min	1.0 g/L	(Chowdhury et al. 2011b)
71.	Rapeseed press cake	17.857	Langmuir	Pseudo 2nd order	Endothermic	6.5	180 min	2.5 mg/L	(Jasińska et al. 2013)
72.	Char from lotus seed biomass	16.75	Langmuir and Freundlich	Pseudo 2nd order	Endothermic	6.84	–	1.5 g/150 mL	(Nethaji et al. 2013)
73.	Citric acid (CA) treated pea shells (CAPS)	14.49	Freundlich	Pseudo 2nd order	Endothermic	7.0	35–40 min	6.0 g/L	(Khan et al. 2014)
74.	Waste Pea ( <i>Pisum sativum</i> L.) shell (PS)	6.20	Freundlich	Pseudo 2nd order	Endothermic	7.0	35–40 min	10.0 g/L	(Khan et al. 2014)





Table 5 continued

Sr. No.	Adsorbents	$Q_{\max}$ (mg/g)	Isotherm study	Kinetics study	Thermodynamic study	pH	Equilibrium time	Dosage of adsorbent	References
75.	Sugar cane dust	4.88							(Khattri and Singh 1999)
76.	Neem sawdust	4.354	Langmuir	Pseudo 1st order	Exothermic	7.2	–	–	(Khattri and Singh 2009)
77.	Poultry feathers	3.55	Langmuir	Pseudo 1st order	Endothermic	4.0	120 min	0.2 g/100 mL	(Beak et al. 2009)
78.	Neem saw dust	3.420	Langmuir	–	Exothermic	7.5	–	–	(Khattri and Singh 2000)
79.	Tamarind fruit shell	1.951	Langmuir	Pseudo 2nd order	Endothermic	5.0	60 min	30 g/L	(Saha et al. 2010a)
80.	Mango bark powder (MBP)	0.53 mmol/g	Langmuir	Pseudo 2nd order	Endothermic	6.03	150 min	2.0 g/50 mL	(Srivastava and Rupainwar 2011)
81.	Neem bark powder (NBP)	0.36 mmol/g	Langmuir	Pseudo 2nd order	Endothermic	6.80	120 min	2.0 g/50 mL	(Srivastava and Rupainwar 2011)
82.	Seashell powder	–	–	–	–	–	–	–	(Chowdhury and Saha 2012)
83.	Eggshell powder	–	–	–	–	–	–	–	(Chowdhury and Saha 2012)
84.	Mesoporous borosilicates (MBS)	–	–	–	–	–	–	–	(Paul et al. 2012)
85.	Kapok hull	–	Langmuir	Pseudo 2nd order	Endothermic	–	–	–	(Syed 2011)
86.	Used black tea (UBT)	–	Langmuir	–	Exothermic	–	10 min	0.7 g	(Tahir et al. 2009)
87.	Formaldehyde treated and sulphuric acid treated saw dusts	–	–	–	–	6.9–9.0	120 min	0.4 g/100 mL	(Garg et al. 2003)
88.	NaOH-modified rice husk (NMRH)	–	–	–	–	10.0	–	–	(Chowdhury and Saha 2013)
89.	Sea shell	–	–	Pseudo 2nd order	–	–	–	–	(Chowdhury and Saha 2010b)
90.	Sagaun sawdust	–	Langmuir	–	–	7.5	–	–	(Khattri and Singh 1999)
91.	Pretreated rice husk	–	–	Pseudo 2nd order	–	–	–	–	(Chowdhury and Saha 2011b)
92.	Sugar cane dust	–	Langmuir	–	–	7.5	–	–	(Dadhaniya et al. 2006)
93.	Snail shell (SS)	–	–	–	–	–	–	–	(Oladoja and Aliu 2009)

Table 5 continued

Sr. No.	Adsorbents	$Q_{\max}$ (mg/g)	Isotherm study	Kinetics study	Thermodynamic study	pH	Equilibrium time	Dosage of adsorbent	References
94.	Dead leaves of plane tree ( <i>Platanus vulgaris</i> )	–	Langmuir	Pseudo 2nd order	Endothermic	–	300 min	0.25 g/100 mL	(Hamdaoui et al. 2008b)
95.	De-oiled soya	–	Langmuir	Pseudo 1st order	Endothermic	5.0	–	0.1 g	(Mittal et al. 2005)
96.	Bottom ash	–	–	–	Endothermic	5.0	1–2 h	0.1 g/100 mL	(Gupta et al. 2004)
97.	Ferro-fluid modified sawdust	–	–	–	–	–	–	–	(Safarik et al. 2007)

thermodynamic studies proved that the adsorption was endothermic and chemisorptions ( $\Delta H^0 > 40$  kJ/mol) on silica. Recovery of dye on silica was studied from 30 to 90 °C and observed that only 3.5% was recovered from silica. The less recovery on silica proved the strong adsorption of dye on silica.

Talc is the most common silicate material, with an idealized chemical formula of  $Mg_3Si_4O_{10}(OH)_2$ . Its ability to remove aqueous MG from solution had been studied by Lee et al. (2013).

**Zeolites** Zeolites are highly porous crystalline aluminosilicates with tetrahedrally connected three dimensional frameworks and extra-framework charge balancing cations. Zeolite structures are commonly described in terms of the size, geometry and connectivity of the pore space. The use of natural zeolite as an adsorbent has gained interest among researchers; mainly because of its sorption properties provide a combination of ion exchange and molecular sieve properties which can also be easily modified (Goursot et al. 1997; Sánchez and Pariente 2011).

Zeolites have been used as chemical sieves, as water softeners, as removers of ammonia from urban, agricultural and industrial waste waters and of toxic gases from gaseous emissions, as filters for odor control, as chemical fertilizer, herbicide and pesticide carriers and in animal nutrition (Sand and Mumpton 1978; Breck 1984; Karge and Weitkamp 1989).

Han et al. (2010) investigated the use of natural zeolite, obtained from Xinyang city in China, for the removal of MG from aqueous solution. The rate constants of sorption for different kinetic models were calculated. Good correlation coefficients were obtained for the pseudo-second order kinetic model. In addition, authors were treated spent zeolite by microwave irradiation and it was found that yield of regeneration was 85.8% in the case of microwave irradiated time 10 min at 160 W.

Table 7 represented the maximum adsorption capacities together with the isotherm, kinetics and thermodynamic results of various natural materials used for the removal of MG

### Biosorbents

Biosorption is defined as the accumulation and concentration of pollutants from aqueous solutions by the use of biological materials. Biological materials, such as yeast, fungi or bacterial biomass and biopolymers are used as adsorbents for the removal of MG from aqueous media (Raval et al. 2016d; Gupta et al. 2015).

**Biomass** Biomass is biological material derived from living, or recently living organisms, which can be applied

**Table 6** The maximum adsorption capacities and other optimal conditions of various industrial waste materials for adsorption of MG from water and wastewater

Sr. No.	Adsorbents	$Q_{\max}$ (mg/g)	Isotherm study	Kinetics study	Thermodynamic study	pH	Equilibrium time	Dosage of adsorbent	References
1.	Acid-activated sintering process red mud (ASRM)	336.40	Langmuir	Pseudo 2nd order	Endothermic	>3.2	180 min	0.25 g/250 mL	(Zhang et al. 2014b)
2.	Bagasse fly ash	170.33	Freundlich	Pseudo 2nd order	–	7.0	240 min	1 g/L	(Mall et al. 2005)
3.	Activated Slag	74.16 (batch capacity) 78.00 (column capacity)	Langmuir and Freundlich	Pseudo 1st order	Endothermic	10.0	6–8 h	1.0 g/L	(Gupta et al. 1997)
4.	Fly ash	40.65	Langmuir	Pseudo 2nd order	Endothermic	>6.0	–	2.0 g/L	(Witek-Krowiak et al. 2012)
5.	Ca(OH) <sub>2</sub> –Treated Fly Ash	17.383	Langmuir	Pseudo 2nd order	Exothermic	7.0	120 min	1.0 g	(Chowdhury and Saha 2011a)
6.	Bottom ash	$6.2 \times 10^{-3}$	Langmuir	Pseudo 2nd order	Endothermic	5.0	4500 s	0.1 g	(Gupta et al. 2004)
7.	Carbon based adsorbents [waste material from paper industry (WMPI) and pine bark (PB)]	–	–	–	–	–	–	0.05 mg/20 mL	(Méndez et al. 2007)

to both animal and vegetable derived material. The major advantages of biosorption over conventional treatment methods include, low cost; high efficiency; minimization of chemical or biological sludge; no additional nutrient requirement and possibility of regeneration of biosorbent (Volesky 1990).

Decolorization/bioadsorption of MG dye from wastewater by (dead/living) biomass of submerged aquatic plant (Rajesh Kannan et al. 2010); white-rot fungi (Kuhar and Papinutti 2013); fresh water algae (Kumar et al. 2005); brown marine algae (Kannan et al. 2009) and immobilized baker's yeast cells (Godbole and Sawant 2006) were studied by many researchers (shown in Table 8)

Wang (2009) used alligator weed (a freshwater macrophyte) as biosorbent for the removal of basic dye malachite green from aqueous solution mainly because alligator weed, originated from South America, occupies agricultural areas and blocks drainage and irrigation channels causing problems on agricultural land. In addition, it causes water pollution from plant decomposition and an increase in mosquito breeding areas. Finally, author concluded that the alligator weed could serve as low-cost adsorbents for removing MG from aqueous medium.

Parthenium (*Parthenium hysterophorus* L.), also known as white top or carrot weed, an annual herbaceous weed was pretreated with H<sub>3</sub>PO<sub>4</sub> and H<sub>2</sub>SO<sub>4</sub> by Lata et al. (2008) and employed for the adsorption of MG dye.

**Biopolymers** Biopolymers are high molecular weight compounds synthesized by living organisms. The performance of chitin hydrogel as an adsorbent to remove MG has been demonstrated by Tang et al. (2012). They found that the maximum adsorption capacity of hydrogel for MG was 26.88 mg/g. Authors concluded from the calculated activation energy (37.18 kJ/mol) and from the results of SEM and FTIR that the adsorption of malachite green on the hydrogel was physical process.

Bekçi et al. (2008) synthesized chitosan beads and examined its adsorption capacity towards MG. In contrast to the chitin hydrogels the authors concluded from the calculated activation energy value (85.6 kJ/mol) that the adsorption of MG onto chitosan beads was chemical in nature.

Although chitin and chitosan are abundantly available biopolymers and are biocompatible and biodegradable material, they have less chemical versatility due to their strong crystal structure, and hence their chemical structures

**Table 7** The maximum adsorption capacities and other optimal conditions of various natural materials for adsorption of MG from aqueous solutions

Sr. No.	Adsorbents	$Q_{\max}$ (mg/g)	Isotherm study	Kinetics study	Thermodynamic study	pH	Equilibrium time	Dosage of adsorbent	Reference
1.	Surfactant-modified alumina (SMA)	185.00	Langmuir	–	–	–	1 h	1.0 g/L	(Das et al. 2009a)
2.	Sodium dodecyl sulfate (SDS) modified alumina	185.00	Langmuir	–	–	–	1 h	1.0 g/L	(Das et al. 2009b)
3.	Bentonite	178.60	Langmuir	Pseudo 2nd order	Endothermic	5.0	60 min	1 g/L	(Bulut et al. 2008)
4.	Aminopropyl functionalized magnesium phyllosilicate (AMP) clay	130.64	Langmuir	Pseudo 1st order	Endothermic	9.8	180 min	0.1 mg/mL	(Lee et al. 2011)
5.	Clayey soil of Indian origin	78.57	Langmuir	Pseudo 2nd order	Exothermic	6.0	90 min	3 g/L	(Saha et al. 2010b)
6.	Kaolin	65.42	Langmuir	Pseudo 2nd order	Exothermic	7.0	90 min	2 g/L	(Nandi et al. 2009)
7.	Non-tetrahedral alumina	61.35	Langmuir	–	Endothermic	5.0	4 h	250 mg/50 mL	(Kannan et al. 2008)
8.	Organically modified clay	56.82	Langmuir	Pseudo 2nd order	Endothermic	6.0	30 min	–	(Arellano-Cárdenas et al. 2013)
9.	Low-cost inorganic powder (Persian Kaolin)	52.91	Langmuir	Pseudo 2nd order	Endothermic	7.0	5 min	0.8 g/L	(Tehrani-Bagha et al. 2011)
10.	Bentonite clay	7.716	Langmuir, Freundlich and D–R	Pseudo 1st order	Endothermic	9.0	10 min	0.05 g	(Tahir and Rauf 2006)
11.	Surfactant-Coated Alumina (SDS- $\text{Al}_2\text{O}_3$ )	2.78	–	–	–	4.7	–	500 mg	(Farhadi et al. 2010)
12.	Rarasaponin–bentonite	0.93 mmol/g	Langmuir	–	–	8.0	2 h	–	(Kurniawan et al. 2012)
13.	Natural kaolinitic-clay	0.64 mmol/g	Langmuir	–	Exothermic	7.0	1 day	1.0 g/L	(Issa et al. 2014)
14.	Iron humate (IH)	0.0527 mmol/g	Langmuir	–	–	–	–	–	(Janoš 2003)
15.	Natural rarasaponin modified kaolin	–	Sips	Pseudo 1st order	Exothermic	–	–	–	(Suwandi et al. 2012)
16.	Inorganic–organic pillared clay granules	–	Langmuir	Pseudo 1st order	–	6.0	120 min	–	(Chekane et al. 2010)
17.	Montmorillonite	–	Langmuir	–	Endothermic	–	–	0.1 g	(Tahir et al. 2010)
18.	Organomineral sorbent–iron humate	–	–	Pseudo 2nd order	–	–	–	–	(Janoš and Šmídová 2005)
19.	Bentonite	–	Temkin and Redlich–Peterson isotherms	–	–	8.2	60 min	1.0 g	(Özdemir and Keskin 2009)

**Table 7** continued

Sr. No.	Adsorbents	$Q_{\max}$ (mg/g)	Isotherm study	Kinetics study	Thermodynamic study	pH	Equilibrium time	Dosage of adsorbent	Reference
20.	Activated $\alpha$ -alumina	–	–	–	–	10.0	10 min	0.1 g/ 250 mL	(Rogaieh and Gharbani 2013)
21.	Sand	–	Freundlich	Pseudo 2nd order	–	4.8	–	0.03 g	(Rauf et al. 2008)
22.	Zeolite	46.35	Langmuir	Pseudo 1st order	–	6.0	–	–	(Wang and Ariyanto 2007)
23.	Tetrahedral silica	45.05	Langmuir	–	Endothermic	6.0	5 h	150 mg/ 50 mL	(Kannan et al. 2008)
24.	Natural zeolite	23.55	–	–	–	–	–	–	(Wu et al. 2010)
25.	Talc (silicate material)	20.968	Langmuir	Pseudo 2nd order	–	8.0	–	–	(Lee et al. 2013)
26.	Perlite	3.36	Freundlich	Pseudo 1st order	Exothermic	8.0–9.0	40 min	0.1 g/ 50 mL	(Govindasamy et al. 2009)
27.	Phillipsite-rich-zeolite tuff	1.22 mmol/g	Langmuir	–	Exothermic	7.0	1 day	1.0 g/L	(Issa et al. 2014)
28.	Natural zeolite	–	Koble–Corrigan model	Pseudo 2nd order	Endothermic	4.0	480 min	0.03 g/ 10 mL	(Han et al. 2010)
29.	Silica gel	–	–	–	–	–	–	–	(Samiey and Toosi 2010)

have been modified to overcome this undesirable characteristic. In an effort to increase the chemical versatility and adsorption efficiency, chitin and chitosan biopolymers have been modified or crosslinked by various surfactants and crosslinking agents.

Huang et al. (2012) explored the use of Chitin grafted poly (acrylic acid) (chi-g-PAA) for the removal of MG from wastewater and concluded that the carboxylic groups that are grafted to the surface of chitin can be hydrolyzed to a sodium salt using dilute  $\text{NaOH}_{(\text{aq})}$  and can be readily utilized to adsorb malachite green from aqueous solution. The monolayer adsorption capacity obtained was 285.70 mg/g which was 10 times higher than the chitin hydrogels (26.88 mg/g).

Wan Ngah et al. (2010) studied the removal of MG from aqueous solutions through adsorption on to chitosan coated bentonite beads. The characterization of adsorbents was performed by Fourier Transform Infrared (FTIR) spectroscopy, scanning electron microscopy (SEM) coupled with energy dispersive spectroscopy (EDS) and X-ray diffraction (XRD) analysis. Authors mentioned that the monolayer adsorption capacity obtained was 435.00 mg/g which was five times greater than the chitosan beads (93.55 mg/g).

**Peat** Peat is a porous and complex natural material, widely available and studied as an alternative adsorbent for different pollutants as well as dyes (Raval et al. 2016c).

Coco-peat was used by Vijayaraghavan et al. (2015) as an adsorbent to study the adsorption of malachite green and crystal violet from wastewater. It was found that a contact time of 60 min was sufficient for the adsorption to reach equilibrium. The optimum pH was found to be 7.0. The data for the adsorption of MG was described well by both the Sips adsorption isotherm model. The adsorption process was found to be endothermic.

### Nanomaterials

Typical nanomaterials include nanotubes, nanoparticles, nanofibers, nanorods, fullerenes, and nanowires (Schmidt et al. 2002; Gupta and Saleh 2013; Gupta and Nayak 2012; Saravanan et al. 2013, 2014).

Carbon nanotubes were discovered accidentally by Iijima (1991), while studying the surfaces of graphite electrodes used in an electric arc discharge. CNTs are divided into two types based on the arrangement of their graphene cylinders: (1) single-walled CNTs (SWCNTs)

**Table 8** The maximum adsorption capacities and other optimal conditions of various biosorbents for adsorption of MG from water and wastewater

Sr. No.	Adsorbents	$Q_{\max}$ (mg/g)	Isotherm study	Kinetics study	Thermodynamic study	pH	Equilibrium time	Dosage of adsorbent	References
1.	Freshwater macrophyte alligator weed	185.54	Langmuir	Ritchie second-order	–	6.0	–	7.0 g/L	(Wang 2009)
2.	<i>Firmiana simplex</i> wood fiber	>142.40	Freundlich	Pseudo 2nd order	Endothermic	11.0	180 min	0.25 g	(Pan and Zhang 2009)
3.	<i>Pleurotus ostreatus</i> (A macro-fungus)	125.00	Freundlich	Pseudo 2nd order	–	8.0	240 min	4.0 g/L	(Chen et al. 2014)
4.	<i>Pithophora</i> sp., a fresh water algae	117.65	Redlich-Peterson	Pseudo 2nd order	–	5.0	8 h	0.015 g	(Kumar et al. 2005)
5.	<i>Hydrilla verticillata</i> biomass	91.97	Freundlich	Pseudo 2nd order	–	8.0	200 min	0.26 g	(Rajeshkannan et al. 2010)
6.	Ashoka ( <i>Saraca asoca</i> ) leaf powder (ALP)	83.30	Freundlich	Pseudo 2nd order	Exothermic	6.0	25 min	2.0 g/L	(Gupta et al. 2012)
7.	<i>Hydrilla Verticillata</i> Biomass	69.88	Langmuir	Pseudo 1st order	–	8.0	150 min	0.55 g	(Rajesh Kannan et al. 2010)
8.	<i>Turbinaria conoides</i> brown marine algae	66.60	Langmuir	Pseudo 2nd order	–	8.0	150 min	0.55 g	(Kannan et al. 2009)
9.	Native anaerobic granular sludge	61.73	Langmuir	Pseudo 2nd order	Exothermic	5.0	2 h	2.4 g/L	(Cheng et al. 2008)
10.	Heat-treated anaerobic granular sludge	59.17	Langmuir	Pseudo 2nd order	Exothermic	5.0	2 h	2.4 g/L	(Cheng et al. 2008)
11.	Eriobotrya japonica (Thunb.) Lindley (Loquat) seed biomass	57.47	Langmuir	Pseudo 2nd order	Endothermic	5.0	60 min	10.0 g/L	(Aksakal et al. 2009)
12.	<i>Daucus carota</i> plant (carrot leaves powder: CLP)	52.60	Freundlich	Pseudo 2nd order	Exothermic	7.0	30 min	2.0 g/L	(Kushwaha et al. 2014)
13.	Mango ( <i>Mangifera indica</i> L.) seed husks [MSH]	47.90	Freundlich	Pseudo 2nd order	Exothermic	5.0	2.0 h	5.0 g/L	(Franca et al. 2010b)
14.	<i>Daucus carota</i> plant (carrot stem powder: CSP)	43.40	Freundlich	Pseudo 2nd order	Exothermic	7.0	30 min	2.0 g/L	(Kushwaha et al. 2014)
15.	Dead needles of Aleppo pine ( <i>Pinus halepensis</i> )	33.56	Freundlich	Intraparticle diffusion	Endothermic	–	330 min	0.5 g/300 mL	(Hamdaoui et al. 2008a)
16.	Almond Shell ( <i>Prunus dulcis</i> )	29.0	Langmuir	Pseudo 2nd order	Endothermic	–	180 min	20 g/L	(Ozdes et al. 2010)
17.	Phosphoric acid treated Parthenium hysterophorus Linn. Biomass (PWC)	25.00	Langmuir	Pseudo 2nd order	–	7.0	90 min	0.2 g/50 mL	(Lata et al. 2008)
18.	Microwave assisted zinc chloride activated epicarp of <i>Ricinus communis</i> (ZRC)	24.39	Langmuir	Pseudo 2nd order	–	5.0	–	0.2 g/mL	(Makeswari and Santhi 2013)
19.	Immobilized <i>Saccharomyces cerevisiae</i>	17.0	Freundlich	–	–	–	–	–	(Godbole and Sawant 2006)
20.	Sulfuric acid treated Parthenium hysterophorus Linn. Biomass	16.81	Langmuir	Pseudo 2nd order	–	7.0	90 min	0.2 g/50 mL	(Lata et al. 2008)
21.	Microwave activated epicarp of <i>Ricinus communis</i> (MRC)	12.65	Langmuir	Pseudo 2nd order	–	5.0	–	0.2 g/mL	(Makeswari and Santhi 2013)

**Table 8** continued

Sr. No.	Adsorbents	$Q_{\max}$ (mg/g)	Isotherm study	Kinetics study	Thermodynamic study	pH	Equilibrium time	Dosage of adsorbent	References
22.	<i>Hydrilla verticillata</i> biomass	–	–	–	–	8.4	194.50 min	11.14 g/L	(Rajeshkannan et al. 2009)
23.	<i>Pithophora</i> sp., a fresh water algae	–	–	Pseudo 1st order	–	6.0	–	–	(Vasanth Kumar et al. 2006)
24.	Yeast <i>S. cerevisiae</i> MTCC 174	–	–	Pseudo 2nd order	Endothermic	6.88	60 min	0.49 g	(Singh et al. 2012)
25.	Chlorella-based biomass	–	–	Pseudo 2nd order	–	7.0	–	2.0 g/2.0 dm <sup>3</sup>	(Tsai and Chen 2010)
26.	White-rot fungus <i>Ganoderma lucidum</i>	–	–	–	–	–	–	–	(Kuhar and Papinutti 2013)
27.	Carboxymethyl cellulose-acrylic acid	555.56	Temkin	Pseudo 2nd order	Endothermic	–	120 min (1 h)	–	(Zhang et al. 2014a)
28.	Chitosan coated bentonite (CCB) beads	435.0	Freundlich	Pseudo 2nd order	–	6.0	30 min	0.01 g/50 mL	(Wan Ngah et al. 2010)
29.	Cellulose modified with maleic anhydride (CMA)	370.00	Langmuir	Pseudo 2nd order	Exothermic	–	–	–	(Zhou et al. 2015)
30.	Amylopectin and poly (acrylic acid) (AP-g-PAA)	352.11	Langmuir	Pseudo 2nd order	Endothermic	7.0	30 min	50 mg	(Sarkar et al. 2014)
31.	Chitin grafted poly (acrylic acid)	285.70	Langmuir	–	–	–	–	–	(Huang et al. 2012)
32.	Chitosan beads	93.55	Langmuir	Pseudo 2nd order	Endothermic	8.0	300 min (5 h)	10 g/L	(Bekçi et al. 2008)
33.	Cyclodextrin-based adsorbent	91.90	Langmuir	Pseudo 2nd order	–	8.0	120 min	0.15 g	(Crini et al. 2007)
34.	Lignin sulfonate polymer	70.077	Langmuir	Pseudo 2nd order	Endothermic	7.0	300 min	0.05 g	(Tang et al. 2014)
35.	Bio-polymer (Cellulose)	2.422	Langmuir and Freundlich	Pseudo 2nd order	Exothermic	7.2	30 min (0.5 h)	5 g/L	(Pradeep Sekhar et al. 2009)
36.	Chitin hydrogels	26.883	Langmuir	Pseudo 2nd order	Endothermic	7.0	25 h	–	(Tang et al. 2012)
37.	Coco-peat	276.80	Sips	Pseudo 1st order	Endothermic	7.0	60 min	0.2 g/100 mL	(Vijayaraghavan et al. 2015)
38.	Peat of Brunei Darussalam (Keramut peat)	0.31 mmol/g	Redlich–Peterson (R–P) model	Pseudo 2nd order	Endothermic	6.0	4 h	0.050 g	(Chieng et al. 2014)

and (2) multi-walled CNTs (MWCNTs) (Khani et al. 2010; Saleh and Gupta 2011).

MWNTs are collections of several concentric graphene cylinders and are larger structures compared to SWNTs which are individual cylinders of 1–2 nm diameter. The former can be considered as a mesoscale graphite system, whereas the latter is truly a single large molecule (Odom et al. 1998). The mechanisms by which the dye molecules are sorbed onto CNTs are very complicated and appear attributable to electrostatic attraction, sorption,

precipitation and chemical interaction between the reactive groups of dye molecules and the surface functional groups of CNTs.

Recently, Rajabi et al. (2016) functionalized MWCNTs with the carboxylate group and used as an adsorbent for the rapid and fast removal of MG dye from the aqueous solutions. The optimized contact time and pH were 10 min and 9, respectively. The effect of temperature revealed that the adsorption capacity of MG dye increased with increasing contact time, temperature and pH. The

**Table 9** The maximum adsorption capacities and other optimal conditions of various nanomaterials, composites and nanocomposite adsorbents for the removal of MG from water and wastewater

Sr. No.	Adsorbents	$Q_{max}$ (mg/g)	Isotherm study	Kinetics study	Thermodynamic study	pH	Equilibrium time	Dosage of adsorbent	References
1.	Copper nanowires loaded on activated carbon	434.80	Langmuir	Pseudo 2nd order	–	5.0	20 min	0.1 g	(Ghaedi et al. 2015)
2.	Zinc oxide nanoparticle loaded on activated carbon (ZnO-NP-AC)	322.58	Langmuir	Pseudo 2nd order	–	7.0	15 min	0.005 g	(Ghaedi et al. 2014)
3.	Metal oxide nanoparticles (ZnO)	310.50	Langmuir and Freundlich	Pseudo 2nd order	Endothermic	8.0	120 min		(Kumar et al. 2013)
4.	Maghemite nanoparticles ( $\gamma$ -Fe <sub>2</sub> O <sub>3</sub> )	227.30	Langmuir	–	–	3.0	–	0.10 g	(Afkhami et al. 2010)
5.	Metal oxide nanoparticles (SnO <sub>2</sub> )	216.90	Langmuir and Freundlich	Pseudo 2nd order	Endothermic	8.0	120 min		(Kumar et al. 2013)
6.	Gold nanoparticles loaded on activated carbon (Au-NP-AC)	164.57	Langmuir	Pseudo 2nd order	Endothermic	7.0	4.4 min	0.015 g	(Roosta et al. 2014)
7.	<i>N</i> -Benzyl- <i>O</i> -carboxymethylchitosan magnetic nanoparticles (OC-BzM)	144.79	Langmuir and Freundlich	Pseudo 2nd order	Endothermic	7.0	60 min	25 mg	(Debrassi et al. 2012)
8.	Functionalized multi wall carbon nanotubes ( <i>f</i> -MWCNTs)	142.85	Langmuir	Pseudo 2nd order	–	7.0	80 min	0.08 g/100 mL	(Shirmardi et al. 2013)
9.	NiO nano flake-based flowerlike architectures	142.08	Langmuir	Pseudo 2nd order	–			333.3 mg/L	(Wei et al. 2014)
10.	Silver nano particles (AgOH-NP) loaded on activated carbon prepared from <i>Rosa canina</i> tree (AgOH-NP-AC-RC)	105.00	Freundlich	Pseudo 2nd order	–	8.0	20 min	0.09 g/50 mL	(Tavakol et al. 2015)
11.	Superparamagnetic sodium alginate-coated Fe <sub>3</sub> O <sub>4</sub> nanoparticles (Alg-Fe <sub>3</sub> O <sub>4</sub> )	47.84	Langmuir	Pseudo 2nd order	Endothermic	9.0	20 min	0.1 g/50 mL	(Mohammadi et al. 2014)
12.	Cadmium hydroxide nanowires loaded on activated carbon (Cd(OH) <sub>2</sub> -NW-AC)	19.0	Langmuir	Pseudo 2nd order	Endothermic	–	–	–	(Ghaedi and Mosallanejad 2014)
13.	Melamine supported magnetic iron oxide nanoparticles (Fe <sub>3</sub> O <sub>4</sub> @Mel)	9.06	Freundlich	Pseudo 2nd order	–	6.5	240 min	0.3 g	(Mirzajani and Ahmadi 2015)
14.	Citrate stabilized magnetite nanoparticles	0.704	Freundlich	Pseudo 2nd order	–	4.0	–	10 mg	(Mishra et al. 2014)
15.	FeCl <sub>2</sub> /FeCl <sub>3</sub> /perlite magnetic nanoparticles (FeCl <sub>2</sub> /FeCl <sub>3</sub> /PMNs),	0.01	BET	Pseudo 2nd order	–	6.0	120 min	0.05 g	(Heydartaemeh et al. 2014)
16.	MnO <sub>2</sub> nanosheets	–	–	Pseudo 1st order	–	5.6	120 min	0.5 g/L	(Saha and Pal 2014)
17.	Green tea extract based iron nanoparticles (GT-Fe NPs)	–	–	Pseudo 1st order	–	9.0	–	1.12 g/L	(Weng et al. 2013)



Table 9 continued

Sr. No.	Adsorbents	$Q_{\max}$ (mg/g)	Isotherm study	Kinetics study	Thermodynamic study	pH	Equilibrium time	Dosage of adsorbent	References
18.	TiO <sub>2</sub> nanoparticles	–	–	Pseudo 2nd order	–	6.9	–	3.0 g/L	(Suresh and Annadurai 2013)
19.	Iron nanoparticles (Fe NPs)	–	–	–	–	–	–	–	(Huang et al. 2014)
20.	Reduced graphene oxide (RGO)–Fe <sub>3</sub> O <sub>4</sub> nanoparticles (NPs)	–	–	–	–	–	–	–	(Geng et al. 2012)
21.	Halloysite nanotubes (HNTs)	99.60	Langmuir	Pseudo 2nd order	Endothermic	9.5	30 min	0.2 g	(Kiani et al. 2011)
22.	ZnS	98.3%	–	–	–	8.0	120 min	0.08 g/L	(Rajabi et al. 2013)
23.	ZnS:Fe	99.0%	–	–	–	8.0	120 min	0.08 g/L	(Rajabi et al. 2013)
24.	Fe <sub>3</sub> O <sub>4</sub> @SiO <sub>2</sub> -NH <sub>2</sub>	–	Freundlich	Pseudo 2nd order	–	7.0	–	100 mg/L	(Sun et al. 2015b)
25.	Lac-PAM-CTS	–	–	–	–	–	–	–	(Sun et al. 2015a)
26.	Magnetic β-cyclodextrin-graphene oxide nanocomposites(Fe <sub>3</sub> O <sub>4</sub> /β-CD/GO)	990.10	Langmuir	Pseudo 2nd order	Endothermic	7.0	120 min	–	(Wang et al. 2015)
27.	K-Carrageenan-g-AA	833.33	Langmuir	Pseudo 2nd order	Exothermic	7.0	180 min	0.05 g	(Pourjavadi et al. 2014)
28.	Kappa-carrageenan-g-polyacrylic acid/TiO <sub>2</sub> -NH <sub>2</sub> hydrogel nanocomposite (K-Carrageenan-g-AA/TiO <sub>2</sub> -NH <sub>2</sub> )	666.66	Langmuir	Pseudo 2nd order	Exothermic	7.0	180 min	0.05 g	(Pourjavadi et al. 2014)
29.	Melamine/maleic anhydride (S-Me/MA)	641.03	Langmuir	Pseudo 2nd order	Endothermic	9.0	24 h	0.06 g	(Rong et al. 2014)
30.	Iron nanoparticles loaded on ash (nFe-A)	500	Langmuir	Pseudo 2nd order	Endothermic	8.0	30 min	–	(Agarwal et al. 2016)
31.	Poly(vinyl alcohol) (PVA) and chitosan (CS)(PVA/CS composite)	380.65	Freundlich	Pseudo 2nd order	Endothermic	6.0	540 min	0.1 g/ 50 mL	(Li et al. 2012)
32.	Alginate/polyaspartate composite hydrogel beads	300–350	–	–	–	–	3.0 h	0.1 g/ 50 mL	(Jeon et al. 2008)
33.	Polyacrylic acid (PAA)–nanoclay nanocomposite	243.11	Freundlich	–	–	9.2	15 min	0.5 g/ 100 mL	(Sonawane et al. 2009)
34.	Fe <sub>3</sub> O <sub>4</sub> @PANI nanocomposites	240.00	Langmuir	Pseudo 2nd order	Exothermic	7.0	4 h	0.01 g	(Mahto et al. 2014)
35.	Vinyl-modified mesoporous poly(acrylic acid)/SiO <sub>2</sub> (PAA/SiO <sub>2</sub> ) composite nanofiber membranes	220.49	Redlich–Peterson	Pseudo 2nd order	–	–	240 min	50 mg/ 50 mL	(Xu et al. 2012)
36.	Activated carbon/CoFe <sub>2</sub> O <sub>4</sub> composite (AC/CFO)	89.29	Langmuir	Pseudo 2nd order	–	5.0	5 min	–	(Ai et al. 2010)

Table 9 continued

Sr. No.	Adsorbents	$Q_{\max}$ (mg/g)	Isotherm study	Kinetics study	Thermodynamic study	pH	Equilibrium time	Dosage of adsorbent	References
37.	Unsaturated polyester phosphate (USPECe(IV)P) composite	44.85	Freundlich	Pseudo 2nd order	Endothermic	8.0	30–35 min	0.1 g/100 mL	(Khan et al. 2013)
38.	Graphene oxide (GO)/cellulose bead (GO/CB) composites	30.090	Langmuir	Pseudo 2nd order	Endothermic	7.0	12 h	0.1 g	(Zhang et al. 2015)
39.	Carbon nanotube/polyaniline composites	15.45	Langmuir	Pseudo 2nd order	Endothermic	–	–	–	(Zeng et al. 2013)
40.	MWCNTs functionalized with the carboxylate group	11.73	Langmuir	Pseudo 2nd order	Endothermic	9.0	10 min	–	(Rajabi et al. 2016)
41.	Magnetoactive nanocomposite fibers	8.809	Langmuir	–	Endothermic	8.0	24 h	–	(Savva et al. 2015)
42.	Polyaniline–nickel ferrite magnetic nanocomposite	4.09	Langmuir	Pseudo 2nd order	–	7.0	210 min	5.0 g/L	(Patil and Shrivastava 2014)
43.	Humic acid-immobilized amine modified polyacrylamide/bentonite composite (HA-Am-PAA-B)	656.50 ( $\mu\text{mol/g}$ )	Freundlich	Pseudo 2nd order	–	8.0	3 h	2.0 g/L	(Anirudhan and Suchithra 2009)
44.	Humic acid-immobilized amine-modified polyacrylamide-bentonite composite (HA-Am-PAA-B)	656.50 ( $\mu\text{mol/g}$ )	Freundlich	Pseudo 2nd order	–	5.0–8.0	1 h	2.0 g/L	(Anirudhan et al. 2009)
45.	Glycine–modified silica nanoparticles	–	Langmuir	Pseudo 1st order	–	10.0	40 min	–	(Mansa et al. 2016)
46.	Magnetic <i>Pycnopus sanguineus</i> -Loaded Alginate Composite Beads	–	–	–	–	–	–	–	(Yang et al. 2014)
47.	Polyaniline/ZnO nanocomposite	–	–	–	–	–	5 h	0.4 g/L	(Eskizeybek et al. 2012)
48.	$\text{Fe}_{0.01}\text{Ni}_{0.01}\text{Zn}_{0.98}\text{O}$ /polyacrylamide nanocomposite	–	–	–	–	–	–	–	(Kant et al. 2014)
49.	Hierarchically macro/microporous silicon–carbon–nitrogen (Si–C–N) hybrid material	–	–	–	–	–	–	–	(Meng et al. 2015)

adsorption equilibrium and kinetic data was well fitted and found to be in good agreement with the Langmuir isotherm model and pseudo second order kinetic model, respectively.

Shirmardi et al. (2013) prepared functionalized multi-walled carbon nanotubes (*f*-MWCNTs) by acid treatment and used for the adsorption of MG dye from aqueous solution in batch mode. The results indicated that by increasing contact time, pH and adsorbent dosage, the removal percentage increased, but by increasing the initial

MG concentration, the removal percentage decreased. Based on correlation coefficient ( $R^2$ ), the experimental data follows the Langmuir isotherm with maximum adsorption capacity of 142.85 mg/g.

Halloysite, a mineral of the kaolin group [forms hollow tubular crystals (halloysite nanotubes—HNTs)], can be used as MG dye adsorbent by Kiani et al. (2011) and found that the equilibrium adsorption was reached within 30 min. The adsorption of MG by HNTs obeyed pseudo-second-order kinetics with activation energy 18.28 kJ/mol,

suggested that the process was physisorption. The best-fit adsorption isotherm was achieved with the Langmuir model, indicating that homogeneous adsorption occurred. The negative values of  $\Delta G^\circ$  and positive value of  $\Delta H^\circ$  showed that the adsorption was a spontaneous and endothermic.

The particles of at least one dimension smaller than 1  $\mu\text{m}$ , and potentially as small as atomic and molecular length scales (0.2 nm) are called nanoparticles. Nanoparticles can have amorphous or crystalline form (Buzea et al. 2007). Due to some of the unique characteristics such as small size, catalytic potential, large surface area, ease of separation, and large number of active sites for interaction with different contaminants the nanoparticles have established themselves as excellent adsorbents (Raval et al. 2016d).

### Composites and nano-composites

The nano-scale inclusions that are imbedded within matrix of a material are referred as composites (Chen et al. 2013).

Poly(vinyl alcohol) (PVA) is a water-soluble material containing many reactive hydroxyl groups. It has been extensively applied in biomedical and pharmaceutical fields due to its low cost, non-toxicity, biocompatibility, good mechanical strength and chemical stability. However, the PVA foam illustrated low adsorption for organic and inorganic pollutants. Chitosan (CS) is one of the most abundant biopolymers in nature. It exhibits good adsorption capacity for organic dyes and heavy metals because it has a large number of hydroxyl and amine groups.

However, the use of CS in the form of flake or powder cannot be separated easily. Therefore, Li et al. (2012) prepared a novel foam adsorbent based on PVA/CS composites by the interpenetrating polymer network (IPN), foaming process and freeze-thaw treatment and found that the composite material had higher adsorption efficiency (380.65 mg/g) compared with the single component.

Hussain et al. (2006) defined nanocomposites as materials consisting of at least two phases with one dispersed in another that is called matrix, and thus forms a three dimensional network.

Wang et al. (2015) prepared Magnetic  $\beta$ -cyclodextrin-graphene oxide nanocomposites ( $\text{Fe}_3\text{O}_4/\beta\text{-CD/GO}$ ) as an adsorbent for MG dye because graphene oxide have abundant hydrophilic groups on its surface, and thus it has good adsorption capacity still its separation was difficult task from sample solution and hence, to simplify the retrieval procedure, magnetic adsorbent ( $\text{Fe}_3\text{O}_4$ ) has been incorporated with GO. In addition,  $\beta$ -CD was also added onto composite (Magnetic-graphene oxide) to provide hydrophobic inner cavity and a hydrophilic exterior which can enhance the adsorption capacity of composite adsorbent for MG dye.

Table 9 presented the maximum adsorption capacities of various nanomaterials, composite and nanocomposite adsorbents used for MG.

### Miscellaneous adsorbents

See Table 10.

**Table 10** The maximum adsorption capacities and other optimal conditions of various miscellaneous adsorbents for the removal of MG from water and wastewater

Sr. No.	Adsorbents	$Q_{\text{max}}$ (mg/g)	Isotherm study	Kinetics study	Thermodynamic study	pH	Equilibrium time	Dosage of adsorbent	References
1.	Zeolitic imidazole framework-67 (ZIF-67)	3227.00	Langmuir	Pseudo 2nd order	Endothermic	–	2 h	0.25 g/L	(Lin and Chang 2015)
2.	Graphite oxide (GO)	248.00	Langmuir	Pseudo 2nd order	–	–	20 min	10 mg/500 mL	(Bradder et al. 2011)
3.	Poly- $\gamma$ -glutamic acid ( $\gamma$ -PGA)	293.32	Redlich-Peterson	Pseudo 2nd order	–	>5.0	2 h	0.4 g/L	(Stephen Inbaraj et al. 2006)
4.	Defective coffee beans press cake	208.30	Langmuir	Pseudo 2nd order	–	5.0	4.0 h	5.0 g/L	(Franca et al. 2010a)
5.	Polyethylene terephthalate (PET) by chemical activation with NaOH (PETNa8)	169.49	Langmuir	Pseudo 1st order	–	10.0	90 min	0.1 g/25 mL	(Akmil-Başar et al. 2005)
6.	Magnetic sorbent (“blue magnetite”)	93.20	Langmuir	–	–	–	30 min	–	(Šafařík et al. 1995)

Table 10 continued

Sr. No.	Adsorbents	$Q_{\max}$ (mg/g)	Isotherm study	Kinetics study	Thermodynamic study	pH	Equilibrium time	Dosage of adsorbent	References
7.	Polymeric gel	4.900	Langmuir	Pseudo 2nd order	Exothermic	–	–	–	(Malana et al. 2010)
8.	Poly lactide (PLA)/spent brewery grains (SBGs) films	1.484	Freundlich	Pseudo 2nd order	–	6.89	95 min	0.42 g	(Chanzu et al. 2012)
9.	Polyethylene glycol (PEG) micelles	–	Langmuir	–	Endothermic	–	10 min	–	(Chen et al. 2009)
10.	polystyrene microspheres	–	–	–	–	–	–	–	(Eckenrode et al. 2005)
11.	Magnetic affinity adsorbent (blue magnetite)	–	–	–	–	–	–	–	(Šafařík and Šafaříková 2002)
12.	Loosely bound extracellular polymeric substances (LB-EPS), tightly bound EPS (TB-EPS)	–	–	–	–	7.0	–	–	(Gao et al. 2011)
13.	Amberlite XAD-4 resin	–	–	Pseudo 1st order	Endothermic	–	150 min	–	(Dos Reis et al. 2011)
14.	Amberlite XAD-2 resin	–	–	Pseudo 1st order	Endothermic	–	150 min	–	(Dos Reis et al. 2011)
15.	Metal–organic framework MIL-100(Fe)	–	Freundlich	Pseudo 2nd order	Endothermic	5.0	–	–	(Huo and Yan 2012)
16.	D201_Lac	–	–	–	–	–	–	–	(Zhang et al. 2012)
17.	Mesoporous Cu/Al <sub>2</sub> O <sub>3</sub> –MCM-41	–	–	–	–	11.0	30 min	1.0 g/L	(Pradhan et al. 2011)
18.	Calcium oxalate—bromopyrogallol red inclusion sorbent	–	–	–	–	–	–	–	(Wang and Gao 2009)
19.	Polyurethane foam (PUF) loaded with sodium dodecylsulfate (SDS)	–	–	–	–	–	–	–	(Robaina et al. 2009)
20.	Functionalized magnetic adsorbents (FMAs)	–	–	–	–	–	–	–	(Wang et al. 2014b)

## Conclusions and future perspectives

Adsorption process being very easy, economical, effective and versatile had become the most favored methods for amputation of toxic and hazardous dyes from wastewater. This review article revealed about various adsorbents, such as activated carbons, low-cost materials, nanomaterials, composites and nanocomposites, used for the adsorption and removal of MG from water and wastewater. It was concluded that amongst all the other adsorbents, agricultural solid wastes and biosorbents, such as biopolymers and biomass, have been extensively used for the removal of MG and are acknowledged as effective and economic adsorbents for the removal of MG dye. Various experimental conditions (pH, temperature, contact time and

amount of adsorbent) have been also mentioned for related adsorbents in the present article.

This review article also disclosed that the Langmuir and Freundlich adsorption isotherm models were frequently applied to evaluate the adsorption capacity of various adsorbents towards MG. In kinetic study, it was observed that the pseudo-second-order rate model was followed for the adsorption of MG and according to thermodynamic parameters the adsorption process was found to be spontaneous in nature.

Since, most of the reported studies had been performed using batch and small-scale column adsorption tests, further research is required for the development of more effective adsorbents, modeling of adsorption mechanism, regeneration of spent adsorbents and treatment of real industrial wastewater.

**Acknowledgements** The authors gratefully acknowledge the financial assistance provided by the INSPIRE Programme under the Assured Opportunity for Research Careers (AORC) scheme, funded by the Department of Science and Technology (DST) (Sanction Order No.: DST/INSPIRE Fellowship/2013/66).

**Open Access** This article is distributed under the terms of the Creative Commons Attribution 4.0 International License (<http://creativecommons.org/licenses/by/4.0/>), which permits unrestricted use, distribution, and reproduction in any medium, provided you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license, and indicate if changes were made.

## References

- Abd-El-Kareem MS, Taha HM (2012) Decolorization of malachite green and methylene blue by two microalgal species. *Int J Chem Environ Eng* 3:297–302
- Adegoke KA, Bello OS (2015) Dye sequestration using agricultural wastes as adsorbents. *Water Resour Ind* 12:8–24. doi:10.1016/j.wri.2015.09.002
- Afkhami A, Moosavi R, Madrakian T (2010) Preconcentration and spectrophotometric determination of low concentrations of malachite green and leuco-malachite green in water samples by high performance solid phase extraction using maghemite nanoparticles. *Talanta* 82:785–789. doi:10.1016/j.talanta.2010.05.054
- Agarwal S, Tyagi I, Gupta VK et al (2016) Kinetics and thermodynamics of Malachite Green dye removal from aqueous phase using iron nanoparticles loaded on ash. *J Mol Liq*. doi:10.1016/j.molliq.2016.04.039
- Ahmad MA, Ahmad N, Bello OS (2014) Adsorptive removal of malachite green dye using durian seed-based activated carbon. *Water Air Soil Pollut* 225:1–18. doi:10.1007/s11270-014-2057-z
- Ahmad MA, Alrozi R (2011) Removal of malachite green dye from aqueous solution using rambutan peel-based activated carbon: equilibrium, kinetic and thermodynamic studies. *Chem Eng J* 171:510–516. doi:10.1016/j.ccej.2011.04.018
- Ahmad R, Kumar R (2010) Adsorption studies of hazardous malachite green onto treated ginger waste. *J Environ Manag* 91:1032–1038. doi:10.1016/j.jenvman.2009.12.016
- Ahmad R, Mondal PK (2010) Application of modified water nut carbon as a sorbent in congo red and malachite green dye contaminated wastewater remediation. *Sep Sci Technol* 45:394–403. doi:10.1080/01496390903484875
- Ai L, Huang H, Chen Z et al (2010) Activated carbon/CoFe<sub>2</sub>O<sub>4</sub> composites: facile synthesis, magnetic performance and their potential application for the removal of malachite green from water. *Chem Eng J* 156:243–249. doi:10.1016/j.ccej.2009.08.028
- Aitchison SJ, Arnett J, Murray KR, Zhang J (2000) Removal of aquaculture therapeutants by carbon adsorption: I. Equilibrium adsorption behaviour of single components. *Aquaculture* 183:269–284. doi:10.1016/S0044-8486(99)00304-X
- Akar E, Altinişik A, Seki Y (2013) Using of activated carbon produced from spent tea leaves for the removal of malachite green from aqueous solution. *Ecol Eng* 52:19–27. doi:10.1016/j.ecoleng.2012.12.032
- Akmil-Başar C, Onal Y, Kiliçer T, Eren D (2005) Adsorptions of high concentration malachite green by two activated carbons having different porous structures. *J Hazard Mater* 127:73–80. doi:10.1016/j.jhazmat.2005.06.025
- Aksakal O, Ucu H, Kaya Y (2009) Application of *Eriobotrya japonica* (Thunb.) Lindley (Loquat) seed biomass as a new biosorbent for the removal of malachite green from aqueous solution. *Water Sci Technol J Int Assoc Water Pollut Res* 59:1631–1639. doi:10.2166/wst.2009.130
- Ali H (2010) Biodegradation of synthetic dyes—a review. *Water Air Soil Pollut* 213:251–273. doi:10.1007/s11270-010-0382-4
- Ali H, Ahmad W, Haq T (2009) Decolorization and degradation of malachite green by *Aspergillus flavus* and *Alternaria solani*. *Afr J Biotechnol*. doi:10.4314/ajb.v8i8.60239
- Aliyan H, Fazaeli R, Jalilian R (2013) Fe<sub>3</sub>O<sub>4</sub>@mesoporous SBA-15: a magnetically recoverable catalyst for photodegradation of malachite green. *Appl Surf Sci* 276:147–153. doi:10.1016/j.apsusc.2013.03.049
- Altınışik A, Gür E, Seki Y (2010) A natural sorbent, *Luffa cylindrica* for the removal of a model basic dye. *J Hazard Mater* 179:658–664. doi:10.1016/j.jhazmat.2010.03.053
- An S-Y, Min S-K, Cha I-H et al (2002) Decolorization of triphenylmethane and azo dyes by *Citrobacter* sp. *Biotechnol Lett* 24:1037–1040. doi:10.1023/A:1015610018103
- Anastopoulos I, Kyzas GZ (2014) Agricultural peels for dye adsorption: a review of recent literature. *J Mol Liq* 200(Part B):381–389. doi:10.1016/j.molliq.2014.11.006
- Anbia M, Ghaffari A (2012) Removal of malachite green from dye wastewater using mesoporous carbon adsorbent. *J Iran Chem Soc* 8:S67–S76. doi:10.1007/BF03254283
- Anirudhan TS, Suchithra PS (2009) Adsorption characteristics of humic acid-immobilized amine modified polyacrylamide/bentonite composite for cationic dyes in aqueous solutions. *J Environ Sci China* 21:884–891
- Anirudhan TS, Suchithra PS, Radhakrishnan PG (2009) Synthesis and characterization of humic acid immobilized-polymer/bentonite composites and their ability to adsorb basic dyes from aqueous solutions. *Appl Clay Sci* 43:336–342. doi:10.1016/j.clay.2008.09.015
- Anjaneyulu Y, Chary NS, Raj DSS (2005) Decolourization of industrial effluents—available methods and emerging technologies—a review. *Rev Environ Sci Biotechnol* 4:245–273. doi:10.1007/s1157-005-1246-z
- Arellano-Cárdenas S, López-Cortez S, Cornejo-Mazón M, Mares-Gutiérrez JC (2013) Study of malachite green adsorption by organically modified clay using a batch method. *Appl Surf Sci* 280:74–78. doi:10.1016/j.apsusc.2013.04.097
- Arivoli S, Sundaravadivelu M, Elango KP (2008) Removal of basic and acidic dyes from aqueous solution by adsorption on a low cost activated carbon: kinetic and thermodynamic study. *Indian J Chem Technol* 15:130
- Asiltürk M, Sayılkan F, Arpaç E (2009) Effect of Fe<sup>3+</sup> ion doping to TiO<sub>2</sub> on the photocatalytic degradation of malachite green dye under UV and vis-irradiation. *J Photochem Photobiol Chem* 203:64–71. doi:10.1016/j.jphotochem.2008.12.021
- Ayed L, Chaieb K, Cheref A, Bakhrouf A (2008) Biodegradation of triphenylmethane dye Malachite Green by *Sphingomonas paucimobilis*. *World J Microbiol Biotechnol* 25:705–711. doi:10.1007/s11274-008-9941-x
- Ayed L, Chaieb K, Cheref A, Bakhrouf A (2010) Biodegradation and decolorization of triphenylmethane dyes by *Staphylococcus epidermidis*. *Desalination* 260:137–146. doi:10.1016/j.desal.2010.04.052
- Babel S, Kurniawan TA (2003) Low-cost adsorbents for heavy metals uptake from contaminated water: a review. *J Hazard Mater* 97:219–243. doi:10.1016/S0304-3894(02)00263-7
- Baek M-H, Ijagbemi CO, Se-Jin O, Kim D-S (2010) Removal of malachite green from aqueous solution using degreased coffee bean. *J Hazard Mater* 176:820–828. doi:10.1016/j.jhazmat.2009.11.110
- Bai C, Xiao W, Feng D et al (2013) Efficient decolorization of Malachite Green in the Fenton reaction catalyzed by [Fe(III)-

- salen]Cl complex. Chem Eng J 215–216:227–234. doi:[10.1016/j.cej.2012.09.124](https://doi.org/10.1016/j.cej.2012.09.124)
- Banat IM, Nigam P, Singh D, Marchant R (1996) Microbial decolorization of textile-dye containing effluents: a review. Bioresour Technol 58:217–227. doi:[10.1016/S0960-8524\(96\)00113-7](https://doi.org/10.1016/S0960-8524(96)00113-7)
- Bansal P, Bhullar N, Sud D (2009) Studies on photodegradation of malachite green using TiO<sub>2</sub>/ZnO photocatalyst. Desalin Water Treat 12:108–113. doi:[10.5004/dwt.2009.944](https://doi.org/10.5004/dwt.2009.944)
- Başar CA (2006) Applicability of the various adsorption models of three dyes adsorption onto activated carbon prepared waste apricot. J Hazard Mater 135:232–241. doi:[10.1016/j.jhazmat.2005.11.055](https://doi.org/10.1016/j.jhazmat.2005.11.055)
- Beak MH, Ijagbemi CO, Kim DS (2009) Treatment of malachite green-containing wastewater using poultry feathers as adsorbent. J Environ Sci Health Part A Tox Hazard Subst Environ Eng 44:536–542. doi:[10.1080/10934520902720132](https://doi.org/10.1080/10934520902720132)
- Bejarano-Pérez NJ, Suárez-Herrera MF (2008) Sonochemical and sonophotocatalytic degradation of malachite green: the effect of carbon tetrachloride on reaction rates. Ultrason Sonochem 15:612–617. doi:[10.1016/j.ultsonch.2007.09.009](https://doi.org/10.1016/j.ultsonch.2007.09.009)
- Bekçi Z, Özveri C, Seki Y, Yurdakoç K (2008) Sorption of malachite green on chitosan bead. J Hazard Mater 154:254–261. doi:[10.1016/j.jhazmat.2007.10.021](https://doi.org/10.1016/j.jhazmat.2007.10.021)
- Bekçi Z, Seki Y, Cavas L (2009) Removal of malachite green by using an invasive marine alga *Caulerpa racemosa* var. *cylindracea*. J Hazard Mater 161:1454–1460. doi:[10.1016/j.jhazmat.2008.04.125](https://doi.org/10.1016/j.jhazmat.2008.04.125)
- Bello OS, Ahmad MA, Ahmad N (2012) Adsorptive features of banana (*Musa paradisiaca*) stalk-based activated carbon for malachite green dye removal. Chem Ecol 28:153–167. doi:[10.1080/02757540.2011.628318](https://doi.org/10.1080/02757540.2011.628318)
- Bello OS, Ahmad MA, Semire B (2014) Scavenging malachite green dye from aqueous solutions using pomelo (*Citrus grandis*) peels: kinetic, equilibrium and thermodynamic studies. Desalin Water Treat 56:521–535. doi:[10.1080/19443994.2014.940387](https://doi.org/10.1080/19443994.2014.940387)
- Bello OS, Bello IA, Adegoke KA (2013) Adsorption of dyes using different types of sand: a review. South Afr J Chem 66:117–129
- Berberidou C, Poullos I, Xekoukoulotakis NP, Mantzavinos D (2007) Sonolytic, photocatalytic and sonophotocatalytic degradation of malachite green in aqueous solutions. Appl Catal B Environ 74:63–72. doi:[10.1016/j.apcatb.2007.01.013](https://doi.org/10.1016/j.apcatb.2007.01.013)
- Bhagavathi Pushpa T, Vijayaraghavan J, Sardhar Basha SJ et al (2015) Investigation on removal of malachite green using EM based compost as adsorbent. Ecotoxicol Environ Saf 118:177–182. doi:[10.1016/j.ecoenv.2015.04.033](https://doi.org/10.1016/j.ecoenv.2015.04.033)
- Bhattacharyya KG, Sarma A (2003) Adsorption characteristics of the dye, brilliant green, on neem leaf powder. Dyes Pigments 57:211–222. doi:[10.1016/S0143-7208\(03\)00009-3](https://doi.org/10.1016/S0143-7208(03)00009-3)
- Bojinova A, Dushkin C (2011) Photodegradation of malachite green in water solutions by means of thin films of TiO<sub>2</sub>/WO<sub>3</sub> under visible light. React Kinet Mech Catal 103:239–250. doi:[10.1007/s11144-011-0295-2](https://doi.org/10.1007/s11144-011-0295-2)
- Boutemedjet S, Hamdaoui O (2009) Sorption of malachite green by eucalyptus bark as a non-conventional low-cost biosorbent. Desalin Water Treat 8:201–210. doi:[10.5004/dwt.2009.684](https://doi.org/10.5004/dwt.2009.684)
- Bradder P, Ling SK, Wang S, Liu S (2011) Dye adsorption on layered graphite oxide. J Chem Eng Data 56:138–141. doi:[10.1021/je101049g](https://doi.org/10.1021/je101049g)
- Breck DW (1984) Zeolite molecular sieves. Krieger, Chicago
- Bulut E, Özacar M, Şengil İA (2008) Equilibrium and kinetic data and process design for adsorption of Congo Red onto bentonite. J Hazard Mater 154:613–622. doi:[10.1016/j.jhazmat.2007.10.071](https://doi.org/10.1016/j.jhazmat.2007.10.071)
- Burkinshaw SM (2016) Physico-chemical aspects of textile coloration, 1st edn. Wiley, New York
- Buvaneswari N, Kannan C (2011) Plant toxic and non-toxic nature of organic dyes through adsorption mechanism on cellulose surface. J Hazard Mater 189:294–300. doi:[10.1016/j.jhazmat.2011.02.036](https://doi.org/10.1016/j.jhazmat.2011.02.036)
- Buzea C, Pacheco II, Robbie K (2007) Nanomaterials and nanoparticles: sources and toxicity. Biointerphases 2:MR17–MR71. doi:[10.1116/1.2815690](https://doi.org/10.1116/1.2815690)
- Cardon D (2007) Natural dyes: sources, tradition, technology and science. Archetype, London
- Chanzu HA, Onyari JM, Shiundu PM (2012) Biosorption of malachite green from aqueous solutions onto polylactide/spent brewery grains films: kinetic and equilibrium studies. J Polym Environ 20:665–672. doi:[10.1007/s10924-012-0479-5](https://doi.org/10.1007/s10924-012-0479-5)
- Cheknane B, Baudu M, Basly J-P, Bouras O (2010) Adsorption of basic dyes in single and mixture systems on granular inorganic-organic pillared clays. Environ Technol 31:815–822. doi:[10.1080/09593331003667758](https://doi.org/10.1080/09593331003667758)
- Chen CC, Lu CS, Chung YC, Jan JL (2007) UV light induced photodegradation of malachite green on TiO<sub>2</sub> nanoparticles. J Hazard Mater 141:520–528. doi:[10.1016/j.jhazmat.2006.07.011](https://doi.org/10.1016/j.jhazmat.2006.07.011)
- Chen F, Ma W, He J, Zhao J (2002) Fenton degradation of malachite green catalyzed by aromatic additives. J Phys Chem A 106:9485–9490. doi:[10.1021/jp0144350](https://doi.org/10.1021/jp0144350)
- Chen J, Mao J, Mo X et al (2009) Study of adsorption behavior of malachite green on polyethylene glycol micelles in cloud point extraction procedure. Colloids Surf Physicochem Eng Asp 345:231–236. doi:[10.1016/j.colsurfa.2009.05.015](https://doi.org/10.1016/j.colsurfa.2009.05.015)
- Chen Y, Zhang Y, Liu C et al (2011) Photodegradation of malachite green by nanostructured Bi<sub>2</sub>WO<sub>6</sub> visible light-induced photocatalyst. Int J Photoenergy 2012:e510158. doi:[10.1155/2012/510158](https://doi.org/10.1155/2012/510158)
- Chen Z, Deng H, Chen C et al (2014) Biosorption of malachite green from aqueous solutions by *Pleurotus ostreatus* using Taguchi method. J Environ Health Sci Eng 12:63. doi:[10.1186/2052-336X-12-63](https://doi.org/10.1186/2052-336X-12-63)
- Chen Z-Y, Gao H-W, He Y-Y (2013) Selective photodegradation and backfilling for regeneration of the inorganic-organic hybrid composite Fe<sub>3</sub>O<sub>4</sub>@C18ADB@Zn<sub>2</sub>SiO<sub>4</sub> which captures organic pollutants from aqueous solution. RSC Adv 3:5815–5818. doi:[10.1039/C3RA22324H](https://doi.org/10.1039/C3RA22324H)
- Cheng W, Wang S-G, Lu L et al (2008) Removal of malachite green (MG) from aqueous solutions by native and heat-treated anaerobic granular sludge. Biochem Eng J 39:538–546. doi:[10.1016/j.bej.2007.10.016](https://doi.org/10.1016/j.bej.2007.10.016)
- Cheriaa J, Bakhrouf A (2009) Triphenylmethanes, malachite green and crystal violet dyes decolourisation by *Sphingomonas paucimobilis*. Ann Microbiol 59:57–61. doi:[10.1007/BF03175599](https://doi.org/10.1007/BF03175599)
- Chiang HI, Lim LBL, Priyantha N (2015) Enhancing adsorption capacity of toxic malachite green dye through chemically modified breadnut peel: equilibrium, thermodynamics, kinetics and regeneration studies. Environ Technol 36:86–97. doi:[10.1080/09593330.2014.938124](https://doi.org/10.1080/09593330.2014.938124)
- Chiang HI, Zehra T, Lim LBL et al (2014) Sorption characteristics of peat of Brunei Darussalam IV: equilibrium, thermodynamics and kinetics of adsorption of methylene blue and malachite green dyes from aqueous solution. Environ Earth Sci 72:2263–2277. doi:[10.1007/s12665-014-3135-7](https://doi.org/10.1007/s12665-014-3135-7)
- Chowdhury S, Chakraborty S, Saha P (2011a) Biosorption of Basic Green 4 from aqueous solution by *Ananas comosus* (pineapple) leaf powder. Colloids Surf B Biointerfaces 84:520–527. doi:[10.1016/j.colsurfb.2011.02.009](https://doi.org/10.1016/j.colsurfb.2011.02.009)
- Chowdhury S, Das P (2012) Utilization of a domestic waste—eggshells for removal of hazardous malachite green from aqueous solutions. Environ Prog Sustain Energy 31:415–425. doi:[10.1002/ep.10564](https://doi.org/10.1002/ep.10564)

- Chowdhury S, Mishra R, Saha P, Kushwaha P (2011b) Adsorption thermodynamics, kinetics and isosteric heat of adsorption of malachite green onto chemically modified rice husk. *Desalination* 265:159–168. doi:10.1016/j.desal.2010.07.047
- Chowdhury S, Saha P (2010a) Sea shell powder as a new adsorbent to remove Basic Green 4 (malachite green) from aqueous solutions: equilibrium, kinetic and thermodynamic studies. *Chem Eng J* 164:168–177. doi:10.1016/j.cej.2010.08.050
- Chowdhury S, Saha P (2010b) Pseudo-second-order kinetic model for sorption of malachite green onto sea shell: comparison of linear and non-linear methods. *IIOAB J* 1:3–7
- Chowdhury S, Saha P (2011a) Adsorption thermodynamics and kinetics of malachite green onto Ca(OH)<sub>2</sub>-treated fly ash. *J Environ Eng* 137:388–397. doi:10.1061/(ASCE)JEE.1943-7870.0000334
- Chowdhury S, Saha PD (2011) Mechanistic, Kinetic, and Thermodynamic Evaluation of Adsorption of Hazardous Malachite Green onto Conch Shell Powder. *Sep Sci Technol* 46:1966–1976. doi:10.1080/01496395.2011.584930
- Chowdhury S, Saha PD (2012) Fixed-bed adsorption of malachite green onto binary solid mixture of adsorbents: seashells and eggshells. *Toxicol Environ Chem* 94:1272–1282. doi:10.1080/02772248.2012.703205
- Chowdhury S, Saha PD (2013) Adsorption of malachite green from aqueous solution by naoh-modified rice husk: fixed-bed column studies. *Environ Prog Sustain Energy* 32:633–639. doi:10.1002/ep.11674
- Chowdhury S, Saha PD (2011b) Comparative analysis of linear and nonlinear methods of estimating the pseudo-second-order kinetic parameters for sorption of malachite green onto pretreated rice husk. *Bioremediat J* 15:181–188. doi:10.1080/10889868.2011.624140
- Chowdhury S, Saha PD, Ghosh U (2012) Fish (*Labeo rohita*) scales as potential low-cost biosorbent for removal of malachite green from aqueous solutions. *Bioremediat J* 16:235–242. doi:10.1080/10889868.2012.731444
- Crini G (2006) Non-conventional low-cost adsorbents for dye removal: a review. *Bioresour Technol* 97:1061–1085. doi:10.1016/j.biortech.2005.05.001
- Crini G, Peindy HN, Gimbert F, Robert C (2007) Removal of C.I. Basic Green 4 (malachite green) from aqueous solutions by adsorption using cyclodextrin-based adsorbent: kinetic and equilibrium studies. *Sep Purif Technol* 53:97–110. doi:10.1016/j.seppur.2006.06.018
- da Fonseca MG, de Oliveira MM, Arakaki LNH (2006) Removal of cadmium, zinc, manganese and chromium cations from aqueous solution by a clay mineral. *J Hazard Mater* 137:288–292. doi:10.1016/j.jhazmat.2006.02.001
- Dadhaniya PV, Patel MP, Patel RG (2006) Swelling and dye adsorption study of novel superswelling [acrylamide/*N*-vinylpyrrolidone/3(2-hydroxyethyl carbamoyl) acrylic acid] hydrogels. *Polym Bull* 57:21–31. doi:10.1007/s00289-006-0531-5
- Dahri MK, Kooh MRR, Lim LBL (2014) Water remediation using low cost adsorbent walnut shell for removal of malachite green: equilibrium, kinetics, thermodynamic and regeneration studies. *J Environ Chem Eng* 2:1434–1444. doi:10.1016/j.jece.2014.07.008
- Daneshvar N, Ayazloo M, Khataee AR, Pourhassan M (2007a) Biological decolorization of dye solution containing malachite green by microalgae *Cosmarium* sp. *Bioresour Technol* 98:1176–1182. doi:10.1016/j.biortech.2006.05.025
- Daneshvar N, Khataee AR, Rasoulifard MH, Pourhassan M (2007b) Biodegradation of dye solution containing malachite green: optimization of effective parameters using Taguchi method. *J Hazard Mater* 143:214–219. doi:10.1016/j.jhazmat.2006.09.016
- Das A, Pal A, Saha S, Maji SK (2009a) Behaviour of fixed-bed column for the adsorption of malachite green on surfactant-modified alumina. *J Environ Sci Health Part A Tox Hazard Subst Environ Eng* 44:265–272. doi:10.1080/10934520802597929
- Das AK, Saha S, Pal A, Maji SK (2009b) Surfactant-modified alumina: an efficient adsorbent for malachite green removal from water environment. *J Environ Sci Health Part A* 44:896–905. doi:10.1080/10934520902958708
- Dawood S, Sen TK (2014) Review on dye removal from Its aqueous solution into alternative cost effective and non-conventional adsorbents. *J Chem Process Eng* 1:1–7
- Debrassi A, Corrêa AF, Baccarin T et al (2012) Removal of cationic dyes from aqueous solutions using *N*-benzyl-*O*-carboxymethyl-chitosan magnetic nanoparticles. *Chem Eng J* 183:284–293. doi:10.1016/j.cej.2011.12.078
- Demirbas A (2009) Agricultural based activated carbons for the removal of dyes from aqueous solutions: a review. *J Hazard Mater* 167:1–9. doi:10.1016/j.jhazmat.2008.12.114
- Dhodapkar R, Rao NN, Pande SP et al (2007) Adsorption of cationic dyes on Jalshakti<sup>®</sup>, super absorbent polymer and photocatalytic regeneration of the adsorbent. *React Funct Polym* 67:540–548. doi:10.1016/j.reactfunctpolym.2007.03.007
- Dos Reis LGT, Robaina NF, Pacheco WF, Cassella RJ (2011) Separation of malachite green and methyl green cationic dyes from aqueous medium by adsorption on Amberlite XAD-2 and XAD-4 resins using sodium dodecylsulfate as carrier. *Chem Eng J* 171:532–540. doi:10.1016/j.cej.2011.04.024
- Du L-N, Wang S, Li G et al (2011) Biodegradation of malachite green by *Pseudomonas* sp. strain DY1 under aerobic condition: characteristics, degradation products, enzyme analysis and phytotoxicity. *Ecotoxicology* 20:438–446. doi:10.1007/s10646-011-0595-3
- Eckenrode HM, Jen S-H, Han J et al (2005) Adsorption of a cationic dye molecule on polystyrene microspheres in colloids: effect of surface charge and composition probed by second harmonic generation. *J Phys Chem B* 109:4646–4653. doi:10.1021/jp045610q
- Eichlerová I, Homolka L, Nerud F (2006) Synthetic dye decolorization capacity of white rot fungus *Dichomitus squalens*. *Bioresour Technol* 97:2153–2159. doi:10.1016/j.biortech.2005.09.014
- Eskizeybek V, Sarı F, Gülce H et al (2012) Preparation of the new polyaniline/ZnO nanocomposite and its photocatalytic activity for degradation of methylene blue and malachite green dyes under UV and natural sun lights irradiations. *Appl Catal B Environ* 119–120:197–206. doi:10.1016/j.apcatb.2012.02.034
- Farhadi K, Maleki R, Nezhad NM, Samadi N (2010) Spectrophotometric determination of malachite green residue in water samples after preconcentration on surfactant-coated alumina. *Spectrosc Lett* 43:101–107. doi:10.1080/00387010903278309
- Forgacs E, Cserháti T, Oros G (2004) Removal of synthetic dyes from wastewaters: a review. *Environ Int* 30:953–971. doi:10.1016/j.envint.2004.02.001
- Franca AS, Oliveira LS, Nunes AA (2010a) Malachite green adsorption by a residue-based microwave-activated adsorbent. *CLEAN—Soil Air Water* 38:843–849. doi:10.1002/clen.201000153
- Franca AS, Oliveira LS, Saldanha SA et al (2010b) Malachite green adsorption by mango (*Mangifera indica* L.) seed husks: kinetic, equilibrium and thermodynamic studies. *Desalin Water Treat* 19:241–248. doi:10.5004/dwt.2010.1105
- Fu Y, Viraraghavan T (2001) Fungal decolorization of dye wastewaters: a review. *Bioresour Technol* 79:251–262. doi:10.1016/S0960-8524(01)00028-1

- Gao J-F, Zhang Q, Wang J-H et al (2011) Contributions of functional groups and extracellular polymeric substances on the biosorption of dyes by aerobic granules. *Bioresour Technol* 102:805–813. doi:[10.1016/j.biortech.2010.08.119](https://doi.org/10.1016/j.biortech.2010.08.119)
- Garg VK, Gupta R, Bala Yadav A, Kumar R (2003) Dye removal from aqueous solution by adsorption on treated sawdust. *Bioresour Technol* 89:121–124. doi:[10.1016/S0960-8524\(03\)00058-0](https://doi.org/10.1016/S0960-8524(03)00058-0)
- Garg VK, Kumar R, Gupta R (2004) Removal of malachite green dye from aqueous solution by adsorption using agro-industry waste: a case study of *Prosopis cineraria*. *Dyes Pigments* 62:1–10. doi:[10.1016/j.dyepig.2003.10.016](https://doi.org/10.1016/j.dyepig.2003.10.016)
- Geng Z, Lin Y, Yu X et al (2012) Highly efficient dye adsorption and removal: a functional hybrid of reduced graphene oxide–Fe<sub>3</sub>O<sub>4</sub> nanoparticles as an easily regenerative adsorbent. *J Mater Chem* 22:3527. doi:[10.1039/c2jm15544c](https://doi.org/10.1039/c2jm15544c)
- Ghaedi M, Ansari A, Habibi MH, Asghari AR (2014) Removal of malachite green from aqueous solution by zinc oxide nanoparticle loaded on activated carbon: kinetics and isotherm study. *J Ind Eng Chem* 20:17–28. doi:[10.1016/j.jiec.2013.04.031](https://doi.org/10.1016/j.jiec.2013.04.031)
- Ghaedi M, Mosallanejad N (2014) Study of competitive adsorption of malachite green and sunset yellow dyes on cadmium hydroxide nanowires loaded on activated carbon. *J Ind Eng Chem* 20:1085–1096. doi:[10.1016/j.jiec.2013.06.046](https://doi.org/10.1016/j.jiec.2013.06.046)
- Ghaedi M, Shojaeipour E, Ghaedi AM, Sahraei R (2015) Isotherm and kinetics study of malachite green adsorption onto copper nanowires loaded on activated carbon: artificial neural network modeling and genetic algorithm optimization. *Spectrochim Acta A Mol Biomol Spectrosc* 142:135–149. doi:[10.1016/j.saa.2015.01.086](https://doi.org/10.1016/j.saa.2015.01.086)
- Godbole PT, Sawant AD (2006) Removal of malachite green from aqueous solutions using immobilised *Saccharomyces cerevisiae*. *J Sci Ind Res* 65:440–443
- Gong R, Feng M, Zhao J et al (2009) Functionalization of sawdust with monosodium glutamate for enhancing its malachite green removal capacity. *Bioresour Technol* 100:975–978. doi:[10.1016/j.biortech.2008.06.031](https://doi.org/10.1016/j.biortech.2008.06.031)
- Gong R, Jin Y, Chen F et al (2006) Enhanced malachite green removal from aqueous solution by citric acid modified rice straw. *J Hazard Mater* 137:865–870. doi:[10.1016/j.jhazmat.2006.03.010](https://doi.org/10.1016/j.jhazmat.2006.03.010)
- Gong R, Sun J, Zhang D et al (2008) Kinetics and thermodynamics of basic dye sorption on phosphoric acid esterifying soybean hull with solid phase preparation technique. *Bioresour Technol* 99:4510–4514. doi:[10.1016/j.biortech.2007.08.061](https://doi.org/10.1016/j.biortech.2007.08.061)
- Gordon PF, Gregory P (1987) *Organic Chemistry in Colour*. Springer, Berlin, Heidelberg
- Goursot A, Vasilyev V, Arbuznikov A (1997) Modeling of adsorption properties of zeolites: correlation with the structure. *J Phys Chem B* 101:6420–6428. doi:[10.1021/jp971230b](https://doi.org/10.1021/jp971230b)
- Govindasamy V, Sahadevan R, Subramanian S, Mahendradas DK (2009) Removal of malachite green from aqueous solutions by perlite. *Int J Chem React Eng* 7:1–22. doi:[10.2202/1542-6580.1889](https://doi.org/10.2202/1542-6580.1889)
- Griffiths J (1976) *Colour and constitution of organic molecules*. Academic Press, London
- Griffiths J (1981) Recent developments in the colour and constitution of organic dyes. *Rev Prog Color Relat Top* 11:37–57. doi:[10.1111/j.1478-4408.1981.tb03714.x](https://doi.org/10.1111/j.1478-4408.1981.tb03714.x)
- Guo Y, Yang S, Fu W et al (2003a) Adsorption of malachite green on micro- and mesoporous rice husk-based active carbon. *Dyes Pigments* 56:219–229. doi:[10.1016/S0143-7208\(02\)00160-2](https://doi.org/10.1016/S0143-7208(02)00160-2)
- Guo Y, Zhang H, Tao N et al (2003b) Adsorption of malachite green and iodine on rice husk-based porous carbon. *Mater Chem Phys* 82:107–115. doi:[10.1016/S0254-0584\(03\)00191-3](https://doi.org/10.1016/S0254-0584(03)00191-3)
- Gupta N, Kushwaha AK, Chattopadhyaya MC (2014) Application of potato (*Solanum tuberosum*) plant wastes for the removal of methylene blue and malachite green dye from aqueous solution. *Arab J Chem*. doi:[10.1016/j.arabj.2011.07.021](https://doi.org/10.1016/j.arabj.2011.07.021)
- Gupta N, Kushwaha AK, Chattopadhyaya MC (2012) Adsorption studies of cationic dyes onto Ashoka (*Saraca asoca*) leaf powder. *J Taiwan Inst Chem Eng* 43:604–613. doi:[10.1016/j.jtice.2012.01.008](https://doi.org/10.1016/j.jtice.2012.01.008)
- Gupta VK, Jain R, Nayak A et al (2011) Removal of the hazardous dye—tartrazine by photodegradation on titanium dioxide surface. *Mater Sci Eng C* 31:1062–1067. doi:[10.1016/j.msec.2011.03.006](https://doi.org/10.1016/j.msec.2011.03.006)
- Gupta VK, Kumar R, Nayak A et al (2013) Adsorptive removal of dyes from aqueous solution onto carbon nanotubes: a review. *Adv Colloid Interface Sci* 193–194:24–34. doi:[10.1016/j.cis.2013.03.003](https://doi.org/10.1016/j.cis.2013.03.003)
- Gupta VK, Mittal A, Krishnan L, Gajbe V (2004) Adsorption kinetics and column operations for the removal and recovery of malachite green from wastewater using bottom ash. *Sep Purif Technol* 40:87–96. doi:[10.1016/j.seppur.2004.01.008](https://doi.org/10.1016/j.seppur.2004.01.008)
- Gupta VK, Nayak A (2012) Cadmium removal and recovery from aqueous solutions by novel adsorbents prepared from orange peel and Fe<sub>2</sub>O<sub>3</sub> nanoparticles. *Chem Eng J* 180:81–90. doi:[10.1016/j.cej.2011.11.006](https://doi.org/10.1016/j.cej.2011.11.006)
- Gupta VK, Nayak A, Agarwal S (2015) Bioadsorbents for remediation of heavy metals: current status and their future prospects. *Environ Eng Res* 20:1–18
- Gupta VK, Saleh TA (2013) Sorption of pollutants by porous carbon, carbon nanotubes and fullerene—an overview. *Environ Sci Pollut Res* 20:2828–2843. doi:[10.1007/s11356-013-1524-1](https://doi.org/10.1007/s11356-013-1524-1)
- Gupta VK, Srivastava SK, Mohan D (1997) Equilibrium uptake, sorption dynamics, process optimization, and column operations for the removal and recovery of malachite green from wastewater using activated carbon and activated slag. *Ind Eng Chem Res* 36:2207–2218. doi:[10.1021/ie960442c](https://doi.org/10.1021/ie960442c)
- Gupta VK, Suhas (2009) Application of low-cost adsorbents for dye removal—a review. *J Environ Manage* 90:2313–2342. doi:[10.1016/j.jenvman.2008.11.017](https://doi.org/10.1016/j.jenvman.2008.11.017)
- Hamdaoui O, Chiha M, Naffrechoux E (2008a) Ultrasound-assisted removal of malachite green from aqueous solution by dead pine needles. *Ultrason Sonochem* 15:799–807. doi:[10.1016/j.ultsonch.2008.01.003](https://doi.org/10.1016/j.ultsonch.2008.01.003)
- Hamdaoui O, Saoudi F, Chiha M, Naffrechoux E (2008b) Sorption of malachite green by a novel sorbent, dead leaves of plane tree: equilibrium and kinetic modeling. *Chem Eng J* 143:73–84. doi:[10.1016/j.cej.2007.12.018](https://doi.org/10.1016/j.cej.2007.12.018)
- Hameed BH, El-Khaiary MI (2008a) Equilibrium, kinetics and mechanism of malachite green adsorption on activated carbon prepared from bamboo by K<sub>2</sub>CO<sub>3</sub> activation and subsequent gasification with CO<sub>2</sub>. *J Hazard Mater* 157:344–351. doi:[10.1016/j.jhazmat.2007.12.105](https://doi.org/10.1016/j.jhazmat.2007.12.105)
- Hameed BH, El-Khaiary MI (2008b) Batch removal of malachite green from aqueous solutions by adsorption on oil palm trunk fibre: equilibrium isotherms and kinetic studies. *J Hazard Mater* 154:237–244. doi:[10.1016/j.jhazmat.2007.10.017](https://doi.org/10.1016/j.jhazmat.2007.10.017)
- Hameed BH, El-Khaiary MI (2008c) Kinetics and equilibrium studies of malachite green adsorption on rice straw-derived char. *J Hazard Mater* 153:701–708. doi:[10.1016/j.jhazmat.2007.09.019](https://doi.org/10.1016/j.jhazmat.2007.09.019)
- Hameed BH, El-Khaiary MI (2008d) Malachite green adsorption by rattan sawdust: isotherm, kinetic and mechanism modeling. *J Hazard Mater* 159:574–579. doi:[10.1016/j.jhazmat.2008.02.054](https://doi.org/10.1016/j.jhazmat.2008.02.054)
- Hammud HH, Shmait A, Hourani N (2015) Removal of malachite green from water using hydrothermally carbonized pine needles. *RSC Adv* 5:7909–7920. doi:[10.1039/C4RA15505J](https://doi.org/10.1039/C4RA15505J)
- Han R, Wang Y, Sun Q et al (2010) Malachite green adsorption onto natural zeolite and reuse by microwave irradiation. *J Hazard Mater* 175:1056–1061. doi:[10.1016/j.jhazmat.2009.10.118](https://doi.org/10.1016/j.jhazmat.2009.10.118)



- Hasnat MA, Siddiquey IA, Saiful IS (2003) Photodegradation of malachite green in the aqueous medium. *Indian J Chem Sect A* 42:1865–1867
- Hema M, Arivoli S (2007) Comparative study on the adsorption kinetics and thermodynamics of dyes onto acid activated low cost carbon. *Int J Phys Sci* 2:10–17
- Heydartaemeh MR, Ardejani FD, Badii K et al (2014) FeCl<sub>2</sub>/FeCl<sub>3</sub> perlite nanoparticles as a novel magnetic material for adsorption of green malachite dye. *Arab J Sci Eng* 39:3383–3392. doi:10.1007/s13369-014-0978-x
- Hu R, Huang J-B, Yang Z-P et al (2011) Biosorption of crystal violet and malachite green by *Rhodotorula graminis* Y-5. *Ying Yong Sheng Tai Xue Bao J Appl Ecol Zhongguo Sheng Tai Xue Xue Hui Zhongguo Ke Xue Yuan Shenyang Ying Yong Sheng Tai Yan Jiu Suo Zhu Ban* 22:3293–3299
- Huang C-M, Chen L-C, Yang H-C et al (2012) Preparation of acrylic acid-modified chitin improved by an experimental design and its application in absorbing toxic organic compounds. *J Hazard Mater* 241–242:190–196. doi:10.1016/j.jhazmat.2012.09.032
- Huang L, Weng X, Chen Z et al (2014) Green synthesis of iron nanoparticles by various tea extracts: comparative study of the reactivity. *Spectrochim Acta A Mol Biomol Spectrosc* 130:295–301. doi:10.1016/j.saa.2014.04.037
- Huo S-H, Yan X-P (2012) Metal–organic framework MIL-100(Fe) for the adsorption of malachite green from aqueous solution. *J Mater Chem* 22:7449. doi:10.1039/c2jm16513a
- Hussain F, Hojjati M, Okamoto M, Gorga RE (2006) Review article: polymer-matrix nanocomposites, processing, manufacturing, and application: an overview. *J Compos Mater* 40:1511–1575. doi:10.1177/0021998306067321
- Idris MN, Ahmad ZA, Ahmad MA (2011) Adsorption equilibrium of malachite green dye onto rubber seed coat based activated carbon. *Int J Basic Appl Sci* 11:32–37
- Iijima S (1991) Helical microtubules of graphitic carbon. *Nature* 354:56–58
- Inbaraj BS, Sulochana N (2002) Basic dye adsorption on a low cost carbonaceous sorbent—kinetic and equilibrium studies. *Indian J Chem Technol* 9:201–208
- Iqbal MJ, Ashiq MN (2007) Adsorption of dyes from aqueous solutions on activated charcoal. *J Hazard Mater* 139:57–66. doi:10.1016/j.jhazmat.2006.06.007
- Issa AA, Al-Degs YS, Al-Ghouti MA, Olimat AAM (2014) Studying competitive sorption behavior of methylene blue and malachite green using multivariate calibration. *Chem Eng J* 240:554–564. doi:10.1016/j.cej.2013.10.084
- Jalil AA, Triwahyono S, Yaakob MR et al (2012) Utilization of bivalve shell-treated *Zea mays* L. (maize) husk leaf as a low-cost biosorbent for enhanced adsorption of malachite green. *Bioresour Technol* 120:218–224. doi:10.1016/j.biortech.2012.06.066
- Janoš P (2003) Sorption of basic dyes onto iron humate. *Environ Sci Technol* 37:5792–5798. doi:10.1021/es020142o
- Janoš P, Michálek P, Turek L (2007) Sorption of ionic dyes onto untreated low-rank coal–oxihumulite: a kinetic study. *Dyes Pigments* 74:363–370. doi:10.1016/j.dyepig.2006.02.017
- Janos P, Sedivý P, Rýznarová M, Grötschelová S (2005) Sorption of basic and acid dyes from aqueous solutions onto oxihumulite. *Chemosphere* 59:881–886. doi:10.1016/j.chemosphere.2004.11.018
- Janoš P, Šmídová V (2005) Effects of surfactants on the adsorptive removal of basic dyes from water using an organomineral sorbent—iron humate. *J Colloid Interface Sci* 291:19–27. doi:10.1016/j.jcis.2005.04.065
- Jasińska A, Bernat P, Paraszkiwicz K (2013) Malachite green removal from aqueous solution using the system rapeseed press cake and fungus *Myrothecium roridum*. *Desalin Water Treat* 51:7663–7671. doi:10.1080/19443994.2013.779939
- Jayaraj R, Mohan MC, Prasath PMD, Khan TH (2011) Malachite green dye removal using the seaweed enteromorpha. *J Chem* 8:649–656. doi:10.1155/2011/141305
- Jeon YS, Lei J, Kim J-H (2008) Dye adsorption characteristics of alginate/polyaspartate hydrogels. *J Ind Eng Chem* 14:726–731. doi:10.1016/j.jiec.2008.07.007
- Jeyagowri B, Yamuna RT (2015) Potential efficacy of a mesoporous biosorbent *Simarouba glauca* seed shell powder for the removal of malachite green from aqueous solutions. *Desalin Water Treat* 57:11326–11336. doi:10.1080/19443994.2015.1042060
- Ju Y, Yang S, Ding Y et al (2008) Microwave-assisted rapid photocatalytic degradation of malachite green in TiO<sub>2</sub> suspensions: mechanism and pathways. *J Phys Chem A* 112:11172–11177. doi:10.1021/jp804439z
- Kadirvelu K, Kavipriya M, Karthika C et al (2003) Utilization of various agricultural wastes for activated carbon preparation and application for the removal of dyes and metal ions from aqueous solutions. *Bioresour Technol* 87:129–132. doi:10.1016/S0960-8524(02)00201-8
- Kan Y, Yue Q, Kong J et al (2015) The application of activated carbon produced from waste printed circuit boards (PCBs) by H<sub>3</sub>PO<sub>4</sub> and steam activation for the removal of malachite green. *Chem Eng J* 260:541–549. doi:10.1016/j.cej.2014.09.047
- Kaneva N, Stambolova I, Blaskov V et al (2010) Photocatalytic activity of nanostructured ZnO films prepared by two different methods for the photoinitiated decolorization of malachite green. *J Alloys Compd* 500:252–258. doi:10.1016/j.jallcom.2010.04.020
- Kannan C, Muthuraja K, Devi MR (2013) Hazardous dyes removal from aqueous solution over mesoporous aluminophosphate with textural porosity by adsorption. *J Hazard Mater* 244–245:10–20. doi:10.1016/j.jhazmat.2012.11.016
- Kannan C, Sundaram T, Palvannan T (2008) Environmentally stable adsorbent of tetrahedral silica and non-tetrahedral alumina for removal and recovery of malachite green dye from aqueous solution. *J Hazard Mater* 157:137–145. doi:10.1016/j.jhazmat.2007.12.116
- Kannan RR, Rajasimman M, Rajamohan N, Sivaprakash B (2009) Brown marine algae *Turbinaria conoides* as biosorbent for malachite green removal: equilibrium and kinetic modeling. *Front Environ Sci Eng China* 4:116–122. doi:10.1007/s11783-010-0006-7
- Kant S, Pathania D, Singh P et al (2014) Removal of malachite green and methylene blue by Fe<sub>0.01</sub>Ni<sub>0.01</sub>Zn<sub>0.98</sub>O/polyacrylamide nanocomposite using coupled adsorption and photocatalysis. *Appl Catal B Environ* 147:340–352. doi:10.1016/j.apcatb.2013.09.001
- Karge HG, Weitkamp J (1989) Zeolites as catalysts, sorbents and detergent builders: applications and innovations. Elsevier, Amsterdam
- Karimi A, Aghbolaghy M, Khataee A, Shoa Bargh S (2012) Use of enzymatic bio-fenton as a new approach in decolorization of malachite green. *Sci World J*. doi:10.1100/2012/691569
- Kattri SD, Singh MK (1999) Adsorption of basic dyes from aqueous solution by natural adsorbent. *Indian J Chem Technol* 6:112–116
- Khan AA, Ahmad R, Khan A, Mondal PK (2013) Preparation of unsaturated polyester Ce(IV) phosphate by plastic waste bottles and its application for removal of Malachite green dye from water samples. *Arab J Chem* 6:361–368. doi:10.1016/j.arabjc.2010.10.012
- Khan TA, Rahman R, Ali I et al (2014) Removal of malachite green from aqueous solution using waste pea shells as low-cost adsorbent—adsorption isotherms and dynamics. *Toxicol Environ Chem* 96:569–578. doi:10.1080/02772248.2014.969268
- Khani H, Rofouei MK, Arab P et al (2010) Multi-walled carbon nanotubes-ionic liquid-carbon paste electrode as a super

- selectivity sensor: application to potentiometric monitoring of mercury ion(II). *J Hazard Mater* 183:402–409. doi:[10.1016/j.jhazmat.2010.07.039](https://doi.org/10.1016/j.jhazmat.2010.07.039)
- Khataee AR, Dehghan G, Zarei M et al (2011a) Neural network modeling of biotreatment of triphenylmethane dye solution by a green macroalgae. *Chem Eng Res Des* 89:172–178. doi:[10.1016/j.cherd.2010.05.009](https://doi.org/10.1016/j.cherd.2010.05.009)
- Khataee AR, Zarei M, Dehghan G et al (2011b) Biotreatment of a triphenylmethane dye solution using a Xanthophyta alga: modeling of key factors by neural network. *J Taiwan Inst Chem Eng* 42:380–386. doi:[10.1016/j.jtice.2010.08.006](https://doi.org/10.1016/j.jtice.2010.08.006)
- Khattri S, Singh M (1999) Colour removal from dye wastewater using sugar cane dust as an adsorbent. *Adsorpt Sci Technol* 17:269–282
- Khattri SD, Singh MK (2009) Removal of malachite green from dye wastewater using neem sawdust by adsorption. *J Hazard Mater* 167:1089–1094. doi:[10.1016/j.jhazmat.2009.01.101](https://doi.org/10.1016/j.jhazmat.2009.01.101)
- Khattri SD, Singh MK (2000) Colour removal from synthetic dye wastewater using a bioadsorbent. *Water Air Soil Pollut* 120:283–294. doi:[10.1023/A:1005207803041](https://doi.org/10.1023/A:1005207803041)
- Kiani G, Dostali M, Rostami A, Khataee AR (2011) Adsorption studies on the removal of malachite green from aqueous solutions onto halloysite nanotubes. *Appl Clay Sci* 54:34–39. doi:[10.1016/j.clay.2011.07.008](https://doi.org/10.1016/j.clay.2011.07.008)
- Kominami H, Kumamoto H, Kera Y, Ohtani B (2003) Photocatalytic decolorization and mineralization of malachite green in an aqueous suspension of titanium(IV) oxide nano-particles under aerated conditions: correlation between some physical properties and their photocatalytic activity. *J Photochem Photobiol Chem* 160:99–104. doi:[10.1016/S1010-6030\(03\)00227-2](https://doi.org/10.1016/S1010-6030(03)00227-2)
- Krauskopf KB (1956) Factors controlling the concentrations of thirteen rare metals in sea-water. *Geochim Cosmochim Acta* 9:1–B32. doi:[10.1016/0016-7037\(56\)90055-2](https://doi.org/10.1016/0016-7037(56)90055-2)
- Kuhar F, Papinutti L (2013) Protective effect of vanilloids against chemical stress on the white-rot fungus *Ganoderma lucidum*. *J Environ Manage* 124:1–7. doi:[10.1016/j.jenvman.2013.03.040](https://doi.org/10.1016/j.jenvman.2013.03.040)
- Kumar KV (2006) Comparative analysis of linear and non-linear method of estimating the sorption isotherm parameters for malachite green onto activated carbon. *J Hazard Mater* 136:197–202. doi:[10.1016/j.jhazmat.2005.09.018](https://doi.org/10.1016/j.jhazmat.2005.09.018)
- Kumar KV (2007) Optimum sorption isotherm by linear and non-linear methods for malachite green onto lemon peel. *Dyes Pigments* 74:595–597. doi:[10.1016/j.dyepig.2006.03.026](https://doi.org/10.1016/j.dyepig.2006.03.026)
- Kumar KV, Porkodi K (2007) Batch adsorber design for different solution volume/adsorbent mass ratios using the experimental equilibrium data with fixed solution volume/adsorbent mass ratio of malachite green onto orange peel. *Dyes Pigments* 74:590–594. doi:[10.1016/j.dyepig.2006.03.024](https://doi.org/10.1016/j.dyepig.2006.03.024)
- Kumar KV, Sivanesan S (2006) Pseudo second order kinetics and pseudo isotherms for malachite green onto activated carbon: comparison of linear and non-linear regression methods. *J Hazard Mater* 136:721–726. doi:[10.1016/j.jhazmat.2006.01.003](https://doi.org/10.1016/j.jhazmat.2006.01.003)
- Kumar KV, Sivanesan S, Ramamurthi V (2005) Adsorption of malachite green onto *Pithophora* sp., a fresh water algae: equilibrium and kinetic modelling. *Process Biochem* 40:2865–2872. doi:[10.1016/j.procbio.2005.01.007](https://doi.org/10.1016/j.procbio.2005.01.007)
- Kumar KY, Muralidhara HB, Nayaka YA et al (2013) Low-cost synthesis of metal oxide nanoparticles and their application in adsorption of commercial dye and heavy metal ion in aqueous solution. *Powder Technol* 246:125–136. doi:[10.1016/j.powtec.2013.05.017](https://doi.org/10.1016/j.powtec.2013.05.017)
- Kurniawan A, Sutiono H, Indraswati N, Ismadji S (2012) Removal of basic dyes in binary system by adsorption using rarasaponin-bentonite: revisited of extended Langmuir model. *Chem Eng J* 189–190:264–274. doi:[10.1016/j.cej.2012.02.070](https://doi.org/10.1016/j.cej.2012.02.070)
- Kushwaha AK, Gupta N, Chattopadhyaya MC (2014) Removal of cationic methylene blue and malachite green dyes from aqueous solution by waste materials of *Daucus carota*. *J Saudi Chem Soc* 18:200–207. doi:[10.1016/j.jcs.2011.06.011](https://doi.org/10.1016/j.jcs.2011.06.011)
- Lata H, Gupta RK, Garg VK (2008) Removal of basic dye from aqueous solution using chemically modified parthenium hysterophorus linn. *Biomass Chem Eng Commun* 195:1185–1199. doi:[10.1080/00986440701691103](https://doi.org/10.1080/00986440701691103)
- Lee Y-C, Kim EJ, Yang J-W, Shin H-J (2011) Removal of malachite green by adsorption and precipitation using aminopropyl functionalized magnesium phyllosilicate. *J Hazard Mater* 192:62–70. doi:[10.1016/j.jhazmat.2011.04.094](https://doi.org/10.1016/j.jhazmat.2011.04.094)
- Lee Y-C, Kim J-Y, Shin H-J (2013) Removal of malachite green (MG) from aqueous solutions by adsorption, precipitation, and alkaline fading using talc. *Sep Sci Technol* 48:1093–1101. doi:[10.1080/01496395.2012.723100](https://doi.org/10.1080/01496395.2012.723100)
- Levin L, Papinutti L, Forchiassin F (2004) Evaluation of Argentinean white rot fungi for their ability to produce lignin-modifying enzymes and decolorize industrial dyes. *Bioresour Technol* 94:169–176. doi:[10.1016/j.biortech.2003.12.002](https://doi.org/10.1016/j.biortech.2003.12.002)
- Li X, Li Y, Zhang S, Ye Z (2012) Preparation and characterization of new foam adsorbents of poly(vinyl alcohol)/chitosan composites and their removal for dye and heavy metal from aqueous solution. *Chem Eng J* 183:88–97. doi:[10.1016/j.cej.2011.12.025](https://doi.org/10.1016/j.cej.2011.12.025)
- Lin K-YA, Chang H-A (2015) Ultra-high adsorption capacity of zeolitic imidazole framework-67 (ZIF-67) for removal of malachite green from water. *Chemosphere*. doi:[10.1016/j.chemosphere.2015.01.041](https://doi.org/10.1016/j.chemosphere.2015.01.041)
- Liu Y, Ohko Y, Zhang R et al (2010) Degradation of malachite green on Pd/WO<sub>3</sub> photocatalysts under simulated solar light. *J Hazard Mater* 184:386–391. doi:[10.1016/j.jhazmat.2010.08.047](https://doi.org/10.1016/j.jhazmat.2010.08.047)
- Low LW, Teng TT, Rafatullah M et al (2013) Adsorption studies of methylene blue and malachite green from aqueous solutions by pretreated lignocellulosic materials. *Sep Sci Technol* 48:1688–1698. doi:[10.1080/01496395.2012.756912](https://doi.org/10.1080/01496395.2012.756912)
- Lv X, Xu Y, Lv K, Zhang G (2005) Photo-assisted degradation of anionic and cationic dyes over iron(III)-loaded resin in the presence of hydrogen peroxide. *J Photochem Photobiol Chem* 173:121–127. doi:[10.1016/j.jphotochem.2005.01.011](https://doi.org/10.1016/j.jphotochem.2005.01.011)
- Mahto TK, Chowdhuri AR, Sahu SK (2014) Polyaniline-functionalized magnetic nanoparticles for the removal of toxic dye from wastewater. *J Appl Polym Sci* 131:1–9. doi:[10.1002/app.40840](https://doi.org/10.1002/app.40840)
- Makeswari M, Santhi T (2013) Removal of malachite green dye from aqueous solutions onto microwave assisted zinc chloride chemical activated epicarp of *Ricinus communis*. *J Water Resour Prot* 5:222–238. doi:[10.4236/jwarp.2013.52023](https://doi.org/10.4236/jwarp.2013.52023)
- Malana MA, Ijaz S, Ashiq MN (2010) Removal of various dyes from aqueous media onto polymeric gels by adsorption process: their kinetics and thermodynamics. *Desalination* 263:249–257. doi:[10.1016/j.desal.2010.06.066](https://doi.org/10.1016/j.desal.2010.06.066)
- Malik R, Ramteke DS, Wate SR (2007) Adsorption of malachite green on groundnut shell waste based powdered activated carbon. *Waste Manag* 27:1129–1138. doi:[10.1016/j.wasman.2006.06.009](https://doi.org/10.1016/j.wasman.2006.06.009)
- Mall ID, Srivastava VC, Agarwal NK, Mishra IM (2005) Adsorptive removal of malachite green dye from aqueous solution by bagasse fly ash and activated carbon-kinetic study and equilibrium isotherm analyses. *Colloids Surf Physicochem Eng Asp* 264:17–28. doi:[10.1016/j.colsurfa.2005.03.027](https://doi.org/10.1016/j.colsurfa.2005.03.027)
- Man LW, Kumar P, Teng TT, Wasewar KL (2012) Design of experiments for malachite green dye removal from wastewater using thermolysis—coagulation–flocculation. *Desalin Water Treat* 40:260–271. doi:[10.1080/19443994.2012.671257](https://doi.org/10.1080/19443994.2012.671257)
- Mane VS, Babu PVV (2011) Studies on the adsorption of brilliant green dye from aqueous solution onto low-cost NaOH treated

- saw dust. *Desalination* 273:321–329. doi:10.1016/j.desal.2011.01.049
- Mansa RF, Sipaut CS, Rahman IA et al (2016) Preparation of glycine-modified silica nanoparticles for the adsorption of malachite green dye. *J Porous Mater* 23:35–46. doi:10.1007/s10934-015-0053-3
- Méndez A, Fernández F, Gascó G (2007) Removal of malachite green using carbon-based adsorbents. *Desalination* 206:147–153. doi:10.1016/j.desal.2006.03.564
- Meng L, Zhang X, Tang Y et al (2015) Hierarchically porous silicon-carbon-nitrogen hybrid materials towards highly efficient and selective adsorption of organic dyes. *Sci Rep* 5:7910. doi:10.1038/srep07910
- Mirzajani R, Ahmadi S (2015) Melamine supported magnetic iron oxide nanoparticles (Fe<sub>3</sub>O<sub>4</sub>@Mel) for spectrophotometric determination of malachite green in water samples and fish tissues. *J Ind Eng Chem* 23:171–178. doi:10.1016/j.jiec.2014.08.011
- Mishra RR, Chandran P, Khan SS (2014) Equilibrium and kinetic studies on adsorptive removal of malachite green by the citrate-stabilized magnetite nanoparticles. *RSC Adv* 4:51787–51793. doi:10.1039/C4RA07651F
- Mittal A (2006) Adsorption kinetics of removal of a toxic dye, malachite green, from wastewater by using hen feathers. *J Hazard Mater* 133:196–202. doi:10.1016/j.jhazmat.2005.10.017
- Mittal A, Krishnan L, Gupta VK (2005) Removal and recovery of malachite green from wastewater using an agricultural waste material, de-oiled soya. *Sep Purif Technol* 43:125–133. doi:10.1016/j.seppur.2004.10.010
- Mittal A, Mittal J, Malviya A, Gupta VK (2009) Adsorptive removal of hazardous anionic dye “Congo Red” from wastewater using waste materials and recovery by desorption. *J Colloid Interface Sci* 340:16–26. doi:10.1016/j.jcis.2009.08.019
- Modirshahla N, Behnajady MA (2006) Photooxidative degradation of malachite green (MG) by UV/H<sub>2</sub>O<sub>2</sub>: influence of operational parameters and kinetic modeling. *Dyes Pigments* 70:54–59. doi:10.1016/j.dyepig.2005.04.012
- Mohammadi A, Daemi H, Barikani M (2014) Fast removal of malachite green dye using novel superparamagnetic sodium alginate-coated Fe<sub>3</sub>O<sub>4</sub> nanoparticles. *Int J Biol Macromol* 69:447–455. doi:10.1016/j.ijbiomac.2014.05.042
- Mondal S (2008) Methods of dye removal from dye house effluent—an overview. *Environ Eng Sci* 25:383–396. doi:10.1089/ees.2007.0049
- Moumeni O, Hamdaoui O (2012) Intensification of sonochemical degradation of malachite green by bromide ions. *Ultrason Sonochem* 19:404–409. doi:10.1016/j.ultsonch.2011.08.008
- Nandi BK, Goswami A, Purkait MK (2009) Adsorption characteristics of brilliant green dye on kaolin. *J Hazard Mater* 161:387–395. doi:10.1016/j.jhazmat.2008.03.110
- Nethaji S, Sivasamy A, Kumar RV, Mandal AB (2013) Preparation of char from lotus seed biomass and the exploration of its dye removal capacity through batch and column adsorption studies. *Environ Sci Pollut Res Int* 20:3670–3678. doi:10.1007/s11356-012-1267-4
- Nethaji S, Sivasamy A, Mandal AB (2012) Adsorption isotherms, kinetics and mechanism for the adsorption of cationic and anionic dyes onto carbonaceous particles prepared from *Juglans regia* shell biomass. *Int J Environ Sci Technol* 10:231–242. doi:10.1007/s13762-012-0112-0
- Nethaji S, Sivasamy A, Thennarasu G, Saravanan S (2010) Adsorption of malachite green dye onto activated carbon derived from *Borassus aethiopicum* flower biomass. *J Hazard Mater* 181:271–280. doi:10.1016/j.jhazmat.2010.05.008
- Ng HW, Lee LY, Chan WL et al (2015) Luffa acutangula peel as an effective natural biosorbent for malachite green removal in aqueous media: equilibrium, kinetic and thermodynamic investigations. *Desalin Water Treat* 57:7302–7311. doi:10.1080/19443994.2015.1016460
- Nidheesh PV, Gandhimathi R, Ramesh ST (2013) Degradation of dyes from aqueous solution by Fenton processes: a review. *Environ Sci Pollut Res* 20:2099–2132. doi:10.1007/s11356-012-1385-z
- Odom TW, Huang J-L, Kim P, Lieber CM (1998) Atomic structure and electronic properties of single-walled carbon nanotubes. *Nature* 391:62–64. doi:10.1038/34145
- Oladoja NA, Aliu YD (2009) Snail shell as coagulant aid in the alum precipitation of malachite green from aqua system. *J Hazard Mater* 164:1496–1502. doi:10.1016/j.jhazmat.2008.09.114
- Onal Y (2006) Kinetics of adsorption of dyes from aqueous solution using activated carbon prepared from waste apricot. *J Hazard Mater* 137:1719–1728. doi:10.1016/j.jhazmat.2006.05.036
- Önal Y, Akmil-Başar C, Eren D et al (2006) Adsorption kinetics of malachite green onto activated carbon prepared from Tunçbilek lignite. *J Hazard Mater* 128:150–157. doi:10.1016/j.jhazmat.2005.07.055
- Önal Y, Akmil-Başar C, Sarıcı-Özdemir Ç (2007) Investigation kinetics mechanisms of adsorption malachite green onto activated carbon. *J Hazard Mater* 146:194–203. doi:10.1016/j.jhazmat.2006.12.006
- Özdemir A, Keskin CS (2009) Removal of a binary dye mixture of congo red and malachite green from aqueous solutions using a bentonite adsorbent. *Clays Clay Miner* 57:695–705. doi:10.1346/CCMN.2009.0570603
- Ozdes D, Gundogdu A, Duran C, Senturk HB (2010) Evaluation of adsorption characteristics of malachite green onto Almond Shell (*Prunus dulcis*). *Sep Sci Technol* 45:2076–2085. doi:10.1080/01496395.2010.504479
- Pan X, Zhang D (2009) Removal of malachite green from water by *Firmiana simplex* wood fiber. *Electron J Biotechnol* 12:9–10
- Pandit P, Basu S (2004) Removal of ionic dyes from water by solvent extraction using reverse micelles. *Environ Sci Technol* 38:2435–2442
- Papinutti L, Mouso N, Forchiassin F (2006) Removal and degradation of the fungicide dye malachite green from aqueous solution using the system wheat bran–Fomes sclerodermeus. *Enzyme Microb Technol* 39:848–853. doi:10.1016/j.enzmictec.2006.01.013
- Parida SK, Dash S, Patel S, Mishra BK (2006) Adsorption of organic molecules on silica surface. *Adv Colloid Interface Sci* 121:77–110. doi:10.1016/j.cis.2006.05.028
- Patil MR, Shrivastava VS (2014) Adsorption of malachite green by polyaniline–nickel ferrite magnetic nanocomposite: an isotherm and kinetic study. *Appl Nanosci* 5:809–816. doi:10.1007/s13204-014-0383-5
- Paul M, Pal N, Bhaumik A (2012) Selective adsorption and release of cationic organic dye molecules on mesoporous borosilicates. *Mater Sci Eng C Mater Biol Appl* 32:1461–1468. doi:10.1016/j.msec.2012.04.026
- Pearce CI, Lloyd JR, Guthrie JT (2003) The removal of colour from textile wastewater using whole bacterial cells: a review. *Dyes Pigments* 58:179–196. doi:10.1016/S0143-7208(03)0064-0
- Pehlivan E, Arslan G (2007) Removal of metal ions using lignite in aqueous solution—low cost biosorbents. *Fuel Process Technol* 88:99–106. doi:10.1016/j.fuproc.2006.09.004
- Pirsaheb M, Shahmoradi B, Khosravi T et al (2015) Solar degradation of malachite green using nickel-doped TiO<sub>2</sub> nanocatalysts. *Desalin Water Treat* 57:9881–9888. doi:10.1080/19443994.2015.1033764
- Podstawczyk D, Witek-Krowiak A, Chojnacka K, Sadowski Z (2014) Biosorption of malachite green by eggshells: mechanism

- identification and process optimization. *Bioresour Technol* 160:161–165. doi:10.1016/j.biortech.2014.01.015
- Porkodi K, Vasanth Kumar K (2007) Equilibrium, kinetics and mechanism modeling and simulation of basic and acid dyes sorption onto jute fiber carbon: eosin yellow, malachite green and crystal violet single component systems. *J Hazard Mater* 143:311–327. doi:10.1016/j.jhazmat.2006.09.029
- Pourjavadi A, Doulabi M, Doroudian M (2014) Adsorption characteristics of malachite green onto novel kappa-carrageenan-g-polyacrylic acid/TiO<sub>2</sub>-NH<sub>2</sub> hydrogel nanocomposite. *J Iran Chem Soc* 11:1057–1065. doi:10.1007/s13738-013-0374-6
- Pradeep Sekhar C, Kalidhasan S, Rajesh V, Rajesh N (2009) Biopolymer adsorbent for the removal of malachite green from aqueous solution. *Chemosphere* 77:842–847. doi:10.1016/j.chemosphere.2009.07.068
- Pradhan AC, Parida KM, Nanda B (2011) Enhanced photocatalytic and adsorptive degradation of organic dyes by mesoporous Cu/Al<sub>2</sub>O<sub>3</sub>-MCM-41: intra-particle mesoporosity, electron transfer and OH radical generation under visible light. *Dalton Trans Camb Engl* 40:7348–7356. doi:10.1039/c1dt10363f
- Prado AGS, Costa LL (2009) Photocatalytic decoloration of malachite green dye by application of TiO<sub>2</sub> nanotubes. *J Hazard Mater* 169:297–301. doi:10.1016/j.jhazmat.2009.03.076
- Rahman IA, Saad B, Shaidan S, Sya Rizal ES (2005) Adsorption characteristics of malachite green on activated carbon derived from rice husks produced by chemical–thermal process. *Bioresour Technol* 96:1578–1583. doi:10.1016/j.biortech.2004.12.015
- Rajabi HR, Khani O, Shamsipur M, Vatanpour V (2013) High-performance pure and Fe<sup>3+</sup>-ion doped ZnS quantum dots as green nanophotocatalysts for the removal of malachite green under UV-light irradiation. *J Hazard Mater* 250–251:370–378. doi:10.1016/j.jhazmat.2013.02.007
- Rajabi M, Mirza B, Mahanpoor K et al (2016) Adsorption of malachite green from aqueous solution by carboxylate group functionalized multi-walled carbon nanotubes: determination of equilibrium and kinetics parameters. *J Ind Eng Chem* 34:130–138. doi:10.1016/j.jiec.2015.11.001
- Rajesh Kannan R, Rajasimman M, Rajamohan N, Sivaprakash B (2010) Equilibrium and kinetic studies on sorption of malachite green using hydrilla verticillata biomass. *Int J Environ Res* 4:817–824
- Rajeshkannan R, Rajamohan N, Rajasimman M (2009) Removal of malachite green from aqueous solution by sorption on hydrilla verticillata biomass using response surface methodology. *Front Chem Eng China* 3:146–154. doi:10.1007/s11705-009-0007-x
- Rajeshkannan R, Rajasimman M, Rajamohan N (2011) Decolorization of malachite green using tamarind seed: optimization, isotherm and kinetic studies. *Chem Ind Chem Eng Quart* 17:67–79. doi:10.2298/CICEQ100716056R
- Rajeshkannan R, Rajasimman M, Rajamohan N (2010) Removal of malachite green from aqueous solution using hydrilla verticillata-optimization, equilibrium and kinetic studies. *Int J Civ Environ Eng* 2:222–229
- Rajeshwarisivaraj Sivakumar S, Senthilkumar P, Subburam V (2001) Carbon from Cassava peel, an agricultural waste, as an adsorbent in the removal of dyes and metal ions from aqueous solution. *Bioresour Technol* 80:233–235. doi:10.1016/S0960-8524(00)00179-6
- Rajeshwarisivaraj, Subburam V (2002) Activated parthenium carbon as an adsorbent for the removal of dyes and heavy metal ions from aqueous solution. *Bioresour Technol* 85:205–206. doi:10.1016/S0960-8524(02)00089-5
- Rajgopal S, Karthikeyan T, Prakash Kumar BG, Miranda LR (2006) Utilization of fluidized bed reactor for the production of adsorbents in removal of malachite green. *Chem Eng J* 116:211–217. doi:10.1016/j.cej.2005.09.026
- Ramaraju B, Manoj Kumar Reddy P, Subrahmanyam C (2014) Low cost adsorbents from agricultural waste for removal of dyes. *Environ Prog Sustain Energy* 33:38–46. doi:10.1002/ep.11742
- Rauf MA, Bukallah SB, Hamour FA, Nasir AS (2008) Adsorption of dyes from aqueous solutions onto sand and their kinetic behavior. *Chem Eng J* 137:238–243. doi:10.1016/j.cej.2007.04.025
- Raval NP, Shah PU, Ladha DG et al (2016a) Comparative study of chitin and chitosan beads for the adsorption of hazardous anionic azo dye Congo Red from wastewater. *Desalin Water Treat* 57:9247–9262. doi:10.1080/19443994.2015.1027959
- Raval NP, Shah PU, Shah NK (2016b) Nanoparticles loaded biopolymer as effective adsorbent for adsorptive removal of malachite green from aqueous solution. *Water Conserv Sci Eng* 1:69–81. doi:10.1007/s41101-016-0004-0
- Raval NP, Shah PU, Shah NK (2016c) Adsorptive amputation of hazardous azo dye Congo red from wastewater: a critical review. *Environ Sci Pollut Res* 23:14810–14853. doi:10.1007/s11356-016-6970-0
- Raval NP, Shah PU, Shah NK (2016d) Adsorptive removal of nickel(II) ions from aqueous environment: a review. *J Environ Manag* 179:1–20. doi:10.1016/j.jenvman.2016.04.045
- Ren S, Guo J, Zeng G, Sun G (2006) Decolorization of triphenylmethane, azo, and anthraquinone dyes by a newly isolated *Aeromonas hydrophila* strain. *Appl Microbiol Biotechnol* 72:1316–1321. doi:10.1007/s00253-006-0418-2
- Robaina NF, Soriano S, Cassella RJ (2009) Polyurethane foam loaded with SDS for the adsorption of cationic dyes from aqueous medium: multivariate optimization of the loading process. *J Hazard Mater* 167:653–659. doi:10.1016/j.jhazmat.2009.01.033
- Robinson T, McMullan G, Marchant R, Nigam P (2001) Remediation of dyes in textile effluent: a critical review on current treatment technologies with a proposed alternative. *Bioresour Technol* 77:247–255. doi:10.1016/S0960-8524(00)00080-8
- Rogaieh Z, Gharbani P (2013) Study on malachite green dye removal by adsorption onto activated nano-alumina. *Appl Chem Environ* 3:71–77
- Rong X, Qiu F, Qin J et al (2014) Removal of malachite green from the contaminated water using a water-soluble melamine/maleic anhydride sorbent. *J Ind Eng Chem* 20:3808–3814. doi:10.1016/j.jiec.2013.12.083
- Roosta M, Ghaedi M, Shokri N et al (2014) Optimization of the combined ultrasonic assisted/adsorption method for the removal of malachite green by gold nanoparticles loaded on activated carbon: experimental design. *Spectrochim Acta A Mol Biomol Spectrosc* 118:55–65. doi:10.1016/j.saa.2013.08.082
- Safarik I, Lunackova P, Mosiniewicz-Szablewska E et al (2007) Adsorption of water-soluble organic dyes on ferrofluid-modified sawdust. *Holzforchung* 61:247–253. doi:10.1515/HF.2007.060
- Šafařík I, Šafaříková M, Vrchotová N (1995) Study of sorption of triphenylmethane dyes on a magnetic carrier bearing an immobilized copper phthalocyanine dye. *Collect Czechoslov Chem Commun* 60:34–42. doi:10.1135/cccc19950034
- Šafařík I, Šafaříková M (2002) Detection of low concentrations of malachite green and crystal violet in water. *Water Res* 36:196–200. doi:10.1016/S0043-1354(01)00243-3
- Saha P, Chowdhury S, Gupta S et al (2010a) Assessment on the removal of malachite green using tamarind fruit shell as biosorbent. *CLEAN—Soil Air Water* 38:437–445. doi:10.1002/clean.200900234
- Saha P, Chowdhury S, Gupta S, Kumar I (2010b) Insight into adsorption equilibrium, kinetics and thermodynamics of

- malachite green onto clayey soil of Indian origin. *Chem Eng J* 165:874–882. doi:10.1016/j.cej.2010.10.048
- Saha S, Pal A (2014) Microporous assembly of MnO<sub>2</sub> nanosheets for malachite green degradation. *Sep Purif Technol* 134:26–36. doi:10.1016/j.seppur.2014.07.021
- Saha S, Wang JM, Pal A (2012) Nano silver impregnation on commercial TiO<sub>2</sub> and a comparative photocatalytic account to degrade malachite green. *Sep Purif Technol* 89:147–159. doi:10.1016/j.seppur.2012.01.012
- Saleh TA, Gupta VK (2011) Functionalization of tungsten oxide into MWCNT and its application for sunlight-induced degradation of rhodamine B. *J Colloid Interface Sci* 362:337–344. doi:10.1016/j.jcis.2011.06.081
- Salima A, Benaouda B, Noureddine B, Duclaux L (2013) Application of *Ulva lactuca* and *Systocera stricta* algae-based activated carbons to hazardous cationic dyes removal from industrial effluents. *Water Res* 47:3375–3388. doi:10.1016/j.watres.2013.03.038
- Salleh MAM, Mahmoud DK, Karim WAWA, Idris A (2011) Cationic and anionic dye adsorption by agricultural solid wastes: a comprehensive review. *Desalination* 280:1–13. doi:10.1016/j.desal.2011.07.019
- Samiey B, Toosi AR (2010) Adsorption of malachite green on silica gel: effects of NaCl, pH and 2-propanol. *J Hazard Mater* 184:739–745. doi:10.1016/j.jhazmat.2010.08.101
- Sánchez PCM, Pariente JP (2011) Zeolites and ordered porous solids: fundamentals and applications. Editorial Universitat Politècnica de València, Valencia
- Sand LB, Mumpton FA (1978) Natural zeolites: occurrence, properties, and use. Pergamon Press Inc, Elmsford
- Santhi T, Manonmani S (2011) Malachite green removal from aqueous solution by the peel of *cucumis sativa* fruit. *CLEAN—Soil Air Water* 39:162–170. doi:10.1002/clen.201000077
- Santhi T, Manonmani S, Smitha T (2010a) Kinetics and isotherm studies on cationic dyes adsorption onto *annona squamosa* seed activated carbon. *Int J Eng Sci Technol* 2:287–295
- Santhi T, Manonmani S, Smitha T (2010b) Removal of malachite green from aqueous solution by activated carbon prepared from the epicarp of *Ricinus communis* by adsorption. *J Hazard Mater* 179:178–186. doi:10.1016/j.jhazmat.2010.02.076
- Saravanan R, Gupta VK, Prakash T et al (2013) Synthesis, characterization and photocatalytic activity of novel Hg doped ZnO nanorods prepared by thermal decomposition method. *J Mol Liq* 178:88–93. doi:10.1016/j.molliq.2012.11.012
- Saravanan R, Prakash T, Gupta VK, Stephen A (2014) Tailoring the electrical and dielectric properties of ZnO nanorods by substitution. *J Mol Liq* 193:160–165. doi:10.1016/j.molliq.2013.12.029
- Saravanan R, Sacari E, Gracia F et al (2016) Conducting PANI stimulated ZnO system for visible light photocatalytic degradation of coloured dyes. *J Mol Liq* 221:1029–1033. doi:10.1016/j.molliq.2016.06.074
- Sarkar AK, Pal A, Ghorai S et al (2014) Efficient removal of malachite green dye using biodegradable graft copolymer derived from amylopectin and poly(acrylic acid). *Carbohydr Polym* 111:108–115. doi:10.1016/j.carbpol.2014.04.042
- Sartape AS, Mandhare AM, Jadhav VV et al (2015) Removal of malachite green dye from aqueous solution with adsorption technique using *Limonia acidissima* (wood apple) shell as low cost adsorbent. *Arab J Chem*. doi:10.1016/j.arabjc.2013.12.019
- Savva I, Marinica O, Papatryfonos CA et al (2015) Evaluation of electrospun polymer-Fe<sub>3</sub>O<sub>4</sub> nanocomposite mats in malachite green adsorption. *RSC Adv* 5:16484–16496. doi:10.1039/C4RA16938G
- Sayilkan F, Asiltürk M, Tatar P et al (2007a) Photocatalytic performance of Sn-doped TiO<sub>2</sub> nanostructured mono and double layer thin films for malachite green dye degradation under UV and vis-lights. *J Hazard Mater* 144:140–146. doi:10.1016/j.jhazmat.2006.10.011
- Sayilkan F, Asiltürk M, Tatar P et al (2007b) Preparation of re-usable photocatalytic filter for degradation of malachite green dye under UV and vis-irradiation. *J Hazard Mater* 148:735–744. doi:10.1016/j.jhazmat.2007.03.036
- Sayilkan F, Asiltürk M, Tatar P et al (2008) Photocatalytic performance of Sn-doped TiO<sub>2</sub> nanostructured thin films for photocatalytic degradation of malachite green dye under UV and VIS-lights. *Mater Res Bull* 43:127–134. doi:10.1016/j.materresbull.2007.02.012
- Schmidt D, Shah D, Giannelis EP (2002) New advances in polymer/layered silicate nanocomposites. *Curr Opin Solid State Mater Sci* 6:205–212. doi:10.1016/S1359-0286(02)00049-9
- Sharma P, Kaur H, Sharma M, Sahore V (2011) A review on applicability of naturally available adsorbents for the removal of hazardous dyes from aqueous waste. *Environ Monit Assess* 183:151–195. doi:10.1007/s10661-011-1914-0
- Sharma YC (2011) Adsorption characteristics of a low-cost activated carbon for the reclamation of colored effluents containing malachite green. *J Chem Eng Data* 56:478–484. doi:10.1021/je1008922
- Sharma YC, Singh B, Uma (2009) Fast removal of malachite green by adsorption on rice husk activated carbon. *Open Environ Pollut Toxicol J* 1:74–78. doi:10.2174/1876397900901010074
- Shedbalkar U, Jadhav JP (2011) Detoxification of malachite green and textile industrial effluent by *Penicillium ochrochloron*. *Biotechnol Bioprocess Eng* 16:196–204. doi:10.1007/s12257-010-0069-0
- Shi Q, Zhang J, Zhang C et al (2010) Preparation of activated carbon from cattail and its application for dyes removal. *J Environ Sci China* 22:91–97
- Shirmardi M, Mahvi AH, Hashemzadeh B et al (2013) The adsorption of malachite green (MG) as a cationic dye onto functionalized multi walled carbon nanotubes. *Korean J Chem Eng* 30:1603–1608. doi:10.1007/s11814-013-0080-1
- Singh A, Manju Rani S, Bishnoi NR (2012) Malachite green dye decolorization on immobilized dead yeast cells employing sequential design of experiments. *Ecol Eng* 47:291–296. doi:10.1016/j.ecoleng.2012.07.001
- Singh DK, Rastogi K (2004) Adsorptive removal of basic dyes from aqueous phase onto activated carbon of used tea leaves: a kinetic and thermodynamic study. *J Environ Sci Eng* 46:293–302
- Sivashankar R, Sathya AB, Vasantharaj K, Sivasubramanian V (2014) Magnetic composite an environmental super adsorbent for dye sequestration—a review. *Environ Nanotechnol Monit Manag* 1–2:36–49. doi:10.1016/j.enmm.2014.06.001
- Solís M, Solís A, Pérez HI et al (2012) Microbial decoloration of azo dyes: a review. *Process Biochem* 47:1723–1748. doi:10.1016/j.procbio.2012.08.014
- Sonawane GH, Shrivastava VS (2009) Kinetics of decolorization of malachite green from aqueous medium by maize cob (*Zea mays*): an agricultural solid waste. *Desalination* 247:430–441. doi:10.1016/j.desal.2009.01.006
- Sonawane SH, Chaudhari PL, Ghodke SA et al (2009) Ultrasound assisted synthesis of polyacrylic acid-nanoclay nanocomposite and its application in sonosorption studies of malachite green dye. *Ultrason Sonochem* 16:351–355. doi:10.1016/j.ultsonch.2008.10.008
- Srinivasan A, Viraraghavan T (2010) Decolorization of dye wastewaters by biosorbents: a review. *J Environ Manag* 91:1915–1929. doi:10.1016/j.jenvman.2010.05.003
- Srivastava R, Rupainwar DC (2011) A comparative evaluation for adsorption of dye on Neem bark and Mango bark powder. *Indian J Technol* 18:67–75

- Stephen Inbaraj B, Chiu CP, Ho GH et al (2006) Removal of cationic dyes from aqueous solution using an anionic poly- $\gamma$ -glutamic acid-based adsorbent. *J Hazard Mater* 137:226–234. doi:10.1016/j.jhazmat.2006.01.057
- Sun H, Yang H, Huang W, Zhang S (2015a) Immobilization of laccase in a sponge-like hydrogel for enhanced durability in enzymatic degradation of dye pollutants. *J Colloid Interface Sci* 450:353–360. doi:10.1016/j.jcis.2015.03.037
- Sun L, Hu S, Sun H et al (2015b) Malachite green adsorption onto Fe<sub>3</sub>O<sub>4</sub>@SiO<sub>2</sub>-NH<sub>2</sub>: isotherms, kinetic and process optimization. *RSC Adv* 5:11837–11844. doi:10.1039/C4RA13402H
- Sun X-F, Wang S-G, Liu X-W et al (2008) Biosorption of malachite green from aqueous solutions onto aerobic granules: kinetic and equilibrium studies. *Bioresour Technol* 99:3475–3483. doi:10.1016/j.biortech.2007.07.055
- Suresh T, Annadurai G (2013) Synthesis, characterization and photocatalytic degradation of malachite green dye using titanium dioxide nanoparticles. *Int J Res Environ Sci Technol* 3:71–77
- Suwandi AC, Indraswati N, Ismadi S (2012) Adsorption of N-methylated diaminotriphenylmethane dye (malachite green) on natural rarasaponin modified kaolin. *Desalin Water Treat* 41:342–355. doi:10.1080/19443994.2012.664738
- Syed SP (2011) Study of the removal of malachite green from aqueous solution by using solid agricultural waste. *Res J Chem Sci* 1:1
- Tahir H, Hamed U, Sultan M, Jahanzeb Q (2010) Batch adsorption technique for the removal of malachite green and fast green dyes by using montmorillonite clay as adsorbent. *Afr J Biotechnol* 9:8206–8214
- Tahir H, Sultan M, Jahanzeb Q (2009) Remediation of azo dyes by using household used black tea as an adsorbent. *Afr J Biotechnol*. doi:10.4314/ajb.v8i15.61858
- Tahir SS, Rauf N (2006) Removal of a cationic dye from aqueous solutions by adsorption onto bentonite clay. *Chemosphere* 63:1842–1848. doi:10.1016/j.chemosphere.2005.10.033
- Tang H, Zhou W, Zhang L (2012) Adsorption isotherms and kinetics studies of malachite green on chitin hydrogels. *J Hazard Mater* 209–210:218–225. doi:10.1016/j.jhazmat.2012.01.010
- Tang Y, Hu T, Zeng Y et al (2014) Effective adsorption of cationic dyes by lignin sulfonate polymer based on simple emulsion polymerization: isotherm and kinetic studies. *RSC Adv* 5:3757–3766. doi:10.1039/C4RA12229A
- Tanthapanichakoon W, Ariyadejwanich P, Japthong P et al (2005) Adsorption–desorption characteristics of phenol and reactive dyes from aqueous solution on mesoporous activated carbon prepared from waste tires. *Water Res* 39:1347–1353. doi:10.1016/j.watres.2004.12.044
- Tavakol M, Azar PA, Tehrani MS, Ghaedi M (2015) Silver nanoparticles loaded on activated carbon as a novel adsorbent for the competitive removal of malachite green and methylene blue. *Int J Life Sci* 9:75–92. doi:10.3126/ijls.v9i2.12053
- Tavlieva MP, Genieva SD, Georgieva VG, Vlaev LT (2013) Kinetic study of brilliant green adsorption from aqueous solution onto white rice husk ash. *J Colloid Interface Sci* 409:112–122. doi:10.1016/j.jcis.2013.07.052
- Tayade RJ, Suroliya PK, Kulkarni RG, Jasra RV (2007) Photocatalytic degradation of dyes and organic contaminants in water using nanocrystalline anatase and rutile TiO<sub>2</sub>. *Sci Technol Adv Mater* 8:455–462. doi:10.1016/j.stam.2007.05.006
- Tehrani-Bagha AR, Nikkar H, Mahmoodi NM et al (2011) The sorption of cationic dyes onto kaolin: kinetic, isotherm and thermodynamic studies. *Desalination* 266:274–280. doi:10.1016/j.desal.2010.08.036
- Tian Y, Liu P, Wang X, Lin H (2011) Adsorption of malachite green from aqueous solutions onto ordered mesoporous carbons. *Chem Eng J* 171:1263–1269. doi:10.1016/j.cej.2011.05.040
- Tolia J, Chakraborty M, Murthy Z (2012) Photocatalytic degradation of malachite green dye using doped and undoped ZnS nanoparticles. *Pol J Chem Technol* 14:16–21. doi:10.2478/v10026-012-0065-6
- Tsai W-T, Chen H-R (2010) Removal of malachite green from aqueous solution using low-cost chlorella-based biomass. *J Hazard Mater* 175:844–849. doi:10.1016/j.jhazmat.2009.10.087
- Uma, Banerjee S, Sharma YC (2013) Equilibrium and kinetic studies for removal of malachite green from aqueous solution by a low cost activated carbon. *J Ind Eng Chem* 19:1099–1105. doi:10.1016/j.jiec.2012.11.030
- Vasanth Kumar K, Ramamurthi V, Sivanesan S (2006) Biosorption of malachite green, a cationic dye onto *Pithophora* sp., a fresh water algae. *Dyes Pigments* 69:102–107. doi:10.1016/j.dyepig.2005.02.005
- Vasanth Kumar K, Sivanesan S (2007) Isotherms for Malachite Green onto rubber wood (*Hevea brasiliensis*) sawdust: comparison of linear and non-linear methods. *Dyes Pigments* 72:124–129. doi:10.1016/j.dyepig.2005.07.021
- Vasu AE (2008) Studies on the removal of rhodamine B and malachite green from aqueous solutions by activated carbon. *J Chem* 5:844–852. doi:10.1155/2008/271615
- Vijayaraghavan K, Premkumar Y, Jegan J (2015) Malachite green and crystal violet biosorption onto coco-peat: characterization and removal studies. *Desalin Water Treat* 57:6423–6431. doi:10.1080/19443994.2015.1011709
- Volesky B (1990) *Biosorption of heavy metals*. CRC Press, Boca Raton
- Wan Ngah WS, Ariff NFM, Hashim A, Hanafiah MAKM (2010) Malachite green adsorption onto chitosan coated bentonite beads: isotherms, kinetics and mechanism. *CLEAN—Soil Air Water* 38:394–400. doi:10.1002/clean.200900251
- Wan Ngah WS, Teong LC, Hanafiah MAKM (2011) Adsorption of dyes and heavy metal ions by chitosan composites: a review. *Carbohydr Polym* 83:1446–1456. doi:10.1016/j.carbpol.2010.11.004
- Wang D, Liu L, Jiang X et al (2015) Adsorption and removal of malachite green from aqueous solution using magnetic  $\beta$ -cyclodextrin-graphene oxide nanocomposites as adsorbents. *Colloids Surf Physicochem Eng Asp* 466:166–173. doi:10.1016/j.colsurfa.2014.11.021
- Wang H, Yuan X, Zeng G et al (2014a) Removal of malachite green dye from wastewater by different organic acid-modified natural adsorbent: kinetics, equilibriums, mechanisms, practical application, and disposal of dye-loaded adsorbent. *Environ Sci Pollut Res Int* 21:11552–11564. doi:10.1007/s11356-014-3025-2
- Wang H-Y, Gao H-W (2009) Preparation of calcium oxalate-bromopyrogallol red inclusion sorbent and application to treatment of cationic dye and heavy metal wastewaters. *Environ Sci Pollut Res Int* 16:339–347. doi:10.1007/s11356-008-0070-8
- Wang J, Zhao G, Li Y et al (2014b) One-step fabrication of functionalized magnetic adsorbents with large surface area and their adsorption for dye and heavy metal ions. *Dalton Trans Camb Engl* 43:11637–11645. doi:10.1039/c4dt00694a
- Wang L, Zhang J, Zhao R et al (2010) Adsorption of basic dyes on activated carbon prepared from *Polygonum orientale* Linn: equilibrium, kinetic and thermodynamic studies. *Desalination* 254:68–74. doi:10.1016/j.desal.2009.12.012
- Wang Q, Chen C, Zhao D et al (2008a) Change of adsorption modes of dyes on fluorinated TiO<sub>2</sub> and its effect on photocatalytic degradation of dyes under visible irradiation. *Langmuir ACS J Surf Colloids* 24:7338–7345. doi:10.1021/la800313s
- Wang S, Ariyanto E (2007) Competitive adsorption of malachite green and Pb ions on natural zeolite. *J Colloid Interface Sci* 314:25–31. doi:10.1016/j.jcis.2007.05.032

- Wang XS (2009) Invasive freshwater macrophyte alligator weed: novel adsorbent for removal of malachite green from aqueous solution. *Water Air Soil Pollut* 206:215–223. doi:10.1007/s11270-009-0097-6
- Wang XS, Zhou Y, Jiang Y, Sun C (2008b) The removal of basic dyes from aqueous solutions using agricultural by-products. *J Hazard Mater* 157:374–385. doi:10.1016/j.jhazmat.2008.01.004
- Waring DR, Hallas G (eds) (1990) *The chemistry and application of dyes*. Springer US, Boston
- Wei A, Liu B, Zhao H et al (2014) Synthesis and formation mechanism of flowerlike architectures assembled from ultrathin NiO nanoflakes and their adsorption to malachite green and acid red in water. *Chem Eng J* 239:141–148. doi:10.1016/j.cej.2013.10.079
- Weng X, Huang L, Chen Z et al (2013) Synthesis of iron-based nanoparticles by green tea extract and their degradation of malachite. *Ind Crops Prod* 51:342–347. doi:10.1016/j.indcrop.2013.09.024
- Witek-Krowiak A (2013) Biosorption of malachite green from aqueous solutions by pine sawdust: equilibrium, kinetics and the effect of process parameters. *Desalin Water Treat* 51:3284–3294. doi:10.1080/19443994.2012.749053
- Witek-Krowiak A, Szafran RG, Modelski S, Dawiec A (2012) Removal of cationic dyes from aqueous solutions using microspherical particles of fly ash. *Water Environ Res Res Publ Water Environ Fed* 84:162–169
- Wu J, Jung B-G, Kim K-S et al (2009) Isolation and characterization of *Pseudomonas otitidis* WL-13 and its capacity to decolorize triphenylmethane dyes. *J Environ Sci China* 21:960–964
- Wu X, Wang Y, Liu J et al (2010) Study of malachite green adsorption onto natural zeolite in a fixed-bed column. *Desalin Water Treat* 20:228–233. doi:10.5004/dwt.2010.1212
- Xing Y, Deng D (2009) Enhanced adsorption of malachite green by EDTAD-modified sugarcane bagasse. *Sep Sci Technol* 44:2117–2131. doi:10.1080/01496390902775588
- Xing Y, Wang G (2009) Poly(methacrylic acid)-modified sugarcane bagasse for enhanced adsorption of cationic dye. *Environ Technol* 30:611–619. doi:10.1080/09593330902838098
- Xu R, Jia M, Zhang Y, Li F (2012) Sorption of malachite green on vinyl-modified mesoporous poly(acrylic acid)/SiO<sub>2</sub> composite nanofiber membranes. *Microporous Mesoporous Mater* 149:111–118. doi:10.1016/j.micromeso.2011.08.024
- Yagub MT, Sen TK, Afroz S, Ang HM (2014) Dye and its removal from aqueous solution by adsorption: a review. *Adv Colloid Interface Sci* 209:172–184. doi:10.1016/j.cis.2014.04.002
- Yang C-H, Shih M-C, Chiu H-C, Huang K-S (2014) Magnetic *Pycnopus sanguineus*-loaded alginate composite beads for removing dye from aqueous solutions. *Mol Basel Switz* 19:8276–8288. doi:10.3390/molecules19068276
- Yang J, Chen C, Ji H et al (2005) Mechanism of TiO<sub>2</sub>-assisted photocatalytic degradation of dyes under visible irradiation: photoelectrocatalytic study by TiO<sub>2</sub>-film electrodes. *J Phys Chem B* 109:21900–21907. doi:10.1021/jp0540914
- Yu J, Chi R, He Z, Qi Y (2011) Adsorption performances of cationic dyes from aqueous solution on pyromellitic dianhydride modified sugarcane bagasse. *Sep Sci Technol* 46:452–459. doi:10.1080/01496395.2010.510125
- Zeng Y, Zhao L, Wu W et al (2013) Enhanced adsorption of malachite green onto carbon nanotube/polyaniline composites. *J Appl Polym Sci* 127:2475–2482. doi:10.1002/app.37947
- Zhang G, Yi L, Deng H, Sun P (2014a) Dyes adsorption using a synthetic carboxymethyl cellulose-acrylic acid adsorbent. *J Environ Sci China* 26:1203–1211. doi:10.1016/S1001-0742(13)60513-6
- Zhang H, Tang Y, Liu X et al (2011) Improved adsorptive capacity of pine wood decayed by fungi *Poria cocos* for removal of malachite green from aqueous solutions. *Desalination* 274:97–104. doi:10.1016/j.desal.2011.01.077
- Zhang J, Li Y, Zhang C, Jing Y (2008) Adsorption of malachite green from aqueous solution onto carbon prepared from *Arundo donax* root. *J Hazard Mater* 150:774–782. doi:10.1016/j.jhazmat.2007.05.036
- Zhang L, Zhang H, Guo W, Tian Y (2014b) Removal of malachite green and crystal violet cationic dyes from aqueous solution using activated sintering process red mud. *Appl Clay Sci* 93–94:85–93. doi:10.1016/j.clay.2014.03.004
- Zhang X, Yu H, Yang H et al (2015) Graphene oxide caged in cellulose microbeads for removal of malachite green dye from aqueous solution. *J Colloid Interface Sci* 437:277–282. doi:10.1016/j.jcis.2014.09.048
- Zhang X, Zhang S, Pan B et al (2012) Simple fabrication of polymer-based *Trametes versicolor* laccase for decolorization of malachite green. *Bioresour Technol* 115:16–20. doi:10.1016/j.biortech.2011.11.063
- Zhou X-J, Guo W-Q, Yang S-S et al (2013) Ultrasonic-assisted ozone oxidation process of triphenylmethane dye degradation: evidence for the promotion effects of ultrasonic on malachite green decolorization and degradation mechanism. *Bioresour Technol* 128:827–830. doi:10.1016/j.biortech.2012.10.086
- Zhou Y, Min Y, Qiao H et al (2015) Improved removal of malachite green from aqueous solution using chemically modified cellulose by anhydride. *Int J Biol Macromol* 74:271–277. doi:10.1016/j.ijbiomac.2014.12.020
- Zou W, Gao S, Zou X, Bai H (2013) Adsorption of neutral red and malachite green onto grapefruit peel in single and binary systems. *Water Environ Res Res Publ Water Environ Fed* 85:466–477