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Review

Adsorption of methylene blue on low-cost adsorbents: A review

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ABSTRACT

In this article, the use of low-cost adsorbents for the removal of methylene blue (MB) from solution has been reviewed. Adsorption techniques are widely used to remove certain classes of pollutants from waters, especially those which are not easily biodegradable. The removal of MB, as a pollutant, from waste waters of textile, paper, printing and other industries has been addressed by the researchers. Currently, a combination of biological treatment and adsorption on activated carbon is becoming more common for removal of dyes from wastewater. Although commercial activated carbon is a preferred adsorbent for color removal, its widespread use is restricted due to its relatively high cost which led to the researches on alternative non-conventional and low-cost adsorbents. The purpose of this review article is to organize the scattered available information on various aspects on a wide range of potentially low-cost adsorbents for MB removal. These include agricultural wastes, industrial solid wastes, biomass, clays minerals and zeolites. Agricultural waste materials being highly efficient, low cost and renewable source of biomass can be exploited for MB remediation. It is evident from a literature survey of about 185 recently published papers that low-cost adsorbents have demonstrated outstanding removal capabilities for MB.

Contents

1. Introduction

The presence of dyes in effluents is a major concern due to their adverse effects to many forms of life. The discharge of dyes in the environment is a matter of concern for both toxicological and esthetical reasons [1]. Industries such as textile, leather, paper, plastics, etc., use dyes in order to colour their products and also consume substantial volumes of water. As a result, they generate a considerable amount of coloured wastewater [2]. It is estimated that more than 100,000 commercially available dyes with over 7×10^5 tonnes of dyestuff produced annually [3–5]. It is recognized that public perception of water quality is greatly influenced by the colour. The colour is the first contaminant to be recognized in wastewater. The presence of even very small amounts of dyes in water – less than 1 ppm for some dyes – is highly visible and undesirable [6,7]. MB is the most commonly used substance for dying cotton, wood and silk. It can cause eye burns which may be responsible for permanent injury to the eyes of human and animals. On inhalation, it can give rise to short periods of rapid or

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difficult breathing while ingestion through the mouth produces a burning sensation and may cause nausea, vomiting, profuse sweating, mental confusion and methemoglobinemia [8–10]. Therefore, the treatment of effluent containing such dye is of interest due to its harmful impacts on receiving waters.

During the past three decades, several physical, chemical and biological decolorization methods have been reported; few, however, have been accepted by the paper and textile industries [11]. Amongst the numerous techniques of dye removal, adsorption is the procedure of choice and gives the best results as it can be used to remove different types of coloring materials [12–14]. Recently, numerous approaches have been studied for the development of cheaper and effective adsorbents. Many non-conventional low-cost adsorbents, including natural materials, biosorbents, and waste materials from agriculture and industry, have been proposed by several workers. These materials could be used as adsorbents for the removal of dyes from solution.

Many treatment processes have been applied for the removal of dyes from wastewater such as: photocatalytic degradation [15,16], sonochemical degradation [17], micellar enhanced ultrafiltration [18], cation exchange membranes [19], electrochemical degradation [20], adsorption/precipitation processes [21], integrated chemical–biological degradation [22], integrated iron(III) photoassisted-biological treatment [23], solar photo-Fenton and biological processes [24], Fenton-biological treatment scheme [25] and adsorption on activated carbon [26,27]. As synthetic dyes in wastewater cannot be efficiently decolorized by traditional methods, the adsorption of synthetic dyes on inexpensive and efficient solid supports was considered as a simple and economical method for their removal from water and wastewater [28].

Methods of dye wastewater treatment have been reviewed by Pokhrel and Viraraghavan [29]; Robinson et al. [6]; Slokar and Majcen Le Marechal [30]; Delee et al. [31]; Banat et al. [7]; Cooper [32]; Crini [33] and Gupta and Suhas [34]. Fungal and bacterial decolorization methods have been reviewed by Aksu [35]; Wesenberg et al. [36]; Pearce et al. [4]; McMullan et al. [3]; Fu and Viraraghavan [37] and Stolz [38].

Adsorption is a well known equilibrium separation process and an effective method for water decontamination applications [39–42]. Adsorption has been found to be superior to other techniques for water re-use in terms of initial cost, flexibility and simplicity of design, ease of operation and insensitivity to toxic pollutants. Adsorption also does not result in the formation of harmful substances.

The present review article deals the technical feasibility of various non-conventional low-cost adsorbents for MB removal from water and wastewater. The main aim of this review is to provide a summary of recent information concerning the use of low-cost materials as adsorbents. For this, an extensive list of adsorbents literature has been compiled. The authors recommend that the reported adsorption capacities be taken as specific set of conditions rather than as maximum adsorption capacities. The reader is strongly encouraged to refer to the original research papers for information on experimental conditions.

2. Adsorbent literature

2.1. Activated carbon

Though commercially available activated carbon (CAC) are usually derived from natural materials such as biomass, lignite or coal, but almost any carbonaceous materials may be used as precursor for the preparation of carbon adsorbents [43–52], because of its availability and cheapness, coal is the most commonly used precursor for activated carbon production. Coal is a mixture of carbonaceous and mineral materials, resulting from the degradation of plants. The sorption properties of each individual coal are determined by the nature of the original vegetation and the extent of the physical–chemical changes occurring after deposition. Coal adsorption capacities are reported in Table 1. Coal based adsorbents have been used by Karaca et al. [53]; El Qada et al. [43]; Tamai et al. [54]; Banat et al. [55] and McKay et al. [56,57] with success for dye removal. However, since coal is not a pure material, it has a variety of surface properties and thus different sorption properties.

Table 1
Adsorption capacities for commercial activated carbon and coal.

Adsorbents	Adsorption capacity (mg/g)	Sources
Commercial activated carbon	980.3	[47]
Activated carbon produced from New Zealand coal	588	[43]
Filtrasorb 400	476	[43]
Activated carbon	400	[48]
Activated carbon produced from Venezuelan bituminous coal	380	[43]
Peat	324	[49]
Coal	323.68	[57]
Filtrasorb 400	299	[50]
Norit	276	[50]
Picacarb	246	[50]
Filtrasorb 300	240	[44]
Activated carbon	238	[52]
Coal	230	[56]
Commercial activated carbon	200	[45]
Bituminous coal	176	[54]
Charcoal	62.7	[55]
Activated carbon	9.81	[51]

Biomass and other waste materials may also offer an inexpensive and renewable additional source of activated carbon. These waste materials have little or no economic value and often present a disposal problem. Therefore, there is a need to valorize these low-cost by-products. So, their conversion into activated carbon would add economic value, help reduce the cost of waste disposal and most importantly provide a potentially inexpensive alternative to the existing commercial activated carbons. A wide variety of carbons have been prepared from biomass and other wastes, such as date pits [58], olive stones [59], furniture, sewage char and tyres [60,61], vermiculata plant [45], bamboo dust, coconut shell, groundnut shell, rice husk and straw [47,62], polyvilnyldienefluoride fibers [63], jute fiber [64], zeolite [65], coconut husk [9,54], oil palm fiber [66,67], waste apricot [68], corncob [69], coir pith [70], Pitch [54], olive-seed waste [44], fir wood [27], rattan sawdust [71], bio-plant of *Euphorbia rigida* [62], vetiver roots [73], durian shell [74], oil palm shell [10], sugars [75], wheat bran [76], *Hevea brasiliensis* seed coat [26], peach stones [77], almond shell, walnut shell, hazelnut shell and apricot stones [78] and *Rosa canina* seeds [79].

The excellent ability and economic promise of the activated carbons prepared from biomass exhibited high sorption properties as shown in Table 2. Kannan and Sundaram [47] reported the adsorption capacities of 472.10 mg/g of activated carbons made from straw. However, the adsorption capacities of carbons depend upon the sources of the raw materials used, the history of its preparation and treatment conditions such as pyrolysis temperature and activation time. Many other factors can also affect the adsorption capacity in the same sorption conditions such as surface chemistry (heteroatom content), surface charge and pore structure. A suitable carbon should possess not only a porous texture, but also high surface area. Recently, Guo et al. [80] showed that the adsorption does not always increase with surface area. Besides the physical structure, the adsorption capacity of a given carbon is strongly influenced by the chemical nature of the surface. The acid and