Journal of Environmental Chemical Engineering 4 (2016) 89–99

Contents lists available at ScienceDirect

Journal of Environmental Chemical Engineering

journal homepage: www.elsevier.com/locate/jece

Application of agricultural based activated carbons by microwave and conventional activations for basic dye adsorption: Review

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ARTICLE INFO

Article history:
Received 10 August 2015
Received in revised form 17 October 2015
Accepted 19 October 2015
Available online 27 October 2015

Keywords:
Activated carbon
Methylene blue
Adsorption
Biomass wastes
Microwave

ABSTRACT

Basic dye, methylene blue (MB), has been known as the most common parameter used to measure the extent of mesoporosity (20–500 Å) of activated carbon (AC). The adsorption performance in terms of uptake along with its dependence on heating techniques has been reviewed for MB on activated carbons prepared by chemical activation of agricultural wastes. Recently, microwave heating has been adopted as an alternative technique for conventional heating, where the latter suffered from thermal gradient, long activation time, high cost, and fast firing. Equilibrium, kinetic, and thermodynamic of adsorption process for MB-AC system were analyzed. The effects of most significant preparation variables on pore structure of AC and adsorption performance were also presented. Conclusively, important observations have been reported for dependence of adsorption performance and mechanism on preparation and adsorption variables for studied system.

Contents

1. Introduction

Methylene blue (MB), a rather big heterocyclic aromatic dye, is a good choice for testing the performance of adsorbents whose mesoporosity suggests their application for adsorption of liquid pollutants. Therefore, MB value is the most popular parameter used to appropriately measure the adsorption capacity of the mesoporous structure (20–500 Å) of activated carbons [1]. On the other hand, the presence of MB dye in effluents of textile and other industries represents a source of environment contamination [2]. The frequent exposure to this pollutant may cause permanent injury to the eyes of human and animals. On inhalation, it leads to short periods of rapid or difficult breathing while ingestion through the mouth produces a burning sensation and may cause nausea, vomiting, and mental confusion [3]. Table 1 shows the characteristics and chemical structure of basic and cationic MB dye.

Commonly, wastewaters contaminated by synthetic dyes cannot be efficiently treated by traditional methods like photocatalytic degradation [4,5], fenton degradation [6,7], electrochemical degradation [8,9], electrocoagulation [10], liquid–liquid extraction [11], biodegradation [12], ultrafiltration membrane [13], ion exchange [14], and persulfate oxidation [15,16]. However, the decolorization of these wastes by adsorption on cheap and

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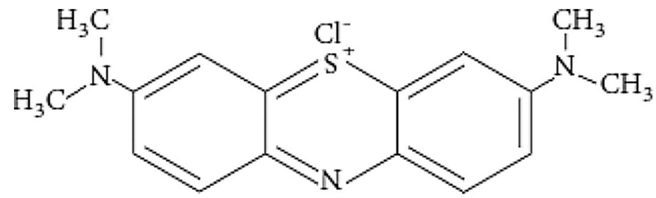
http://dx.doi.org/10.1016/j.jece.2015.10.027
2213-3437/

Table 1
Main properties of MB dye.

Parameter	Character/value
Molecular structure	
Molecular formula	$C_{16}H_{18}N_3SCl$
Molar mass	319.85 g/mol
λ_{max}	664 nm

available solid adsorbents, including natural and agro-industrial wastes is considered as a flexible and cost-effective separation technique [17–21]. High adsorption capacity for dyes can be obtained by modification of these raw materials to activated carbon (AC) adsorbent [22–39]. AC is widely used to remove gaseous and liquid organic pollutants due to its large surface area, high porosity, internal structure and the presence of various surface functional groups [40–44].

The sorption performance and pore characteristics of AC depend on the physical and chemical properties of the precursor as well as on the activation technique [45]. Various carbonaceous solids which may be either natural or synthetic can be used as precursors for preparation of AC. The choice of precursor is largely dependent on its availability, cost and purity, but the manufacturing process and intended of application of the product are also important factors. Due to environmental considerations, agricultural wastes are considered to be very important precursors because they are cheap, renewable, safe, available at large quantities and easily accusable sources; in addition they have high carbon and low ash content [46,47].

Generally, ACs are prepared either by physical or chemical activation where the latter is preferred owing to the simplicity, lower temperature, shorter activation time, higher yield, and good development of the porous structure [48]. Recently, microwave activation has the potential to become a viable alternative for the conventional activation in preparation of AC. It has the advantages of uniform interior heating, high heating rate, lower time, selective heating, precise and immediate control of startup and shutdown, no direct contact between the heating source and heated materials and reduced equipment size and waste [49,50]. Application of agricultural based ACs for the removal of dyes from aqueous solutions has been reviewed by a number of articles with poor informations for MB dye. The present review focuses on the adsorption behavior of MB dye on AC prepared from various agricultural wastes by chemical activation. It includes in detail the effect of preparation and adsorption variables and heating techniques on performance, isotherms, kinetics and thermodynamics of MB-AC adsorption system.

2. Heating techniques

In addition to the raw materials and preparation methods, the technique of heating during activation can also strongly affect the physical and chemical characteristics of AC structure. Conventional and microwave heating techniques represent two different types of activation methods. In conventional heating, the heat source is located outside the carbon bed and energy is transferred to the samples from the surface to the interior through the convection, conduction, and radiation mechanisms [51,52]. Hence, there is a thermal gradient from the hot surface of the sample to its interior until it reaches steady state conditions. To avoid this thermal gradient, a slower rate of heating with isothermal holding is used. This slow heating rate increases the duration of the activation process which results in greater energy consumption [53,54]. The thermal gradient impedes the release of pyrolysis gases to the surroundings, and therefore, some volatile components may remain inside the samples, leading to non-uniform microstructure and low values for total pore volume V_t and BET surface area [55]. Conventional heating is not only slow, but also inhomogeneous where the surfaces, edges and corners being much hotter than the inside of the material. Consequently, the quality of product is variable and frequently inferior to the desired result [56].

Microwave heating is both internal and volumetric, where the materials receive energy through dipole rotations and ionic conduction. This providing shorter processing time and saving energy, and consequently resulted in low-cost product [57]. Microwave irradiation interacts directly with the particles inside the pressed compact material and changes electromagnetic energy into heat transfer inside the dielectric materials. It is not conducted into the sample from an external heat source, providing quick volumetric heating [58,59]. The problems of fast firing in conventional heating can be overcome by non-contact microwave technique where the heat is transferred to the product via electromagnetic waves, and large amounts of heat can be transferred to the interior of the material [60,61]. Among the many types of materials, carbon materials are effective microwave absorbents. This characteristic allows transformation of these carbonaceous materials by microwave heating, giving rise to new materials with modified properties [62]. Microwave radiation has the advantages of energy transfer; selective heating; improved efficiency; immediate startup and shutdown; smaller steps; lower activation temperature; improved safety; simplicity; smaller equipment size and less automation [63,64]. However, it can generate hot spots (as a consequence of mineral impurities) inside the carbon particles where the temperature is much higher than the overall temperature of the sample. Therefore, it is nearly impossible to accurately measure the sample temperature, and only the surface temperature of the sample is measurable using an infrared pyrometer. The internal temperature of the sample may be tens or hundreds of degrees higher than the sample surface temperature due to the internal and volumetric nature of microwave heating. Hence, the temperature could not be a variable condition in the preparation of AC using the microwave irradiation method [65].

3. Adsorption performance

Time, impregnation ratio (IR), power and temperature represent the main activation variables that affect performance of AC