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Review

Review of modifications of activated carbon for enhancing contaminant uptakes from aqueous solutions

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Abstract

Due to its versatility and wide range of applications, activated carbon is widely used as contaminant removal media. Recent research have focused on enhancing the effectiveness of activated carbon by modifying their specific properties in order to enable the carbon to develop affinity for certain contaminants. In view of this, a comprehensive list of literatures on chemical, physical and biological modification techniques of activated carbon pertaining to enhancement of contaminant removal from aqueous solutions was compiled and reviewed. Acidic treatment to introduce acidic functional groups onto surface of activated carbon was by far, the most studied technique. It was apparent from the literature survey that the beneficial effects of specific modification techniques on activated carbon adsorption of targeted contaminant species from aqueous solutions were profound, with some studies reported increase of contaminant uptake factors of more than 2. Concurrently, considerable decreases associated with certain contaminant uptakes can also occur depending on the technique used.

Keywords: Activated carbon modification; Surface functional groups; Impregnation; Contaminant; Aqueous solution

Contents

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1. Introduction

Activated carbon (AC) has been proven to be an effective adsorbent for the removal of a wide variety of organic and inorganic pollutants dissolved in aqueous media, or from gaseous environment. It is a widely used adsorbent in the treatment of wastewaters due to its exceptionally high surface areas which range from 500 to 1500 $m^2 g^{-1}$, well-developed internal microporosity structure as well as the presence of a wide spectrum of surface functional groups [1]. As an inert porous carrier material, it is capable of distributing chemicals on its large hydrophobic internal surface, thus making them accessible to reactants [2]. While the effectiveness of ACs to act as adsorbents for a wide range of contaminants is well noted [3,4] more and more research on AC modification are gaining prominence due to the need to enable ACs to develop affinity for certain contaminants to cater for their removal from varying types of wastewater in the industries.

It is, therefore, essential to understand the various factors that influence the adsorption capacity of AC prior to their modification so that it can be tailored to their specific physical and chemical attributes to enhance their affinities toward metal, inorganic and/or organic species present in aqueous solutions. These factors include specific surface area, pore-size distribution, pore volume and presence of surface functional groups. Generally, the adsorption capacity increases with specific surface area due to the availability of adsorption site while pore size, and micropore distribution are closely related to the composition of the AC, the type of raw material used, the degree of activation during production stage and the frequency of regeneration [5]. Recent research have placed emphasis on modifying these physical and chemical attributes and this paper aims to review and summarize the various AC modification techniques and their effects on adsorption of chemical species from aqueous solutions. In order to facilitate a more focused discussion, only studies on modification of AC in granular or powdered form were reviewed. Also, it should be noted that the term modification in this paper represents treatment applied to as-received commercial AC or carbonaceous materials after activation. Studies on activation of carbonized material that incorporated modifying chemicals are not presented. Based on extensive literature reviews, the authors have categorized the techniques into three broad groups, namely, modification of chemical, physical and biological characteristics which are further subdivided into their pertinent treatment techniques (Fig. 1). These techniques were intended to significantly alter a characteristic and not two or more characteristics concurrently, even though in actual fact, all treatment effected to AC to modify a single characteristic may cause unintended minor alteration in other characteristics. Table 1 lists and compares the advantages and disadvantages of existing modification techniques with regards to technical aspects which are further elucidated in the following sections. While these characteristics are reviewed separately as reflected by numerous AC modification research, it should be noted that there were also research with the direct intention of significantly modifying two or more characteristic and that the techniques reviewed are not intended to be exhaustive. For information pertaining to detailed experimental methodology and conditions, readers are referred to the full articles listed in the references.

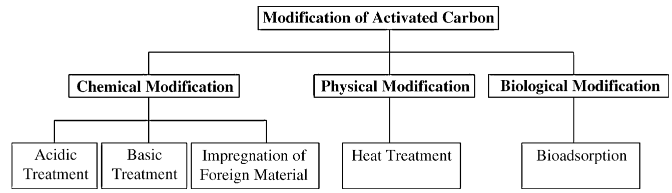

Fig. 1. Categories of activated carbon modification techniques.

2. Modification of chemical characteristics

It is an established fact that the AC surface can display acidic, basic and/or neutral characteristics depending on the presence of surface functional groups [6]. As such, modification of chemical

Table 1
Technical advantages and disadvantages of existing modification techniques

Modification	Treatment	Advantages	Disadvantages
Chemical characteristics	Acidic	Increases acidic functional groups on AC surface. Enhances chelation ability with metal species	May decrease BET surface area and pore volume
			Has adverse effect on uptake of organics May give off undesired SO_2 (treatment with H_2SO_4) or NO_2 (treatment with HNO_3) gases
	Basic	Enhances uptake of organics	May, in some cases, decrease the uptake of metal ions
	Impregnation of foreign material	Enhances in-built catalytic oxidation capability	May decrease BET surface area and pore volume
Physical characteristics	Heat	Increases BET surface area and pore volume	Decreases oxygen surface functional groups
Biological characteristics	Bioadsorption	Prolongs AC bed life by rapid oxidation of organics by bacteria before the material can occupy adsorption sites	Thick biofilm encapsulating AC may impede diffusion of adsorbate species