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Review

A critical review on preparation, characterization and utilization of sludge-derived activated carbons for wastewater treatment

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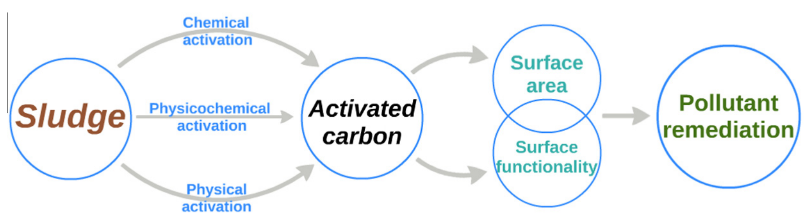
HIGHLIGHTS

- Review of the activated carbon production from sludge.
- Physical and chemical techniques for activation.
- Adsorption of metals and dyes by sludge-based adsorbents.
- Effect of various factors on the uptake capacity of the adsorbents.
- Critical views on the activated carbon preparation and adsorption processes.

GRAPHICAL ABSTRACT



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ABSTRACT

Sludge, a byproduct produced from numerous industrial activities, has been recognized as an ecological burden for the society. However, viewing the sludge, as a carbon-rich material, has stimulated new gateways for the production of porous activated carbons for water treatment applications. Herein, various textural properties of the sludge-based activated carbons have been compiled and critically reviewed with the focus on surface area, pore size and pore size distribution for both physically and chemically activated carbons. It has been found that chemical activation using various activating agents yields more superior adsorbents with high specific surface areas than physical activation methods. Moreover, the potential of sludge-derived activated carbons for the sequestration of metals and dyes from aqueous media has been discussed. Furthermore, the adsorption mechanism in several adsorbent–adsorbate systems and the effect of various parameters on the adsorption behavior of different dyes and metals on sludge-based activated carbons have been reviewed. It has been shown that the pollutant uptake capacities of the adsorbents derived from sewage sludge are not only governed by the textural properties of the adsorbents, but also by their surface properties, such as the functional groups and the surface charge and thus it is proposed that both of these crucial factors be considered concurrently.

Contents

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1. Introduction

During the past century, the quantity of the sludge production resulting from human activities has increased vastly due to the surge of industrialization and urbanization. The unmanageable amount of sludge from various sources coupled with the imposition of highly stringent regulations for the sludge disposal and high cost and complexity of environmentally-benign sludge disposal/treatment have led to the exploration of reliable and lasting technological solutions. A few traditional sludge disposal routes include ocean discharge, incineration, composting and land application [1], either being phased out or coming under pressure due to the emergence of environmental concerns towards this complex material. Landfill disposal is the most widely used disposal option due to its ease and low cost, but is not recognized as a sustainable technique because of the concerns over pollution and lack of material recovery [2]. Also incineration, in addition to high capital cost, is perceived by public to have adverse environmental impacts and thus lacks public acceptability. A comprehensive study by Bennett and Knapp revealed the emission of considerable amounts of particulates from some sludge incinerators. They found that several heavy metals, such as Cd, Pb and Zn, and sulfur and nitrogen oxides are emitted from the incineration plants [3]. Hence, the challenge for sludge management has pushed industries to search for more environmentally-benign sustainable techniques for sludge handling. One of the most favored options for sustainable development is the sludge waste recycling highly preferred over traditional methods such as landfill and incineration. Several recycling routes include forestry and silviculture, land reclamation and utilization as fertilizer [4]. The presence of nitrogen, phosphorus and various organic matters similar in composition and quantity to the farmyard manure renders it very attractive as a supplement to other fertilizers. Despite the low cost of this waste material, the lack of controllability on its quality and components, such as heavy metals and pathogens, is considered as a major drawback [5,6].

There are a number of sludge treatment options to remove the unwanted contaminants of sludge for further more secure applications. Some of these conditioning and conversion treatment options include chemical addition (such as lime and iron), thermal hydrolysis, thickening, dewatering, drying and biological treatment. Nevertheless, these treatment methodologies for the ultimate purpose of ecological sludge disposal/recycling add a financial burden to the wastewater treatment investment. Bearing in mind the continual escalating standards for sludge treatment, it will inevitably increase the costs which might affect the inclination of companies for traditional methods such as incineration rather than recycling. Therefore in order to retain a balance between the ecological and economical aspects, the recycled material should have a high financial value in order to compensate for the treatment costs [7].

In the past few years, the modification and reuse of sludge as a value-added adsorbent for the removal of contaminants has been one of the most popular emerging R&D techniques for sludge recycling [8–12]. One of the pioneering studies in the employment of a pyrolyzed sludge for pollutant abatement purposes was carried out by Beeckmans and Ng in 1971 [11]. They showed the intermediate adsorption capacity of pyrolyzed sludge in the removal of crystal violet dye and proposed the potential application of this material in the tertiary treatment of renovated wastewater. Application of such low-cost solid waste for wastewater treatment purposes has a twofold ecological prominence, the conversion of a waste to a value-added material which alleviates the disposal problems and also the removal of pollutants from wastewater streams. The utilization of sludge as a precursor for environmental applications stems from both the carbonaceous nature of this waste and the existence of organic materials in it [12]. Hence, numerous studies have looked into either the production of activated carbon from waste sludge via the pyrolysis/activation method or the bio-remediation of the wastewater by sludge microorganisms.

An overview of the current methodologies to produce porous carbons/chars from sludge and the effect of various activation conditions on the textural characteristics of the sludge-derived activated carbons, such as surface area, pore volume, pore size and pore size distribution have been thoroughly reviewed in this paper. Furthermore, the behavior of sludge-based activated carbons and the adsorption parameters on the uptake of dyes and metals has comprehensively been examined. More specifically, the various mechanisms of pollutant removal from wastewater have been extensively endeavored for various adsorbent–adsorbate systems.

It is notable that sludge has different sources which vary in water, organic and inorganic materials contents and composition [13]. It can be fairly criticized that the effects of these properties and the complex nature of the sludge are not systematically studied in the final characteristics of the produced activated carbons.

2. Preparation of activated carbon from carbonaceous sources

Several factors influence the pollutant removal efficiency of activated carbons, namely their porous structure and surface functional groups [14,15]. The porous structure of the activated carbons can be manipulated by altering the activation parameters, such as the type of activation (physical and/or chemical), activating agent, pyrolysis/activation temperature, impregnation ratio (defined, throughout this paper, as the weight ratio of the activating chemical to the precursor) and pyrolysis/activation sequence. Also, the choice of the activating agent is of crucial importance to control the type of suitable functional groups on the surface of the material [16–18]. Therefore the careful tailoring of these characteristics to yield the desired physicochemical properties will have a dramatic effect on the uptake of certain pollutants.