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Potential of *Arundo donax L.* stems as renewable precursors for activated carbons and utilization for wastewater treatments: Review

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A B S T R A C T

Arundo donax Linn is one of the best-known herbaceous crops whose industrial potential is now being intensively reconsidered. The high productivity and low input requirements make it a promising feedstock for production of chemicals and biofuels. Besides, many studies have discussed its great potential as a renewable precursor with unique chemical composition for preparation of activated carbons (ACs) with high-grades. This article provided an overview of the different studies that included conversion of *A. donax* Linn or giant reed to carbon by various techniques. The effects of preparation variables such as time, temperature or power, impregnation ratio, and different activators on pore characteristics and yield of carbon were reviewed. Application of giant reed-carbons as adsorbents for attraction of organic and inorganic pollutants has also been reviewed. ACs obtained from giant reed biomass have shown excellent performance for wastewater treatment, thus solving environmental problems of waste disposal and pollution control.

1. Introduction

Lignocellulosic biomass is currently a promising energy source in terms of biofuels and chemicals production by thermochemical or biochemical conversion processes due to its abundance, renewability, eco-friendly nature, and cost effectiveness [1-3]. Stalk or stem biomass is a rich source for production of activated carbons (ACs) with high surface areas and adsorption performances compared to those from leaves or roots due to their high volume, low ash, high carbon, and reasonable hardness [4-6]. Corn stalk [7-9], grape stalk [10-12], lotus stalk [13-15], cotton stalk [16-18], banana stalk [19-21], tobacco stem [22-24], palm stem [25,26], and cane stem [27-29] have been utilized as efficient precursors for ACs with well-developed porous structures.

Giant reed, the common name of *Arundo donax* L., is one of the most promising crops for the production of fuels and chemicals due to its high biomass productivity, low input requirement, quick growth, and easy adaptability to different environments [30,31]. It has been extensively cultivated throughout Asia, southern Europe, North Africa, and the middle East [32]. With high biomass productivity (27–32 t/ year/ha), giant reed is readily available and inexpensive [33]. Thus, a large number of biomass residues are generated every year. However, only a small portion of them are rational used as bio-source for energy generation or for pulp in the paper industry. Most are often burned in the open air for the purpose of quick disposal and land clearing, causing serious atmospheric contamination [28]. Hence, environmentally and economically, these wastes are desirable to be used as good precursors for high efficient adsorbents.

The applicability of agricultural biomass in their original state has been found to be constrained by their relatively small surface area, inadequate pore size distribution, and leaching of some organics into the process stream [34]. Thus, various modifications have been carried out to get high equality and ecological friendly adsorbents from raw giant reed for wastewater treatments [35-40]. The favorable lignocellulosic composition, high carbon content, and low ash content of giant reed biomass make it a good precursor for production of ACs with high grades [41]. Physical and chemical activations have been alternative techniques for ACs preparation [42]. The lower activation temperature and the higher yield of AC have promoted the application of chemical activation [43,44].

Various water treatment technologies are available with varying degree of success such as coagulation, filtration, ion exchange, aerobic and anaerobic treatment, advanced oxidation processes, solvent extraction, adsorption, and electrolysis [45]. However, most of them require substantial financial input and their use is restricted due to cost factors. Among these techniques, adsorption is

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Table 1
Characteristics of raw giant reed [35, 107].

Proximate analysis (wt%)				Lignocellulosic composition (wt%)			
Ash	Moisture	Volatile	Fixed carbon	Cellulose	Lignin	Hemicellulose	Extractives
2.54	4.20	75.05	22.21	31.1	21.1	30.3	12.1

considered better because of convenience, ease of operation and simplicity of design [46]. Further, this process can treat different types of pollutants and thus it has a wider applicability in water pollution control. AC adsorbent has the advantages of exhibiting a high adsorption performance for pollutants due to its high surface area, well-developed porous structure, and favorable surface properties [47]. ACs from plant stalks have been effectively utilized for adsorptive removal of synthetic dyes [48-51], heavy metals [52-56], aromatics [57-59], pesticides [60, 61], and antibiotics [62, 63]. Preparation of porous carbon from biomass wastes and its application for pollution control has been reviewed by number of articles [64-71]. The present review includes preparation of ACs from abundantly available *A. donax* Linn (giant reed) which has not been previously addressed by researchers. The application of prepared ACs for adsorptive removal of organic and inorganic pollutants was also presented. The effects of activation variables on yield and pore structure of giant reed-ACs have been discussed in details. The adsorption behavior of various pollutants on such adsorbent at different experimental conditions has also been presented.

2. Origin and properties of giant reed

Giant reed or *A. donax* Linn is a perennial rhizomatous grass native from Asia where it is well suited to subtropical and warm temperate regions, especially in the area of Mediterranean [72,73]. It belongs to the Poaceae family and considered as one of the largest Gramineae with a growing rate of 0.3–0.7 m/week during several months in ideal conditions [74]. The adaptability of the giant reed to different kinds of environments, besides the high biomass production and the low input required for its cultivation, confer on it many advantages when compared to other energy crops [75].

The biomass yield of giant reed in the range 30–40 t/ha makes it a cost-effective feedstock for an integrated production of bioenergy and biofuels [76]. It finds application in the production of papers [77,78], fuels [79-88], and chemicals [89-91]. In addition, *A. donax* Linn has been utilized for adsorption treatment of various pollutants [92-97]. However, the use of raw giant reed in treating wastewater has not received adequate attention where it has been modified to value-added products [37]. This is due to the large amount of easily available hydroxyl groups existing in the cellulose, hemicelluloses and lignin, which can easily actuate a series of chemical reactions [98]. The characteristics of giant reed are shown in Table 1. The appropriate lignocellulosic composition and high volatile matter make it efficient precursor for activated carbons [99] and char [100,101]. Other parts of *A. donax* Linn plant such as root [102] and leaves [103, 104] were also used for wastewater treatment.

3. Preparation of activated carbon

In general, there are basically two methods for preparing ACs (Fig. 1), namely physical and chemical activation [105]. Physical activation consists of carbonization of the raw materials under an inert atmosphere followed by activation of the resulting char at elevated temperature in the presence of oxidizing gas such as steam or carbon dioxide [106]. On the other hand, chemical activation involves a single step process where the carbonization and activation occurs simultaneously by impregnating the raw materials with

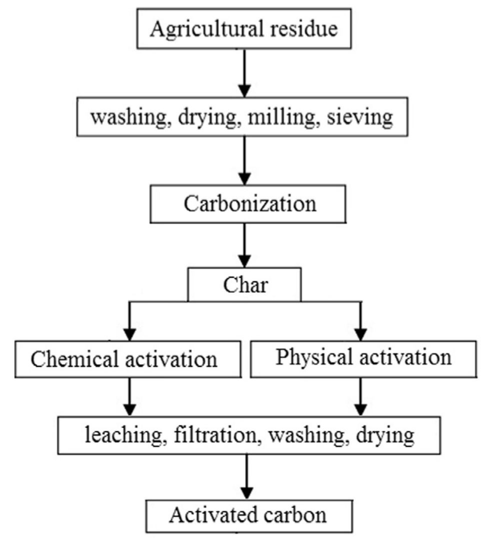

Fig. 1. Process flow diagram of activated carbon preparation from agricultural residue [66].

chemical agents like KOH, NaOH, K_2CO_3, H_3PO_4, $ZnCl_2$, *etc.*, and heating in an inert atmosphere and moderate temperatures [107]. Chemical activation usually requires lower temperatures and gives higher carbon yield with well-developed porous structure as compared to physical activation [108].

Giant reed has been widely adopted as a precursor for conventional preparation of ACs using different activating agents [109-113]. The microwave heating technique has been recently applied for preparation of AC from giant reed with the advantages of less energy consumption and short processing time [114, 115]. The pore properties and yield of ACs prepared from renewable giant reed by different preparation methods are summarized in Table 2.

3.1. Effect of variables on pore structure

The specific surface area and pore structure are the main properties of porous carbon that determine its applications [116]. Different parameters, such as activation temperature and time, type and concentration of activator could control the pore structure. Thus, many studies addressed the effects of most important variables on porous characteristics of carbon from giant reed using various activation techniques.

Vernersson et al. [109] showed the influence of the temperature, impregnation ratio IR, and time on the pore structure of ACs from *A. donax* L. (giant reed) by H_3PO_4 conventional activation. Maximum surface area of 1312 m^2/g along with pore volume of 1.10 cm^3/g and average pore diameter of 1.7 nm were reported at 500°C, 2 g/g IR, and 0.25 h. The temperature variable was of the greatest effect on pore structure where the increase in temperature from 400 to 500 °C enhanced surface area from 688 to 1114 m^2/g, pore volume from 0.55 to 1.22 cm^3/g, and average pore diameter from 1.6 to 2.2 nm, and then decreased at 550 °C. This might be due to contraction of the carbon structures and reduction in porosity development. The effects of activation variables on surface properties were in the order of: temperature > IR > time. It