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Preparation of banana frond activated carbon by microwave induced activation for the removal of boron and total iron from landfill leachate

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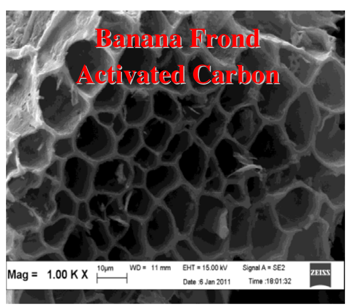
HIGHLIGHTS

- Highlight the renewable use of banana frond.
- Explore the efficient use of microwave irradiation.
- Short activation time of 4 min.
- To evaluate the potential for the adsorptive treatment of landfill leachate.
- Outline the adsorption isotherms, kinetics and thermodynamics.

GRAPHICAL ABSTRACT



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ABSTRACT

The present work demonstrates the preparation of banana frond derived activated carbon (BFAC) by microwave induced KOH activation for the adsorptive removal of boron and total iron from the semi-aerobic landfill leachate. The physical and chemical properties of BFAC were evaluated by pore structural analysis, scanning electron microscopy and Fourier transform infrared spectroscopy. The effects of adsorbent dosage, contact time, solution pH and temperature on the adsorption performance were examined in a batch mode study. The experimental results manifested that the adsorptive removal of boron and total iron increased with increasing the adsorbent dosage, contact time and temperature, accomplished the adsorptive removal of boron and total iron of 93.56% and 95.14%, respectively. Equilibrium data was best confronted to the pseudo-second-order kinetic model, while the adsorptive removal of boron and total iron onto BFAC was satisfactory described by the Freundlich and Langmuir isotherm models. The findings illustrated the applicability of BFAC as an ideal on-site solution for the adsorptive treatment of boron and total iron from the contaminated landfill leachate.

1. Introduction

Landfill leachate is a complex mixture of soluble organic and mineral compound, formed by the interaction of waste layers with excess water percolating within the landfills [1]. The leachate is commonly characterized by a high strength of dissolved organic matters, inorganic macro components, halogenated hydrocarbons, suspended solids, xenobiotic organic substances, and a significant concentration of heavy metals and inorganic salts [2]. If poorly managed, the landfill leachate may become a source of hydro-geological contamination. Over the years, there has been increasing concern and more stringent regulation standards pertaining to the indiscriminate disposal of metal ions, due to their detrimental

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deterioration towards the human health, flora, fauna, aquatic living organisms and the ecological environments [3,4].

According to the guidelines of drinking water quality published by the World Health Organization (WHO), the standard concentration of boron and total iron has been proposed at 0.5 and 2.0 mg/L, respectively [5]. Acute exposure to boron has been susceptible to chronic poisoning, damages of digestive system, mucous membranes, liver, kidney, and central nervous and reproductive failure [6,7]. Increasingly, prolonged administration of excessive quantities of iron is vulnerable to a wide spectrum of neurobehavioral disorders and abnormalities, presage as coma, metabolic acidosis, shock, coagulopathy, and rand respiratory distress syndrome [8,9]. In view with the above matter, the treatment of risky metal ions of leachate prior to discharge is a legal necessity to avoid both severe and continual toxicity. In particular, liquid–solid adsorption system, based on the ability of carbonaceous solids to preferentially concentrate specific substances from solutions onto their surfaces, has been proposed to be a promising technique for removing toxic and non-biodegradable metal ions [10]. Although there is a great deal of research demonstrating the feasibility of metal ions removal by means of adsorption process [11,12], there are limited studies that reported a comprehensive overview of metal ions treatment under more realistic conditions, using the real landfill leachate.

In this study, specific efforts are devoted to mimic the real conditions as closely as possible, to examine the preparation of banana frond derived activated carbon (BFAC) by microwave heating for the adsorptive treatment of boron and total iron from the semi-aerobic landfill leachate. Structural, functional and surface chemistry of the prepared adsorbent was carried out. The effects of adsorbent dosage, contact time, solution pH and temperature on the adsorption performance were evaluated. Moreover, the adsorption isotherms, kinetics and thermodynamics are outlined.

2. Materials and methods

2.1. Landfill leachate

The leachate samples were collected from a municipal waste sanitary landfill (Pulau Burung Landfill Site, PBLS), located within the Byram Forest Reserve, Penang, in the northern region of Malaysia. Its geographical coordinates are 5°24′N, 100°24′E. The site was developed semi-aerobically in March, 2001, and has a natural marine clay liner with the total area of 33 ha [13].

The leachate samples were collected from the active detention pond with a leachate age of less than 5 years, and instantaneously transported to the laboratory, and stored in darkness at 4 °C with minimum exposure to surrounding air as to minimize the chemical and biological changes. The characteristics of leachate samples were based on 6 samplings collected for 3 months from May to July, 2012. Chemical analysis was performed according to the Standard Method of Water and Wastewater [14].

Table 1
Characteristics of the leachate samples.

Parameter	Unit	Average value
COD	mg/L	2336
BOD_5	mg/L	147
Ammonical nitrogen	mg/L	2550
Arsenic	mg/L	0.10
Cadmium	mg/L	0.02
Lead	mg/L	0.27
Copper	mg/L	0.14
Manganese	mg/L	0.65
Chromium +6	mg/L	0.08
Chromium +3	mg/L	0.14
Nickel	mg/L	0.19
Boron	mg/L	7.50
Total iron	mg/L	9.31

All experiments were undertaken in triplicates. The chemical oxygen demand (COD), biological oxygen demand (BOD_5) and ammonia strength of the leachate varied between 2336, 147 and 2550 mg/L, while the boron and total iron content was identified to be 7.50 and 9.31 mg/L, respectively. The mean characteristics of the leachate samples are presented in Table 1. To recognize the environmental risks of the leachate, the achieved parameters values were compared with the Malaysian Environmental Quality (Control of Pollution from Solid Waste Transfer Station and Landfill) Regulations 2009, under the Malaysia Environmental Quality Act 1974 [15].

2.2. Preparation of activated carbon

Banana frond used as raw material in this work was procured from a local plantation area. The raw precursors were manually chosen, washed exhaustively with distilled water to remove adhering impurities from the surface, air-dried, cut and screened to the desired mesh size of 1–2 mm. The carbonization process was performed in a muffle furnace at 700 °C under inert atmosphere, with a ramping rate of 10 °C/min [16]. The char produced was mixed with potassium hydroxide (KOH) solution with an impregnation (char: KOH) ratio of 1:1.75 (wt%).

Microwave heating was conducted in a 2.45 GHz commercial microwave oven with suitable modifications [17]. The reaction was performed in a Pyrex glass reactor fixed in the chamber of microwave oven, with a continuous output power of 600 W, and the irradiation time of 4 min. Nitrogen gas at a pre-set flow rate of 300 cm^3/min was used to purge air in the reactor before the start of microwave heating, and it continued to flow during the cooling intervals [18]. The resultant activated carbon was washed with hydrochloric acid of 0.1 M and rinsed repeatedly with hot and cold distilled water until the filtrate reached to neutral pH.

2.3. Characterization of activated carbon

The pore structural characteristics of BFAC were determined by nitrogen adsorption using an automatic Micromeritics ASAP-2020 volumetric adsorption analyzer. Prior to analysis, the sample was degassed for 2 h under vacuum at 573 K. After degassing, the sample was transferred to the analysis system where it was cooled in liquid nitrogen. A 21-point analysis was carried out at 77 K to obtain the nitrogen adsorption isotherm.

Scanning electron microscopy (SEM) analysis was carried out to study the textural morphology of BFAC. Chemical characterization of surface functional groups was detected using the pressed potassium bromide (KBr) pellets containing 5% of carbon sample by Fourier transform infrared spectrometer (FTIR-2000, Perkin Elmer). The FTIR spectra were recorded between 4000 and 400 cm^{-1}.

2.4. Batch equilibrium studies

The batch adsorption experiments were conducted in a set of 250 mL Erlenmeyer flasks containing a prefixed amount of BFAC and 200 mL of leachate solution. The mixture was agitated at 30 °C for a predetermined period using a thermostatic orbital shaker operated at an agitation speed of 120 rpm. The samples were collected at prescribed time intervals, and the analytical determination of boron and total iron was performed spectrophotometrically using the Carmine and FerroVer methods, with a spectrophotometer (HACH DR2500) at the maximum wavelengths of 605 and 510 nm, respectively.