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Preparation of activated carbon from sugarcane bagasse by microwave assisted activation for the remediation of semi-aerobic landfill leachate

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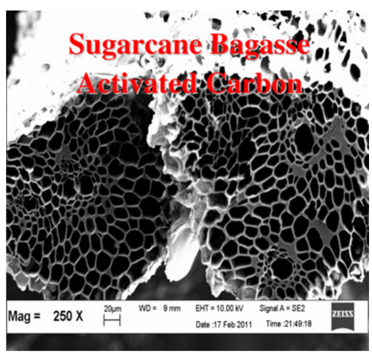
HIGHLIGHTS

- Highlight the renewable use of sugarcane bagasse.
- Explore the efficient use of microwave irradiation.
- Short activation time of 5 min and low chemical impregnation ratio of 1.25.
- High BET and Langmuir surface area of 1620.69 and 2430.16 m^2/g.
- To evaluate the potential for the adsorptive treatment of landfill leachate.

GRAPHICAL ABSTRACT



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ABSTRACT

This study evaluates the sugarcane bagasse derived activated carbon (SBAC) prepared by microwave heating for the adsorptive removal of ammonical nitrogen and orthophosphate from the semi-aerobic landfill leachate. The physical and chemical properties of SBAC were examined by pore structural analysis, scanning electron microscopy, Fourier transform infrared spectroscopy and elemental analysis. The effects of adsorbent dosage, contact time and solution pH on the adsorption performance were investigated in a batch mode study at 30 °C. Equilibrium data were favorably described by the Langmuir isotherm model, with a maximum monolayer adsorption capacity for ammonical nitrogen and orthophosphate of 138.46 and 12.81 mg/g, respectively, while the adsorption kinetic was best fitted to the pseudo-second-order kinetic model. The results illustrated the potential of sugarcane bagasse derived activated carbon for the adsorptive treatment of semi-aerobic landfill leachate.

1. Introduction

The burial of municipal solid waste in landfills is the most common and desirable integral indispensable solid waste management strategy for sustainable disposal of residue waste from separation, recycling and incineration, both in fully industrialized and developing countries (Sandip et al., 2012). Landfill leachate is a soluble organic and mineral compound formed by excess water percolating through the waste layers in a landfill, induced by the gravity force, precipitation, irrigation, surface runoff, rainfall, snowmelt, refuse decomposition, groundwater intrusion and initial moisture content presents within the landfills (Foo and Hameed, 2009a).

If poorly managed, the landfill leachate may become a source of hydro-geological contamination due to the risk of leachate infiltrating into the natural environment and groundwater table

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(Foo et al., 2013). The adverse impacts of overloading in the sensitive ecosystems are becoming increasingly noticeable with several substances with confirmed carcinogenic or co-carcinogenic potential were indicated in the landfill leachate, while others were expected to be persistent and highly bio-accumulative (Scaglia et al., 2011). In view with the above matter, a wide range of new tertiary treatment technology has been abounded (Foo and Hameed, 2010a). Of major interest, activated carbon adsorption process is recognized as the most efficient and promising fundamental approach in the wastewater treatment processes, in term of its simplicity of design, ease of operation, insensitivity to toxic substances, and high adsorption capability (Foo and Hameed, 2011a).

The preparation of activated carbon is usually conducted at relatively high temperatures in conventional convective or conductive heating systems. The thermal process may take long processing time to reach to the desired level of activation. There is also a considerable risk of overheating, leading to the complete combustion of the carbon (Foo and Hameed, 2011b). Microwave heating is gaining importance as it is capable of reducing the heating period, energy consumption, gases consumption, promotes rapid and precise temperature control, and compact equipment size (Foo and Hameed, 2009b).

Sugarcane is the world's largest crop, which accounts approximately 80% of the sugar produced. The extracted juice is adopted as the primary source of sucrose, while the fermented juice has been reputed as an ideal precursor for the manufacture of bio-ethanol (Dhaliwal et al., 2011). Nevertheless, its wide scale implementations are hampered by the massive generation of fibrous bagasse, which constitutes 30% of the entire plant (Bian et al., 2013). Typically, ammonical nitrogen and orthophosphate have always been the crucially problematic parameters, which provide a prerequisite insight into the prediction of leachate quality (Liu et al., 2012). In this sense, the focus of this study was to prepare low cost activated carbon from sugarcane bagasse (SBAC) by microwave heating for the adsorptive treatment of ammonical nitrogen and orthophosphate from the semi-aerobic landfill leachate. Structural, functional and surface chemistry of the prepared adsorbent was evaluated. Moreover, the adsorption equilibrium, isotherms and kinetics are elucidated.

2. Methods

2.1. Adsorbate

The leachate samples used in this study were collected from a municipal waste semi-aerobic landfill (Pulau Burung Landfill Site, PBLS), situated within the Byram Forest Reserve in Penang, Malaysia. PBLS has been developed semi-aerobically into a Level II sanitary landfill by the establishment of a controlled tipping technique in 1991 and it was upgraded to a Level III sanitary landfill by controlled tipping with leachate recirculation in 2001. The site has a natural marine clay liner with the total area of 33 ha, equipped with a leachate collection pond.

The leachate samples were collected from the active detention pond with the leachate age of less than 5 years, and stored in darkness at 4 °C with minimum exposure to surrounding air to keep the leachate characteristics unchanged. The characteristics of leachate samples were based on six samplings collected for 3 months from May to July, 2012. All experiments were undertaken in triplicates. The chemical oxygen demand (COD) of the leachate varied between 2060 and 2700 mg/L, while the biological oxygen demand (BOD_5) was less than 200 mg/L. Ammonia strength, a major pollutant in the landfill leachate was around 2550 mg/L, while the orthophosphate level was identified to be 285 mg/L.

2.2. Preparation of activated carbon

Sugarcane bagasse (SB), a by-product procured from a local sugar processing factory was the precursor used in this study. The collected sample was washed exhaustively with deionized water to remove adhering dirt particles from the surface. Dried SB was cut, ground and screened to the desired mesh size of 1–2 mm. The carbonization process was performed by loading 500 g of dried precursor into a vertical furnace, and heated up to a carbonization temperature of 700 °C under purified N_2 flow (Foo and Hameed, 2012a). The char produced was mixed in potassium hydroxide solution with a char/KOH impregnation ratio of 1:1.25 (wt.%) with occasional stirring.

A modified microwave oven with a microwave input power of 600 W and frequency of 2.45 GHz (Foo and Hameed, 2012b) was applied for the activation step. The irradiation time of 5 min was selected as the heating period based on preliminary runs. Nitrogen gas at a pre-set flow rate of 300 mL/min was used to purge air in the reactor before the start of microwave heating and it continued to flow during the cooling intervals. The resultant activated carbon (SBAC) was washed with 0.1 M hydrochloric acid and rinsed repeatedly with hot and cold distilled water until the filtrate reached to neutral pH.

2.3. Characterization of activated carbon

The surface morphology was imaged using the Zeiss Supra 35 VP scanning electron microscope equipped with W-Tungsten filament (Lanthanum-Hexabonde Field Emission) operated at 10–15 kV of speed voltage, 155 eV of resolution and orientation of 35° with Mn K_α as the energy source.

The pore structural analysis was characterized by nitrogen adsorption at 77 K with an accelerated surface area and porosimetry system (Micromeritics ASAP 2020). The specific surface area (S_{BET}) was calculated by the Brunauer–Emmett–Teller (BET) equation; the total pore volume (V_T) was evaluated by converting the adsorption volume of nitrogen at relative pressure of 0.95 to equivalent liquid volume of the adsorbate, while the micropore volume, micropore surface area and external surface area were deduced using the *t*-plot method.

Chemical characterization of functional groups was detected using the pressed potassium bromide (KBr) pellets containing 5% of carbon sample by Fourier transform infrared spectrometer (FTIR-100, Shimadzu) in the scanning range of 4000–400 cm^{-1}. The ultimate analysis was performed using an Elemental Analyzer (Perkin–Elmer-2400).

2.4. Batch equilibrium studies

The batch adsorption experiments were conducted in a series of 250 mL Erlenmeyer flasks containing 200 mL of leachate solution. The flasks were capped and agitated in an isothermal water bath shaker at 120 rpm and 30 °C until the equilibrium was reached. The influence of adsorbent dosage on the adsorptive uptake of ammonical nitrogen and orthophosphate was performed by varying the SBAC dosage from 0.50 to 8.00 g, while keeping the other parameters constant. The effect of pH was examined by regulating the pH from 2 to 10, with a SBAC dosage of 5.00 g/200 mL and adsorption temperature of 30 °C. The pH was measured using a pH meter (Model Delta 320, Mettler Toledo, China).

The samples were collected at prescribed time intervals and the concentration of ammonical nitrogen and orthophosphate was determined using the Nesslerization and FerroZine methods, with a spectrophotometer (HACH DR2500) at the maximum wavelength of 425 and 480 nm, respectively. All samples were filtered using a syringe filter (Whatman 0.45 μm) prior to analysis as to minimize