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Preparation and characterization of banana trunk activated carbon using H_3PO_4 activation: A rotatable central composite design approach

Mohammed Danish [a], Zhou Pin [b], Lou Ziyang [c], Tanweer Ahmad [d], Shahnaz Majeed [e], Ahmad Naim Ahmad Yahya [f], Waheed Ahmad Khanday [g], H.P.S. Abdul Khalil [a]

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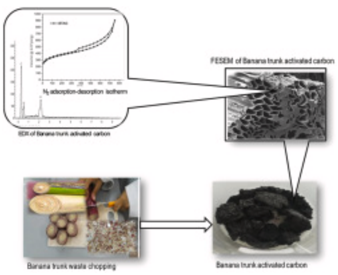
Abstract

Banana trunk waste was utilized to produce activated carbons with improved surface area and phosphorous atom dispersed surface through the chemical activation method using phosphoric acid. Banana trunk activated carbon (BTAC) production was optimized through the rotatable central composite design (RCCD) approach of the response surface methodology (RSM). The independent variables selected for optimization were activation time (35.5–134.5 min), activation temperature (367–932 °C), and H_3PO_4 concentrations (0.36–8.14 mol/L). The optimized conditions of the independent variables obtained through RCCD were 50 min (activation time), 583 °C (activation temperature), and 6.60 mol/L (H_3PO_4 concentration) for a maximum Brunauer-Emmett-Teller (BET) surface area of 1290 m^2/g. Banana trunk activated carbon samples were characterized for bulk and surface elemental composition, surface morphology, thermal stability, functional groups, pHzpc, and crystallinity behavior. The characterization results suggested that BTAC has a porous surface with carbon as the backbone element with the highest percentage of 78%. The oxygen atom occupies the surface with 12%, and the phosphorus atom is spread almost 6% over the carbon surface. The raw banana trunk was thermally decomposed at an onset temperature of 240 °C and above, whereas the banana trunk (BTAC) was thermally stable up to 700 °C. Phosphoric acid-activated banana trunk activated carbon composed of the following surface functional groups: –OH, –C = O, -P = O, -P-O-C, and multiple carbon-carbon bonds.

Graphical abstract



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Introduction

For centuries, charcoal (conventionally obtained through half-burn woody materials) was used to purify or separate dissolved colorants and soluble compounds from liquids such as water, wine, and oils. With the expansion of various chemical industries, the range of solvents to be purified has increased exponentially. Mitigating obnoxious industrial chemicals requires a large surface area and suitable functional group-anchored activated carbons. It is a more advanced form of carbon material than charcoal.

The demand for non-conventional products triggered a rapid growth of small and medium industries without specific research and development (R&D) activities, spreading a varied range of chemical dispersion in various solvent mediums. Separation of toxic chemicals from solvents requires an effective material with an extended large surface area and suitable pore width. The demand for renewable and low-cost activated carbon in industries is expected to increase significantly in the coming days. Traditionally, inferior quality coal (a non-renewable source), such as peat and lignite, was used as precursors to form activated carbons. Researchers explored the renewable source of carbon-rich biomass waste as precursors for activated carbon production. The conversion of biomass waste to activated carbon will help to ensure sustainable waste management. As a result, it reduces the pollution caused by its disposal by burning or dumping in an open environment. Biomass waste generated from agricultural activities is a promising precursor for producing quality activated carbons. Raw biomass has a high carbon content (because of the organic compounds present) and is abundantly available from renewable sources [1].

Researchers explore the short rotation of renewable biomass and sludge waste in search of renewable, cheap, and effective activated carbon materials [2,3]. The banana plant is one of such biomasses grown in a short rotation period (8–10 months). Its growth rate is fast and produces plenty of biomass waste after fruit harvest. Furthermore, the banana plant produces one-time fruit in a lifetime. So, after every fruiting cycle, the plant must be destroyed for the next batch of plantations [4]. Conversion of these discarded banana plant waste into an effective material will stimulate the agricultural sector and help in the management of agricultural waste. In recent past, many agricultural waste biomasses were subjected to conversion into activated carbon materials through different activation routes such as single-step pyrolysis (only activation at one fixed temperature) [5,6], two-step pyrolysis (carbonization followed by activation at two different temperatures) [7], chemical activation followed by single-step pyrolysis (biomass first treated with chemicals followed by activation at any fixed temperature) [8], physical activation (activation in the presence of steam or any inert gas) [9,10], microwave activation (heating conducted in the microwave) [11,12]. The carbon-rich material produced as a result of these activation processes is termed 'activated carbon' materials. There are several suitable agricultural wastes including date stone [13,14], wood [15], oil palm empty fruit bunches [16], rice husks [17], sugarcane bagasse [18], orange peel [19], bamboo [20], fox nut [21], pistachio shell [22], kenaf core fiber [23], corncob [24], tea and coffee waste [25,26], coconut shell [27] and banana waste [4].

The activated carbons produced through different carbon sources have varying properties, depending on the activation process and the raw material [28]. Activated carbon with various surface areas, pore diameter, and surface elemental composition can be obtained from the same biomass. The unique feature of activated carbon is its pore size and extended large surface area, making it more helpful for trapping vapors [29], storing hydrogen gas [30], and scavenging water-soluble pollutants [31]. The activated carbons with a significant proportion of surface area that lie in the mesopore size range (2 nm–50 nm) are more suitable for trapping many molecular liquids in aqueous solutions. Moreover, micropore-dominated activated carbon has low adsorption capacity against dye molecules. Danish et al. [10] reported physically activated carbon from *Acacia mangium* wood, which has 81% microporous area (pore size <2 nm), its adsorption capacity against methyl orange dye (aqueous molecular size ~2.6 nm) was 7.5 mg/g. Whereas chemically activated carbon from *Acacia mangium* wood with 95% mesopore area (2 nm<pore size <50 nm) [8] has an adsorption capacity of 181 mg/g against methyl orange dye [32].

Characterization of biomass-transformed activated carbon is essential because it explores the surface morphology, elemental constituents, pore size distribution, and surface textural behavior. Surface morphology and textural information are helpful to the user before applying any activated carbon material against liquid or gas phase pollutants [33]. The macropores neither enhance the surface areas nor provide a surface to facilitate adsorption. Instead, it acts as a channel for the adsorbate to enter the interior pores of activated carbon, where most of the adsorption occurs [34]. The surface area, pore size distribution, and pore volume are essential parts of the characterization of activated carbon. Moreover, surface functional groups, bulk and surface elemental composition, surface morphology, amorphic/crystallinity behavior, and structural stability against various temperatures are the other characteristics that should be studied for any activated carbon. A thoroughly characterized activated carbon is a valuable material that can be applied for any specific purpose [35]. Therefore, substantial research is required to develop more competent and effective methods to produce highly porous, large-surface-area activated carbons from biomass and biomass waste.

In contemporary research, the response surface methodology (RSM) approach has been extensively used to optimize the independent factors involved in the conversion of biomass or biomass waste into activated carbon [36,37]. The RSM is a statistical tool through which a series of experiments can be designed based on statistical data points within the selected range of independent variables. Based on the output results at each statistical data point, an empirical model can be developed; that model helps in evaluating the effects of independent factors and finding the optimum value of desired output. Moreover, the response surface methodology approach reduces the number of experiments and simultaneously observes the impact of change of multiple independent variables and their interactions on the response output. It also calculates the standard deviation in the measurement at the values of the center point of the independent variable and is distributed over the entire range of variables [32]. So far, no studies have reported on the optimization of the surface area of the carbons activated by banana trunk waste.

Therefore, the following objectives were established as a result of this research: (1) explore the banana trunk waste as a precursor for the activated carbon H_3PO_4, (2) find the optimum operating conditions to produce activated carbon from the banana trunk by chemical activation and simultaneously considering the activating agent concentration, activation temperature, and activation time, (3) desirable activated carbon based on the BET surface area, micropore surface area, and external surface area was evaluated as a response, (4) characterization of activated carbon from banana trunk for elemental composition in bulk as well as on the surface, surface functional groups, and surface morphology.

Section snippets

Materials

The banana trunk was collected from the local banana plantation field in the Cherana Putih area in Melaka state of the western peninsula of Malaysia. It was washed with water to remove the dust and dirt that adhered during collection from the plantation fields and transportation. The clean banana trunk was chopped into small pieces (~2 cm × 5 cm) and, for partial drying, kept in the sunlight for one day. The partially dried samples were kept in a hot air oven for complete drying at 105 °C for…

Central composite design regression model analysis

The short central composite design (CCD) was applied to correlate the surface area of the BET (Y1), the micropore surface area (Y2), and the external surface area (Y3) with the activation time of the independent variables (A), the activation temperature (B) and the concentration of the activating agent (C). Micropore, mesopore, and total surface areas are the most critical features of activated carbon in the context of adsorption properties. The design of the experimental data set with the…

Conclusions

This study investigates the potential for the use of banana trunk waste as an environmentally sustainable raw material to produce quality activated carbon through chemical activation with phosphoric acid. Banana trunk was used as a low-cost activated carbon source material. The rotatable central composite design (RCCD) was used to maximize the BET surface area (1295 m^2/g) of the prepared banana trunk activated carbon (BTAC) under the optimal conditions of the variables. The optimal variables…

CRediT authorship contribution statement

Mohammed Danish: Writing – review & editing, Data curation. **Zhou Pin:** Data curation. **Lou Ziyang:** Supervision. **Tanweer Ahmad:** Writing – original draft. **Shahnaz Majeed:** Visualization. **Ahmad Naim Ahmad Yahya:** Resources, Providing research material help during experimentation at UniKL-MICET. **Waheed Ahmad Khanday:** Formal analysis, of, Data curation. **H.P.S. Abdul Khalil:** Resources.…

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.…

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> *Citation Excerpt :*
> …From literature reports, it known that the surface of carbonaceous materials can also be modified to increase its adsorption capacity and/or its electrocatalytic properties. In this way, the use of metal oxides (MnO_2, Ta_2O_5, V_2O_5, CeO_2) [29,30], heteroatom doping (N, F and B) [14], the use of a

particular structure (carbon black, carbon nanotubes, graphene, etc.) [31–33] and the oxidation degree of the surface groups (using oxidation agents such as HNO3, KMnO4, H2O2) have been reported [34–39]. The oxidation degree of the carbon surface is particularly important since it changes the nature and the chemical structure of the surface.…

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…The most significant limitation in the common use of activated carbon in industries is the cost of production and preliminary steps which increase production time [20]. In order to minimize production cost and time, it should be found a new alternative route to produce activated [21,22]. Activated carbon production includes two main steps: (i) the carbonization step (thermal process) comprises conventional or microwave heating, and (ii) the activation step includes chemical or physical activation [23].…

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The role of bromides upon electrochemical mineralization of bisphenol A with boron-doped diamond anode

2022, Journal of Hazardous Materials

Citation Excerpt :

…Noting that except for Entry 20 in Table SM-1, the applied current intensity (jappl) employed in our work are all higher than the limiting one (γ = 1.3–5.2), which guarantees both efficient TOC removal and moderate mineralization current efficiency (10–30%) (Garcia-Segura et al., 2018a). As reported, the employment of central composite rotatable design (CCRD) with response surface methodology (RSM) allows us to optimize the experimental conditions with as few as possible number of trials (Almeida et al., 2011; Danish et al., 2022; Pereira et al., 2019). More importantly, this methodology can also avert the reasoning of the interrelationship between important variables (Xian et al., 2018).…

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