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Synthesis of magnetic biochar from agricultural waste biomass to enhancing route for waste water and polymer application: A review

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ABSTRACT

The development of magnetic biochar from biomass and the prospect of developing magnetic nanomaterials have attracted many researchers worldwide. The conversion of this biomass into something more prospective has reduced the waste management issue without any hassle. Magnetic biochar which is derived from various types of biomass exhibits a good magnetic property with high surface area and significant morphology through various production methods. These magnetic biochar showed a remarkable application as an adsorbent for various wastewater treatments and were cooperated in certain selected polymer composites for application in supercapacitor. This study provides an extensive summary of various production methods of magnetic biochar along with its application in wastewater treatment and selected polymer cooperation.

Contents

1. Introduction

The continuous growth in various industries in this modernization era requires a continuous improvement in every aspect with a manageable cost to increase the profit margin of these industries. Agricultural waste has always been given extra attention due to it's extensively and abundantly availability throughout the world. On that note, countries like Malaysia which has its one part of major economy turnover solely based on the agricultural sector; produces more than 2 million tons of agricultural waste annually which are either dumped or burned in an open landfill which leads to extensive environmental related issues such as groundwater contamination or air pollution [1]. Materials such as empty fruit bunch, rice husk and coconut shell were found to be one of the abundantly available agricultural waste which contains high amount of mineral such as silica, magnesium and potassium along with a high porosity as well [2–5]. These agricultural waste were

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further developed into biochar by a common pyrolysis process which is well-known for its successful application in various sectors such as enhancing the soil fertility for a higher crop production by increasing the fertilizer's retention time [6,7], as a dopant to increase the capacitance value of a supercapacitor [8] and as an adsorbent in the removal of various wastewater's contaminants such as lead [9], copper, zinc [10] and natural organic matter [11]. An additional centrifugation process is required for the separation of biochar from aqueous solution [12] or a further activation process by the oxygen plasma method with a strong base prior is required prior to its application in supercapacitor [13,14]. This difficulty is overcome by the development of magnetic biochar with the attachment of various metallic ions on the surface of biochar to enhance its magnetic effect and application in various fields. Common production methods such as conventional heating in an electrical furnace [15–17], microwave heating in a modified furnace or oven [2,18,19], co-precipitation [20–22] and calcination [23,24] were employed for the production of magnetic biochar in laboratory scale. These produced magnetic biochar showed an extensive application as an adsorbent in wastewater treatment for the removal of contaminants such as cadmium [25,26], arsenic [16,27], lead [28,29], methylene blue [2,17,30] and phosphate [31]. Besides that, certain selected magnetic biochar showed an excellent capability to be used as electrode for supercapacitor to increase the capacitance and electrical conductivity value as well [32].

In this study, a brief summary of different production methods of magnetic biochar is presented along with the characterization of the magnetic biochar produced. Further applications of these magnetic biochar in wastewater treatment, supercapacitor and polymer composite are also discussed.

1.1. History and development of biochar

Biochar, generally defined as the solid carbon-rich residue obtained from the thermal decomposition of plant derived biomass in the absence of oxygen or in a partial oxygen condition [33], faced a series of development originating from char throughout these many years to attain its current position in the market. Although the production and application of biochar reached its peak level only in this modernization era, its history goes all the way back to the early stages of human life. Biochar were believed to be initially discovered after activities such as forest fires and burning activities in pits which are solely reserved for open-air combustion of trash. These char were then added to the soil for improving its nutrient intake and growth rate. Although the pits where the burning process done is solely reserved and far away from humanity, the release of toxic gases into the surrounding environment does lead to harmful effects [34].

Certain research suggests that biochar was initially found at the Amazon Basin of South America where the Native Indians began to produce biochar by pilling up wood stock in pits and slowly burning them without the presence of air during the early stage of civilization [35]. These types of dark and fertile soil, known as terra preta soil were scattered patchily all over the locations of historic living place, approximately 20 hectares in area in which the high content of biochar being the main cause of the dark colour of the soil [36,37]. On the same note, these black soils were found to provide a high quantity of enhanced calcium, nitrogen, phosphorus and potassium along with organic matter which eventually be the main reason behind the increase of crop's production rate.

Apart from that, matching soils as the terra preta soil were found in few other locations such as Ecuador, Peru and West Africa in the agricultural application as well [38]. Besides the American continent, biochar were found to be widely used in Asian continents as well for the agricultural processes since ancient times. At that moment, Japan led the carbon production's market by producing charcoal for commercial purposes with a trading rate of 15,000 tones yearly [39]. On the other hand, the very first batch of activated carbon was industrially produced in the twentieth century where agricultural products were used as the raw material for the synthesis of activated carbon in the sugar refining industry [40]. Prior to the usage in sugar refining industry, powder activated carbon was generated from wood in Europe in the early 19th century for commercial purpose. As for the United States, activated carbon was produced from black ash which was discovered from its capability in decolorizing liquids [41]. Besides that, activated carbon was also widely used in the 19th century in England for water treatment to eliminate any unwanted and undesirable tastes and odours from drinking water [40].

1.2. Development of magnetic biochar

The continuous growth in technology has always been a key factor for further improvement in any current product or technology in the world market. The development of magnetic biochar rose after the difficulty faced in the application of biochar in a vast area of interest.

Recently, magnetic materials are being offered a great interest of research in many sectors such as catalysis [42], magnetic resonance imaging [43], data storage [44] and environmental remediation [2]. Magnetic materials were found to provide optimum performance when it has a particle size in a range of 10–20 nm. Magnetic materials were generally produced by utilizing metallic salt which are able to provide the magnetic medium such as iron chloride hexahydrate [45], iron sulfate heptahydrate [46], manganese oxide tetrahydrate [28] and manganese sulfate hydrate [47]. The production of magnetic materials was then focused on the utilization of agricultural waste material as the raw material and the produced magnetic materials were known as magnetic biochar. A wide range of waste material such as pine wood [48], corn cob [49], cottonwood [30] and chitosan [47] has already been roped into the production of magnetic biochar which exceled in various applications. The next section focuses on the various synthesis methods of magnetic biochar by the employment of different magnetic material and agricultural waste material.

1.3. Production of magnetic biochar

Generally, there are three common techniques employed to produce magnetic material such as pyrolysis, co-precipitation and calcination method. These methods are utilized by many researches to produce high quality and high yield of magnetic materials. Every method has its own advantage and pullback in which a set of innovative skills is required to utilize the advantage of single production method to produce novel magnetic biochar with a significant production method.

1.3.1. Pyrolysis

Generally, pyrolysis is defined as the chemical and thermal decomposition of an organic material to temperature greater than 400°C in the absence of oxygen [50,51] which leads to the production of three main substances which consist of a residual solid char (biochar), a liquid product commonly known as bio-oil, pyrolysis oil or bio-crude and a non condensable gas known as syngas which consist of carbon monoxide (CO), carbon dioxide (CO_2), hydrogen (H_2), and methane (CH_4) [52]. An additional understanding of the nature of the biomass and the reactor conditions provides an extra knowledge of the complex physics and chemistry that occur during a pyrolysis reaction [53,54]. Biomass is generally defined as the susbtance of a mixture of lignin, cellulose, hemicellulose and minor amounts of other organics in which each