

The new era of biochar in environmental chemistry: Microcarbon materials

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Biochar is renowned as a solid carbonaceous material which is commonly used in various environmental applications; as a material for soil amendment, sustainable option for solid waste management, wastewater treatment, and carbon sequestration. Natural organic waste material such as wood waste, compost residue, rice husk, corn cob, coconut and fruit shells (e. g. Dorian shell) are some of the feedstock materials utilized in the production of biochar. Specific properties, such as biochar yield, elemental composition, surface area, and porosity, are governed by feedstock characteristics, the production process, temperature, and residence time [1]. The relative fractions of lignin, cellulose, and hemicellulose in lignocellulosic biomass also play a major role in the dominant properties of the final biochar product [2]. Considering these exceptional and various properties, biochar is now being explored for energy production, use in electrodes, supercapacitors, and sensors and healthcare applications [3]. Nevertheless, scientists have introduced different modification methodologies to enhance the inherent properties of biochar.

Preparation of biochar based composites and biochar/nanocomposites are some of the successful modifications. However, activation of biochar has gained the most exceptional research attention due to the simplicity of the method. Physical and chemical activation processes are the two major types of activation techniques; each can be further separated into pre and post-modification processes [4]. However, based on the chemical-free green production pathway, the milling process, which is a physical modification, has gained the most considerable attention. Therefore, enhancement of properties by reducing the particle size into colloidal and nanocarbon has initiated the new era of biochar, introducing a paradigm shift in biochar research. Mechanical grinding of biochar using a ball mill is the prominent preparation method of nanobiochar. Macroscale biochar (particle size of 1 μm or higher) has been ground to the nanoscale to produce nanobiochar (NBC), which is <100 nm at least in one dimension [5].

When the ground biochar dissolved in water or ethanol and centrifuged, it separates the nanobiochar fraction. Colloidal biochar is an intermediate product in the preparation process of nanobiochar, which presents in size range of 1 μm – 100 nm.

Nanobiochar demonstrates higher surface area to mass ratio, excellent adsorption potential, and other prospective applications, for instance, as a sensor, capacitor and photocatalytic material. Scaling down biochar to the nanoscale, using a top-down approach, is the most common method to prepare nanobiochar. The very first successful attempt of nanobiochar preparation has been carried out by Liu et al 2013 using sawdust biochar to form a solid acid catalyst using a fast pyrolysis-sulfonation process [6]. An interesting study that is unique has been conducted to produce nanobiochar using pretreatment and high-temperature thermal-chemical flash exfoliation for corn cob. Production of carbon nanosheets with a high specific surface area without the milling process was revealed through this study [7]. In 2016, Oleszczuk and colleagues reported the first publication on nanobiochar characterization. They produced various nanobiochars which, upon the characterization, showed considerable structural and chemical differences to their macroscopic counterparts [8]. Similar research interest has been exhibited for colloidal biochar as well. The very first study on a colloidal fraction of biochar reported in 2017 by Kumari et al 2017 to assess the effects on the dispersibility of biochar colloids in agricultural soils. Nevertheless, no studies published in 2018 and from 2019 onwards a considerable increase in the number of studies can be observed up to date.

Nanobiochar has been used in many different purposes; as a material for contaminant removal, catalyst, sensing material, and battery industry. Both organic and inorganic substances, potentially toxic elements [Ni(II) and As(III)], agrochemicals (phenanthrene) and pharmaceuticals (Carbamazepine) have been examined for their removal using nanobiochars with a 94.7% increment in adsorption capacity was observed with

increased milling time from 3 to 6 hrs for pinewood nanobiochar [9]. Compared to carbonaceous materials, such as activated carbon, carbon nanotubes, and graphene oxides, pinewood NBC demonstrated higher adsorption capacity for organic substances specifically for carbamazepine (95%) [9]. Rice straw derived NBC was mixed with goethite to form a composite that was then used to remove phenanthrene indicated a maximum adsorption capacity of 253.9 mg/g at 700 °C [10]. Interestingly, literature revealed that NBC disperses minerals, becomes efficient adsorbents and at the same time, potential vectors for organic contaminants via forming stable clusters in the environments [11], [5].

Colloidal biochar similarly demonstrates high adsorption capabilities. Safari et al. 2019 have demonstrated the removal of Cu(II) with a maximum adsorption capacity of 22 mg/g [12]. Despite adsorptive removal, colloidal biochar demonstrated its possibility of transport of biochar colloids in porous media. Literature confirms the high stability and mobility of colloidal biochar over macrobiochar and it becomes more hydrophilic with the time. However, the research on colloidal biochar is limited.

Recently our research group at the Ecosphere Resilience Research Centre, University of Sri Jayewardenepura has published a study on the removal of both organic (i.e. Oxytetracycline and glyphosate) and inorganic contaminants (i.e. Cd(II) and Cr(VI)) using nanobiochar as an adsorbent [13]. The nanobiochar used in this study presented a graphitic nature which was unique. This nanobiochar was produced by dendro biochar which was a by-product of a dendro power industry. The disc milled biochar was dispersed in ethanol and the nano fraction of biochar was separated using the density separation method. In another study which is under revision, the efficiency of adsorptive removal between macro, colloidal and nanobiochars was compared for antibiotics in synthetic hydrolyzed human urine and observed that colloidal biochar demonstrates an efficient removal capacity over macro and nanobiochar. Nevertheless, more studies are needed to assess the adsorptive removal as well as their enhanced capacities to be used in other fields of science, i.e. battery, capacitors, sending etc. The next generation biochar applications depict a range of new fields which will have a paradigm shift from the conventional biochar research.

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Guest Articles

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Glowing the nano-bio world

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Introduction

Nanotechnology is a common technological term in the current world, and it has received wide attention of scientists, medical personnel, and the public, due to its vast variety of applications ranging from your food plate and water bottle to more sophisticated industries. In technical terms, a nanoparticle has one of its dimensions within the range 1 – 100 nm. The size, shape, morphology, surface functionalities and the type of the nanoparticle decide its suitability to be used in an application. Nanomaterials are used in many chemical industries as catalysts to facilitate chemical reactions. Recently, their use in biomedical applications has gained much attention as they have been used in biosensors as well as in biomedical imaging.

Fluorescent silica nanoparticles

Biological imaging itself is a broad topic to be discussed but here, our focus would be to discuss biological imaging with the use of ‘glowing’ nanoparticles. The term ‘glowing’ may sound too general and therefore, let us focus our attention only on fluorescent nanoparticles. Fluorescent nanoparticles are mainly of two types. They are, those that can emit a specific fluorescence signal on their own (e.g. quantum dots) and those that need to be tagged with fluorescent labels (e.g. mesoporous silica nanoparticles)¹. This article will focus on fluorescent silica

nanoparticles and some of their popular applications in the chemical and biological world.

Silica nanoparticles are very easily synthesized by the traditional Stöber method which was developed by Werner Stöber and co-workers² in 1968. This sol-gel method by far is the most popular method used in the synthesis of silica nanoparticles using an alkoxide precursor such as tetraethyl orthosilicate as the precursor in ethanol medium in the presence of an acid catalyst or a base catalyst. However, in the preparation of fluorescent silica nanoparticles, reverse microemulsion method has proven to be more successful in the “doping” of the fluorescent dye molecules to the nanoparticle.

The reverse microemulsion method

We are mostly familiar with the term “emulsions”. An emulsion is a dispersion of immiscible liquids and it is not thermodynamically stable, whereas a microemulsion which generally consists of a polar phase (usually water), oil phase and a surfactant is thermodynamically stable. Schulman et al., proposed this magic word called “microemulsion”³ as early as 1959. The interfacial region between the oil phase and the water phase, which is formed by the surfactant, may contain oil droplets dispersed in a continuous water phase or water droplets dispersed in a continuous oil phase. The former is called an oil-in-water (O/W) microemulsion and the latter is