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A comparative review of biochar and hydrochar in terms of production, physico-chemical properties and applications

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ABSTRACT

Slow-pyrolysis of biomass for the production of biochar, a stable carbon-rich solid by-product, has gained considerable interest due to its proven role and application in the multidisciplinary areas of science and engineering. An alternative to slow-pyrolysis is a relatively new process called hydrothermal carbonization (HTC) of biomass, where the biomass is treated with hot compressed water instead of drying, has shown promising results. The HTC process offers several advantages over conventional dry-thermal pre-treatments like slow-pyrolysis in terms of improvements in the process performances and economic efficiency, especially its ability to process wet feedstock without pre-drying requirement. Char produced from both the processes exhibits significantly different physiochemical properties that affect their potential applications, which includes but is not limited to carbon sequestration, soil amelioration, bioenergy production, and wastewater pollution remediation. This paper provides an updated review on the fundamentals and reaction mechanisms of the slow-pyrolysis and HTC processes, identifies research gaps, and summarizes the physicochemical characteristics of chars for different applications in the industry. The literature reviewed in this study suggests that hydrochar (HTC char) is a valuable resource and is superior to biochar in certain ways. For example, it contains a reduced alkali and alkaline earth and heavy metal content, and an increased higher heating value compared to the biochar produced at the same operating process temperature. However, its effective utilization would require further experimental research and investigations in terms of feeding of biomass against pressure; effects and relationships among feedstocks compositions, hydrochar characteristics and process conditions; advancement in the production technique(s) for improvement in the physicochemical behavior of hydrochar; and development of a diverse range of processing options to produce hydrochar with characteristics required for various industry applications.

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1. Introduction

Current energy crises are the consequence of a rising world total population and tremendous amount of pressure on demand and consumption of fossil fuels, especially in industrial countries, for energy generation. The world's total energy consumption was estimated at about 524 exajoules per year (EJ/y) and has been predicted to increase by about 27% by the year 2020 and by about 65% by 2040 [1,2]. The increase in cost, depletion in availability, and deleterious environmental concerns associated with the use of fossil fuels are the main topic of debates in energy meetings. One of the most effective approaches for dealing with these issues would be reducing its consumption by substituting it with a clean-green sustainable and renewable energy resource. Biomass is a lignocellulosic material derived from the living or recently living organic materials such as wood and agricultural residuals. In a board vision, non-lignocellulosic materials, like animal and municipal solid wastes (MSWs), are also termed as biomass [3]. Biomass is the one and only renewable energy resource that can be converted into any form of fuel including solid, liquid, and gaseous [4]. Its non-edible nature, ability to grow relatively quickly even on unfertile land, and abundant availability on earth nominates it as a potential energy resource for a sustainable energy production, which is the overall goal in the vision of a bioenergy development [5].

1.1. Lignocellulosic composition and combustion properties of biomass

Typically, biomass (like plants and trees) is composed of three main components: cellulose, hemicellulose, and lignin as shown in Fig. 1. These components are strongly intermeshed, chemically bonded by non-covalent forces, and are cross-linked together, thereby providing structure and rigidity to the plant. The physical and chemical properties of these components are discussed in Table 1.

Even though biomass is a common source of energy, particularly in developing countries, it is still not regarded as an ideal fuel due to its inferior physical and chemical properties such as fibrous nature, low bulk density and low heating value, high moisture content, high volatile components, and high alkali and alkaline earth metallic content [6–11]. The seasonal variation affects continuous availability of biomass feedstock; moreover, the wide diversification in the physical shape, chemical compositions, and energy densities among different biomasses results in inefficient handling, transportation, storage and sizing of feedstock. To overcome these aforementioned limitations, pre-treatment of biomass is a highly necessary step before it is utilized as an efficient energy resource. A broad range of biological and thermochemical pre-treatment processes like torrefaction, pyrolysis, gasification, anaerobic digestion, fermentation, etc. is available to enhance the combustion properties of biomass and its conversion to liquid or gaseous biofuels [12,13]. However, thermochemical pre-treatments are generally preferred over biological pre-treatments, as they offer advantages like short reaction time and high conversion efficiency [14]. Recent research interests in reducing greenhouse gases (GHGs) emission by means of carbon sequestration and simultaneously improving food productivity with the application of biochar in the soil have resulted in biomass regaining its attention for developing sustainable energy production and eco-friendly environment [15].

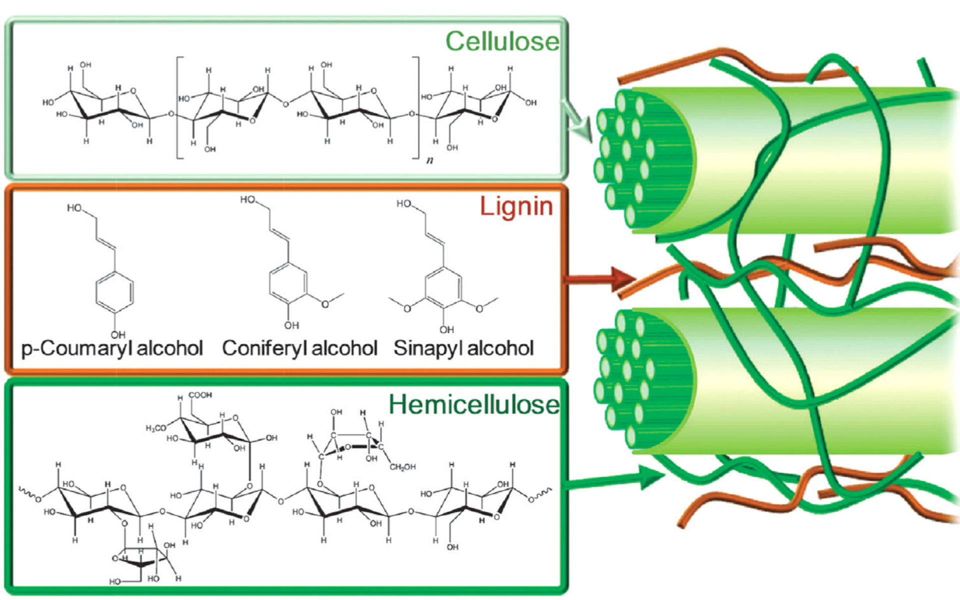

Fig. 1. Structural representation of lignocellulosic biomass with cellulose, hemicellulose, and building blocks of lignin (adapted from [16] with permission).