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Review of physicochemical properties and analytical characterization of lignocellulosic biomass

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ABSTRACT

Lignocellulosic biomass is the most abundant and renewable material in the world for the production of biofuels. Using lignocellulosic biomass derived biofuels could reduce reliance on fossil fuels and contribute to climate change mitigation. A profound understanding of the physicochemical properties of lignocellulosic biomass and the analytical characterization methods for those properties is essential for the design and operation of associated biomass conversion processing facilities. The present article aims to present a comprehensive review of physicochemical properties of lignocellulosic biomass, including particle size, grindability, density, flowability, moisture sorption, thermal properties, proximate analysis properties, elemental composition, energy content and chemical composition. The corresponding characterization techniques for these properties and their recent development are also presented. This review is intended to provide the readers systematic knowledge in the physicochemical properties of lignocellulosic biomass and characterization techniques for the conversion of biomass and the application of biofuels.

1. Introduction

Biofuels offer the prospective to reduce the reliance on use of fossil fuels, address the fuel security and environment issues, and favor some socioeconomic benefits such as sustainable development and creating jobs [1]. According to International Energy Agency, biomass energy accounts for about 14% of the world's total primary energy supply [2]. Lignocellulosic biomass is the most abundant and renewable material in the world for the production of biofuels [3], which can be used as a fuel resource alternative to fossil resources.

Lignocellulosic biomass refers to plant dry matter, which is mainly composed of cellulose, hemicellulose and lignin [4]. The lignocellulosic biomass feedstocks available for energy purpose are mainly from the following sectors: agriculture, forest, and industry. Table 1 lists various types of lignocellulosic biomass with some examples. Agricultural wastes and forest residues are the most promising biomass feedstocks for their abundance and relatively low cost [5].

Traditional use of lignocellulosic biomass has been limited to burning for cooking and heating, which leads to significant negative environmental impacts such as land degradation and desertification [6]. By means of thermochemical or biochemical conversion routes, lignocellulosic biomass can be converted into energy or energy carriers. Thermochemical conversion uses heat and chemical processes to produce energy products from biomass, including combustion, pyrolysis, gasification, and liquefaction [7]. Biochemical conversion of biomass involves the use of bacteria, microorganisms or enzymes to breakdown biomass into gaseous or liquid fuels, such as biogas or bioethanol [8]. Typical biomass conversion technologies and their primary products and end-uses are illustrated in Fig. 1.

The whole biomass-to-biofuel process includes the logistics, pretreatment and conversion processes of lignocellulosic biomass [9]. The logistics process includes the collection, handling, storage and transportation of biomass feedstocks. The pretreatment process contains the drying, grinding and sieving of feedstocks. The conversion process includes feeding, conversion, separation of intermediate products, collection and upgrading and collection of products. The physicochemical properties of lignocellulosic biomass are essential data of reference for the design and implementation of these processes (Fig. 2). Table 2 lists the engineering application of these properties [10,11].

Many researchers have investigated the effect of the aforemen-

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Table 1
Lignocellulosic biomass feedstocks available for energy purposes.

Supply sector	Type	Examples
Agriculture	Lignocellulosic energy crops	Herbaceous crops (e.g. switchgrass, miscanthus, reed)
	Crop residues	Crop straw (e.g. rice straw, wheat straw, corn stalk, cotton stalk)
	Oil, sugar and starch energy crops	Rape seed; Sugarcane; Corn
Forest	Dedicated forestry	Short rotation plantations (e.g. willow, poplar, eucalyptus)
	Forestry by-products	Barks; Wood blocks; Wood chips from tops and branches; Wood chips from thinning; Logs from thinning
Industry	Lignocellulosic agro-industrial residues	Rice husk; Sugarcane bagasse; Corn cob
	Wood industry residues	Industrial waste wood; Sawdust from sawmills
Other	Lignocellulosic waste	Lignocellulosic residues from parks and gardens (e.g. prunings, grass)

tioned properties of lignocellulosic biomass on its conversion performance [11,12]. Several studies focus on the properties of biomass. Xu et al. [13] reviewed studies of biomass compositions and structures using infrared techniques and discussed the progress and prospects for the applications of those techniques. Lin et al. [14] addressed the relationship between biomass compositions and liquid products from biomass pyrolysis. Räisänen and Athanassiadis [15] presented the basic chemical compositions of three forest biomasses (pine, spruce and birch). Arnoult et al. [16] gave a review on miscanthus biomass production and composition for bioenergy use. Isikgor and Becer [17] summarized the cellulose, hemicellulose and lignin contents of various biomasses including hardwood, softwood, agricultural residues and grasses. Vassilev et al. [18] focused on the elemental compositions of biomass including the contents of C, O, H, N, Ca, K, Si, Mg, Al, S, Fe, P, Cl, Na, Mn, and Ti. Vassilev et al. [19] compared the advantages and disadvantages of compositions of biomass and coal and obtained that the disadvantages of biomass for biofuel prevail over the advantages, but the environmental, economic and social benefits appear to compensate the technological and other barriers. However, there remains no comprehensive compilation of various physicochemical properties of lignocellulosic biomass and the analytical characterization methods for those properties in literature. This review concentrates on the physicochemical properties of lignocellulosic biomass, the analytical characterization methods for those properties, and recent progress in understanding those physicochemical properties.

2. Basis of analysis

In research practice, there are four types of bases of analysis commonly used for expressing biomass analysis results, i.e., as received basis, air dried basis, dry basis, and dry ash free basis [20].

As received basis is the means of expressing an analytical result based on the total weight of sample as it arrived at the laboratory and prior to any pre-treatment.

Air dried basis is the means of expressing an analytical result based on the condition in which the sample is in equilibrium with atmospheric humidity. Air dried basis neglects the presence of moisture other than inherent moisture.

Dry basis is the means of expressing an analytical result based on the condition in which biomass is free from moisture. Dry basis leaves all moistures including external and inherent moistures.

Dry ash free basis is the means of expressing an analytical result based on a condition in which the sample is considered to be free from both all moistures and ash. This is frequently used in ultimate analysis to show the contents of elements in the organic fractions of the biomass sample.

Fig. 3 shows the components of biomass reporting to different bases of analysis.

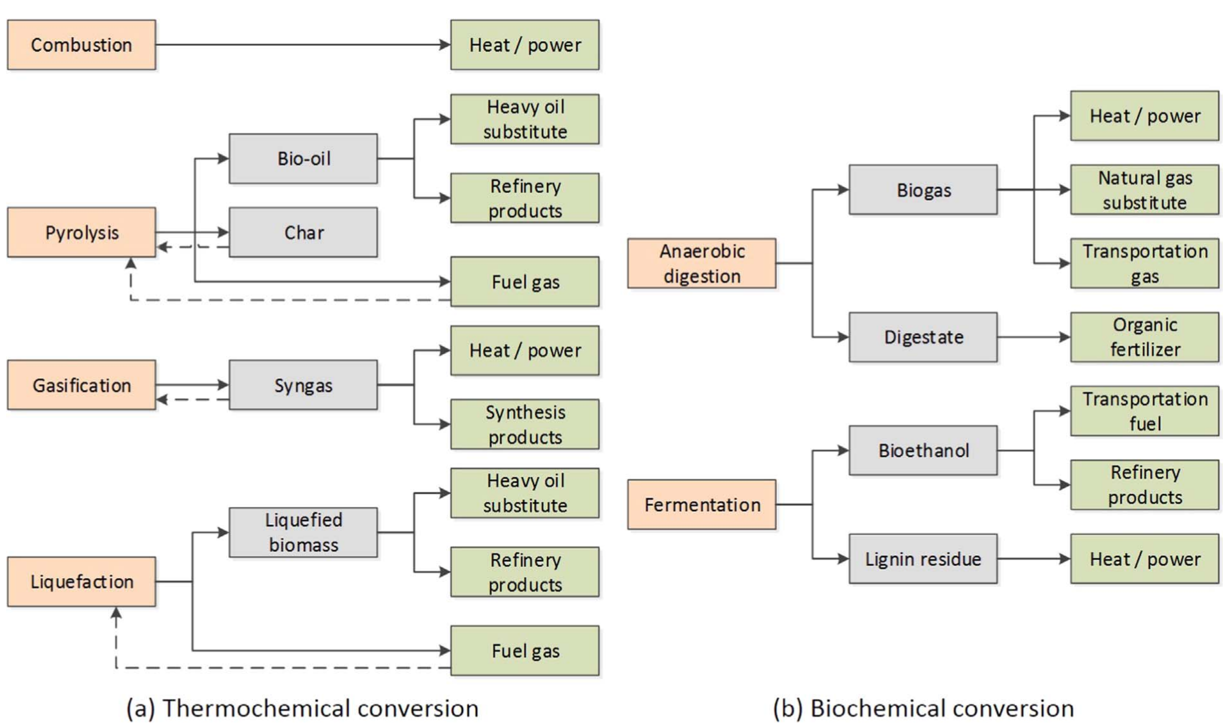

Fig. 1. Thermochemical and biochemical conversion of lignocellulosic biomass.