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Qualitative and quantitative analysis of lignocellulosic biomass using infrared techniques: A mini-review

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HIGHLIGHTS

▶ Infrared techniques are fast, accurate, and low-cost for biomass analysis.
▶ A comparison of infrared techniques and chemical method is made.
▶ Chemometric analysis provides prediction model for composition analysis.

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ABSTRACT

Current wet chemical methods for biomass composition analysis using two-step sulfuric acid hydrolysis are time-consuming, labor-intensive, and unable to provide structural information about biomass. Infrared techniques provide fast, low-cost analysis, are non-destructive, and have shown promising results. Chemometric analysis has allowed researchers to perform qualitative and quantitative study of biomass with both near-infrared and mid-infrared spectroscopy. This review summarizes the progress and applications of infrared techniques in biomass study, and compares the infrared and the wet chemical methods for composition analysis. In addition to reviewing recent studies of biomass structure and composition, we also discuss the progress and prospects for the applications of infrared techniques.

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1. Introduction

Lignocellulosic biomass has become an alternative source for production of chemicals and fuels because it is renewable and could reduce greenhouse gas emissions by replacing petroleum sources [1]. The major components of lignocellulosic biomass are cellulose, hemicellulose, and lignin. Cellulose and hemicellulose are polysaccharides, which could be hydrolyzed to molecules via a relatively low degree of polymerization for further biological/chemical utilization [2]. The next generation of cellulosic ethanol is being developed from these polysaccharides with microbial fermentation [3,4]. Lignin, a phenolic polymer, is also an important source for industrial applications such as adhesive resin [5,6] and lignin gels [7,8]. Lignin and cellulose are being developed for the synthesis of biodegradable polymers [9]. Biomass composition varies by variety and production location/conditions [10], which, in turn, significantly affects processing strategies. For example, alkali pretreatment is more effective with low lignin-content biomass [11]. Biomass composition also changes significantly during biomass processing [12], so a fast and accurate determination of biomass composition is critical for accelerating biomass utilization.

Classic wet chemical methods for biomass determination, which employ a two-step sulfuric acid hydrolysis, have been used for over a century, and improvements have adapted them to different objects and conditions [13,14]. The National Renewable Energy Laboratory also distributed a series of procedures for biomass determination that have become the de facto procedures for biomass application [15]. Standard wet chemical methods provide reliable information about biomass composition and have been proven to work well with both wood and herbaceous feedstock, but they are labor-intensive and time-consuming, which make them inappropriate for industrial applications or large numbers of samples; for example, a complete analysis using wet chemical methods costs $800–2000 per sample [16]. Recent developments in the wet chemical method include a small-scale, high-throughput method that is able to process a large number of samples in reduced time [17]. However, besides the additional costs of the instruments/devices (e.g., powder/liquid-dispensing system), these methods still need development because some components of biomass (e.g., acid-soluble lignin and ash) are not determined. Other disadvantages of the wet chemical methods are that they require pre-conditioning to remove extractives, and they generate reliable results only from samples within a certain range of particle size [18]. In addition, chemical methods are not able to differentiate among types of hemicellulose, such as xyloglucan and arabinoxylan [19]. Thus, a reliable low-cost, time-saving method is urgently needed for biomass analysis.

Infrared spectroscopy (IRS) has been widely used for qualitative and quantitative analysis in various areas such as the food and pharmaceutical industries [20–23]; for example, the composition of protein and oil in meat products, cereal crops, and food products was predicted successfully using near-infrared spectroscopy (NIRS) [24–26], as were Brix value and starch content in fruits [27]. The cost of analysis of grain materials using NIRS ($13 per sample) is lower than that using feed analysis (over $17 per sample) [28]. Infrared spectroscopy also has been proven able to produce qualitative and quantitative results for biomass application [16,29]; for example, Fourier transform infrared spectroscopy (FTIR) has been used successfully for compositional analysis of lignocellulosic biomass [30]. The main advantages of IRS technology are that sample preparation is simple, analysis is fast and precise, and many constituents can be analyzed at the same time. Thus, the cost of biomass sample analysis could be reduced to about $10 for each sample [16]. One exclusive characteristic of the IRS method is that it is non-destructive, so the sample could be used for other analysis after IRS measurement. IRS analysis also uses no hazardous chemicals. A comparison of IRS and wet chemical methods on biomass analysis is shown in Fig. 1. In addition to the determination of the major polysaccharides in biomass, IRS is capable of providing other structural information. Although numerous chemicals or reagents, such as enzymes and alkali, could be used to extract the polymeric components in plant cell walls, the complicated cross-linkages between the polymer chains may not be well elucidated by chemical extraction. The IRS techniques could be used for composition and structural analysis, such as detection of functional groups [31]. Only a few studies have been reported for the determination of biomass composition, because earlier IRS analysis suffered from blanket absorption of water [32], but the development of Fourier transform data processing and computer modeling could solve this problem.

To date, a critical review of IRS application on biomass analysis is not available. This review, in addition to summarizing the basic principle of IRS and the characterization of biomass, discusses the applications of IRS in biomass utilization.

2. Physical principles of IRS

Infrared spectroscopy is usually a result of the fundamental molecular vibration mechanism, which refers to energy-matter interaction [33]. Upon an interaction of the IR radiation with an oscillating dipole moment associated with a vibrating bond, the absorption of the radiation corresponds to a change of the dipole moment. Generally, different functional groups correspond to dif-

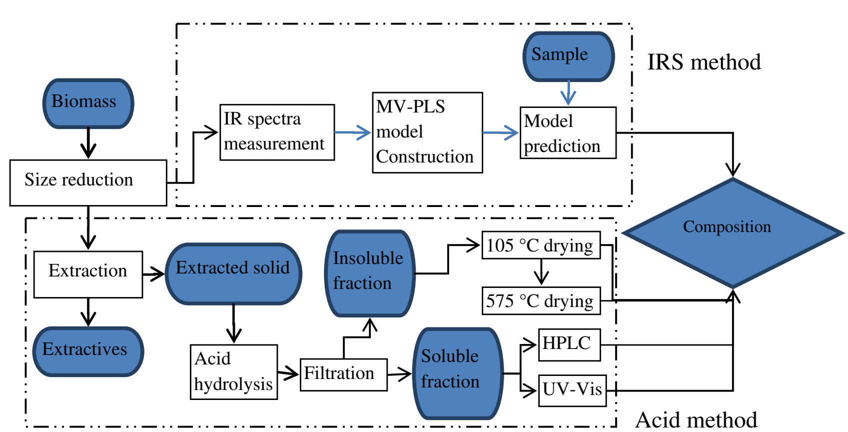

Fig. 1. Comparison of the compositional analysis methods for biomass. (IR: Infrared; MV-PLS: multivariate partial least squares regression; HPLC: high performance liquid chromatography; UV–Vis: ultraviolet–visible spectroscopy.).