Renewable and Sustainable Energy Reviews 60 (2016) 155–172

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

The world availability of non-wood lignocellulosic biomass for the production of cellulosic ethanol and potential pretreatments for the enhancement of enzymatic saccharification

Ying Ying Tye [a], Keat Teong Lee [b], Wan Nadiah Wan Abdullah [a], Cheu Peng Leh [a,*]

[a] School of Industrial Technology, Universiti Sains Malaysia, Minden, 11800 Penang, Malaysia
[b] School of Chemical Engineering, Universiti Sains Malaysia, Engineering Campus, Seri Ampang, 14300 Nibong Tebal, Penang, Malaysia

A R T I C L E I N F O

Article history:
Received 23 October 2014
Received in revised form
30 December 2015
Accepted 13 January 2016

Keywords:
Agricultural residues
Native plants
Non-wood plant fibres
Pretreatment
Second generation bioethanol
Glucose

A B S T R A C T

Non-wood lignocellulosic biomass is abundantly available, low cost, easy to process and consists of a short growth and harvest period; therefore, it is introduced as a potential feedstock biomass for bioethanol production. Common non-wood lignocellulosic biomasses are categorised into agricultural residues, native and non-wood plant fibres. The potential of non-wood lignocellulosic biomass as a resource for cellulosic ethanol production are determined and, analyzed in the context of their chemical composition, fibre production yield, total cellulose availability as well as the enzymatic saccharification efficiency after pretreatment. Based on the obtained data, agricultural residues show significant advantages in all contexts over other non-wood lignocellulosic biomasses. Moreover, pretreatment plays an important role in enhancing the enzymatic accessibility and hydrolysability of non-wood biomass. This review found that various pretreatments could be applied to enhance the enzymatic hydrolysability of different biomasses; however the major factors that vary the effectiveness of particular pretreatment on improving of different biomass hydrolysability have not been clearly highlighted. In addition, even though enzymatic saccharification of pretreated biomass is mainly highlighted in most of the cellulosic ethanol studies to evaluate the improvement of biomass hydrolysability, this data is unable to show the total glucose that obtained from the untreated biomass directly. In this study, the importance of total glucose yield is emphasized and it is calculated from various research data by multiplying the solid recovery yield by the enzymatic saccharification yield of the pretreated biomass, as it presents the percentage of the total glucose that could be converted directly from the original biomass. This work verifies that besides enzymatic saccharification yield, the solid recovery yield is also one of the major factors to be identified in cellulosic ethanol study.

Contents

* Corresponding author. Tel.: +60 4 6532147; fax: +60 4 6573678.
E-mail address: cpleh@usm.my (C.P. Leh).

http://dx.doi.org/10.1016/j.rser.2016.01.072
1364-0321/

1. Introduction

Renewable energy has become an important natural energy resource for reducing the total dependency on the rapidly depleting fossil-fuel resource. Biofuels such as bioethanol represent one of the potential renewable sources of energy that can replace fossil fuels and gasoline that are particularly utilised in the transportation sector. Generally, bioethanol is easily produced through the fermentation of starch (corn) or sugar (sugarcane) into ethanol. However, using starch- or sugar-based feedstocks for bioethanol production may give rise to a serious food versus fuel debate. Hence, this phenomenon will drive the amount of available food supplies down and food prices up as the demand for biofuel increases [1]. Current research and development has been focused on utilising lignocellulosic biomass for bioethanol production without causing a dispute between food and fuel supply.

Lignocellulosic biomass can be divided into wood and non-wood lignocellulosic biomass. Generally, wood lignocellulosic biomass often refers to hardwood and softwood, whereas non-wood lignocellulosic biomass is denoted as agricultural residues, native plants and non-wood plant fibres such as sugarcane bagasse, switchgrass and cotton fibre. The major differences between wood and non-wood lignocellulosic biomasses are their chemical compositions and physical properties [2]. Both materials have their own advantages and disadvantages. Nevertheless, in considering an environmental approach, non-wood lignocellulosic biomass is suggested for cellulosic ethanol production. Non-wood lignocellulosic biomass is widely being used for various applications, such as fillers in composite materials, absorbents and as pulp in papermaking. As non-wood lignocellulosic biomass has widespread valuable uses across industries, it indicates that these resources provide sufficient supply, which also verifies its potential use in various additional applications such as bioethanol production.

Usually, cellulose is required to be degraded chemically or enzymatically into glucose before fermentation take places. However, pretreatment prior to enzymatic hydrolysis is necessary, owing to the presence of recalcitrant polymers, in particular lignin, which probably hinder the enzymatic hydrolysis process [3,4]. Therefore, the main objective of the present review article is to discuss the availability of non-wood lignocellulosic biomass around the world and its potential in bioethanol production, particularly in terms of its fibre production yield and chemical composition, as it has yet to be reviewed in any study. Moreover, important information for evaluating the pretreatment performance on this fibre for bioethanol production is also studied.

2. Feedstock for bioethanol production

Bioethanol can be produced from sugar or starchy materials as well as lignocellulosic biomass. Conventional feedstock resources such as sugarcane and corn are widely being used for ethanol production, especially in Brazil and the United States, respectively. However, plantation crops that used to produce bioethanol actually create an environmental issue, particularly pollution from the farming materials and practices. Therefore, an increase in the number of plantations substantially increases the amount of pesticides and fertilisers used. Furthermore, as the demand for biofuels increases, some food crops are used for fuel production, forcing a decrease in food supplies and, subsequently, causing an increase in food prices. According to the Unites States Department of Economic and Social Affairs, from a world population of 7.2 billion in the middle of 2013, it is projected to increase by 1 billion people within the subsequent 12 years, reaching 8.1 billion by 2025. It is estimated that the world population might further increase to 9.6 billion by 2050 [5]. Owing to the increasing world population, the demands for crop production are rising. Therefore, more than a 60% increment in global agricultural production is required by 2050 in order to keep up with the population growth and to provide food security. However, current research shows that, based on the four most important food crops (maize, rice, soybean and wheat), production only increases by about 0.9–1.6% per annum. At this rate, it is believed that the production of these crops is likely to increase by 38–67% by 2050, which is lower than the estimated requirement [6].

Moreover, the production cost of bioethanol from food crops is very high, of which the raw materials (maize or sugar cane) constitute about 40–70% of the production cost. As a result, promoting the use of second-generation bioethanol from lignocellulosic biomasses such as non-food crops, crop residues and food/crop waste is an alternative way to alleviate the land use conflict between food needs and fuel needs. In Brazil, sugarcane is chosen as a feedstock to produce bioethanol. Presently, Brazil has more than 80% of its vehicles running with bioethanol. To overcome the huge demand of its ethanol-vehicle fleets, Soccol et al. [7] reported that the conversion of polysaccharides from sugarcane bagasse, leaves and straws could increase ethanol production, because about two-thirds of the sugarcane plantation consists of sugarcane residues. Similar studies have stated that in the United States, corn stover is the potential feedstock that could reduce dependence on corn crops for ethanol production [8,9].

3. Second-generation bioethanol from lignocellulosic biomass

The term of “lignocellulosic” comes from cellulose that is linked to lignin in the plant cell wall, and “biomass” is more often