Applied Energy 142 (2015) 240–246

Contents lists available at ScienceDirect

Applied Energy

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

Mechanical dissociation and fragmentation of lignocellulosic biomass: Effect of initial moisture, biochemical and structural proprieties on energy requirement

Abdellatif Barakat [a,*], Florian Monlau [a,b], Abderrahim Solhy [c], Hélène Carrere [b]

[a] INRA, UMR 1208, Ingénierie des Agropolymères et Technologies Emergentes (IATE), 2 Place Pierre Viala, Montpellier cedex 1 F-34060, France
[b] INRA, UR0050, Laboratoire de Biotechnologie de l'Environnement, Avenue des Etangs, Narbonne F-11100, France
[c] Université Mohammed VI Polytechnique, Lot 660 – Hay Moulay Rachid, 43150 Ben Guerir, Morocco

HIGHLIGHTS

- Mechanical dissociation and fragmentation of lignocellulosic biomass.
- Specific Energy Requirement (SER) and particle size.
- Effect of initial moisture on SER.
- Impact of biochemical and structural proprieties on SER.

ARTICLE INFO

Article history:
Received 3 July 2014
Received in revised form 9 December 2014
Accepted 26 December 2014
Available online 16 January 2015

Keywords:
Biomass
Mechanical pretreatment
Energy
Milling
Physicochemical features
Multivariate regression

ABSTRACT

Mechanical size reduction is considered as a primordial step of current and future lignocellulosic biorefinery. In this sense, it is of high interest to understand who are the biochemical and structural features of the lignocellulosic biomass, which affect the Specific Energy Requirement (SER), and in consequence the cost of mechanical size reduction processes. First, it was shown that the initial moisture content of the lignocellulosic biomass affect the SER and the final particle size distribution. The highest the moisture content gives raise the highest SER. Then, at fixed initial moisture content (≈7% DW), structural and biochemical features of lignocellulosic biomass that can affect the SER were determined. It was noticed that both arabinose/xylose ratio and accessible surface area lead to increasing the SER. On the contrary, the content of cellulose, lignin, crystallinity and *p*-coumaric acids links were found to have a positive effect on the reduction of the SER.

1. Introduction

The lignocellulosic biorefinery has attracted recently a lot of attention to produce chemicals and biofuels as an alternative to fossil fuels [1,2]. However, major challenges such as feedstock cost, production, transportation, preprocessing along with development of new technologies with increased efficiency of lignocellulosic conversion are critical to successful large-scale implementation of biomass biofuels production [3–9]. However, the lignocellulosic plant cell walls consist mainly of cellulose, hemicelluloses and lignin. The cellulose polymers consist of D-glucose subunits, linked by β-(1 → 4) glycosidic bonds, which contain crystalline and amorphous parts. The hemicelluloses are branched polymers with short lateral chains built up of different sugar monomers mainly xylose and arabinose. Hemicelluloses serve as a connection between the lignin and the cellulose fibers and give cohesion to the whole cellulose–hemicellulose–lignin network [10–13]. Then, the lignin is an amorphous heteropolymer, which is consisted of an assembly of three different phenylpropane alcohols such as *p*-coumaryl (H), coniferyl (G) and sinapyl (S) residues [10–13]. It should be noticed that the major interunit linkage of these monomers is aryl–aryl ether type (β-O-4). These polymers exist together with small amount of other components, like acetyl groups, mineral

Abbreviations: LS, lignocellulosic substrates; Ext, extractives; VS, volatile solids; Cell, cellulose; Hem, hemicelluloses; UA, uronic acids; A/X, arabinose/xylose ratio; Lig, lignin; S, Syringyl units; G, Guïacyl units; H, Hydroxycinnamic units; p-CA, p-coumaric acid; CrI, crystallinity index; SA, surface area; VP, volume pore; SER, Specific Energy Requirement; DW, dry weight.

* Corresponding author. Tel.: +33 (0) 499612581.
E-mail address: barakat@supagro.inra.fr (A. Barakat).

http://dx.doi.org/10.1016/j.apenergy.2014.12.076
0306-2619/

and phenolic substituents. They are organized in complex three-dimensional structures that are neither uniform nor completely described for different plants [10,13,14]. The composition in term of major compounds (i.e. cellulose, hemicellulose, lignin) is different for various plant fractions and development stages, as well as for different types of plant cell wall. The bioconversion of lignocellulosic materials is dependent not only on the biochemical composition of the matrix but also on the tissues and cell wall organization and of their constituents and the interaction between them [11,14–16]. Thus, the information about the composition and organization of plant cell walls is of vital importance to understand the mechanisms of mechanical conversion and further to optimize the utilization of lignocellulosic materials [2,10,11]. The breakdown or mechanical size reduction of lignocelluloses is a necessary step within biofuels production processes and presents the advantages of being environmentally friendly as chemical catalysts are not required (Fig. 1) [4]. Furthermore, mechanical pretreatments present also the interest of avoiding byproducts generation (i.e. furfural, 5-HMF, phenolic compounds...) that can further inhibit the fermentative process [17].

Mechanical treatment process or size reduction leads to the rupture of plant cell walls and the dissociation of tissues (epidermal, parenchymatous and vessel tissue). It allows the separation of the main botanical parts of the crop into different fractions, which can be used as feedstock for various applications [4,18]. Thus, mechanical fractionation of lignocellulosic biomass is one promising routes that can contribute to a future sustainable dry biorefinery without water consumption and without waste production. The most important factors to be considered when lignocellulosic biomass is pretreated by mechanical fractionation are the type of biomass and energy requirement, moisture content, and final particle size and separation and/or modification degree of organs, tissues and polymers. A large number of mechanical pretreatments have been developed so far by using milling or grinding machines such as vibro-balls, hammers, knifes, balls, colloids as well as extruders [2,19–36]. Some mechanical pretreatments are known to be effective; however, these methods have some disadvantages in terms of Specific Energy Requirement (SER) corresponding to the energy demand. The SER of mechanical size reduction has been studied intensively for the last ten years. Nevertheless, SER of mechanical fractionation or mechanical size reduction is still poorly understood because of concomitant effects such as biochemical and physical properties of the substrate, supramolecular organization of biopolymers cell wall and tissues. The structural heterogeneity and complexity of cell wall constituents and tissues association are some reasons causing the high-SER of mechanical pretreatment or size reduction. In addition, earlier studies investigating the influence of structural features on SER of mechanical size reduction have been limited to the measurement of the effect of moisture content. Some works reported that, the higher the moisture content, the higher SER [2]. It can be explained by the fact that an increase in moisture content of straw samples initially increases the shear strength of the material, although, thereafter shear strength rapidly decreases with

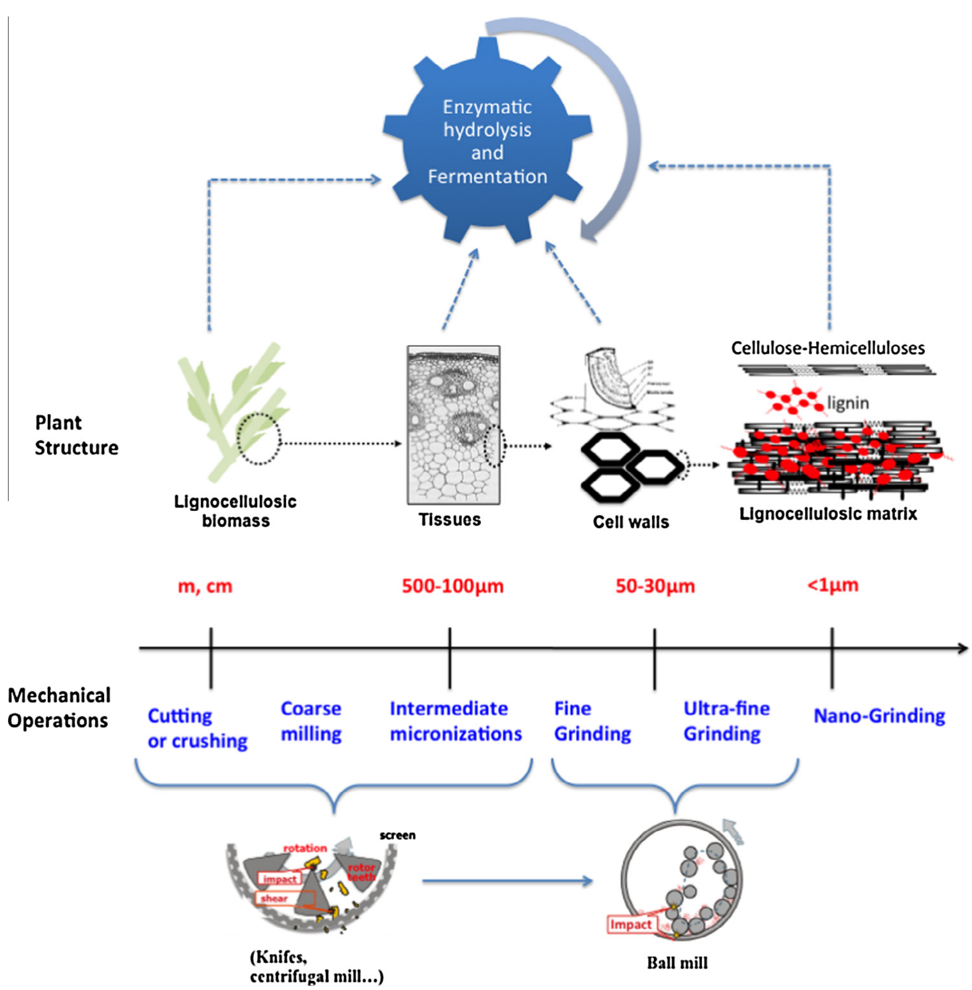

Fig. 1. Mechanical fragmentation and dissociation of lignocellulosic biomass at various plant scales.