Bioresource Technology 181 (2015) 200–206

Contents lists available at ScienceDirect

Bioresource Technology

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

One-Pot dry chemo-mechanical deconstruction for bioethanol production from sugarcane bagasse

C. Sambusiti [a], A. Licari [a], A. Solhy [b], A. Aboulkas [c], T. Cacciaguerra [d], A. Barakat [a,*]

[a] INRA, UMR 1208, Ingénierie des Agropolymères et Technologies Emergentes (IATE), 2, Place Pierre Viala, 34060 Montpellier cedex1, France
[b] Université Mohammed VI Polytechnique, Lot 660 – Hay Moulay Rachid, 43150 Ben Guerir, Morocco
[c] Laboratoire Interdisciplinaire de Recherche en Sciences et Techniques, Faculté Polydisciplinaire de Béni-Mellal, Université Sultan Moulay Slimane, BP 592, 23000 Béni-Mellal, Morocco
[d] Institut Charles Gerhardt de Montpellier- MACS UMR 5253 8, rue de l'Ecole Normale, 34296 Montpellier Cedex 5, France

HIGHLIGHTS

- Vibratory (VBM), centrifugal (CM) and ball (BM) milling pretreatments were compared.
- VBM was most effective in the reduction of particle size and cellulose crystallinity.
- NaOH-BM and NaOH-VBM were preferred to enhance glucose and bioethanol yields.
- The highest energy efficiency was obtained with NaOH-CM.
- Dry NaOH-CM pretreatment appears the most suitable for bioethanol production from SB.

ARTICLE INFO

Article history:
Received 2 December 2014
Received in revised form 12 January 2015
Accepted 13 January 2015
Available online 21 January 2015

Keywords:
Bagasse
Pretreatment
Chemical
Mechanical
Energy efficiency

ABSTRACT

The aim of this study was the application of an innovative dry chemo-mechanical pretreatment using different mechanical stresses to produce bioethanol from sugarcane bagasse (SB). The effect of different milling methods on physicochemical composition, enzymatic hydrolysis, bioethanol production and energy efficiency was also evaluated. SB was pretreated with NaOH and H_3PO_4 at high materials concentration (5 kg/L). Results indicate that vibratory milling (VBM) was more effective in the reduction of particles size and cellulose crystallinity compared to centrifugal (CM) and ball (BM) milling. NaOH pretreatment coupling to BM and VBM was preferred to enhance glucose yields and bioethanol production, while CM consumed less energy compared to BM and VBM. Moreover, the highest energy efficiency (η = 0.116 $kg_{glucose}$/kWh) was obtained with NaOH–CM. Therefore, the combination of dry NaOH and CM appears the most suitable and interesting pretreatment for the production of bioethanol from SB.

1. Introduction

Face to the inevitable depletion and negative environmental impact of fossil fuels, almost all countries worldwide address the use of renewable energies, specially the liquid biofuels (i.e. ethanol and biodiesel) and gaseous fuels (i.e. methane, biohydrogen and syngas).

Among the various agricultural and industrial residues, sugarcane bagasse (SB), a fibrous residue generated during the extraction of cane juice in mills, is a suitable substrate for bioethanol production, mainly due to its abundance, non-competitiveness with food/feed requirements, ease to be transported, and richness in carbohydrates (Chandel et al., 2012).

This adds to the fact that, in tropical countries (i.e. China, India and Brazil), more than 500 Mt of bagasse are generated as by-product every year. Generally, approximately a half of bagasse is burnt to generate heat and power for plant operation, and the remaining fraction is unused (Pandey et al., 2000; Shi et al., 2012). It is nevertheless certain that the suitability of producing bioethanol from bagasse derives from its high carbohydrates content, which constitutes around 70–80% of the overall chemical composition. Indeed, bagasse is mainly composed of cellulose (40–45%), hemicelluloses (30–35%), and lignin (20–30%), with a minor amount of extractives and inorganic compounds (Vallejos et al., 2012).

However, the presence of crystalline cellulose nano-fibrils, embedded in an amorphous matrix of cross-linked lignin and hemicelluloses, limits the microbial and enzymatic accessibility to cellulose. For this reason, the key driver for the successful conversion of bagasse into bioethanol is the selection of efficient pretreatments that permit to maximize the sugars recovery and

* Corresponding author. Tel.: +33 (4) 99 61 25 81; fax: +33 (4) 99 61 23 93.
E-mail address: Abdellatif.barakat@supagro.inra.fr (A. Barakat).

http://dx.doi.org/10.1016/j.biortech.2015.01.058
0960-8524/

to minimize their degradation with the consequent formation of toxic derivatives (i.e. furan compounds) (Monlau et al., 2014).

In the last few years, several physicochemical pretreatments have been developed and applied to lignocellulosic biomass (i.e. sugarcane bagasse) for this purpose, including diluted acid, steam and ammonia fiber explosion, hydrothermal, peroxidation, alkaline, organosolv, ionizing radiation, ultrasound and microwave radiation (Barakat et al., 2013, 2014a; Da Silva et al., 2010; Biswas et al., 2014; Yu et al., 2013). However, although most of them are known to be effective in hydrolyzed the matrix and enhancing sugars recovery, they are energy consuming and not always cost effective. Some authors consider that the lignocellulosic pretreatment is among the most costly steps in the biochemical conversion of lignocellulosic biomass. For instance, Aden and Foust (2009) stated that pretreatment accounts for more than 16–19% of the total equipment cost of a lignocellulosic biorefinery, which includes (1) the feedstock or raw material cost, (2) the capital equipment (upfront investment) costs, and (3) operating costs, including utilities and chemicals/water consumed (Dale and Ong, 2012). Another important aspect to take into account is related to the environmental impact of pretreatment, caused by the use of high quantity of water and chemicals that generate large amount of waste streams, even toxic for the environment.

Thus, in recent years, some authors proposed innovative dry chemo-mechanical pretreatments to reduce water consumption and maximize the energy saving, overcoming the high operational costs of many physical–chemical pretreatments (Barakat et al., 2013, 2014a). In a recent study, Barakat et al. (2014b) proposed an eco-friendly dry chemo-mechanical pretreatment in order to enhance enzymatic hydrolysis of wheat straw, saving energy consumption and without producing of the waste streams.

In this context, the aim of the study was the application of an innovative dry chemo-mechanical pretreatment to produce bioethanol from sugarcane bagasse. To this purpose, different milling methods were compared, evaluating their effects on physicochemical composition, enzymatic hydrolysis, bioethanol production and energy efficiency (Fig. 1).

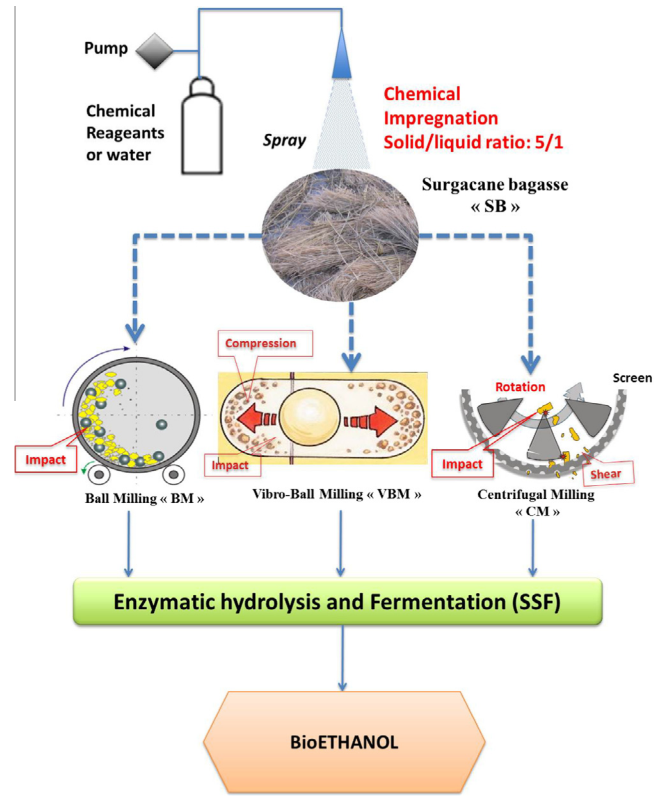

Fig. 1. One-Pot dry chemo-mechanical deconstruction of sugarcane bagasse (SB) for bioethanol production.

2. Methods

2.1. Sugarcane bagasse

Sugarcane bagasse (SB) was generously provided by COSUMAR (Company located in Morocco, and which monopolizes the sugar industry). SB was air dried to a moisture content of 8–10%, and then coarsely cut to lower than 2 mm by a knife mill (Retsch SM 100, Haan, Germany). Total solids (TS) and ash content were determined according to the APHA standard method (APHA, 2005). The milled SB was then treated chemically and mechanically using different milling equipment, as described below.

2.2. "Dry" chemical pretreatment

Sodium hydroxide (NaOH) and phosphoric acid (H_3PO_4) were dissolved in distilled water to adjust the chemical concentration at 10% w/w (10 g of catalyst/100 g of SB). The acidic and alkaline solutions were made with the amount of water required to adjust the moisture content to 30% (dry basis), equivalent to a biomass/liquid ratio of 5/1. A control sample was also set up by treating biomass with distilled water instead of chemicals.

2.3. Mechanical fractionation

The untreated and chemically pretreated SB samples (milled to a particle size lower than 2 mm) were fractionated using different milling equipment characterized by different mechanical stresses such as impact, compression, friction, and shear (Fig. 1). For this reason, different apparatus were used in this study: (i) a centrifugal mill "CM-0.12 mm" (Retsch ZM 200, Haan, Germany) with 0.12 mm screen size (the material was milled until it passed through the grid), operated at ambient temperature with a speed of 12,000 rpm and a feed rate of 6.7 gTS/min; (ii) A ball mill "BM-24 h" operated at ambient temperature with a speed of 50 rpm for 24 h, (iii) a vibratory ball mill "VBM-1 h" (Retsch MM400, Haan, Germany) operated also at ambient temperature at a frequency of 15 s^{-1} for 1 h. The particle size was analyzed by a laser granulometry (Mastersizer 2000, Malvern Instrument, Orsay, France) and the energy consumed by the milling apparatus was also measured.

2.4. Crystallinity analysis

The crystallinity of different SB fractions was determined by X-ray diffraction. Powder X-ray diffraction patterns were recorded on a Bruker diffractometer D8 Advance (Bruker corporation, Germany). The measurements were conducted on powder compacted on small mats. DRX data were collected from $2\theta = 5–50°$ with a step interval of 0.02°. The degree of crystallinity can be expressed as the percentage crystallinity index (Barakat et al., 2014a,b). It is noteworthy that all determinations were performed in duplicate.

2.5. Surface area and porosity measurement

The gas adsorption data were collected using a 3Flex Surface characterization analyzer using N_2 (Micromeritics, Verneuil en Halatte, France). Prior to N_2 sorption, all samples were degassed at 50 °C overnight. The specific surface areas were determined from the nitrogen adsorption/desorption isotherms (at −196 °C),