Industrial Crops & Products 115 (2018) 330–339

Contents lists available at ScienceDirect

Industrial Crops & Products

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

Extraction and isolation methods for lignin separation from sugarcane bagasse: A review

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ARTICLE INFO

Keywords:
Lignin of sugarcane bagasse
Sugarcane bagasse
Ionic liquid methods
Alkaline pulping methods
Alkaline dioxane extraction methods

ABSTRACT

This paper intends to review different extraction and isolation methods recently explored for lignin separation from sugarcane (*Saccharum officinarum* L.) bagasse. Initial bagasse processing is a pre-treatment mechanical action (milling) that facilitates applying further conversion technologies. There are several methods that have been developed for the extraction and isolation of the solubilized lignin from sugarcane bagasse; these include alkaline and ionic liquid methods. The insoluble lignin can be separated by the treatment of concentrated sulfuric acid. The quantity of sugarcane lignin fraction depends on the techniques applied and the aim of studies, but it has a range of 17–32% of biomass while the average value is about 23% of biomass. This fraction value has a major content in non-wood biomass and it is rich with aromatic chemical compounds.

1. Introduction

The lignin (*lignum*) means wood and it is a component of lignocellulose which consists also of cellulose and hemicellulose. This material is a natural complex biopolymer structure of carbohydrates.

An increased interest has been noted recently in the extraction of lignin from non-wood biomass such as, sugarcane, wheat (*Triticum aestivum*) straw, bamboo (*Bambusa vulgaris*), alfalfa (*Medicago sativa*), kenaf (*Hibiscus cannabinus*) and flax (*Linum usitatissimum*) fiber (Río et al., 2004; Ververis et al., 2004; Zhang et al., 2013). The focus of this paper is concentrated only on the sugarcane bagasse as biomass raw material of lignin source. This waste fiber is considered as the amount of remaining material after milling in sugar manufacturing or as residues in-land after harvests. It consists of two types of herbaceous plant fibers: rind and pith, which are longer than hardwood fibers and shorter than softwood fibers (Arni and Converti, 2012). All factories that are producing sugar from sugarcane have amount residues of this waste fiber, and typically produced about 30% of bagasse. It contains about 10–15% sucrose and 12–16% fiber (Arni and Converti, 2012). This biomaterial has a certain value, especially because of its sustainable and its economic interest for production fine chemical from renewable resource.

Today, there are a lot of bagasse applications; a search in literature data shows a number of studies have been done on sugarcane bagasse use and its application (Sene et al., 2001; Arni, 2004a,b; Zilli et al., 2004; Junior et al., 2006; Doherty et al., 2007; Boussarsar et al., 2009; Griffin, 2011; Cunha et al., 2011; Rocha et al., 2015a,b; Wahba et al., 2015; Costa et al., 2017). There are different levels for the reuse of bagasse as a raw material starting from domestic to commercial use. It is used to cultivate edible mushrooms, such as shiitake (*Lentinula edodes* (Berk.)) (Arni and Converti, 2012), also it is used as fertilizers (Espinoza-Acosta et al., 2014). The sugarcane bagasse is used in industry to produce power as a fuel to generate electricity (Deepchand, 2005), to make paper (Poopak and Reza, 2012), in building materials (Loh et al., 2013) and feedstock to different products based on fermentation for the production of bio-based materials (Carvalho et al., 2002a,b; Carvalho et al., 2004; Carvalho et al., 2005; Converti et al., 2003; Santos et al., 2003; Santos et al., 2005a,b; Moldes et al., 2006; Sarrouh et al., 2007; Cunha et al., 2006,2009; Capecchia et al., 2015). Bagasse also used as biosorbents for the removal of heavy metals ions such as Cd, Cu, Pb, Zn, Ni and Cr (VI) ions (Junior et al., 2006), also for oil absorbing in the absence of water (Said et al., 2009). The summary of usage of bagasse is presented in Fig. 1.

The main focus of the present paper is the delignification processes that employed in the treatment of sugarcane bagasse to extract and isolate lignin fraction.

2. Processes for decomposition of lignocellulosic materials

Technologies used for bagasse decomposition are the same used in agricultural waste biomass decomposition. Usually, the decomposition processes depend on the ending goal of treatment, biomass type and quantity. Many researchers have established various processing techniques that can be used to convert these materials into various new products (Sun et al., 2000; Lavarack et al., 2002; Ou et al., 2009; Laopaiboon et al., 2010; Li and Ge, 2011; Rocha et al., 2011, 2012, 2015a).

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https://doi.org/10.1016/j.indcrop.2018.02.012
Received 29 May 2017; Received in revised form 2 February 2018; Accepted 4 February 2018
Available online 23 February 2018
0926-6690/

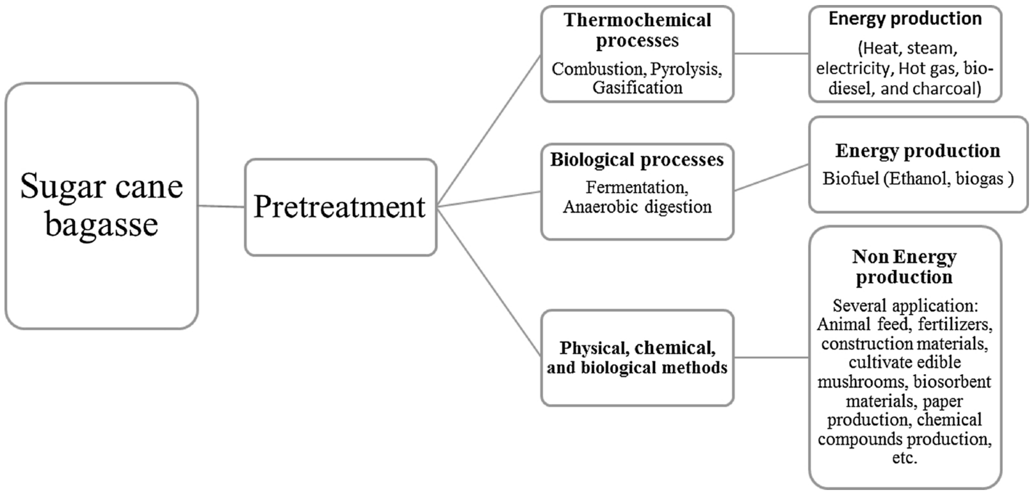

Fig. 1. Schematic diagram of processing and potential uses of bagasse.

There are two general categories of technologies for conversion of bagasse, firstly, the processing for conversion into energy products and secondly, processing for conversion into non energy products. Fig. 1 gives a general overview of processes and potential uses of sugarcane bagasse.

Processing of energy products aims to produce power in its different forms, such as, heat and steam, electricity, synthetic fuel oil, charcoal, producer gas, methane, ethanol, methanol and bio-diesel. The main conversion processes to energy products are thermochemical processes, such as, combustion, pyrolysis, and gasification. The most frequent using of sugarcane bagasse for energy production is the direct combustion (process based on solid-state) which consumed on-site (Mullinger and Jenkins, 2008; Arni et al., 2010c).

The biological processes to convert bagasse into energy are based on fermentation processes to produce ethanol, and Anaerobic Digestion (AD) to produce biogas (Converti and Del Borghi, 1996; Converti, 1998; Converti et al., 1998, 1999). Saxena et al. (2009) presented a review article on various biochemical processes for conversion of biomass into biological hydrogen gas and ethanol.

Biological pretreatment is sometimes used in combination with chemical treatment to solubilize lignin in order to make cellulose more accessible to hydrolysis and fermentation. Different microorganisms are able to partially or completely degrade biomass which is described elsewhere (Pandey et al., 2000). In addition, for lignin depolymerization can be performed by fungal as bio-catalytic to lignin degradation. This process can be also done by certain bacteria or consortia bacteria (Cho et al., 2004). Jääskeläinen et al. (2003) found a high yield (83%) of lignin by enzymatic hydrolysis.

On the other hand, there are a variety of methods that can be used to convert bagasse into non energy products, such as physical methods, chemical methods, mechanical extraction methods and biological methods. The selection of the adequate process of treatment depends on the final goal of treatment.

The physical and chemical pretreatment methods may be used to break down biomass components. The physical pretreatment refers to reduce the size of raw material by mechanical actions to make it accessible into successive treatment such as biological and/or chemical treatment.

The major techniques employed to break down biomass components are based on the hydrolysis method. This method, which is sometimes called saccharification, that is used to break down the hydrogen bonds in the lignocellulosic biomass fractions by removal of the surrounding hemicellulose and/or lignin along with modification of the cellulose microfibril structure and recovering the resulting soluble monomeric and/or oligomeric sugars (Motaung and Anandjiwala, 2015; Rocha et al., 2015b).

The steam explosion is a physical pretreatment method that is used for cellulosic materials pretreatment to the solubilization and separation of one or more of the four major components of biomass (hemicellulose, cellulose, lignin, and extractives). During this process, steam permeates the biomass material and initiates a chemical autohydrolysis reaction, because some organic acids that are presented in biomass can be catalyzed and help remove of the hemicellulose and lignin from their biomass structure (Pol et al., 2015). This phenomenon is observed during the steam processes, such as the formation of acetyl groups (Rocha et al., 2015a,b). Sometimes, chemicals, such as sulfuric acid, can be added to improve efficiency of the process (Rocha et al., 2015b). On the other hand, the most common chemical pretreatment methods make use of dilute acid, alkaline, organic solvent, ammonia, sulphur dioxide, carbon dioxide or other chemicals to make the biomass more adequate for further applications (Motaung and Anandjiwala, 2015).

Rocha et al. (2015a), in their investigation of 60 sugarcane samples, presented ratios of mass fractions of lignin extracted from sugarcane bagasse which are determined by pretreatment of concentration sulfuric acid method. These ratios are 7.4/1 (total lignin/soluble lignin), 1.2/1 (total lignin/insoluble lignin) and 0.2/1 (soluble lignin/insoluble lignin). This means that the extraction of lignin need successive treatment, because the major of lignin is insoluble. On the other hand, the acid method is not adequate to treat lignin, but it can treat hemicellulose effectively (Lavarack et al., 2002; Fogel et al., 2005; Geddes et al., 2010; Rocha et al., 2011).

The alkaline hydrolysis process is a breakdown of the intermolecular ester bonds cross-linking with lignin and other material components as celluloses and hemicelluloses. It is more effective to solubilize a greater fraction of lignin (Mosier et al., 2005; Rocha et al., 2012). Rocha et al. (2012) demonstrated that the steam explosion and alkaline delignification processes are good for extraction of lignin from bagasse.

3. Extraction and isolation of lignin from sugarcane bagasse

Establishing and selecting a method for isolation and recovery of lignin from non-wood biomass such as bagasse is not an easy task. However, there are several methods that are recently developed to extract and isolate the lignin from sugarcane bagasse, such as alkaline method (Li and Ge, 2011; Moubarik et al., 2013; Wahba et al., 2015), and ionic liquid (Tan and MacFarlane, 2009; Tan et al., 2009).

3.1. Alkaline methods

In this section, a briefing of some extraction and isolation of solubilized lignin from sugarcane bagasse methods, is presented (Wahba et al., 2015; Moubarik et al., 2013).