Industrial Crops and Products 67 (2015) 239–248

Contents lists available at ScienceDirect

Industrial Crops and Products

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

Bio-catalytic action of twin-screw extruder enzymatic hydrolysis on the deconstruction of annual plant material: Case of sweet corn co-products

Virginie Vandenbossche[a,b,*], Julien Brault[a,b], Gérard Vilarem[a,b], Luc Rigal[a,b]

[a] *Université de Toulouse, INP, Laboratoire de Chimie Agro-Industrielle, ENSIACET, 4 Allée Emile Monso, BP 44362, 31030 Toulouse Cedex 4, France*
[b] *INRA, Laboratoire de Chimie Agro-Industrielle, 31030 Toulouse Cedex 4, France*

ARTICLE INFO

Article history:
Received 12 September 2014
Received in revised form
18 December 2014
Accepted 21 January 2015
Available online 6 February 2015

Keywords:
Sweet corn co-product
Twin-screw extruder
Enzymatic hydrolysis
Bioextrusion
Alkaline pre-treatment

ABSTRACT

A continuous process combining an alkaline thermo-mechano-chemical pretreatment neutralization step, followed by injection of enzymes into the twin-screw extruder, was developed using sweet corn co-products as a biomass model. The implementation of the continuous process is described. Particular attention is paid to the influence of the bio-catalytic action of enzymatic hydrolysis on the deconstruction of annual plant material in the twin-screw extruder (a process called “bioextrusion”). The use of a twin-screw extruder allows working with high consistency (20%), in a high shear environment, for a short time (~2 min). In the present work, the nature of the ligno(hemi)cellulosic material transformations, covering solubilization and extraction of saccharides and modification of cellulosic fibers, were investigated. 41% of hemicelluloses and 14% of lignin are extracted by the alkaline pretreatment. Hydrolytic enzymes are not deactivated during bioextrusion, which has a destructing effect on the fiber. It leads to a change of rheological properties and induces an increase of sugars released in the form of mono and polysaccharides (up to 13%/DM of total sugars) with longer chains than in the case of a batch reactor. At the same time, the degree of polymerization decreases and a shortening of the cellulose chains occurs.

1. Introduction

The lignocellulosic materials from agriculture and forest by-products represent an important source of renewable and carbon-neutral energy. These resources are clean, cheap, available in large quantities, and are independent of geographical location, plus they are carbon neutral and renewable. However, the lignocellulosic biomass is a complex assembly of cellulose, hemicelluloses and lignin whose extraction and conversion requires the use of a refining process (Himmel et al., 2007).

These transformation processes are actually studied worldwide and many reviews exist on the subject (Van Dyk and Pletschke 2012). They are typically realized in two steps: one of pretreatment intended to improve the accessibility of the cellulose and a second allowing hydrolysis of the cellulose by enzymatic action. Sun and Cheng, 2002, Mosier et al. (2005), Zheng et al. (2009), Harmsen et al. (2010) and Alvira et al. (2010) have reviewed pre-treatment technologies for a bioethanol production process based on enzymatic hydrolysis. Most cited pretreatments, among which dilute acid pretreatment (Saha et al., 2005), steam explosion (Oliva et al., 2003; Cara et al., 2006; Varga et al., 2004; Ballesteros et al., 2006) and ammonia fiber explosion (Galbe and Zacchi, 2007) are the most well known, are penalized by implementation constraints, technology or reagent costs, or inhibitor production for enzymatic hydrolysis or ethanolic fermentation.

Soft alkaline pretreatment is one approach that has several potential advantages compared to other pretreatment processes, including lower operating cost, reduced degradation of holocellulose, and subsequent formation of inhibitors for downstream processing (Carvalheiro et al., 2008; Kumar et al., 2009; McIntosh and Vancov, 2011; Taherzadeh and Karimi, 2008). The main mechanisms of soft alkaline pretreatment are hydroxyl group solvation, leading to the rupture of intra or inter molecular hydrogen bonds, and the breakdown of ester bonds with cleavage of linkages in the lignocellulosic cell wall matrix, all of which lead to the alteration of the lignin structure, the hydrolysis of the lignin–hemicellulose complex, cellulose swelling, and the partial decrystallization of the cellulose (Bobleter, 1994; Sun and Cheng, 2002).

A way to improve process costs is to increase the solid concentration of biomass in each unit operation. Such high solid

---

* Corresponding author at: Université de Toulouse, INP, Laboratoire de Chimie Agro-Industrielle, ENSIACET, 4 Allée Emile Monso, BP 44362, 31030 Toulouse Cedex 4, France. Tel.: +33 5 34 32 35 49; fax: +33 5 34 32 35 99.
E-mail address: Virginie.Vandenbossche@ensiacet.fr (V. Vandenbossche).

http://dx.doi.org/10.1016/j.indcrop.2015.01.041
0926-6690/

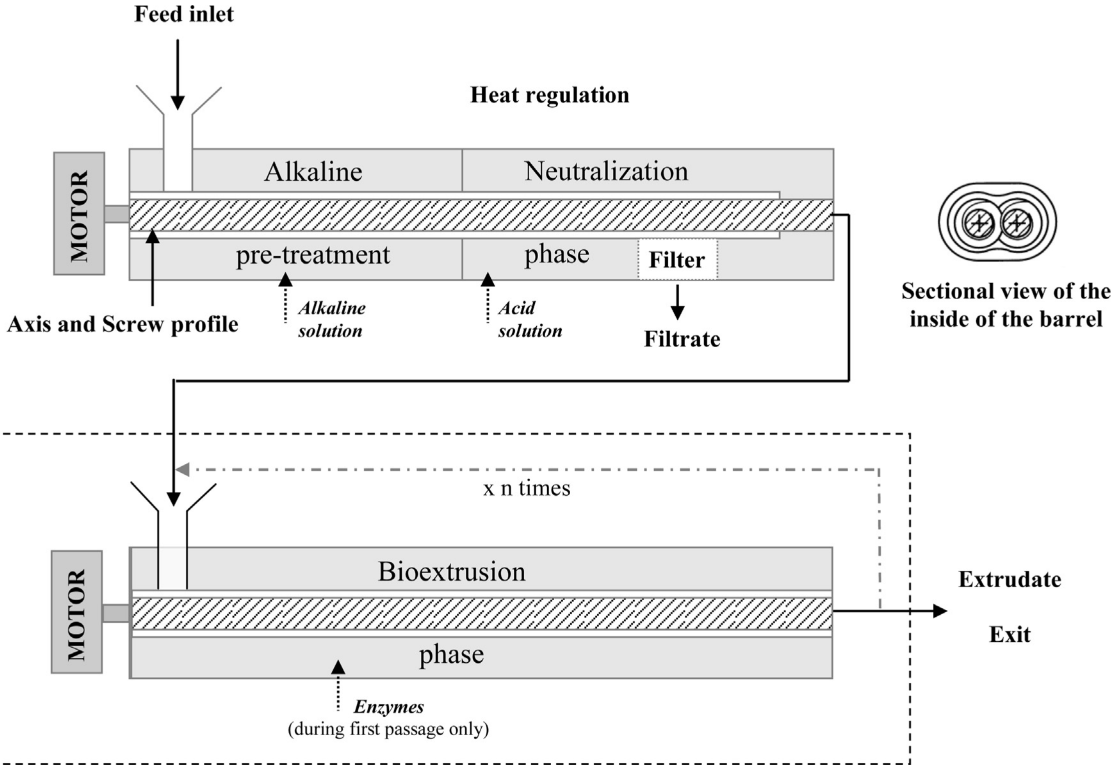

Fig. 1. Schematic representation of the sequences of the process carried out in two successive twin screw extruders with recirculation of the bioextrudate in the second twin screw extruder with or without a filtration module.

concentrations dramatically increase economic viability, reducing operating costs due to decreased volumes. However, increasing solid concentration increases the apparent viscosity of biomass slurries, making mixing and conveying operations more challenging. Among the processes used to carry out pretreatment with a minimum number of steps, twin-screw extrusion technology has many advantages and allows working with high solid concentrations. It produces a high shear, rapid heat transfer, and effective and rapid mixing, in a continuous operation, with good adjustability of treatment steps.

Co-penetrating and co-rotating twin-screw extruders are most common (Dziezak, 1989), and a very wide choice of screw elements is available. The screw profile is defined by the arrangement of the different screw elements and their characteristics (pitch, length, number and shape of screw, and angle between two successive elements in case of paddle screws) in different positions and spaced differently.

The performance of twin-screw extrusion and the influence of the operating parameters have been studied on biomass fractionation from poplar (N'Diaye and Rigal, 2000), *Miscanthus* sp. (De Vrije et al., 2002), sugar beet pulp (Rouilly et al., 2006), sunflower (Evon et al., 2007; Kartika et al., 2006), soybean hulls (Yoo et al., 2011), rice straw (Chen et al., 2011), and wheat straw and bran (Marechal et al., 2004; Zeitoun et al., 2010; Vandenbossche et al., 2014a).

More particularly, twin-screw extrusion can be used to pretreat different biomasses for the production of sugars, and several authors have reported this type of application over the last few

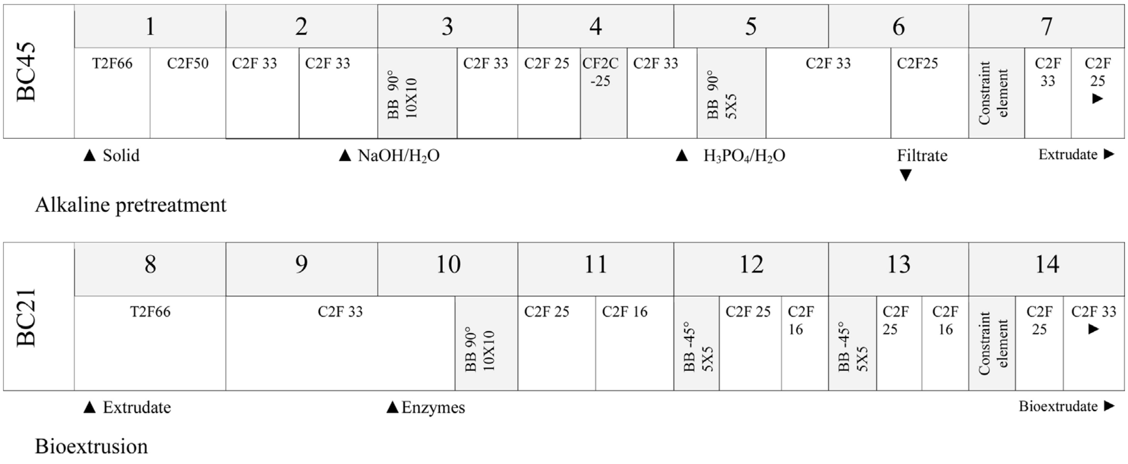

Fig. 2. Screw configuration for the combined process of pretreatment and bioextrusion with or without liquid/solid separation zone. (T2F = trapezoidal double-thread screw; C2F = conveying double-thread screw; BB = bilobe paddle screw; CF2C = reversed double-thread screw. The numbers following the type of the screw indicate the pitch of T2F, C2F, and CF2C screws or the angle between two successive elements in case of BB screws).