Energy Conversion and Management 84 (2014) 633–639

Contents lists available at ScienceDirect

Energy Conversion and Management

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

Cascade processing of wheat bran through a biorefinery approach

Melih Soner Celiktas [a,*], Christian Kirsch [b], Irina Smirnova [b]

[a] Solar Energy Institute, Ege University, 35100 Bornova-Izmir, Turkey
[b] Institute of Thermal Separation Processes, Hamburg University of Technology, Eissendorfer Strasse 38, 21073 Hamburg, Germany

ARTICLE INFO

Article history:
Received 2 February 2014
Accepted 11 April 2014
Available online 22 May 2014

Keywords:
Biorefinery
Lignocellulosic biomass
Wheat bran
Liquid hot water
Cellulase

ABSTRACT

Structural characteristics of wheat bran such as surface area, crystallinity, cellulose, hemicellulose, and lignin content significantly affect the yield of biorefinery products such as protein, fermentable sugar and lignin. The aim of the study was to use a sequence of high pressure extraction and hydrolysis processes in a cascade to create high potential value added products, namely, proteins, fermentable sugars and lignin. In the present study, four different sets of experiments were carried out step by step in a cascade sequence. The main experiments were the sequential extraction and hydrolysis which were optimized using design of experiments. Protein extraction from wheat bran was performed in a fixed bed reactor and was maximized to 1.976 g/L at the elicited optimum conditions which were 80 °C, pH 9.3 for a duration of 30 min. In the sequential experiment, process parameters such as temperature, flow rate and duration were optimized for liquid hot water (LHW) hydrolysis. The maximum reducing sugar concentration was 200 g/kg which corresponded to 34% per dry biomass obtained at a flow rate of 5 ml/min, temperature of 210 °C during a 45 min treatment. The following step was enzymatic hydrolysis to saccharify the cellulose under high pressure, where the independent variables were pressure, temperature and process time in order to ascertain the process conditions maximizing the reducing sugar content, where a positive correlation was observed between the solid–liquid loading ratio and reducing sugar yield. In the final step, the lignin content of all analyzed lignin fraction was found 70% (w/w).

1. Introduction

With an analogy to refinery facilities and an attempt to shift the demand from petroleum based products to bioproducts, conversion of plant and algae based biomass to biochemicals, energy and materials is referred as biorefinery which has become imperative in developed societies. Lignocellulosic feedstock, whole-crop and green biorefineries are considered as the pillars of biorefinery among which lignocellulosic feedstock is the most promising concept due to the fact that lignocellulosic materials are widely available and the prices are comparatively low [27,5,4].

Lignocellulosic raw materials are generally composed of 40–50% cellulose, 25–35% hemicelluloses and 15–20% lignin [22], whereby processing can lead to a wide spectrum of chemicals and sugar molecules which can be fermented to biofuels and converted to various materials [27]. Therefore, various pretreatment techniques for lignocellulosic biomass such as physical, chemical, biological and thermal has been of great interest in recent years [1,7,25,17]. Hydrolysis of lignocellulosic biomass are typically conducted by strong acids and enzymes such as cellulase and cocktails of hydrolytic enzymes [2,11,14,15,16,23,29,30].

However, pretreatment is one of the most expensive and least technologically mature unit operations in lignocellulosic conversion processes using enzymatic hydrolysis [13]. Many industries and researchers have been working on weak acid hydrolysis of lignocellulosic biomass as a pretreatment technique in spite of the long history of low yield and non-economical acid hydrolysis of lignocellulosic materials to ethanol. On the other hand, a lot of efforts have been dedicated to steam explosion process in order to loosen the cellulose structure and prepare for the hydrolysis step [10].

As for thermal pretreatment techniques, liquid hot water (LHW) arises as a green approach which was firstly developed by Bobleter et al. [20]. The main strength of this technique is solubilizing hemicellulose while providing better access to cellulose along with avoiding the formation of inhibiting compounds. The amount of solubilized products was reported to be higher in a LHW pretreatment in comparison to steam explosion [18,19]. LHW can be performed under subcritical or supercritical conditions based on the temperature and pressure applied where the critical point of water is 374 °C and 221 bar. The physicochemical properties of supercritical water differ from water at ambient conditions by displaying a lower dielectric constant and viscosity coefficient [24].

Hemi cellulose is regarded as a promising alternative to existing petroleum based chemicals due to the fact that it is the second most abundant source of biomass next to cellulose [8]. Wheat bran

* Corresponding author. Tel.: +90 (232) 3111229; fax: +90 (232) 3886027.
E-mail address: soner.celiktas@ege.edu.tr (M.S. Celiktas).

http://dx.doi.org/10.1016/j.enconman.2014.04.039
0196-8904/

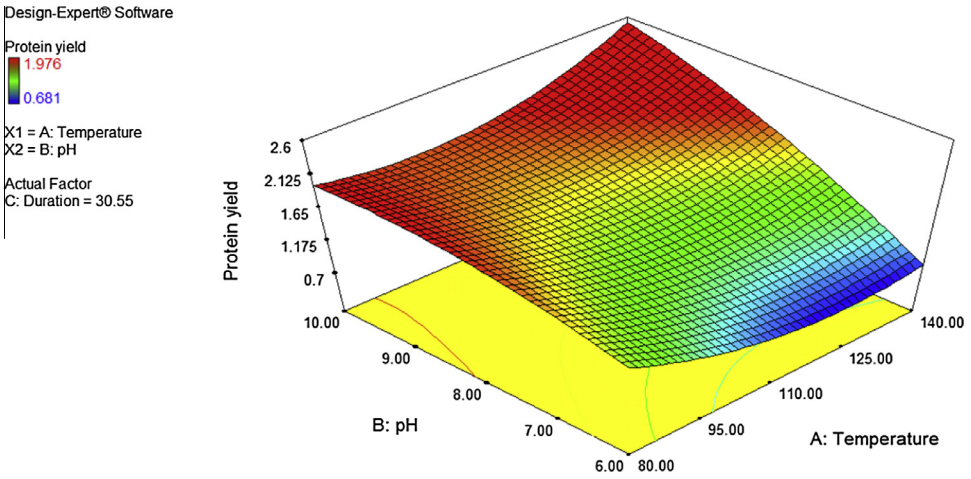

Fig. 1a. Three dimensional plots of LHW protein extraction displaying the interactions of pH and temperature on extraction yields.

usually accounts for 14–19% of the grain and comprises the outer coverings, the aleurone layer and the remnants of the starchy endosperm [32] and is a valuable source of hemicelluloses, cellulose and lignin which is produced worldwide in large quantities as a by-product of the wheat milling industry. Wheat bran has the potential to be a low-cost feedstock for biofuel production as it is mainly comprised of starch, arabinoxylans, cellulose, betaglucan, protein and lignin [6].

The aim of this study was to process wheat bran using a sequence of high pressure extraction and hydrolysis steps in a cascade to obtain high potential value added products, namely, proteins, fermentable sugars and lignin in order to be able to propose alternative utilization approaches which can contribute to bioeconomy.

2. Materials and methods

2.1. Feedstock

Wheat bran was received from the company, BioWanze located in Belgium. The dry matter content of the biomass was 92% which was stored in plastic bags at room temperature until use.

2.2. Chemicals

Nitrogen was taken from Westfalen AG, Austria. Citric acid monohydrate and sodium hydroxide were purchased from Carl Roth GmbH (Karlsruhe, Germany). Hydrochloric acid was supplied from Merck (Darmstadt, Germany), whereas 3,5-dinitrosalicylic acid was from ABCR (Karlsruhe, Germany) and Bradford solution for protein determination was purchased from AppliChem, (Darmstadt,Germany). Cellic CTec2 was donated by Novozyme (Bagsvaerd, Denmark). Distilled water used in all the analyses were prepared by using the distilled water system at TUHH.

2.3. The cascading processes using biorefinery approach

2.3.1. Optimization of protein extraction by subcritical water

Protein extraction optimization was carried out at fixed bed reactor with a volume of 50 ml which was operated in a continuous mode at the facilities of TUHH. Protein extraction was optimized by Box Behnken design. Three independent variables, temperature (80, 110, 140 °C), pH (6.0, 8.0, 10.0), and time (30, 75, 120 min) were studied at fixed flow rate (4 ml/min) and

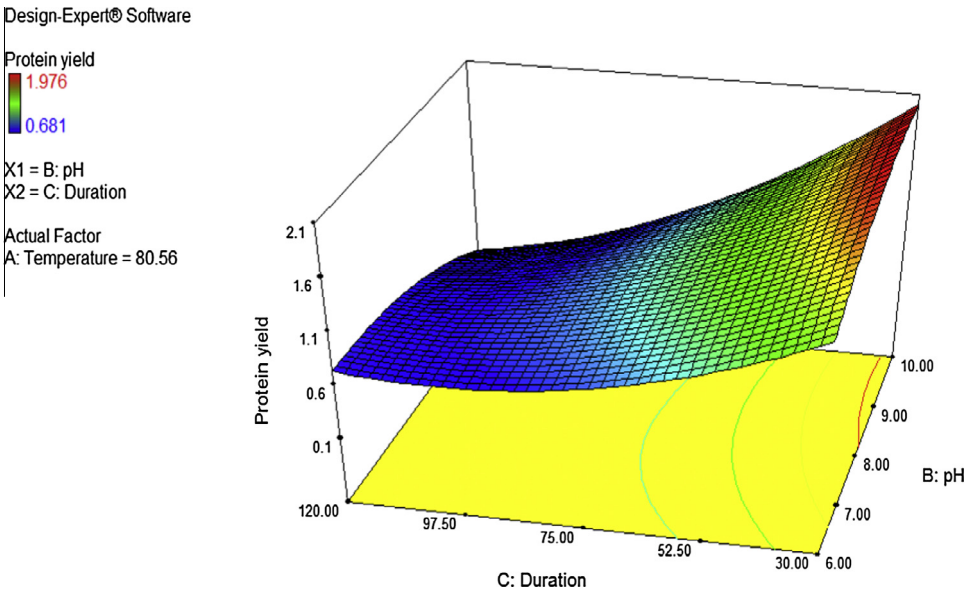

Fig. 1b. Three dimensional plots of LHW protein extraction displaying the interactions of pH and duration on extraction yields.