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Research paper

Thermo-economic evaluation of a new approach to extract sugarcane wax integrated to a first and second generation biorefinery

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ABSTRACT

This study evaluates the integration of supercritical fluid extraction process to obtain sugarcane wax extract from the sugarcane filter cake residue. This cake is eliminated from the decantation process of sugarcane juice in the sugarcane biorefinery and it is generally used as a fertilizer. From this cake a lipophilic material, containing long-chain fatty alcohols and phytosterols, can be selectively recovered by means of the use of supercritical CO_2 as extracting solvent. Aspen Plus® software was used to simulate the sugarcane biorefinery producing electricity, conventional and cellulosic ethanol and wax extract. A thermal-economic model was developed in Matlab software to perform energy integration and the economic analysis of this novel biorefinery concept. The results showed that by increasing temperature and pressure of the extraction process it is possible to produce more wax extract at an overall lower investment as lower extraction time is necessary, decreasing the number of extractors working in parallel. The integration of the extraction process to the sugarcane biorefinery had no impact on the overall ethanol production and had small impact on the electricity available for sale to the grid, decreasing only around 3% the net electricity. Payback time is strongly reduced by this integration strategy, decreasing 74% when the best configuration for SFE is adopted. The selling price for the wax extract strongly influences on the economic viability of this process, indicating that the integration of this extraction process to the sugarcane biorefinery is only economic attractive if the wax extract selling price is higher than 26.5 USD/kg.

1. Introduction

Sugarcane is a very important biomass for the Brazilian economy. It is used to produce electricity, ethanol and sugar in a biorefinery concept. Embracing the biorefinery concept, this sector is investigating bioproduct diversification and mostly putting a lot of effort and investment on second generation ethanol production. The use of process "wastes" to increase biofuel and bioproducts productivity of this biorefinery, without the necessity to increase sugarcane harvested, is a necessary action being investigated by different authors [1–3].

Filter cake is the residue eliminated from the decantation process of sugarcane juice, after it is filtered for recovery of residual sugar. This sugarcane biorefinery by-product is a dark solid fibrous residue that has an estimated composition to be approximately: 10–14% wax, oil, and resin, 12–16% protein, 8–12% ash, 3–5% P_2O_5, 2.5% CaO, 10–14% saccharose and reductive carbohydrates, 18–25% cane core, and 25–35% other materials. From this cake, which is generally used as a fertilizer, a lipophilic material, containing long-chain fatty alcohols, known as policosanol, and phytosterols, can be recovered. These compounds can be used as nutraceuticals or pharmaceuticals [4–6].

The principal product obtained from the filter cake is the sugarcane crude wax. The industrial process for the extraction of sugarcane crude wax from filter cake is heptane extraction. Three fractions are usually separated in this process: wax, oil and resin. The separation consists of different successive multiple steps and enables the initial fractionation of the resin compounds followed by the separation in a second step of the oils and refined wax [4,8]. The biological effects of active compounds extracted from sugarcane crude wax, such as long chain n-alcohols, fatty acids, or ethanolic extracts, have been reported by various groups to have applications in atherosclerotic vascular coronary heart disease and other therapeutic applications [6].

The selective recovery of policosanol from sugarcane filter cake by the environmental friendly technique named supercritical fluid extraction (SFE) was demonstrated and patented by Shintaku and Meireles [7]. This study showed that the obtained extract can be compared to commercially available policosanol products extracted and purified with toxic organic solvents, such as hexane and dichloromethane [8]. Policosanol is a mixture of alcohols with chain

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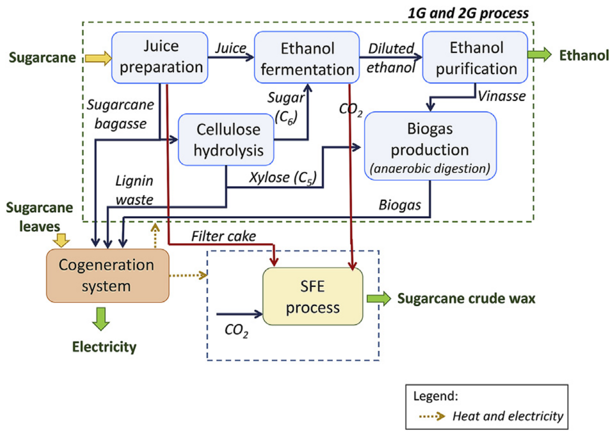

Fig. 1. Simplified process representation of the proposed integrated sugarcane biorefinery.

lengths varying from 24 to 34 carbon atoms, where octacosanol, containing 28 carbon atoms, is the main constituent [4].

In this context, this paper evaluates thermal-economically an integrated sugarcane biorefinery producing conventional and cellulosic ethanol, electricity and sugarcane wax extract using process simulation tools. It will be assessed the roll of product diversification in the sugarcane biorefinery by evaluating a high added-value product, sugarcane wax extract rich in Policosanol. Supercritical technology for bioactive compounds extraction purpose will be evaluated comparing different supercritical CO_2 extraction conditions based on the experimental data of laboratory and pilot scale experiments performed at LASEFI/UNICAMP (Brazil).

2. Material and methods

2.1. Process description

The integrated sugarcane biorefinery producing electricity, conventional and cellulosic ethanol and sugarcane wax extract was evaluated following the simplified process representation (Fig. 1).

2.1.1. Ethanol production in the sugarcane biorefinery

The ethanol production process, both first and second generation ethanol, in the sugarcane biorefinery was simulated using the commercial flowsheeting software Aspen Plus [9].

For the first generation ethanol production, the process is comprised of the following steps: sugarcane cleaning, juice extraction, juice treatment and concentration, glucose fermentation, ethanol distillation and dehydration. For process simulation, it was considered the available technology in modern ethanol distilleries in Brazil, such as sugarcane dry cleaning, concentration in multi-effect evaporators, sterilization of the sugarcane juice before entering the fermentation system, ethanol dehydration using monoethylene glycol. The description of the model for the conventional ethanol production, as well as the property models used, was fully described in details elsewhere [2,10]. Sugarcane bagasse, produced after juice extraction in the conventional ethanol production process, is used 90.7% to cellulosic ethanol production. The remaining 9.3% partially is used as fuel to the cogeneration system and the other part is saved to be used during the cogeneration system startup or sugarcane crushing shutdowns.

In the second generation ethanol production process, the bagasse goes through a physical and chemical treatment to break the lignin-cellulose-hemicellulose matrix and increase cellulose availability to the hydrolysis process. During the enzymatic hydrolysis, cellulose is converted into sugar monomers and the resulting sucrose solution is concentrated. The concentrated sucrose solution is then mixed with the concentrated juice obtained at the first generation process and the

Table 1
Main parameters adopted for the computational simulation of the proposed integrated sugarcane biorefinery.

Parameter	Value	Unit
Conventional ethanol production process		
Sugarcane juice extraction and treatment		
Sugarcane processed	500	t/h
Efficiency of dirt removal on sugarcane cleaning	60	%
Efficiency of sugars extraction on the mills	97	%
Sugarcane bagasse moisture content	50	% w/w
Recovery of sugars on juice treatment	99.4	%
Ethanol production and recovery		
Fermentation yield	89	%
Ethanol recovery on distillation and dehydration	99.7	%
Cellulose hydrolysis process		
Bagasse catalyzed steam explosion pretreatment		
pretreatment temperature	463	K
reaction time	5	min
Hemicellulose–xylose conversion	61.4	%
cellulose-glucose	4.1	%
xylose-furfural	5.1	%
hemicellulose-acetic acid	9.2	%
soluble lignin extraction	50	%
Bagasse saccharification through enzymatic hydrolysis (ENZH)		
Reaction time	24	h
Hydrolysis solid loading	5	%
Temperature	323	K
Enzyme load[a]	30	mg/g Cellulose
Cellulose–glucose conversion	69.2	%
Hemicellulose-xylose conversion	35.7	%

Data based on [3,11].
[a] the enzyme load accounts for cellulose and β-glycosidase.

resulting solution is sent to fermentation. From this point, first and second generation ethanol are sent to the distillation and dehydration system of conventional ethanol production. Table 1 shows the main parameters considered for the simulation.

2.1.2. Process waste to energy

Process waste was considered to be used as fuel to the cogeneration system. Solid wastes were used with moisture content under 50%, when necessary a press filter was used to remove excess of water. The solid fuels considered for the cogeneration were the lignin waste generated at the hydrolysis process. Sugarcane leaves were also considered as a solid fuel, but with low moisture content (15%), for cogeneration at a flow rate of 33 ton/h. This flow was calculated considering that 40% w/w of the leaves obtained during the harvest were collected, whereas the rest were left in the field for sugarcane cultivation soil protection. Liquid process waste with high organic load was considered to biogas production in an anaerobic system [12].

2.1.3. Cogeneration system

The cogeneration system was modeled as a steam-based cycle including condensing extraction steam turbines supplying heat and power to the process. Live steam considered at 793 K and 9 MPa and condensing extraction steam turbines are simulated. The entire system is integrated with the process design when the heat cascade problem is solved. For the cogeneration system, the following were considered as fuels: sugarcane leaves, part of sugarcane bagasse, lignin cake and biogas.

2.1.4. SFE process

The simulation of the SFE plant was performed using the commercial flowsheeting software Aspen Plus [9]. The thermodynamic model used to represent the process was the RK-ASPEN model when supercritical fluid extraction was considered and UNIQUAC model for low pressure processes. It was considered a prior dewatering of the filter cake to achieve solid concentration of 50% using a press filter. The