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Technical and economical evaluation of bioethanol production from lignocellulosic residues in Mexico: Case of sugarcane and blue agave bagasses

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ABSTRACT

Bioethanol is the main biofuel used in Brazil and USA, produced from sugarcane and corn. Nevertheless, the use of food to produce ethanol has to be replaced by agroindustrial waste or energy crops. The alternative raw material for bioethanol production in Mexico could be sugarcane and blue agave bagasses. In this work, we built a complete simulation process using Superpro Designer® software considering only the upstream units of fermentation for the technical and economical evaluation of lignocellulosic ethanol. Such consideration is based on a state-of-the-art analysis of the technology, indicating that technical and economical bottlenecks include pretreatment, saccharification and hexoses and pentoses fermentation. The simulation was carried out at different efficiency levels through a statistical analysis of surface responses and, three different saccharification processes to analyze ethanol production in terms of complete substitution of oxygenates in gasoline distributed in Mexico. The results indicate that ethanol production cost is 1.34 and 1.46 USD/gallon and potential production is 40.13 and 1380 MM gallon/year using blue agave bagasse and sugar cane bagasse, respectively.

1. Introduction

Biofuels are obtained from biomass through chemical, physical or biological processes. The main biofuels currently in use around the world are biodiesel, biogas, and bioethanol; such biofuels are used neat or more often mixed with fossil fuels for vehicles and less for electricity generation (wood pellets and biogas). Biofuels are produced from raw materials coming from agriculture, forestry and cattle industries but also from organic wastes and residues from all kind of industries. The interest on biofuels in Mexico is very recent and mainly due to an effort to reduce vehicles emissions that contribute to the formation of ground-level ozone and greenhouse gases, but also to impulse and diversify its agriculture practices and industrial activities. Also, the blending of biofuels with fossil fuels may help to diminish the decay of crude oil reserves. In 2008, the Mexican Congress approved the Bioenergetics Act that favors the use of biodiesel and bioethanol in diesel and gasoline sell in Mexico by Petróleos Mexicanos (PEMEX), the State-owned company that explores, produces, refines, and transforms crude oil. Concerning to gasoline oxygenates, PEMEX produces some Methyl *tert*-butyl ether (MTBE), Ethyl

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tert-butyl ether (ETBE) and *tert*-amyl methyl ether (TAME), but the rest is imported due to refining and conversion limitations in current PEMEX's facilities. One alternative to current oxygenates is bioethanol, that can be used neat, but usually mixed with gasoline at different ratios and commonly called gasohol. Brazil and USA are the main producers of ethanol around the world with a production over 73,406 million of liters per year from sugar and maize, respectively (Renewable Fuels Association (RFA), 2013). Moreover, the Renewable Fuel Standard (RFS) ensures that the cellulosic biofuels volume standard is tied directly to production, which acknowledges the efforts of advanced biofuel investors and innovators (Coleman, 2013). In Mexico, ethanol production comes primarily from sugar cane fermentation and produced about 15.3 million of liters in 2011–2012 (Comité Nacional para el Desarrollo Sustentable de la Caña de Azúcar, 2015a); but it is used only on conventional industries as spirits, pharma, chemical and cosmetics. On the other side, Mexico is sufficient in sugar production, in 2013–2014 exported 2.5 millions of tons (Comité Nacional para el Desarrollo Sustentable de la Caña de Azúcar, 2015b) that could be instead transforming to ethanol. Nevertheless, the production of ethanol is insufficient to satisfy the potential demand for bioethanol and PEMEX could be attracted to import ethanol from producing countries as USA and Brazil. Such policy may have a negative important impact on the agriculture, industrial, economic and social development in Mexico.

Nowadays, there are many technical and economical limitations for production of ethanol from lignocellulosic materials and a lot of research is currently done to develop a suitable technology. Here, process simulations may be a helpful tool to identify and understand technical bottlenecks that impact the full economy process. Indeed, some process simulation-based works have been carried out to understand the effect of a double acid hydrolysis of a theoretical lignocellulosic material on ethanol production (Zhang et al., 2009), to estimate the cost of corn dry-grind process for ethanol production (Kwiatkowski et al., 2006), an analysis for feasibility studies of biorefineries (Sadhukhan et al., 2008); and several works on optimization and cost estimation of a wheat biorefining (Arifeen et al., 2007a,b, 2009; Du et al., 2009; Misailidis et al., 2009). In Mexico, some important but scarce works have been done on engineered microorganisms for ethanol production, (Romero et al., 2007; Martinez et al., 2000; Chuck-Hernandez et al., 2011; Orencio-Trejo et al., 2010) kinetics of hydrolysis of sugarcane bagasse (Aguilar et al., 2002; Conde-Mejía et al., 2012; Pavon-Orozco et al., 2012); and comparative hydrolysis and fermentation of sugarcane and agave bagasses (Hernández-Salas et al., 2009). Nevertheless, there is no information, to our knowledge, concerning the process simulation of sugarcane and Blue agave bagasses for ethanol production in Mexico. This work presents results of the technical and economical evaluation of production of bioethanol from lignocellulosic residues largely found in Mexico, sugarcane and Blue agave bagasse, co-products of sugar refineries and Tequila industries. We built the process simulation using currently values for economics and varied the technical efficiencies of fermentation up-stream processing units in order to ascertain the technical limitations and their impact on the economics of the process. Finally, we analyze the prospect about the possible impact of lignocellulosic bioethanol in demand scenarios for its introduction in the gasoline produced by PEMEX in Mexico.

Table 1 – Dry-basis composition of sugar cane (49% dry-basis; Unión Nacional de Cañeros, 2007) and agave (51% dry-basis; Iñiguez-Covarrubias et al., 2001) bagasses used in simulations.

Component	Base-case blue agave bagasse (%)	Base-case sugar cane bagasse (%)
Cellulose	43	42
Hemicellulose	19	28
Lignin	15	20
Other polysaccharides	13	4.6
Saccharose	10	3
Ash	ND	2.4

2. Materials and methods

2.1. Process description

2.1.1. Feedstock and composition

Blue agave (*Agave tequilana Weber* var.) is cultivated in vast zones of west-central and northeastern Mexico in 138,236 ha and harvested (*Jima* in Spanish) for Tequila manufacture (Sistema de Información Agroalimentaria y Pesquera (SIASP), 2009). The blue agave pinecones (*piña*) without leaves are cooked to hydrolyze inulin to fermentable monosaccharides. After cooking, the pinecones are grinded and pressed to extract the maximum syrup and maximize yield. Then, the residue obtained from the process is the agave bagasse (352,200 metric tons per year), which may be burned to generate heat and steam at the distillery but is frequently used as fertilizer on fields.

On the other side, sugarcane (*Saccharum officinarum*) is cultivated in almost all Mexico (774,243 ha; Sistema de Información Agroalimentaria y Pesquera (SIASP), 2013) and 53 sugar refineries produce diverse sugar grades and molasses. Some of them produced around 19.3 million liters of ethanol in 2009 according to the sugarcane union (Unión Nacional de Cañeros). The residue obtained from the process, sugar cane bagasse (14,870,846 metric tons/year), is mostly used to generate heat and steam for the sugar refinery and only 3% was processed sometime for paper production (Gonzalez-Cesar, 2002). One advantage to produce ethanol from blue agave and sugarcane bagasses is that these residues are concentrated in Tequila industries and sugarcane refineries, where they may be transformed to ethanol without extra cost for transportation. In the case of blue agave bagasse, it contains less hemicellulose and lignin that sugar cane bagasse (Table 1) which makes it attractive as a source of fermenting sugars produced by conventional chemical and/or biologically hydrolysis and saccharification.

2.1.2. Process steps

The process model was built on software for process simulations (SuperPro Designer®) and describes ethanol production from grinded bagasses to ethanol dehydration (Fig. 1). Fuel ethanol production from raw materials includes three major steps (pretreatment, saccharification and fermentation) that are the main units studied in the present work since they are still on development; represent the bottleneck of the process and main sources of ethanol production cost. The fermentation downstream process units (ethanol distillation/drying and solid treatment) were built on the basis of a corn-grind process for ethanol production (Linerio-Gil and Guzmán-Carrillo, 2004) since we considered that technologies concerning ethanol purification and solid treatment (lignin