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Evaluation of technological alternatives for process integration of sugarcane bagasse for sustainable biofuels production—Part 1

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ABSTRACT

Nowadays, there is a tremendous global interest in the biofuels production. However, first generation biofuels have been debated about that energy-crop compete with food crops and thus cause food deficiency and price increases. In this sense, researchers have started looking for potential feedstock for ethanol such as lignocellulosic biomass (e.g., sugarcane bagasse), which does not affect food security. In this paper, the integrated use of sugarcane bagasse is analyzed as raw material for second generation of biofuels production. This case study implements a design and process integration to compare several biorefinery topologies using the typical mass flow rate of residual biomass produced by the sugar industry (1200 ton per day). Based on evaluation of chemical composition of bagasse (cellulose, hemicellulose, and lignin) several process schemes for integral utilization of biomass were proposed. This paper is the first part of the study on the exergy, life cycle analysis (LCA) and economic analysis of sugarcane bagasse for sustainable biofuels production using Aspen Plus^{TM} software. Part 1 presents the exergy and life cycle analysis developed while part 2 describes economic analysis and selection of an optimal configuration with minimal environmental impact, by means of the combined use of raw material and energy integration.

Keywords: Biorefinery; Sugarcane bagasse; Second generation biofuels; Exergy analysis; LCA; Sustainable development

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1. Introduction

Currently, there is a tremendous world-wide interest in the production of ethanol from biomass. Major national biofuels programs have been initiated to produce cost-efficient ethanol and other fuels from agricultural and forestal lignocellulosic biomass in countries like the USA and China. Conventionally, lignocellulosic biomass is pretreated by chemical and physical methods, followed by enzymatic hydrolysis to open the plant fibers and to convert the polymers of cellulose and hemicellulose to sugars, which can be subsequently fermented (Westermann et al., 2007). The hydrolysis processes are, however, costly and control the economics of the biomass conversion processes (Chew and Bhatia, 2008). Other considerations for developing a successful biofuels production include additional resources for a sustainable feedstock supply (land, water, etc.), net energy gains, and environmental impacts such as waste disposal and emissions (Chen, 2008). Lignocellulosic biomass, such as sugarcane bagasse, which is residual in sugar–ethanol industry, allows the possible integration of second and first generation biofuels production. Application of process integration (mass and energy) between these alternatives may generate reduction of hot utilities requirements and raw material savings. Thus, the selection of appropriate raw materials and the development of biorefinery-based strategies to support sustainable processes are therefore essential (Du et al., 2008). For that reason, the main objective of this paper is to apply exergy, life cycle analysis (LCA) and economic analysis to insight into how to improve the sustainability of the biofuels production.

2. Lignocellulosic biomass

The main potential feedstock for ethanol is lignocellulosic biomass such as agricultural residues (e.g., corn stover, and sugarcane bagasse), herbaceous crops, forestry wastes, wood, wastepaper, and other wastes such as municipal waste (Wyman, 1996). Lignocellulosic biomass consists of three major components (in mass fractions of dry substance): $w(\text{cellulose}) = 35–50\%$, $w(\text{hemicellulose}) = 20–35\%$ and $w(\text{lignin}) = 10–25\%$. Conversion of lignocellulosic materials to higher value products requires fractionation of the material into its components: lignin, cellulose, and hemicellulose. As indicated by Hayes (2008), the key to exploiting the chemical value of biomass is to depolymerise the lignocellulosic matrix in order to obtain smaller molecules that can be utilized, or further converted to platform chemicals and biofuels.

2.1. *Lignocellulosic biomass in the "food vs. fuel" debate*

The production of biofuels through second generation technologies disputes many food vs. fuel and socio-economic concerns since they use waste resources and, hence, do not compete with food crops (Hayes, 2008). Land unsuitable for food production can instead be utilized for lignocellulosic energy crops. Therefore, lignocellulosic biomass is one of the most important feedstock in ethanol industry. Cellulosic ethanol is principally made from agricultural residues which are not used for human food production.

Another point to be considered in biofuels production is "energy consumption vs. energy content in produced ethanol". The processing of a renewable energy source usually involves the consumption of nonrenewable resources thought it is necessary confirm that the energy obtained in the bioethanol is significantly greater than the energy used in the process to design an energy sustainable process.

3. Bioethanol from lignocellulosic biomass—main production process

Overall, fuel ethanol production from lignocellulosic biomass includes five main steps: pretreatment, hydrolysis, hexose fermentation, purification, and effluent treatment. Furthermore, detoxification and fermentation of pentoses released during the pretreatment step can be carried out (Cardona and Sánchez, 2007). The sequential configuration employed to obtain cellulosic ethanol implies that the fraction of solid lignocelluloses material pretreated undergoes hydrolysis (saccharification); this component contains a cellulose form more accessible to acid or enzyme attacks. Once the hydrolysis is complete, the resulting cellulose hydrolyzate is fermented and converted into ethanol.

The significant variety of pretreatment methods of biomass has led to the development of many flowsheet options for ethanol production. Pretreatment is currently one of the most expensive stages in second generation technologies (Mosier et al., 2005). Pretreatment is, however, crucial for ensuring good ultimate yields of sugars from polysaccharides; yields from enzymatic hydrolysis without pretreatment are usually less than 20%, whereas with pretreatment, yields can rise to over 90% (Hamelinck et al., 2005). There are two major pathways by which biorefineries operate: through hydrolytic mechanisms that aim to liberate free monosaccharides from the lignocellulosic polysaccharides, and through thermochemical processes that degrade more extensively the components of both, polysaccharides and lignin.

Consistent with Fitzpatrick (1990), the Biofine process is unique among all the near-commercial biorefining technologies employing hydrolytic mechanisms in that it does not require any biotic activity for the conversion of biomass to the final marketable product. It uses dilute sulphuric acid in a two-reactor system engineered to obtain high yields of the platform chemicals levulinic acid (with hydroxymethylfurfural as a key intermediate) and furfural from the degradation of the hexoses and pentoses liberated from the structural polysaccharides of lignocellulosic biomass.

Dias et al. (2009) considered a three-step hydrolysis process (prehydrolysis of hemicellulose, Organosolv delignification and cellulose hydrolysis) of surplus sugarcane bagasse. This configuration of the organosolv process allows the removal of pentoses prior to the extreme conditions of cellulose hydrolysis that enhance pentose decomposition and the consequent production of fermentation inhibitors, such as furfural, leaving cellulose and lignin fractions unaltered (Aguilar et al., 2002).

Ingram et al. (1999) carried out significant research on the development of recombinant strains of enteric bacteria for use during the biomass-to-ethanol process. At present, research efforts are being oriented to the development of a single microorganism capable of efficiently fermenting both hemicellulosic and cellulosic substrates, which will make possible the development of the direct conversion of biomass into ethanol (Cardona and Sánchez, 2007).