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Surplus electricity production in sugarcane mills using residual bagasse and straw as fuel

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ABSTRACT

The cogeneration system is one of the most important parts of sugarcane mills which use the bagasse as fuel. In the recent years, modern equipments and energy efficiency measures made possible to the sugarcane industry, the production of surplus electricity which become, besides the sugar and ethanol, a third product from the same renewable source, the sugarcane. This work analyses the surplus electric power systems for three different schemes of cogeneration system in the sugarcane industry through the simulator Thermoflow®. The analysis is made considering both the available bagasse and sugarcane straw recovery as fuel in three different scenarios for the industrial process energy requirements. The results show that the CEST (Condensing Extraction Steam Turbine) system can have a surplus of electricity of up to four times higher than the BPST (Backpressure Steam Turbine) system. The system CEST can have an increase in surplus power above 23% and 102% for the rate of 10% and 50% of cane straw recovery in the field respectively. The BPST-C (Backpressure and Condensing Turbines) system can produce similar values of surplus electricity when compared with the system CEST, but may represent an opportunity of flexible operation of the cogeneration systems in harvest and off-seasons.

1. Introduction

In last few decades the research involving renewable energy sources has been growing. The biomass energy is a major source of energy available in nature, and has been widely studied due to future oil shortages.

The use of biomass can reach up to 18% of total primary energy worldwide by the year 2050, four times the current value. Pratical, political and economic factors hinder its use as an alternative energy source [1].

Cortez et al. [2] report that biomass residues have a large energy potential for power generation, and highlights the need for proper exploration of these residues. The main agricultural products produced in the world, which consequently generate large amounts of waste are sugarcane, corn, wheat, rice, cassava, soybeans [3].

Furthermore, sugarcane is one of the largest global agricultural productions with 1.68 million Mt, while Brazil accounts for 43% of total world production [3]. Apart from sugarcane juice used for sugar and ethanol production, processing of sugarcane results in residues like bagasse and straw that can be used as fuel in the cogeneration systems of the sugarcane mills.

The first cogeneration projects of this industry used sugarcane bagasse to produce steam to meet the thermal energy demand of the process, producing saturated or slightly superheated steam [4].

In the late 1990s, the goal of sugar and ethanol plants was to be self-sufficient in thermal and electrical energy, especially for the generation of surplus electricity for sale to the grid [5]. The modern sugarcane mills are designed to achieve a better use of bagasse and straw for the electricity generation.

Fig. 1 shows the scheme of integration between sugarcane mills and the cogeneration system consuming bagasse and straw as fuel and providing energy requirements of the process.

The sugarcane mills cogeneration systems commonly used in countries like Brazil, India, South Africa and Australia are steam-based cycles producing live steam at the boilers that is expanded in steam turbines, generating low pressure steam and electricity to the industrial process. This industry use BPST (Backpressure Steam Turbine) or CEST (Condensing Extraction Steam Turbine) cogeneration systems, which operate mainly during the harvest of sugarcane.

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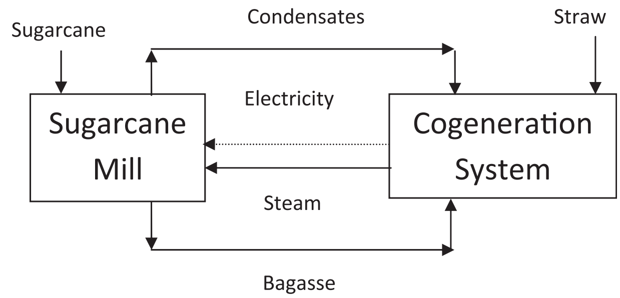

Fig. 1. Integration between a sugarcane mills and its cogeneration system.

This paper aims to carry out a study of the surplus electricity generation potential in sugarcane mill, using Thermoflow® [6] software as a modelling tool, and considering residual biomass like bagasse and straw as fuel. Three types of systems are considered in this work, being two traditional cogeneration systems used in this industry, the BPST and CEST previously mentioned, operating during the harvest season of the sugarcane, and a system that operates throughout the year (BPST-C) composed by a BPST and a autonomous power plant using condensation turbines.

2. Methodology

The Thermoflex®, a module of the Thermoflow® software, is used in this work. This software is a simulator for the industry specialized in power generation systems and has a comprehensive database of the composition of materials that can be used as fuel, but different material compositions can also be inserted in the simulator by the user [6]. In this work the package IAPWS-IF97 (Industrial Formulation 1997 for the Thermodynamic Properties of Water and Steam) was used as a thermodynamic model, which is a specific thermodynamic model developed by Thermoflow®. The use of this thermodynamic model was carried out satisfying the mass and energy balances for the author's case study. Table 1 shows the fuel and operation period of the three cogeneration systems simulated in this paper.

For the calculations performed in this paper the harvest season takes 214 days, with 87% capacity, resulting in 186 effective operation days or 4464 h as described by Larson et al. [8]. These are average values for the sugarcane harvest in the Center-South region of Brazil which concentrates most of the production of this biomass in the country.

The operation throughout the year considers 335 days, being 121 days of operation in the off season, 214 days of operation in the harvest season [8] and 30 days of maintenance of the thermal plant. Hence, the total hours of operation during the year are 7368 h.

It is considered as well in the simulations 14% of fiber content in the sugarcane as described by Hugot [9], resulting in a total bagasse production of 280 kg/t cane (50% of wet-basis moisture content).

Table 1
Fuel and operation period of the system.

Biomass	Moisture content [%]	Cogeneration system	Operation period
Sugarcane bagasse	50	BPST	Harvest season
		CEST	Harvest season
		BPST − C	Harvest and off season
Sugarcane straw	15	CEST	Harvest season
		BPST − C	Harvest and off season

Source: [7].

Table 2
Biomass available as fuel for the cogeneration system.

	[kg/t cane]	[t/h]	[kg/s]
Sugarcane crushed		500.0	138.9
Bagasse produced[a]	280.0	140.0	38.9
Bagasse available[a]	252.0	126.0	35.0
Bagasse stored[a] (10% for the total produced)	28.0	14.0	3.9
Straw produced[b]	165.0	82.4	22.9

[a] 50% of wet-basis moisture.
[b] 15% of wet-basis moisture.
Source: [7].

For the straw it is considered a total production of 165 kg/t cane, with 15% of wet-basis moisture content [8].

Table 2 describes the mass flow of the bagasse and sugarcane straw available for generation of steam in the boilers for sugarcane mills with crushing rates of 500 t cane/h.

Usually 10% of the bagasse produced by the mills should be stored for emergential use in the start up the plant in the beginning of the season or after unavoidable stops caused by technical problems. Almost 90% of sugarcane bagasse is considered available for use in cogeneration.

Tests performed with existing bagasse boilers in sugarcane mills supported the mix of straw in the bagasse used as fuel up to 10%, with no damage to equipment [10]. Higher shares of straw into the bagasse mass can cause fouling and slaging due to high mineral present in the sugarcane straw.

In this paper two scenarios of straw recovery in the field are studied. The first considers that 10% of the straw is collected and available as fuel to the cogeneration together with bagasse. In the second, a straw collection of 50% is considered as a future scenario when technical problem may be solved with new biomass boilers development.

The physico-chemical characteristics of bagasse and straw used in the simulation are described in Table 3 and the ash compositions of these fuels are shown in Table 4.

In this work seven different cases are carried out to shown the importance of the cogeneration system efficiency and the process steam requirements in the electricity generation potential. Table 5 shows the parameters adopted for each case describing the three types of boilers with different levels of temperature, pressure and efficiency and the three process steam consumption levels.

The cases 1, 2 and 5 are studied only for the BPST cogeneration system option, since it presents high steam demand by the process like old process design in sugarcane mills, with no thermal integration and low efficiency equipments. The characteristics of this system, without a condensation system, makes it advantageous for electricity generation when high steam demand occurs.

Table 3
Sugarcane bagasse and straw composition.

Description	Bagasse	Straw
Ash	7.4[a]	11.0[b]
Fixed Carbon	12.6	9.0
Volatile[a]	80.0	80.0
HHV (MJ/kg − dry fuel)	18.2[a]	17.8[b]
Ultimate Analysis of dry fuel [wt%]	Bagasse[a]	Straw[b]
Carbon C	45.2	44.2
Hydrogen H	5.4	5.4
Nitrogen N	0.2	0.6
Oxygen O	41.8	38.7
Sulfur S	0.02	0.06
Chlorine Cl	0.03	0.32

Source: [a] [11]; [b] [12].