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Thermodynamic and economic evaluation of reheat and regeneration alternatives in cogeneration systems of the Brazilian sugarcane and alcohol sector

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A B S T R A C T

This work makes a technical and economic evaluation of incorporation of reheating and regeneration, as a way to increase efficiency of energetic systems and bagasse surplus, in cogeneration systems of Brazilian sugar and ethanol sector. Four scenarios were analyzed: Conventional (C0), with Reheat (C1), Regenerative (C2) and with Reheat and Regeneration (C3). Some of thermodynamic indicators used in evaluation were Surplus Bagasse Index and Exergetic Efficiency, for economic evaluation the Monte Carlo Method was used to give a Net Present Value (NPV) > 0 for each scenario. Technical evaluation indicates that Reheating (C1) increases bagasse surplus by 39.9% and exergetic efficiency by 1.90%, with respect to C0. Incorporation of 1–8 regenerators (C2) increases surplus bagasse and exergetic efficiency in the ranges of 103–160% and 5.03–8.07%, respectively. Reheat stage incorporation of 1–8 regenerators (C3) increases surplus bagasse in the range of 121–166% and increases exergetic efficiency in a range of 5.91–8.46%. Finally, it was estimated the potential of additional electric power generation during off-season and second generation ethanol production from surplus bagasse, with satisfactory results.

1. Introduction

Biomass accounts for 8.8% of installed capacity in Brazilian Electric Power Matrix, and sugarcane bagasse has the largest share in this type of source [1]. Brazil is world's largest sugarcane producer, followed by India, China and Thailand [2].

Being responsible for more than half of the sugar sold in the world free sugar market and is expected to reach an average production increase rate of 3.25% by 2018/19 [3].

Currently, bagasse obtained in sugar and/or alcohol production is basically destined to energy generation, in thermal (70%), mechanical and electrical (30%) forms, being energy obtained by burning this residue in boilers sufficient to supply demand of producing units and also generate surplus amount exportable to national grid. Besides use as primary source of energy in ethanol industry, sugarcane bagasse has other applications [4]. Recently, use of bagasse in other industrial sectors has shown a considerable growth, as in pulp and paper industry, where used as main raw material. Other applications are in manufacturing of industrial plastics and paints and also in lignocellulosic ethanol production. First second generation biofuel plant was inaugurated in 2014 in Alagoas State [5].

At the time, biomass represents the option of a coherent, safety and ecofriendly reply world not being able to guaranty its food security, to satisfy its energy demand, and not even to get rid of its own residues – But the enthusiasm of such an appealing offer make us forget that the photosynthesis creating biomass is not total

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Nomenclature

B	Exergy (kW)
DCA	Drain Cooler Approach (°C)
E1G	First-generation ethanol
E2G	Second generation ethanol
TTD	Terminal Temperature Difference (°C)
IRR	Internal rate of return
LHV	Lower heating value (kJ/kg)
m_{per}	Steam fraction extracted for regeneration
n	Counter
NPV	Net Present Value, P Pressure (bar//kPa//MPa)
$\overline{PR}$	Pressure ratio
T	Temperature (°C)
VA	Annual uniform value method
Greek	
β	Amount of bagasse (t)
Δ	Increment
η	Efficiency (%)
Subscripts and superscript	
av	Available
b	Relative to boiler
cons	Consumed
e	Input
exc	Surplus
exe	Relative to Exergetic
F	Relative to fuel
ff	Cold source
fq	Hot source
opt	Optimum
P	Relative to product
Q	Relative to heat
r	Relative to Reheat
s	Output
sat	Relative to the saturation state
sim	Relative to simulation

potent and as well as any system has its limits, if ignored, claims it parts.

So, it is mandatory to start thinking about a wise and responsible exploitation of biomass to ensure its sustainability, as a base to support looking after alternatives to obtain more energy from available biomass.

Correspond, several studies have appeared:

Ensinas et al. [6] analyzed four cogeneration systems schemes, based on conventional and advanced technologies in a sugar-ethanol plant, results show best alternative, from the point of view of efficiency, is incorporation of combined cycle with biomass gasification.

Pellegrini and Oliveira Jr [7] made a simulation of a sugar mill, where an exergetic, thermoeconomic and environmental analysis is performed. A magnitude of irreversibility in the productive process and in generation systems, as well as, alternatives to eliminate those identified. It has been shown that minimization of entropy generation, in energy conversion process, allows a better thermoeconomic-environmental performance.

Palacios-Bereche et al. [8] develop an exergetic analysis referred to integration of a second generation ethanol production in a conventional ethanol process, results show that integration of 2nd generation brought about an increase of production and a higher global exergetic efficiency.

Silva and Oliveira Jr (2014) [9] did an exergetic analysis of four cases of pretreatments of lignocellulosic biomass, highlighting the relevance of each route in defining overall exergetic efficiency of second-generation bioethanol production routes.

Dias et al. [10] simulating an autonomous distillery, studied impact of different cogeneration systems for production of steam and electricity in anhydrous ethanol production plants in Brazil. Three configurations of cogeneration systems were assessed: traditional Rankine Cycles with backpressure and condensing steam turbines and BIGCC. A process integration analysis was performed to promote important energy savings in bioethanol process as a whole.

Dias et al. [11] made a simulation of a full scale plant producing bioethanol from sugarcane bagasse and juice, considering a three steps hydrolytic process of bagasse, concluding, if the maximum availability of lignocellulosic is desired, sugarcane trash as fuel is mandatory and double-effect distillation means a better option.

Pina et al. [12] went through a study of process steam demand and water usage by means of energy integration; analyzing two configurations, one of all sugarcane juice used for ethanol, and a second one of 50%–50% juice distribution for sugar and ethanol production; they confirmed that thermal integration reduced steam demand by 35% and water usage by 24% and 13% in each case.

Renó et al. [13] compared the thermodynamic and environmental performance of five cases of biorefinery, for biofuels and energy production.

Pellegrini and Oliveira Jr [14] present a comparative thermoeconomic study of supercritical steam cycle and gasification –based systems. Supercritical system analyzed incorporates reheating and regeneration systems, however, evaluating impact of these alternatives on the cycle is not the main objective of the work. Main conclusions is that supercritical steam cycles are not suitable for small installed capacity, being feasible only for big ones due to problems related to turbine first stages operation with small mass flows (reduced volumetric flow) requiring very small blades, including inefficient design related to leakage between stages.

Morandin et al. [15] analyzed best trade between operating costs and plant complexity to exploit best options of process integration and combined heat and power (CHP), showing a CHP system fueled with bagasse, as base case, will cover all process heat demand and still sold 153 kWh/tc to the grid.

A similar study conducted by Guerra et al. [16], analyzed influence of steam parameters and incorporation of reheating and regeneration systems over cogeneration systems in Brazilian sugar and alcohol sector, using thermodynamic and environmental indicators. However, this study does not address neither how reheat and regeneration operating parameters of the system should be selected, nor the influence of number of regenerators on the performance of the cogeneration system.

A deep analysis of more recent and significant bibliography, indicates that results of the R&D efforts had been given to the integration of energy and production processes and systems, the possibilities of novel combined systems with high steam pressure and temperatures, also to sugarcane trash as additional fuel source, to bioconversion of biomass, to energy and exergetic efficiency; confirming, in this way, the originality and novelty of the study done about options that reinforcing of steam by reheating and similar recovering alternatives presents, in obtaining better efficiency in CHP integrating procedures.

This study evaluated thermodynamic scenarios to improve