INTEGRATION OF BIGCC BASED-SYSTEMS TO SUGARCANE MILLS

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Abstract. Current technology used for power and heat generation in sugarcane mills presents low exergetic efficiency (around 20%) when compared to other technologies. The technology employed is based on back-pressure steam turbines that uses steam generated at 300°C@21 bar in bagasse-fired boilers. These turbines are used to provide electro-mechanical energy to the process and back-pressure steam (127°C@2.5 bar), used in heating processes. In most cases, the electricity generation intends to attend only the internal demand, since the price paid by the grid for this electricity is not considered advantageous for the mills. However, in perspective to changes in the electric sector, many studies have been done in order to demonstrate the techno-economical feasibility of sugarcane-based electricity. In this sense, the introduction of biomass gasification based cycles is the option with the greatest potential for electricity generation. On the other hand, it is known that its use is restricted to mills, which require less than 350 kilograms of steam per ton of crushed cane. In so, this paper aims in determining a strategy to thermal integration of BIGGC based-systems to sugarcane mills, through additional burning of bagasse in boilers to meet the mills' heating requirements.

***Keywords**: sugarcane mills, bagasse, gasification, cogeneration, thermal integration*

1. Introduction

The gradual thermal integration of cogeneration cycles based on bagasse gasification to sugarcane mills has been studied by Larson and co-workers (2001). In that work, a partial BIGCC *(Biomass Integrated Gasification Combined Cycle)* cogeneration system was coupled to existing cogeneration equipment to meet the steam requirements of the process. Systems established upon back-pressure steam turbines and condensing-extraction steam turbines were considered during the intermediate steps of the steam consumption savings. However, full thermal integration was only possible for steam consumptions below 280 kg/tc (mass of steam consumed per ton of cane crushed) (Larson et al., 2001).

Rodriguez and co-workers (2003) proposed the use of natural gas as an energetic complement to the produced gas in gas turbine operation. The work evaluated the co-firing of gas derived from biomass and natural gas in combined cycles. Following this idea, Zamboni et al. (2005) compared (via an Exergy and Thermoeconomic analysis) that option with a combined cycle configuration, in which natural gas is burned in a gas turbine and sugarcane is burned in the Heat Recovery Steam Generator (HRSG). The results showed that systems based on bagasse gasification were more efficient, but the high costs associated to the gasification system made these systems less favorable from a thermoeconomic view. Nevertheless, the use of such hybrid systems is restricted to regions where both natural gas and sugarcane bagasse are available. Also, the introduction of a fossil fuel jeopardizes the environmental performance of bagasse based cogeneration systems.

Thus, this work seeks to establish a thermal integration strategy of BIGCC systems to sugarcane mills, through additional burning of bagasse in boilers to meet the requirements of the process. In this sense, two systems are proposed: one that burns sugarcane bagasse in the HRSG, and another that uses bagasse in additional boiler.

2. Data used

The data used in developing the analysis was taken from an actual mill, after measurements made by the authors in July of 2004. As a result, it was determined: the amount of cane crushed, bagasse production, steam consumption, and the steam's generation condition. It is important to highlight that the present work does not intend to evaluate the gains in the electricity generation due to the introduction of BIGCC systems. Regarding this issue, the authors suggest the works of Walter and Overend (1998a e 1998b), and Arrieta and Sanchez (1999).

Table 1 shows the data considered in the analysis.

Table 1 – Operation data of the mill

Amount of sugarcane crushed	20,756	t/day
Bagasse production	222.3	t/hour
Steam production	482	t/hour
Specific steam consumption	557	kg/tc
Specific electro-mechanical energy consumption	33.8	kWh/tc
Energetic efficiency	67	%
Exergetic efficiency	22	%

According to the chief engineering manager in the Mill, 5% of the produced bagasse must be stored for safety operation. Therefore, the amount of available bagasse has been set to 210 t/hour for the analysis.

3. Gasification Model

Gasification is a thermo-chemical process in which a fuel, solid or liquid, is fragmented with the use of heat, in an oxidizer atmosphere, for the generation of a gas (mixture of gases) with low/medium heating value. This process is an alternative to the combustion of solid and liquids fuels.

The model considered in this paper is the same proposed by Pellegrini and Oliveira Jr (2005), which is based on a chemical equilibrium approach for the gasification process. The model consists in the minimization of the Gibbs free energy of the produced gas, constrained by mass and energy balances for the system and the use of parameters to account for kinetic aspects, as proposed by Li et al. (2004).

Pellegrini and Oliveira Jr. (2005) identified an optimum operation region for air ratios *(*Φ*)* varying from 0.15 to 0.30. Thus, in this paper it is used an air ratio value of 0.25, which results in the following produced gas composition – Tab. 2 – (for 20% moisture content), after the cleaning stage (assumed gas temperature of 25°C):

Table 2 – Produced gas composition

Component	Molar fraction (%, wet basis)
CH_4	3.23
CO	11.33
CO_2	18.37
H_2	25.08
H_2O	3.17
N_2	38.82

The lower heating value of the produced gas is 5001 kJ/kg.

4. Proposed Systems

As stated previously, this paper proposes two systems:

a) BIGCC system with an additional bagasse fired boiler.

→ In this configuration, part of the bagasse generated is sent to the gasifier, and the rest is used to run a conventional steam generation boiler to meet the process' requirements (Fig. 1).

b) BIGCC system with bagasse burning in the HRSG.

→ In this configuration, part of the bagasse generated is sent to the gasifier, and the rest is burned in the HRSG, with air injection if necessary (Fig. 2).

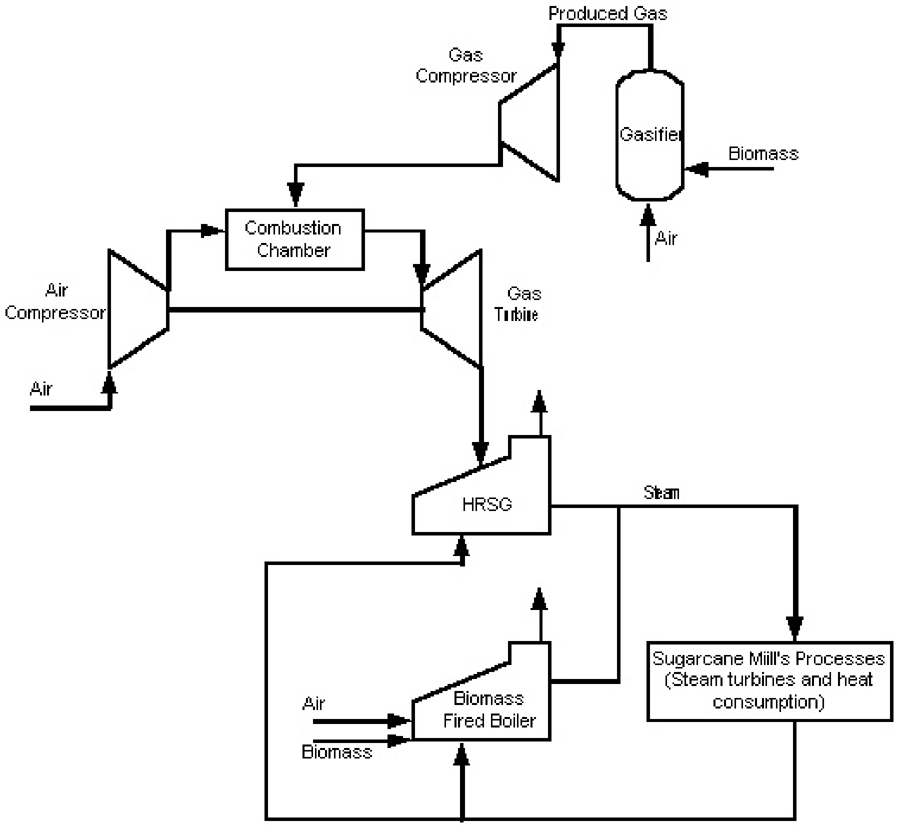

Figure 1 - BIGCC system with an additional bagasse fired boiler.

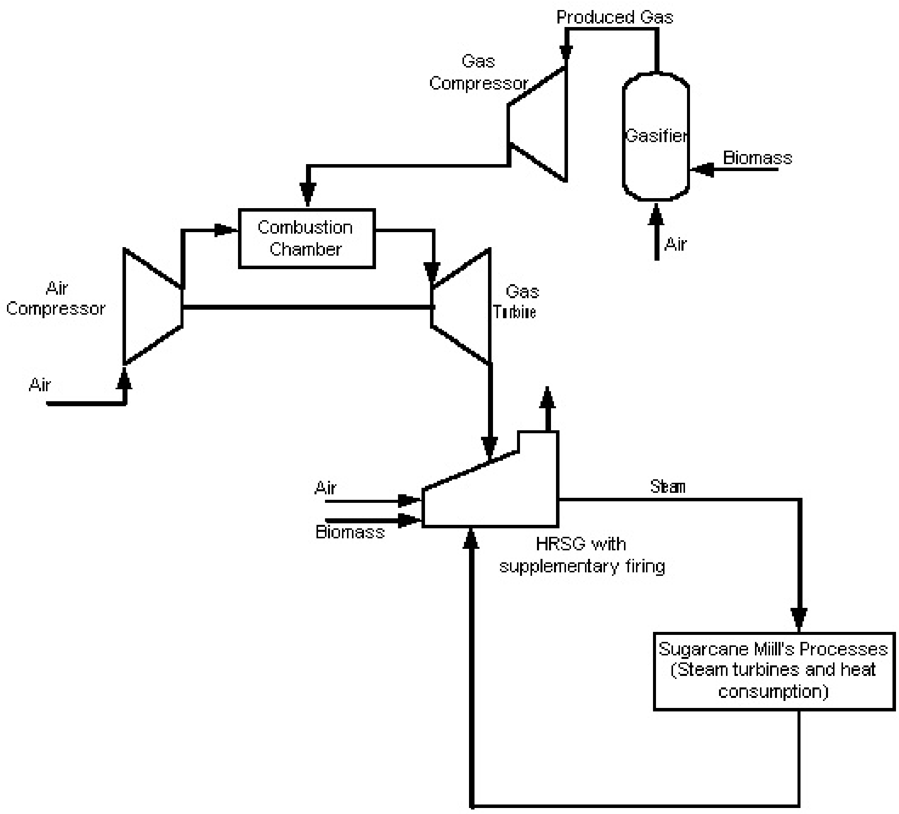

Figure 2 - BIGCC system with bagasse burning in the HRSG.

4. Modeling and Simulation of the Systems

All gaseous components have been modeled as perfect gas, and the bagasse enthalpy was calculated following the procedure presented in Pellegrini e Oliveira Jr (2005). Other important values used in the simulation can be found in Tab. 3.

Table 3 – Values used in the simulation

Moisture content in the bagasse sent to gasification	20%
Moisture content in the bagasse sent to boilers	50%
LHV of bagasse (50% moisture)	8026 kJ/kg
Temperature of the gases leaving the combustion chamber in the gas turbine	1200ºC
Compressor isentropic efficiency	85%
Gas turbine isentropic efficiency	85%
Temperature of the steam generated	300ºC
Boiler pressure	21 bar
Energetic efficiency of the bagasse fired boiler*	80%
Air excess coefficient for bagasse fired boilers	1.35
Temperature of stack gases in the HRSG	200ºC

* In accordance to values of existing boilers in the sugarcane mill

The systems were simulated using EES software (2004). The pressure ratio (PR) in the gas turbine was chosen in order to maximize the net power produced, also, considering the power consumption in the produced gas compressor. Figure 3 shows the chosen condition (PR = 25).

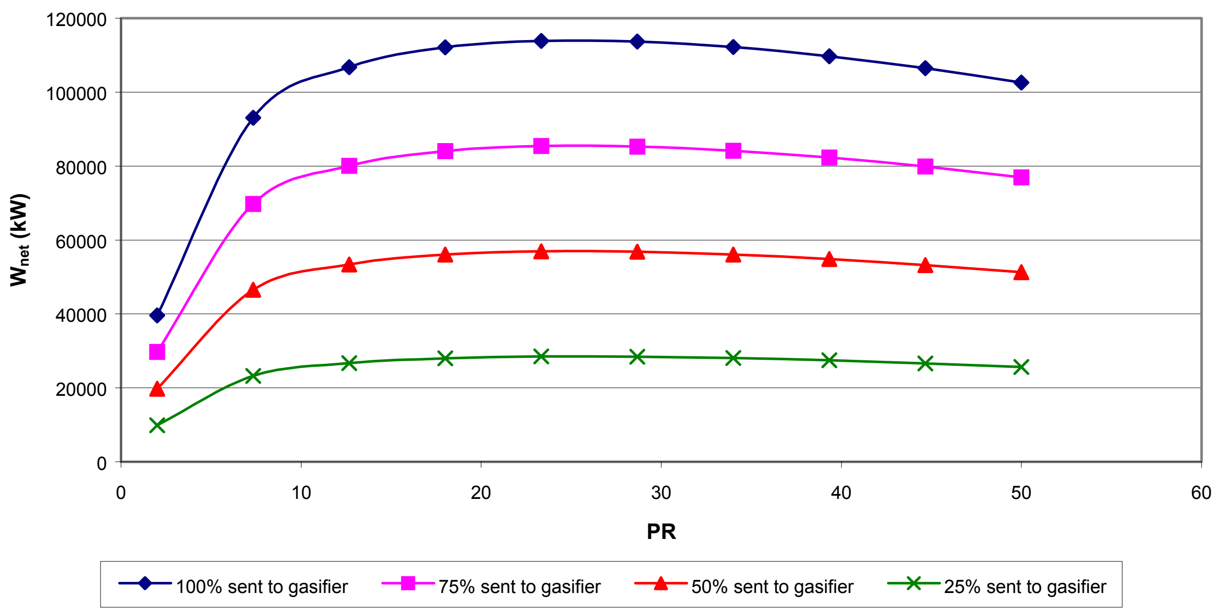

Figure 3 – Produced net power for various pressure ratios

The curves were drawn taking into consideration different amounts (from 25% to 100%) of the available bagasse sent to the gasifier. The following charts were drawn considering different percentages of the available amount of bagasse sent to the gasifier.

5. Results

It has been noticed that the thermal integration of BIGCC systems to the requirements of the mill is only possible for configurations with bagasse burning in the HRSG, and when the amount of bagasse sent to gasification is below 50% of the available amount.

Systems with bagasse-fired boilers allow full integration when all available bagasse is consumed, and only 10-20% of the total amount available is sent to the gasifier. Yet, this operation is too close to the real needs, so for operational safety these systems should not be adopted before some measures regarding steam economy are made.

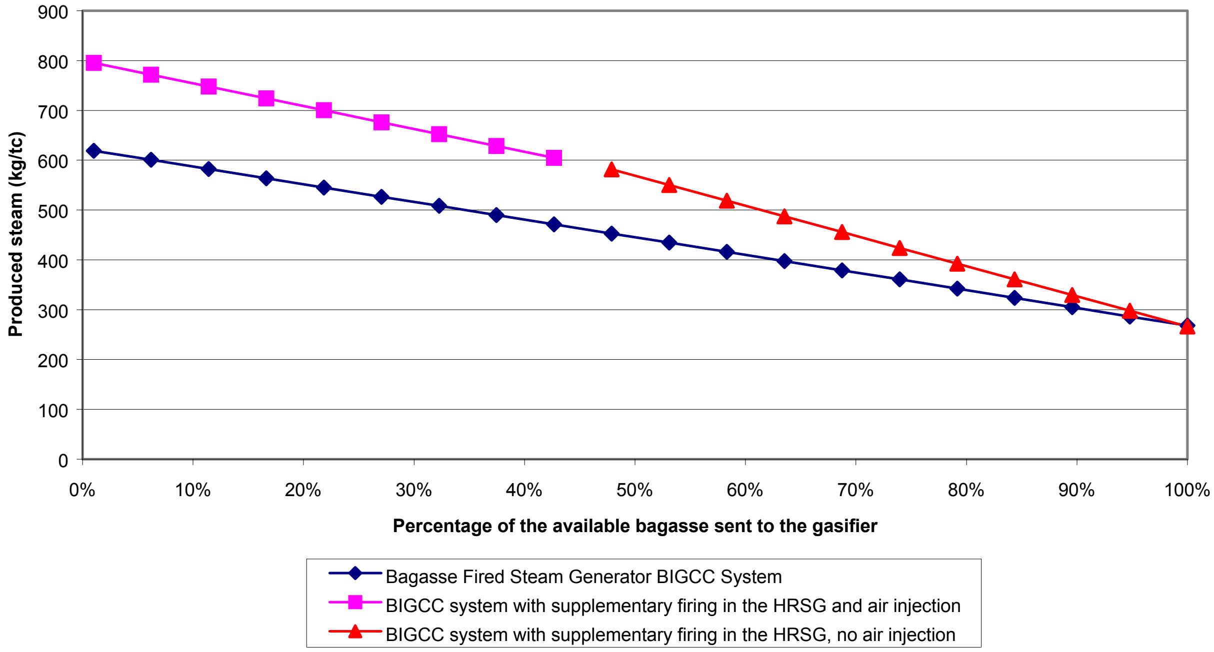

Figure 4 – Amount of steam produced by the systems

In Fig. 4, it can be seen that, for amounts of bagasse sent to the gasifier below 45-50% of the total amount available, it is necessary the injection of air in the HRSG. This necessity is a result of the fact that the quantity of oxygen in the exhaust gases from the gas turbine is insufficient to guarantee the total combustion of bagasse in the HRSG.

It is important to draw attention to the high steam production for amounts of bagasse sent to gasification below 15%. These values should not be regarded as the actual production for these boilers, due to operational conditions imposed in the simulations, which are far more efficient than those of bagasse-fired boilers. One might expect that as more bagasse is sent to the HRSG, this boiler becomes similar to a bagasse-fired one. Therefore, values in Fig. 4 should be regarded as an indication of the superiority of systems with additional firing of bagasse in the HRSG over the ones with additional bagasse-fired boilers.

Another significant issue concerns the steam production in the bagasse-fired boiler in the simulations. When all available bagasse is sent to the boiler, it should be expected that the steam production would be similar to the value shown in Tab. 1. However, the results are higher because the LHV value considered in the simulation is also higher than the one used to calculate Tab. 1. This hypothesis was made to be in accordance to the gasification model adopted.

From an exergetic point of view, the system with an additional boiler destroys more exergy than the one with additional firing in the HRSG. It is because of the higher irreversibilities associated with the bagasse-fired boilers. The air injection in the HRSG increases the destruction of exergy, because there is an increase in the temperature difference between reactants and products. As more bagasse is sent to gasification, the lesser become the irreversibilities of the system, since the rate of combustion reaction is lowered, and less mass flow rates are added. Figure 5 illustrates these results.

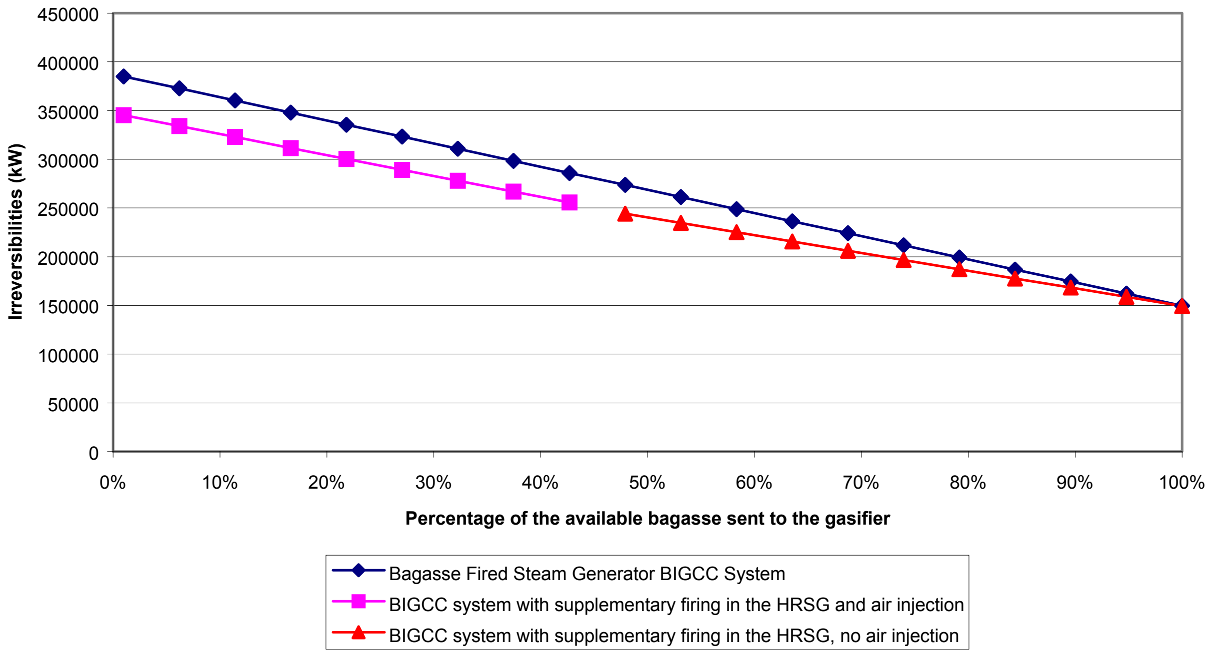

Figure 5 – Irreversibilities in the systems

6. Conclusions

It is possible to develop a strategy to integrate BIGCC based systems to sugarcane mills, without changes in the requirements of the process. However, it is required investments in acquiring more efficient boilers, gas turbine systems, gasification systems, and personnel training.

Among the systems studied, only the one with additional firing and air injection in the HRSG should be considered to full integration with a sugarcane mill. This system allows the additional production of 70 kWh/ton of cane crushed regarding the current operation.

Nonetheless, the development of more rigorous models for the HRSG must be studied, allowing the evaluation of the real gains derived from the adoption of such systems. This model should include the influence of moisture, excess air, exhaust gases conditions, and work with more elaborated thermodynamic properties database. It would avoid a very efficient (impractical) behavior of the HRSG, when low amounts of bagasse are sent to gasification.

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