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RANKINE CYCLE ASSESSMENT FOR COGENERATION IN SURGARCANE BIOREFINERIES WITH SECOND GENERATION BIOETHANOL PRODUCTION

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Abstract. *The purpose of the Rankine cycle cogeneration system assessment is to find the thermodynamic cycle parameters for reaching the maximum power generation and second generation bioethanol production in sugarcane biorefinery of 300 tc/h of milling capacity. A condensing extraction steam turbine Rankine cycle with a deaerator and temperators was modeled in the Gate Cycle ™ software. The turbine steam inlet pressure and temperature changed in the range 50-66 bar and 335-395°C respectively, while the deaerator operating pressure was ranged between 2,5 and 13 bar. One value of process steam consumption were adopted: 500 kg/tc. The results included the generated power and the bioethanol production as function of the variables aforementioned. We have concluded that when the turbine inlet temperature and the deaerator pressure were fixed, if the turbine inlet pressure raises, both increase, the generated power and the bioethanol production. We have also noted that at constant turbine steam inlet pressure and deaerator operating pressure, if the turbine inlet temperature raises, the generated power increases while the bioethanol production falls. Finally, at fixed turbine steam inlet pressure and temperature, if the deaerator operating pressure raises, the generated power operaters at the maximum value while the bioethanol production operates at the minimum one and vice versa.*

Keywords: *Second generation bioethanol production, Rankine cycle, Cogeneration, Thermal schematic simulation.*

1. INTRODUCTION

In Brazil, first generation ethanol has been produced from sugarcane on large scale for more than thirty years (Soccol et al., 2010). However, the production of second generation bioethanol started in 2014, and several studies are being developed to improve it. The increased energy demand, the progressive depletion of fossil fuel reserves and the consequent rise in prices are some of the reasons that have encouraged the use of bioethanol as a replacement for gasoline or additive.

2. LITERATURE REVIEW

The second generation bioethanol, derived from lignocellulose material, has advantages over the first generation as it does not compete with food production, abundance and low price of feedstock (Cucek et al., 2011). Thus, the production of second generation, by using sugarcane bagasse, integrated with the first generation of ethanol increases the viability of the process. In comparison with a stand-alone second generation unit, the integrated process will require a lower investment, because some operations, such as fermentation and distillation, may be shared between both plants (Dias et al., 2009).

Since sugarcane bagasse is used as fuel in boilers for the conventional production of steam and electricity, the amount of lignocellulose material used for the production of bioethanol depends on the energy consumption of the production process. Thus, the configuration of the cogeneration system, by defining parameters such as boiler pressure, the consumption of biomass, the turbine efficiency and others, have significant impact on fuel consumption and power output (Dias et al., 2012).

Several authors have evaluated the integration of first and second generation ethanol production, and also the power and steam consumption, through simulations and optimization tools. Furlan et. al (2012) evaluated process demands and indicated optimal process configurations. The authors have concluded that with the production of second generation bioethanol, the thermal demands increased by at least 25% and the surplus electric power decreased at least 31%, which have a great economic impact, since electricity is used in the industry. Dias et al. (2009) conducted simulations and thermal integration analysis of traditional distilleries. The simulations were carried on a large capacity cogeneration system and two distillation columns configurations (single-pressure and double-effect) were considered. After the simulations, similar results were obtained for ethanol production, however, the double-effect configuration provided less energy generation in 19.5kWh/t. In another study, Dias et al. (2011) evaluated the distillation and improved heat integration of bioethanol plant systems. Four configurations were studied. The results of the double effect distillation with thermal integration process showed lower steam demand, 226kg/tc, and the conventional distillation configuration without thermal integration achieved the highest energy production, 62.66kWh/tc. However, the steam demand was only 468kg/tc. Walter and Encinas (2010) analyzed the second generation biofuels production. The study was conducted by computational simulations of high pressure steam cogeneration plants (90 bar, 520ºC) with two alternative routes to a conventional distillery. The bagasse hydrolyze system studied by the authors presented a yield of 15,9 m³/h of second generation ethanol and 27,4 MW of surplus electricity production. Rocha et al. (2012) evaluated the chemical composition and the use of pretreatment in sugarcane bagasse for ethanol production. They used 20 bagasse samples with 50% humidity and pretreated with steam explosion up to a pressure of almost 1,3 MPa and 190°C. The authors concluded that the cellulose concentration obtained after the pretreatment was approximately 14% higher than the samples without the same process. Placio-Bereche et al. (2013) made an exergetic analysis of ethanol production from first and second generation for a new bagasse hydrolysis process. They considered a conventional cogeneration system with steam at 67 bar and 480ºC supplied only with the amount of bagasse required for steam production. After the analysis, they verified that the exergy destroyed by the new process was between 7 and 10%, but the exergetic efficiency was approximately 12% more than in the conventional system. Dias et al. (2013) analyzed the cogeneration integrated first and second generation ethanol from sugarcane. They evaluated different configurations of boiler pressure, temperature, steam demand, among others. Economic analyzes were used to compare the different settings. The authors concluded that second generation systems with low pressure boiler, 22 bar, and electrical production integrate can be profitable and, high pressure systems produce more electricity available for sale.

3. METHODOLOGY

In this work, simulations of a Rankine cycle for cogeneration in a biorefinery sugarcane of 300 tc/h of milling capacity were carried out using GateCycle™ Software. The parameters of Rankine cycle cogeneration system, such as turbine steam inlet pressure and temperature, steam consumption in the process and the deaerator operating pressure were evaluated for maximum power generation and second generation bioethanol production. Details about the Rankine cycle and data for simulation procedures are explained below.

3.1 Rankine Cycle cogeneration GateCycle™ description

The study was developed in a cycle with a main line pressure and three secondary lines (13 bar, 6 bar and 2.5 bar), used for steam supply the sugarcane processing. The cycle schematic, which was modeled in the GateCycle™ software, can be observed in Figure 1.

In the main line, there is a flow distributor used for supply water compressed to steam temperature control in the secondary lines. The main distributor flow is directed to the boiler and heated to the necessary condition of steam. The steam turbine has four levels of extraction where, in three conditions of pressure, the steam flow is extracted and the remainder flow is expanded until the condenser.

The secondary lines are used to steam supply three stages of sugarcane processing. The steam extracted from each level of pressure can be divided into two lines: primary, directed to the sugarcane processing and the optional, used to supply the deaerator. The deaerator is set to work with any of the three pressure levels, to the best performance of the cycle. For the two biggest steam pressure level, separated for the primary flow, it may be mixed with the compressed liquid, extracted from the distributor, to reach the steam saturated condition.

3.2 Process simulation

After preparing the cycle configurations, a base simulation was executed to assess the system's operation. Input data were based on a small plant milling capacity, low vapor pressure (22 bar, 300°C), and the deaerator steam pressure set to work at 2.5 bar.

To expand production of sugarcane plant, new working conditions were used. The boiler was modified to operate at steam pressures of 50 bar to 66 bar and temperatures of 335ºC to 395ºC. All deaerator pressure settings (2.5, 6 and 13 bar) were used to evaluate the performance and yield of the thermal cycle temperature and pressure conditions selected for the boiler. Table 1 shows the main data used for the simulations of the cycle. Other data used for the simulation that were keep constant are: 85% of boiler efficiency, 85% of pumps efficiency, 80% of turbine isentropic efficiency, 10 kPa of condenser operating pressure, mechanical draft cooling tower with 3 bays, 80% of fan efficiency.

Table 1. Typical values of sugarcane process.

Parameters	Value	References
Milling capacity	300 tc/h	-
Sugarcane fibers content (50% humidity)	30%	Dias et. al (2011)
Lower heating value of bagasse	7500 kJ/kg	Dias et. al (2011)
Steam demand		
Pretreatment Hydrolysis	78 kgv/tc	Rocha et. al (2012)
Alcohol Second Generation	72 kgv/tc	Palacios-Bereche et. al (2013)
Sugarcane & Distillery	500 kgv/tc	Palacios-Bereche et. al (2013)
Steam pressure		
Boiler	50 bar - 66bar	-
Pretreatment Hydrolysis	13 bar	Rocha et. al (2012)
Alcohol Second Generation	6 bar	Palacios-Bereche et. al (2013)
Sugarcane & Distillery	2.5 bar	Palacios-Bereche et. al (2013)
Deaerator	2.5 bar/6 bar/13 bar	-
Steam temperature		
Boiler	300ºC - 395°C	-
Pretreatment Hydrolysis	191.6 ºC	Rocha et. al (2012)
Alcohol Second Generation	158.8 ºC	Palacios-Bereche et. al (2013)
Sugarcane & Distillery	127.4 ºC	Palacios-Bereche et. al (2013)
Deaerator	127.43ºC/158.85ºC/191.64ºC	-

4. RESULTS AND DISCUSSION

Fig. 1 represents the simulation results of the cycle proposed in the initial settings, mentioned in the previous section. With the plant configured for producing sugar and ethanol 1G, the installation has output capacity of approximately 45 tons of sugar and 24.5m³ of anhydrous ethanol per hour.

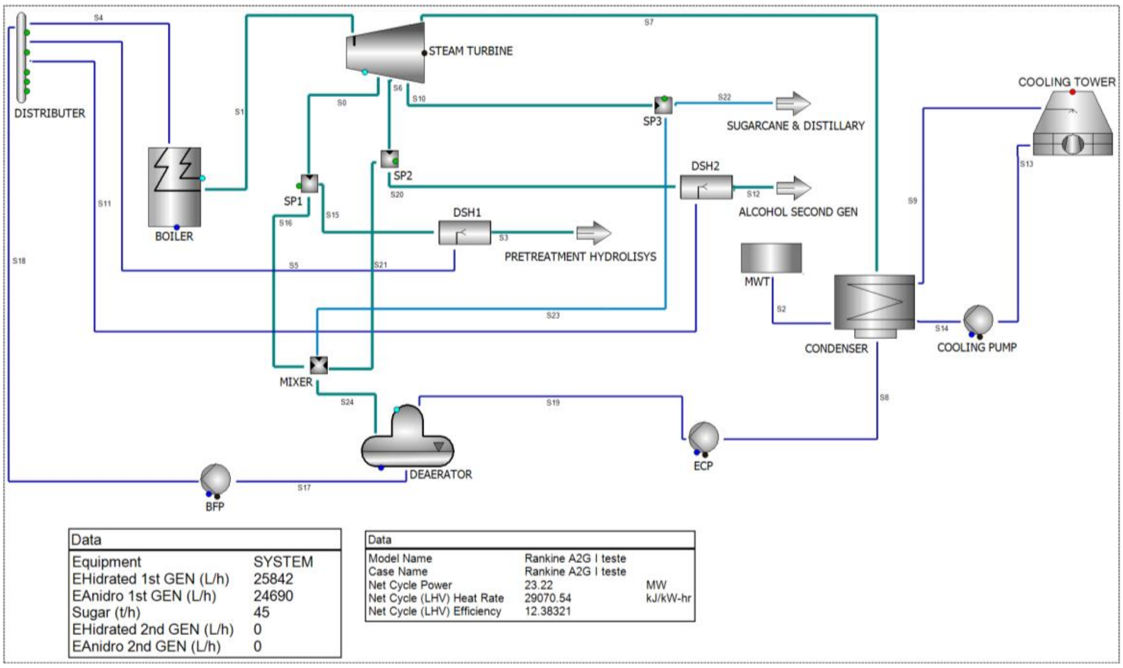

Figure 1. Rankine cycle cogeneration system.

The Power generation values, for the Rankine cycle evaluated, were obtained according to the operating settings used in the deaerator (2.5 bar, 6 bar and 13 bar). Fig. 2 shows the results for the three power generation configurations according to the inlet working fluid temperature and pressure on steam turbine. The condition that generated the greatest power output, ~31.90MW, occurred in the boiler temperature and pressure of 395ºC, 66 bar and the deaerator set to 6 bar.

The results show that for higher steam inlet temperatures and pressures, higher power generation values are obtained. This occurs because with the increased pressure in the boiler, there is an increase of boiling temperature of the fluid, so the average temperature from which heat is transferred to the steam is also increased. Thus, the steam will have higher exergy, increasing the cycle efficiency, as seen by Oliveira (2014).

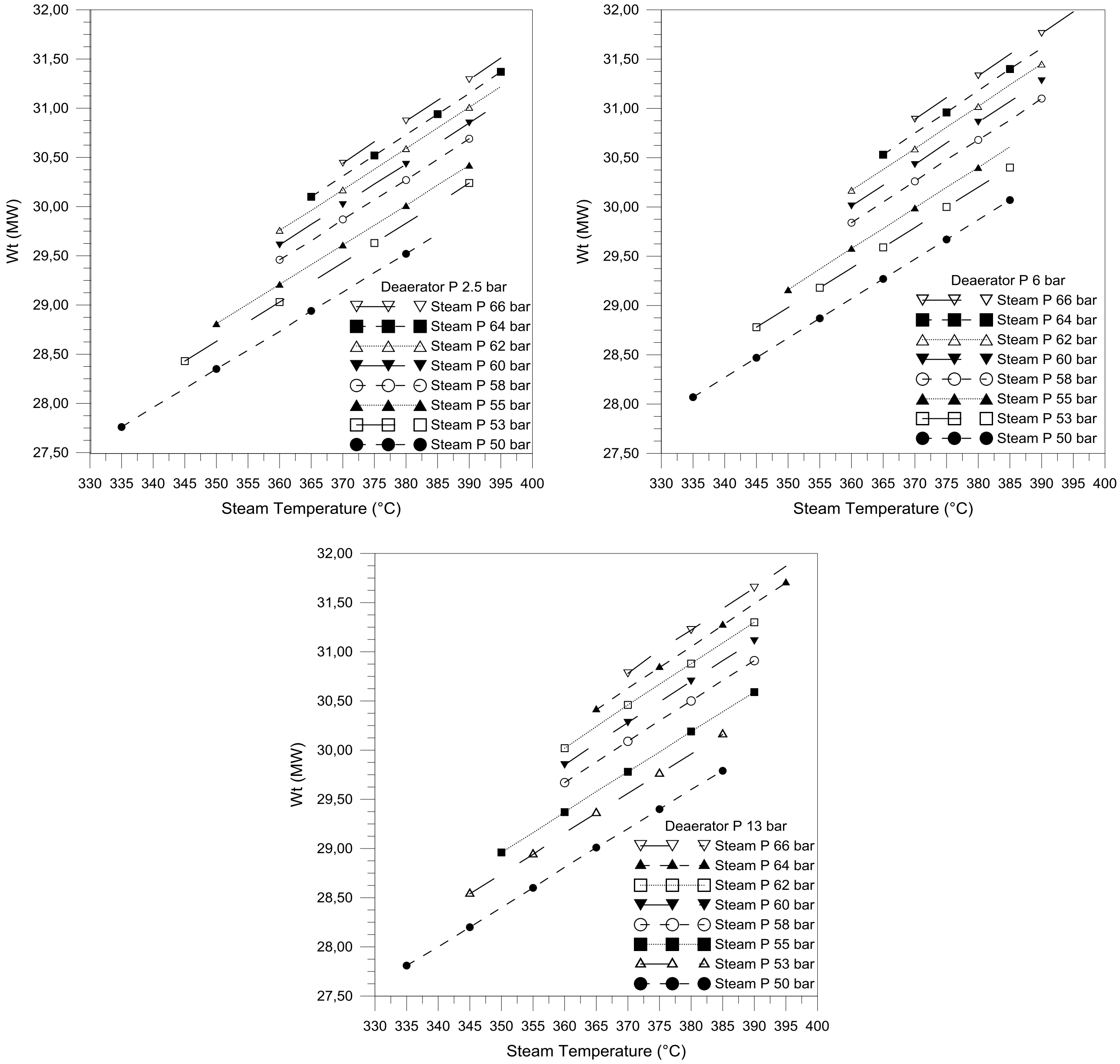

Figure 2. Extended operational configuration results.

Fig. 3 shows the power generation according to the deaerator operating pressures. Three steam inlet temperatures were adopted (370°C, 380°C and 385°C) and three pressure values (50 bar, 58 bar and 66 bar). As expected, at higher pressure and temperature in the boiler, 385°C 66 bar, higher values of power generation are obtained, mainly for a deaerator pressure of 6 bar. The performance curves in Fig. 3 also shown the generated power behavior along the deaerator pressure range. According to the results, if there were a set up of another steam turbine extraction to supplement the deaerator of this plant, the extraction pressure would be approximately 8 bar, on average, for all conditions presented.

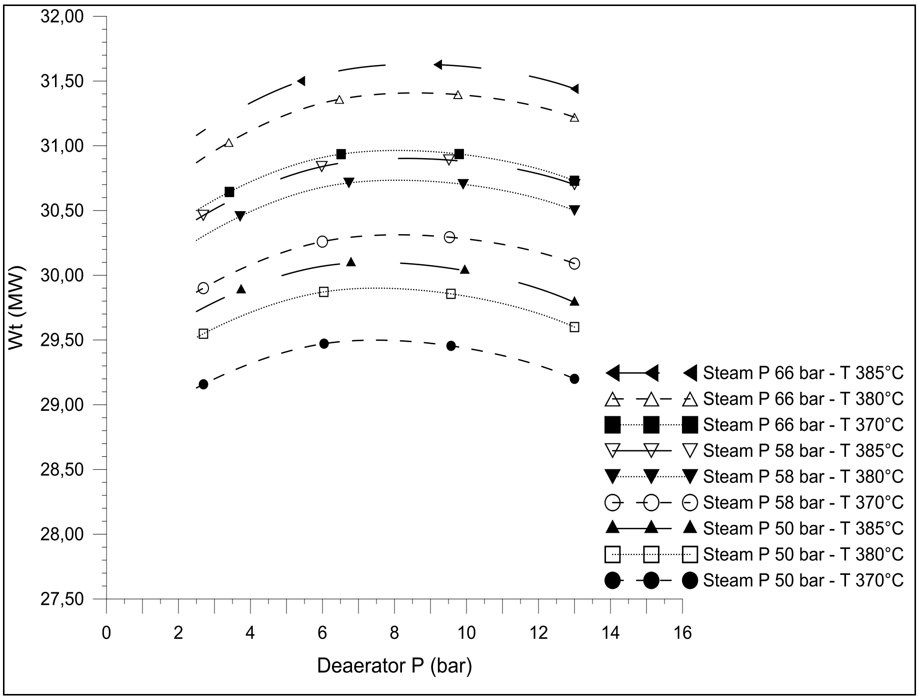

Figure 3. Net power generated with variation of the input parameters.

Fig. 4 shows the production of bioethanol second generation according to the deaerator pressures and the same pressures and temperatures used for power generation were adopted. For operating pressure of 6 bar, there is less production of ethanol compared to pressures of 2.5 bar and 13 bar. This occurs because it is used most of the lignocellulose material to energy production rather than for the production of bioethanol, on the other hand, in order to maximize the power, less steam is available for second generation ethanol production. About the steam inlet pressures and temperatures, the results show that the variation of pressure is not so significant for bioethanol production, when compared to power generation, as seen by Dias (2012). Furthermore, at lower temperatures, there is increased production of second generation bioethanol.

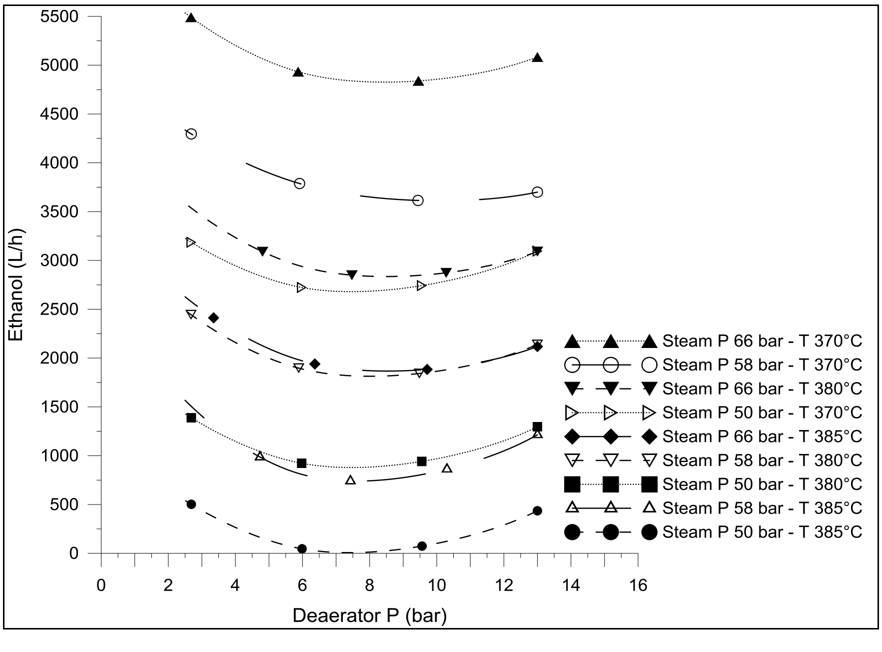

Figure 4. Second generation ethanol produced with variation of the input parameters.

5. CONCLUSIONS

The cogeneration system in a 300 tc/h of capacity sugar cane biorefinery was evaluated in order to obtain maximum power generation and bioethanol when it was integrated into the first generation ethanol. In this sense it is possible to express de following conclusions:

- Operating the boiler at maximum temperature and pressure is possible to obtain the maximum power at any deaerator operating pressure;
- However, more bagasse is consumed per amount of steam produced, thus the benefits of employing high pressure must be evaluated relating to the second generation bioethanol production;
- To set the deaerator operating pressure should depend on the plant and market, because according to the variation of this parameter an inversely variation in the production of second generation bioethanol with respect to the generated power could be observed;
- The maximum power was obtained at 6 bar of deaerator pressure. At this condition the generated power and the second generation ethanol production could reach about 32 MW and 5500 L/h.

6. ACKNOWLEDGEMENTS

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