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EXERGETIC ANALYSIS OF A SUPERCRITICAL COGENERATION SYSTEM PROPOSED FOR A SUGARCANE MILL PRODUCING SUGAR AND ETHANOL

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Abstract. *The world's concerns about the decrease in the availability of some fossil energy sources, the pollution generated by most of them and the concept of sustainable development, make the use of cogeneration systems based on the use of biomass an important topic of research. In this scenario, supercritical steam cycles are a good alternative for cogeneration thermal power plants, as they can achieve higher efficiency values compared to subcritical steam cycles. In Brazil, the cogeneration of biomass from agricultural waste, especially from sugarcane, replaces the use of fossil fuels with a renewable source of energy, providing environmental benefits. Currently, the cogeneration systems of Brazilian sugar and ethanol process operate with sugarcane bagasse available, in subcritical thermal cycle. Given that the supercritical steam generation technology is well defined and widespread in the world, it is interesting to analyze the possibility of cogeneration of sugarcane wastes under these operating conditions and to assess its feasibility in the country. Thus, this work aims to carry out a thermodynamic analysis of a supercritical cogeneration plant operating with sugarcane bagasse as a fuel. The modelling of the electricity generation process is done through mass and energy balances, using a Rankine thermal plant with closed regenerators and reheating system.*

Keywords: *exergy analysis, cogeneration, biomass, sugarcane, bagasse, supercritical cycle.*

1. INTRODUCTION

Brazil is in a privileged position with approximately 40% of its energy matrix made up of renewable resources (EPE, 2021). In this scenario, sugarcane residues have an important role in the brazilian energy matrix, going from 5% in 1970 to 15% in 1985, and today it is at 16.9% (GORAYEB and BRANNSTROM, 2016). Sugarcane is one of the main crops in the country and in recent years the sector has been more concerned with aspects of energy efficiency as well as the treatment and disposal of its waste. One of the products with great capacity for expansion in this industry is bioelectricity, produced from cogeneration systems (CASTRILLÓN, 2017).

The production of electric energy in cogeneration systems applied to sugarcane mills use bagasse as fuel, being this a traditional practice in this segment. From the biomass produced by its production process, the potential for generating excess electricity has as main parameter the technological alternative adopted for the thermoelectric cogeneration cycle, the growth of the sugarcane crop, the technical changes to reduce specific consumption of mechanical, thermal and electrical energy in the production process of sugar and alcohol and the harvest method adopted (ROMÃO, 2009).

The mills in operation have a self-consumption of electrical energy from the plant (12 kWh/ton-cane) and the use of mechanical energy (16 kWh/ton-cane). Furthermore, the plants use about 330 kWh/ton-cane of thermal energy (ENSINAS, 2008). For these mills to increase the efficiency of electricity generation, the evolution of cogeneration systems would be necessary. In addition to the simple improvements to low pressure steam cycles, the normal way would be to use high pressure cycles with extraction-condensing turbines and reduce the steam consumption of the processes. These technologies are commercial and, in recent years, have begun to be implemented by several plants (ENSINAS, 2008).

The increase in steam pressure and temperature helps to enhance the generation of excess electricity in traditional cogeneration systems. It is proposed in this work to study what would happen if a cogeneration system were developed using supercritical conditions of steam, using reheating and regenerative heat exchangers systems to heat the return condensate. This type of configuration represents the most efficient systems for generating electricity based on the Rankine Cycle. Supercritical plants for power generation have been used since the 30’s, mainly in Europe (CASTRILLÓN, 2017). In the United States, the first supercritical plants were developed in the 50's and 60's. Countries like China, Japan, United States, Germany and Denmark will adopt new technologies for the generation of energy using coal as fuel. These technologies were developed to generate electricity more efficiently and with less environmental impact than conventional power plants. The first 100 MW coal-fired supercritical cogeneration plant was built in Russia and started operating in Kashira in 1966, it had steam conditions of 306 bar and 565 °C (CASTRILLÓN, 2017). Progress in the development of new materials and increasing demand for more efficient power generation units have made supercritical plants the best option for coal-fired power plants around the world (ŁUKASZ, ANNA and JANUSZ, 2015).

The present work aims to evaluate the potential of electric energy production for different configurations of the cogeneration system, including steam cycles in supercritical conditions, using a mixture of bagasse and straw as fuel in sugarcane mill producing sugar and ethanol.

2. DESCRIPTION OF CASE STUDIES

The influence of the increase in steam pressure and temperature at the boiler outlet was studied under three conditions. As a first condition (C1), the parameters of steam traditionally used by the sugarcane mills in Brazil, with boilers that use only bagasse as fuel, were established. The second condition (C2) corresponds to the pressure and temperature used in most new projects of cogeneration systems that have been implemented in the sector, with more efficient boilers and which have energy recovery systems from exhaust gases, such as pre-heaters. air and economizers; different sugarcane mills have this type of technology. The third condition (C3) refers to a more advanced system, which works with steam reaching supercritical conditions, which are not yet used in the sugar and ethanol sector, and which may, however, provide an increase in the potential of electric generation in the future and an increase in efficiency. These three conditions can be seen in Tab. 1.

Table 1. Operating conditions as a function of the pressure and temperature of the steam generated.

Steam Condition at the Boiler Outlet	Pressure (bar)	Temperature (°C)
C1[(1)]	65	480
C2[(1)]	120	520
C3[(2)]	300	600

[(1)](CASTRILLÓN, 2017), [(2)]PELLEGRINI, DE OLIVEIRA and BURBANO, 2010).

2.1 Case I - Steam cycle with back-pressure turbine

This system is characterized by generating only the steam necessary to supply the process, not being able to consume excess bagasse and having its operation restricted to the period of the sugarcane harvest, when the production process is in operation (ENSINAS, 2008). The main disadvantages of this system are the variation in relation to the load change (electrical power is determined by the steam consumption of the process) and the technical-economic limitation in relation to the implementation of high steam parameters (ALVES, 2011).

The figure of the cogeneration system shown in Fig. 1, has a set of biomass boiler and steam turbine in two stages. In addition to the electric generator coupled to the steam turbine, the system also has a deaerator, electric pumps to feed the boiler and condensate return, and a desuperheater to control the reduction of the temperature of the exhaust steam used in the process, both operating with injection of condensate from the cogeneration system itself.

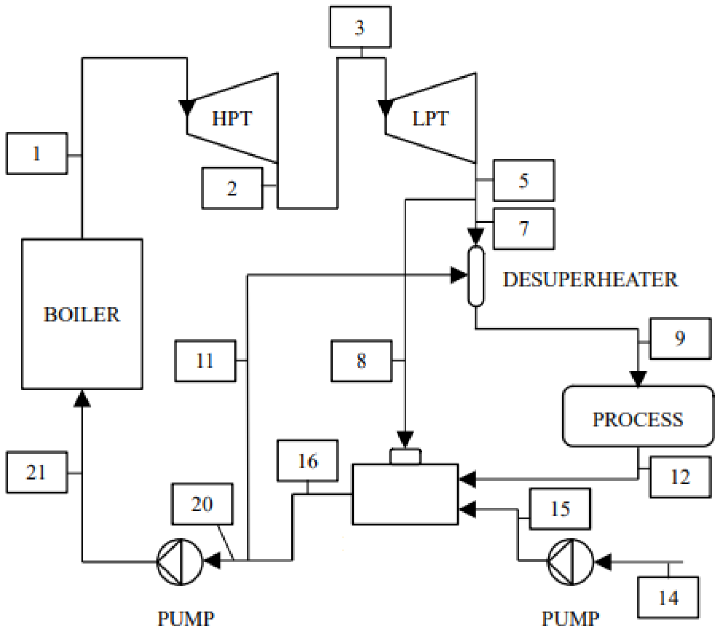

Figure 1. Configuration of the cogeneration system with back-pressure turbine.

2.2 Case II - Steam cycle with extraction-condensation turbine

This system is characterized by the fact that all available bagasse is burned. The use of 30% of dry straw mixed with bagasse as an additional fuel in the cogeneration system would allow a greater production of steam in the boiler and, consequently, a greater amount of excess electricity that could be sold on the grid.

The cogeneration system shown in Fig. 2 is similar to that adopted in case I, with the addition of a third stage of steam turbine that expands up to the operating pressure of the condenser (10 kPa) maximizing the generation of excess electricity.

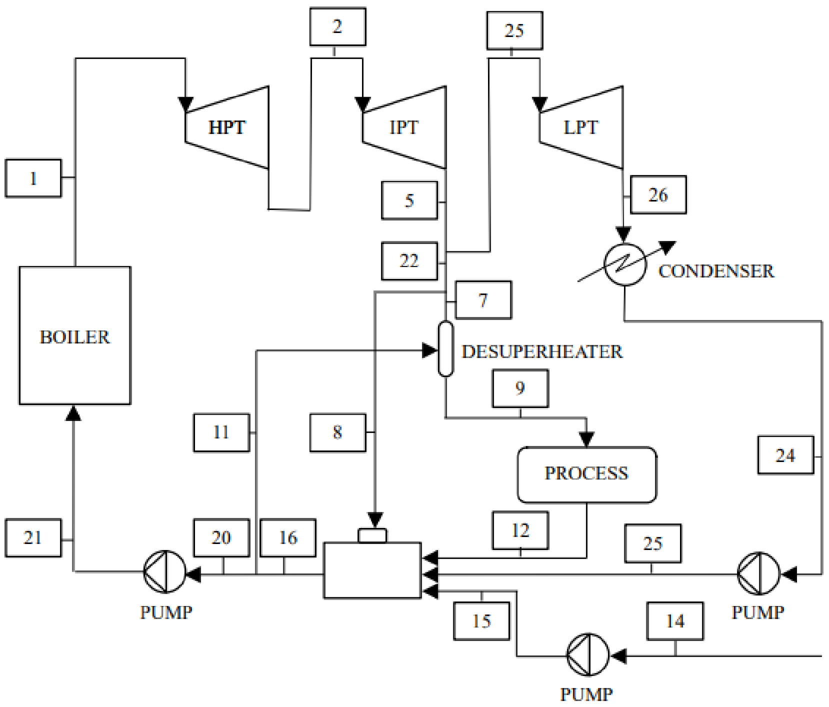

Figure 2. Configuration of the cogeneration system with extraction-condensing turbine.

2.3 Case III – Increase the cycle efficiency of cases I and II with regeneration and reheating

A reheating stage in the cycle is introduced for configurations shown in case I and II with C2 steam conditions. After passing through the high-pressure turbine, the fluid is forwarded to the boiler, where it will increase its temperature to 500 °C at constant pressure and return to the medium turbine to continue the work production and follow the path of the simple cycle. With reheating, the amount of excess electrical energy is greater and the moisture content of the steam in the last stage of the turbine is reduced.

A closed regenerator (shell and tube heat exchanger) will also be added to the configuration. Regeneration occurs through the transfer of heat from two fluid lines, a hot one that needs to be cooled, and a cold one that needs to be heated, the fluids do not have direct contact, in which the boiler feed water passes through the tubes. being heated by steam that passes through the outside where condensation takes place. A steam line will be taken from the high-pressure turbine and sent to the closed regenerator.

It can be seen in Fig. 3 the configurations shown in case I and II modified with regeneration and reheating to increase the thermal efficiency of the conventional cycle.

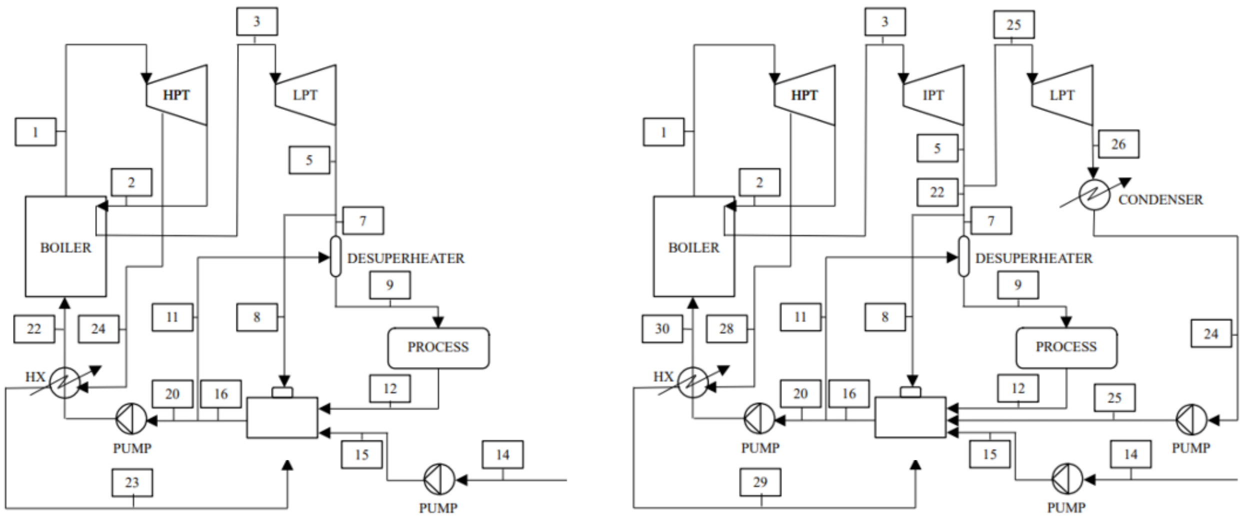

Figure 3. Configuration of cases I and II with additional regeneration and reheating stages.

2.4 Case IV – Supercritical steam cycle

In this configuration, it is proposed to study what would happen if a cogeneration system were developed using supercritical conditions of steam generation, using steam reheating and regenerative heat exchangers to heat the return condensate. This type of configuration does not yet exist in the Brazilian sugar-alcohol industry, but it represents the most efficient systems for generating electricity based on the Rankine Cycle.

As a supercritical cycle operates at pressures and temperatures above the critical point, it needs reheating of the steam leaving the high-pressure turbine to increase cycle efficiency and decrease the percentage of moisture in the last turbine stage, also needs a series of regenerators to increase the temperature of the water before entering the boiler and thus increase the efficiency of the system (PELLEGRINI, DE OLIVERA and BURBANO, 2010). The cogeneration system, shown in Fig. 4, is similar to the one adopted in the configuration with extraction-condensation turbines to take advantage of all the bagasse available and 21% of dry straw in the mixture with bagasse. Steam is generated at 300 bar and 600°C, being reheated to 600°C after expansion in the high-pressure turbine up to 62 bars, considering the highest values practiced (PELLEGRINI, 2009).

3. METODOLOGY

In this work, some configurations of the cogeneration system normally used in the sugar and alcohol sector are analyzed, as well as new technologies that can be used to increase the efficiency in the generation of electric energy, such as the supercritical steam power cycle. Options for steam cycles with different levels of pressure and temperature and the use of counter-pressure and extraction-condensation steam turbines with reheating and regeneration were explored.

The systems were simulated considering as a constraint that the demand for steam and electricity of the process are met by the system that consumes a mixture of bagasse and straw as fuel for the generation of steam. The simulations of the cogeneration case studies were carried out using the Engineering Equation Solver ® program, with which, based on data collected from bibliographic sources, mass, energy and exergy balances, necessary for a detailed description of them. The data referring to the current flows of the systems are presented in the Appendix of this study.

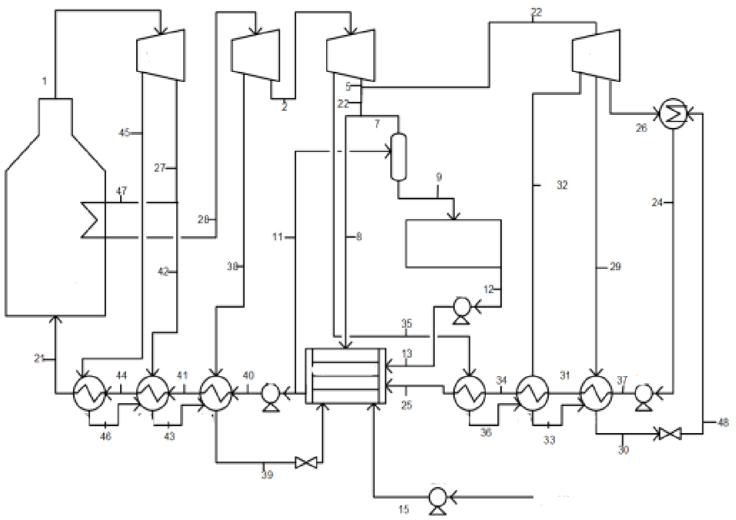

Figure 4. Configuration of the supercritical steam cycle system.

The general characteristics of the cogeneration process of the standard plant, as well as parameters used for the modeling, are described in Tab. 2. These values will be considered in all other cases addressed in this study.

Table 2. Simulation parameters used for the models.

Parameter	**Unity**	**Value**
Processed sugarcane	ton/h	500
Produced bagasse	ton/h	138,3
Bagasse to the filter	ton/h	2,5
Bagasse to reserve	ton/h	6,9
Produced straw	kg-dry straw/ton-cane	140
Straw burned for cogeneration	ton/h	35
Straw mixture with bagasse	%	21
Boiler efficiency in LHV basis	%	86
High-pressure turbine stage isentropic efficiency	%	88
Low-pressure turbine stage isentropic efficiency	%	80
Pump isentropic efficiency	%	80
Turbine mechanical efficiency	%	97
Generator efficiency	%	96
Outlet steam pressure of the low-pressure turbine	bar	2,5
Reference state pressure	bar	1,01325
Reference state temperature	°C	25
Deaerator operation pressure	bar	2,5
Consumed steam temperature in the process	°C	127,4
Steam losses	%	4,00
Process steam pressure	bar	2,5
Process steam demand	ton/h	480
Electricity consumption in the process	kWh/ton-cane	28

(PALACIOS et al., 2009), (ENSINAS, 2008), (CARVALHO, 2011).

The values of biomass characterization are described in Tab. 3. Both bagasse and straw are on a dry basis, that is why a correction has to be made in the value of the calorific value including moisture (CORTEZ, 2010), the calculation was made with Eq. (1).

Table 3. Sugarcane straw and bagasse characterization.

Reference	**Biomass**	**C(%)**	**H(%)**	**O(%)**	**N(%)**	**S(%)**	**Cl(%)**	**Moisture(%)**	**HHV^d. (MJ/kg)**
Hassuani et al., 2005.	Straw	45,7	6,2	42,8	1	0,1	0,4	10,05	16,98
Bragato et al., 2012	Bagasse	44,48	5,4	38,1	0,4	0,03	0,02	51,1	18,89

$$LHV^{w} = \left(HHV - 2{,}31 \cdot \left(\frac{W}{100 - W} + 0{,}09 \cdot H\right)\right)\left(\frac{100 - W}{100}\right) \tag{1}$$

Where W is the moisture content (%).

3.1 Exergetic analysis

According to Kotas (1985) exergetic analysis provides a way to assess the magnitude of irreversibilities in relation to the exergy provided in a plant or a certain component. Thus, the calculation of irreversibilities can be evaluated through an exergetic balance for a defined control volume (MOSQUEIRA, 2012).

The interacting streams can be in the form of heat, work, or mass respectively. It is noteworthy that irreversibility is always greater than or equal to zero, being null for reversible processes and greater than zero for irreversible processes.

Irreversibilities have two components: external irreversibilities or exergy losses, which are products of flows that go into the environment and that contain exergy, but that are not useful or are not used; and internal irreversibilities or destroyed exergy, which occur within the limits of the defined control volume, due to the intrinsic process that has taken place.

The total specific exergy was calculated as the sum of the physical (b_{ph}) and chemical (b_{ch}) exergies, as shown in Eq. (2).

$$b = b_{ph} + b_{gh} \tag{2}$$

The physical exergy was calculated according to Eq. (3), neglecting the potential and kinetic components.

$$b_{ph} = (h - h_0) + T_0(s - s_0) \tag{3}$$

Where the subscript 0 indicated the reference state level.

Considering that bagasse and sugarcane straw represent the fibrous part of the sugarcane stalk and assuming that it is separated from the juice in the extraction process, the proposal by Szargut et al. (1988) for calculating the exergy of solid fuels can be used. The physical exergy of bagasse and straw can be ignored due to their low values when compared to chemical exergy (MOSQUEIRA, 2012). In addition to that they are normally fed at room temperature.

Bagasse and straw are not compounds with a defined chemical formulation; the calculation of their exergy is difficult. However, the proposal by Szargut et al. (1988) solves this problem by developing correlations obtained from properties of organic compounds and which were extended to more complex substances such as wood (SZARGUT, MORRIS and STEWARD, 1988).

Thus, the relationship between chemical exergy and the lower calorific value of biomass can be calculated by the correlation presented in Eq. (4).

$$\beta = \frac{b_{ch,biomass}}{LHV^{w}} \tag{4}$$

The beta ratio (β) establishes the relationship between the chemical exergy of the fuel under analysis and its Lower Calorific Value (LHV). According to Szargut et al. (1988) the calculation of the parameter β as a function of its mass composition can be calculated with Eq. (5).

$$\beta = \frac{\left(1{,}0412 + 0{,}2160\left(\frac{X_{H_2}}{X_C}\right) - 0{,}2499\left(\frac{X_{O_2}}{X_C}\right)\left(1 + 0{,}7844\left(\frac{X_{H_2}}{X_C}\right)\right) + 0{,}0450\left(\frac{X_{N_2}}{X_C}\right)\right)}{1 - 0{,}3035\left(\frac{X_{O_2}}{X_C}\right)} \tag{5}$$

4. RESULTS AND DISCUSSION

The simulations of the case studies for different types of cogeneration systems for a sugarcane mill producing sugar and ethanol were made with the EES software. Mass, energy and exergy balances were also made with the following hypothesis:

a) Steady state for all control volumes.
b) Turbines, pumps, heat exchangers and valves are adiabatic.
c) Output water of deaerator is saturated liquid.
d) Bleeding in the boiler was not assumed.

4.1 Electricity excess for steam cycle with back pressure turbine

Figure 5 shows the results obtained for the generation of excess electricity by changing the pressure and temperature conditions of the generated steam (C1 and C2) and including the reheating and regeneration of the Rankine Cycle in order to increase the amount of excess electricity and cycle efficiency

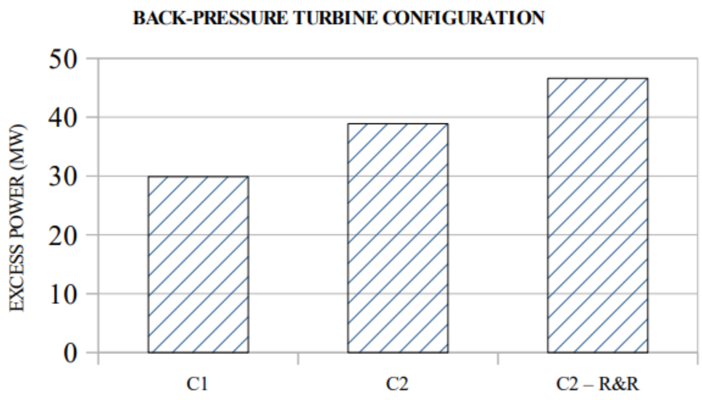

Figure 5. Excess power generated from the back-pressure turbine cogeneration system.

The cogeneration system that works under C1 conditions, which is currently used in plants with electric drive of the preparation and extraction systems, has an excess power of 29.9 MW and can be increased to 38.9 MW just changing the conditions of temperature and pressure of the generated steam to C2, obtaining an increase of 30.1% in the generation of excess electricity. Currently, there are Brazilian plants that work with this type of technology in their boilers (CASTRILLÓN, 2017). In the case of optimization the Rankine cycle with regeneration, there is an amount of excess electricity of 46.6 MW, obtaining an increase of 56% in relation to the operating conditions C1 and a 20% increase over C2 conditions for single Rankine cycle. It is necessary to consider that to change the conditions C1 to C2, additional investment is needed in the boiler, on the other hand, to change the simple Rankine cycle with C2 conditions to the Rankine cycle with regeneration and reheating, it needs additional investment in the boiler, turbine, steam piping and in the regenerator (closed heat exchanger). This comparison of C1 and C2 conditions is most often used when the assembly of a new cogeneration system is studied.

4.2 Electricity excess for steam cycle with extraction-condensing turbine

Figure 6 shows the results of the excess electricity obtained for the extraction-condensing turbine configuration, varying the operating conditions C1, C2 and C2 with reheating and regeneration.

Note that the electricity excess can be increased by 13%, from 80.2 MW to 89.7 MW just by changing the conditions of the steam generated from C1 to C2. Electricity excess can be further increased by reheating and regenerating the Rankine cycle at C2 steam conditions; this modification according to Fig. 6 generates an increase of 12.3% compared to the simple Rankine cycle at C2 conditions. Currently in Brazil there are many plants that have this type of configuration with conditions of the steam generated C1, according to this study the excess of electricity can increase by 24.2% just by increasing the conditions of steam to C2 and modifying the Rankine cycle with regeneration and reheating.

The results show that for sugarcane mills cogeneration processes with extraction-condensation turbines, the generation of excess electricity can be significantly increased, with boilers that operate with better technology, such as those that generate steam at 120 bar and 520°C (C2) and even more when there is regeneration and reheating in the cycle.

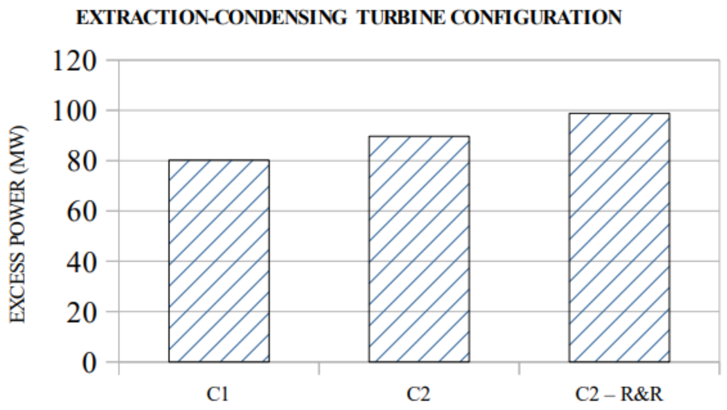

Figure 6. Excess power generated from the extraction-condensing turbine cogeneration system.

4.3 Electricity excess for supercritical steam cycle

For the supercritical configuration, the electricity excess is 122.4 MW, the increase over the back-pressure turbine configuration under C1 conditions is 322% and with respect to extraction-condensing turbine configuration under C1 conditions is 55%. The excess electricity increases over case I configuration with C2 and regeneration and reheat is 116% and over case II configuration with conditions C2 regeneration and reheat is 27%.

Figure 7 compares the three configurations of cogeneration systems with regeneration and reheating. It is notable the increase in excess electricity in supercritical conditions due to the increase in pressure and temperature of the generated steam. It can be seen that a very important variable in the generation of excess power are the boiler operating conditions.

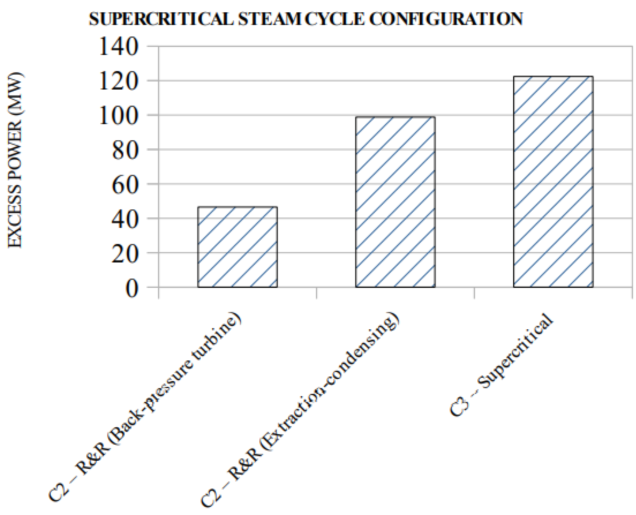

Figure 7. Comparison of the excess power between the cogeneration systems.

It is important in the study of cogeneration with supercritical boiler the size of the equipment and the amount of steam generated.

4.4 Exergetic analysis for each case study

The cogeneration system was divided into its main components: boiler, turbines, pumps, valves, deaerator and condenser, in order to obtain greater detail in the results. The steam generated in the boiler is supplied to the electricity generation group, which supplies the electricity requirements necessary for each of the subsystems, with the excess being exported to the electricity grid.

According to Tab. 4, the main generator of irreversibility is the boiler in all cases analyzed, regardless of the configuration, or the conditions of the generated steam.

As can be seen in Fig. 8, for the supercritical configuration, approximately 90% of the irreversibilities occur in the boiler; thus, the irreversibilities of the combustion process are the main source of exergy destruction. The greatest irreversibility occurs in the boiler of the supercritical configuration with 358.9 MW, due to a greater volume of steam produced.

Table 4. Irreversibilities of the main components of the cogeneration systems.

Irreversibilities	**Back-pressure turbine system**			**Extraction-condensing turbine system**			**Supercritical system**
kW	**C1**	**C2**	**C2 -R&R**	**C1**	**C2**	**C2 -R&R**	**C3**
Boiler	156.988	158.677	173.653	294.802	286.860	361.301	358.987
HHPT turbine	--	--	--	--	--	--	1.069
HPT turbine	--	--	--	1.904	3.017	3.607	869,3
IPT turbine	1.356	2.253	2.257	3.836	3.525	4.279	1.451
LPT turbine	2.732	2.633	2.688	1.298	1.088	1.988	13.579
Regeneration HX	--	--	2.542	--	--	2.589	1857,2
Condenser	--	--	--	3.291	2.765	4.774	3566
Pump 1	2,54	2,54	2,54	3,50	3,50	3,50	44,16
Pump 2	229	238,5	241	322,9	319,1	323,1	1767
Pump 3	0,14	0,14	0,14	0,14	0,14	0,14	2,40
Deaeretor	141,5	141,5	152,3	806,3	723,3	802,3	15553
Total (kW)	**161.489,9**	**163.986,37**	**178.983,2**	**306.304,53**	**298.341,73**	**377.078,3**	**398.745,01**

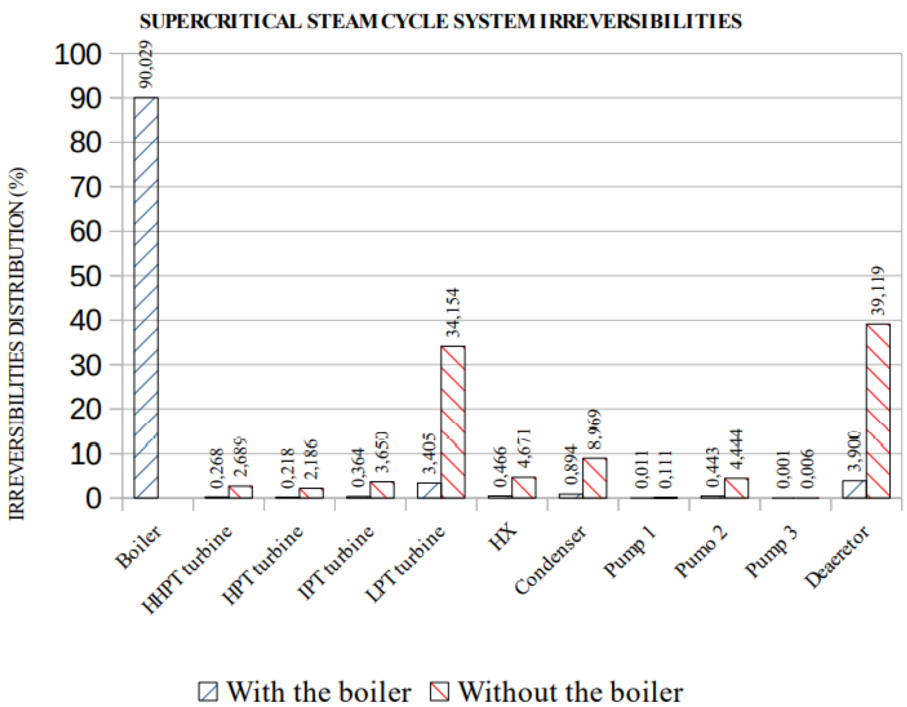

Figure 8. Irreversibilities comparison among the supercritical steam cycle system.

5. CONCLUSIONS

Currently, the configuration of the cogeneration system that has the largest amount of excess electricity is given by new technologies in boilers operating at 520 °C and 120 bar and extraction-condensation turbines, but it can improve even more. with including a reheat and a closed regenerator, increasing the electricity excess by 12.3%. After comparing this configuration with a more advanced technology, such as the supercritical cycle configuration, the results presented show a great advantage for the latter in relation to the generation of excess electricity. A conventional cycle with condensation extraction turbines and generated steam parameters of 120 bar and 520°C generates approximately 89.7 MW of excess electricity, while in a supercritical cycle the generation reaches 122.4 MW.

The irreversibility of the combustion process is the main source of exergy destruction in all cases studied. The greatest irreversibility in the boiler occurs in the supercritical steam cycle configuration due to a greater volume of steam produced.

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7. APPENDIX

Table 5. Stream flows of the back-pressure turbine system.

Stream	Cogeneration system with back-pressure turbine configuration.								
	C1			C2			C2 – R&R		
	m (kg/s)	T (°C)	p (bar)	m (kg/s)	T (°C)	p (bar)	m (kg/s)	T (°C)	p (bar)
1	65	480	65	70,79	520	120	78,79	520	120
2	65	325,9	21	70,79	282	21	62,26	500	21
3	29,27	325,9	21	70,79	282	21	62,26	500	21
5	29,27	127,4	2,5	70,79	127,4	2,5	62,26	237,4	2,5
7	28,6	127,4	2,5	66,67	127,4	2,5	60,4	237,4	2,5
8	0,6678	127,4	2,5	4,1	127,4	2,5	1,86	237,4	2,5
9	28,66	127,4	2,5	66,67	127,4	2,5	66,67	127,4	2,5
11	0	127,4	2,5	0	127,4	2,5	6,27	127,4	2,5
12	64	115,2	2	64	115,2	2	64	115,2	2
14	2,667	25	1,013	2,67	25	1,01	2,67	25	1,01
15	2,667	25,02	1,8	2,67	25,01	1,8	2,67	25,03	2,5
16	67,34	116,9	1,8	67,37	116,9	1,8	85,06	127,4	2,5
20	65	117	2,5	70,79	117	2,5	78,79	127,4	2,5
21	65	118,5	65	70,79	185,5	65	78,79	130,5	120
22	--	--	--	--	--	--	78,79	250	120
23	--	--	--	--	--	--	16,53	127,4	2,5
24	--	--	--	--	--	--	16,53	326,7	30,8

Table 6. Stream flows of the extraction-condensing turbine system.

Stream	Cogeneration system with extraction-condensing turbine configuration.								
	C1			C2			C2 – R&R		
	m (kg/s)	T (°C)	p (bar)	m (kg/s)	T (°C)	p (bar)	m (kg/s)	T (°C)	p (bar)
1	118,9	480	65	117,5	520	120	126	520	120
2	118,9	325,9	21	117,5	282	21	99,11	280,5	21
3	--	--	--	--	--	--	99,11	500	21
5	118,9	127,4	2,5	117,5	127,4	2,5	99,11	237,4	2,5
7	66,67	127,4	2,5	70,09	127,4	2,5	60,4	237,4	2,5
8	6,74	127,4	2,5	6,476	127,4	2,5	6,456	237,4	2,5
9	66,67	127,4	2,5	66,67	127,4	2,5	66,67	127,4	2,5
11	0	127,4	2,5	0	127,4	2,5	6,271	127,4	2,5
12	64	115,2	2	64	115,2	2	64	115,2	2
14	2,67	25	1,01	2,667	25	1,013	2,667	25	1,013
15	2,67	25,01	1,8	2,667	25,01	1,8	2,667	129,1	2,5
16	118	116,9	1,8	114,1	116,9	1,8	132,3	127,4	2,5
20	118,9	117	2,5	117,5	117	2,5	126	127,4	2,5
21	118,9	118,5	65	117,5	118,5	65	126	129,1	65
22	74,38	127,4	2,5	76,56	127,4	2,5	66,86	237,4	2,5
23	44,55	127,4	2,5	40,97	127,4	2,5	32,25	237,4	2,5
24	44,55	45,82	0,1	40,97	45,82	0,1	32,25	45,82	0,1
25	44,55	45,85	1,8	40,97	45,85	1,8	32,25	45,85	1,8
26	44,55	45,82	0,1	40,97	45,82	0,1	32,25	45,82	0,1
28	--	--	--	--	--	--	26,93	326,7	30,8
29	--	--	--	--	--	--	26,93	127,4	2,5
30	--	--	--	--	--	--	126	250	65

Table 7. Stream flows of the back-supercritical steam cycle system.

Cogeneration with supercritical steam cycle system.			
Stream	**m (kg/s)**	**T (°C)**	**p (bar)**
1	133,6	570	292
2	109	397,1	21
5	106,7	160,8	2,5
7	64,2	160,8	2,5
8	17	160,8	2,5
9	66,67	127,4	2,5
11	2,468	207,2	18
12	64	115,2	2
14	2,667	25	1,013
15	2,667	25,3	18
16	136,1	207,2	18
20	133,6	207,2	18
21	133,6	300	292
22	81,14	160,8	2,5
23	25,55	160,8	2,5
24	27,86	45,82	0,1
25	27,86	169,4	18
26	22,34	45,82	0,1
27	125,4	300	62,2
28	110,2	570	62,2
29	1,451	99,63	1
30	5,515	45,82	1
31	27,86	87,6	18
32	1,759	140,8	2
33	4,064	120,2	2
34	27,86	125,4	18
35	2,305	278,4	8
36	2,305	170,4	8
37	27,86	321,4	18
38	1,17	461	30,6
39	24,61	207,2	18
40	133,6	216,7	292
41	133,6	235	292
42	15,24	321,4	62,2
43	23,44	278	62,2
44	133,6	278,9	292
45	8,194	377,1	87,1
46	8,194	301	87,1
47	110,2	321,4	62,2
48	5,515	45,82	0,1