CLEISEANO EMANUEL DA SILVA PANIAGUA
(ORGANIZADOR)

Collection:
APPLIED CHEMICAL ENGINEERING
2

Atena
Editora
Ano 2022

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APRESENTAÇÃO

The e-book: “Collection: Applied Chemical Engineering 2” consists of seven book chapters. The first and second chapters sought to apply computer simulation both to analyze the flow of water from the faucet, evaluating from the fluid dynamics and volume of the liquid, as well as the behavior of the air-particle interaction and the variables that influence: temperature, pressure and particle velocity volume, the pressure and velocity of particles inside an aerosol can.

The teaching of chemistry is still seen as an abstract and meaningless science in the student’s daily life, since most basic education institutions do not have spaces for carrying out laboratory practices. In this context, researchers from the state of Maranhão, Piauí and Recife proposed the use of music as a facilitating tool in the learning process that was called CHEMUSICS.

Chapter 4 discusses the benefits of using energy production from the sugar-energy sector, especially from sugarcane bagasse residues that can sustain the Brazilian energy matrix.

Chapters 5 to 7 evaluated the issue of solid waste management and contamination of water resources. Chapter 5 presented a review study regarding the generation of waste from cemetery activities, as well as the potential impact on the environment and public health. Chapter 6 presented the potential of pumice in the adsorption of metals present in galvanic effluents. Finally, chapter 7 presents the development of a bimetallic Fenton catalyst supported on natural zeolite for the removal of dyes in aqueous matrices.

In this perspective, Atena Editora has been working with the aim of stimulating and encouraging researchers from Brazil and other countries to publish their work with a guarantee of quality and excellence in the form of books and book chapters that are available on the Editora’s website and elsewhere. digital platforms with free access.

Cleiseano Emanuel da Silva Paniagua

SUMÁRIO

CAPÍTULO 4

TECHNICAL AND ECONOMIC EFFICIENCY MODELING IN SUCROENERGETIC MILLS STEAM GENERATION CENTERS

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ABSTRACT – The energy generation by the sugar-energy sector occurs simultaneously in the modalities: process heat, mechanical energy, electric energy for own consumption and excess, predominantly from sugarcane bagasse. It is intended the technological and economic aspects systemic approach, in order to contribute to the bioenergy definitive insertion, coming from the sugar-energy sector, as a great relevance complementary alternative, to support the Brazilian energy matrix. Considering that the 68 bar and 100 bar units yield were modeled at 38.97% and 42.80%, no doubt the steam generator system replacement could be an extreme importance procedure from the technical and economical view point, for increasing efficiency and, consequently, raising the revenues with the surplus electric energy generation, in the 25.63% to order 86,499 MWh / crop, equivalent to 15.57 million Reais, to a MWh traded at CCEE / ANEEL at R$ 180.00, corresponding to a R$ 15.57 million value to be added, for a 212.80 tons sugarcane bagasse processing.

KEYWORDS: Sugarcane mill modeling. Steam Generation Center. 68 bar and 100 bar Boilers. Steam Boiler Efficiency. Cogeneration.

1 I INTRODUCTION

Up until the 1970s, large hydroelectric plants were predominant due to the generating electricity low cost production due to the excellent scale factor that had a huge impact on the generating energy cost, and also due to the prohibition policies lack to the environmental impacts resulting from their activity (SANTOS, 2014).

The electric energy generation, surplus in the sugar and alcohol sector, predominantly exported to the National Interconnected System (SIN), had its discussion started a long time ago, however, even so, the quantities produced are far below their real production and export capacity (SANTOS, 2014).

On the other hand, a significant advantage for the sugar and alcohol industry associated with bioelectricity is the constant financial contribution guarantee from the energy commercialization, as opposed to the cane production seasonality to which they are subject (EPE, 2013).The electric power purchase by the sugar and alcohol plants was almost extinct when the Steam Generator (GV) operating pressure exceeded the 22bar (2.2MPa) at 300ºC mark. In this technological generation, by 21Bar; 2.1

MPa to 22 Bar; 2.2 MPa, which occurred, predominantly, around the 80s, the GV efficiency did not allow to sell surplus electric power, but with amount the bagasse by 0 to 10%, it did not have enough biomass, to generate such electric energy surpluses. At that time, the sugar and ethanol mills maintained an energy balance for almost 15 years, producing and consuming for each ground cane ton, electric energy 12 kWh, mechanical energy 15 kWh and thermal energy 330 kWh in 550 kg of steam per tonne (SOSA ARNAO, 2007).

With the 45Bar (4.5 MPa) Steam Generator (GV) system introduction, which is now intermediate efficiency considered, it was possible to obtain bagasse leftovers, in quantities sufficient to supply this GV, as well as to produce electric energy, with significant commercial value. Today are considered modern, 65 Bar (6.5MPa) and 100 Bar (10 MPa) the order SG systems (SOSA ARNAO, 2007; SOUZA & AZEVEDO, 2006).

The electricity excesses are exported to the Brazilian Interconnected Electric System (SIN) by contracts used and prepared by the Brazilian Electric Energy Trading Chamber and supervised on the Brazilian Electric Energy Agency (CCEE / ANEEL), which has the electric power purchase intermediation role and sale, among the actors. The biomass plants can market their surplus to electricity distribution concessionaires for free and special electricity consumers, in accordance with Brazilian Decree Nº 6,048/2007 (EPE, 2013; SOUZA & AZEVEDO, 2006; OLIVEIRA, 2013).

This work objective is to model two the existing system stands for steam generators operating at 68 bar, 510 ° C and 100 bars at 510 ° C, respectively, where their design drawings are adapted for modeling and, according to the operation reality, using real industrial data. It is the authors intention with this auxiliary study elaboration to the Productive System in the investment and technical decision making, through this technological way.

2 I METHODOLOGY

2.1 Traditional Rankine Cycle with GV-CTR-68bar

The traditional Rankine Cycle (CTR), as can be seen in figure (01), is the most widely used model to evaluate the industrial unit efficiency generating bioenergy, since this CTR is a realistic and practical model, that is in opposition to the idealized Carnot cycle. Some care should be taken when evaluating a CTR, such as energy efficiency reduction, and maintenance costs, when care with turbine feeding do not observe saturated steam, with high liquid content associated with their flowout taking into account turbine blades erosion possibility (SMITH, 2007).

In order to improve the CTR performance, after the condensation stage, it is necessary to focus on the need to completely condensate the vapor, and with this, to facilitate the saturated liquid adiabatic pumping to the boiler. It has also proved important to overheat the steam, the constant pressure in the GV, in order to increase its average temperature, the heat transfer to steam. All of these steps make it possible to increase CTR efficiency. Another interesting procedure to increase the CTR efficiency is to insert a second heating stage for the turbine, thereby maintaining the superheated steam, raising the average turbine feed temperature, and concomitantly lowering the turbine rejected heat average temperature. Such measures make it possible to increase the CTR efficiency (SMITH, 2007).

The CTR's operating curve is shown in figure (2), where the entropy (S) on the horizontal axis, and on the vertical axis the temperature (T). When considering the areas involved it is possible to evaluate the work developed by the heat transferred to the fluid. The following is a (01) to (08) analytical model equations based on steam tables in VAN WYLEN (2003), an applicable model for the CTR average efficiency determination [ηt (%)], as a the various phases consequence that occur, based on the first one and the thermodynamics second law, where kinetic and potential energy variations are neglected as well as the various heat losses in the various facilities equipment.

$\eta_t (\%) = w_{liq} / q_h$	*the traditional Rankine cycle yield*	(01)
$w_{liq} = w_{t\,-}\, w_b$	*the network = the turbine work - the pump work*	(02)
$q_h = h_{3\,-}\, h_2$	*heat supplied, boiler = enthalpy outlet-enthalpy input*	(03)
$h_2 = h_1 + \int v.\, dp$	*he boiler inlet enthalpy*	(04)
$w_b = v.\,(p_2 - p_1)$	*the pump work + specific volume. Δpressure*	(05)
$h_4 = h_{L4} + x_4.\, h_{Lv4}$	*the turbine output enthalpy*	(06)
$w_{t\,=}\, h_{3\,-}\, h_4$	*the turbine work=the enthalpy input-the enthalpy output*	(07)
$S_4 = S_3 = S_{L4} + x_4.\, S_{Lv4}$	*the entropy in (3) and (4) are equal, then the title x_4 is determined, based on the steam tables*	(08)

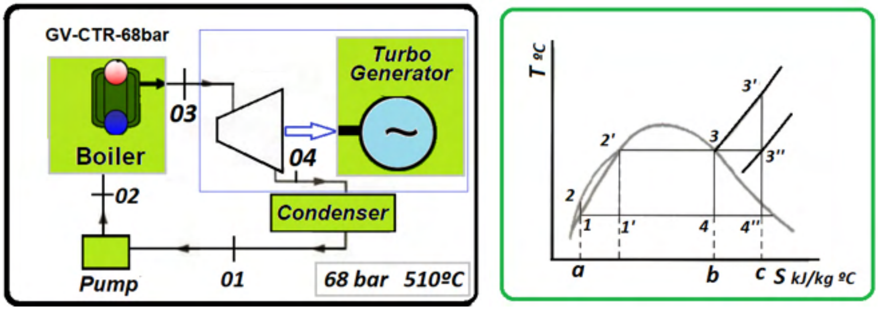


Figure 01 and 02: The traditional Rankine cycle and Entropy & Temperature Curve.

Source: author, adapted from VAN WYLEN (2003).

The GV-CTR-68bar used as a base is basically two aquatubber boilers composed, two steam turbines, operating 68 bar, 6.8 MPa, 510 ° C, as shown in figure (01), for the modeling purposes, the thermodynamic parameters, were based on available steam tables (VAN WYLEN, 2003), as well as on the data used by Abreu (2015), where the sugarcane bagasse was has considered contain 50% humidity, and 7,200 kJ / kgc (kilogram of cane) lower calorific value (CIP), the 275 kg per tonne cane bagasse content, and in addition two condensers operating in 0.1 bar (10 kPa), two pumps used to transport the water and pressurizing the boilers. The total bagasse consumption is 212.80 tb / h, with the boiler's operation in 5,853 hours per harvest.

GV-CTR-68bar, used as a basis in this model, with simplifications, is located in the Quirinópolis, Goiás State Municipality, and is an Independent Producer and Electric Energy Self-Producer, located in the Southeast / Center-West energy submarket. It has two aquatubber boilers, each one with a 250 tons / hour flow, with two Generator Units, in a 40MW each simple thermal cycle, installed capacity totaling 80MW, authorized to operate by Ordinance No. 123 / MME / BRASIL / 2007, with the conventional energy generation concession, with the 50 MW for generation Distribution System use contract - MUSD. The internal contract plant energy consumption is 8 MW in the Peak position, 8 MW for out the tip.

2.2 Regenerative Rankine Cycle and Mixing Heater-GV-CRRAM-100bar

In this section, the methodology for the efficiency determination in the Regenerative Rankine Cycle with Mixing Heater (CRRAM), is shown in figure (03), and figure (04). In this CRRAM the steam enters the turbine through the stage (5). After expansion is extracted to the (6) state, and the steam remainder continues the expansion in the turbine to the (7) stage, and is then brought to the condenser, and from there, to make the mixture with the steam extracted from the turbine. Since the steam extracted amount is only sufficient to convert the condensate into fully saturated liquid in (3) stage, as soon as it leaves the mixing heater. At this stage end the saturated liquid is pumped to the boiler pressure (4) stage, and then the average temperature at which the fluid is supplied rises (VAN WYLEN, 2003).

The CRRAM operating curve is shown in figure (04), with the entropy (S) on the horizontal axis, and the temperature (T) on the vertical axis. When considering the areas involved it is not possible to accurately assess the heat transferred to the fluid by the work developed, since the steam part is diverted to the water heater.

In the following table, we will analyze, in an analytical way, based on steam tables (VAN WYLEN, 2003), a (09) to (20) analytical model equations to determine the CRRAM average efficiency [η*t* (%)], as the several phases consequence that occur.

$\eta_t\ (\%) = w_{liq}/q_h$	*the CRRAM yield*	(09)
$w_{liq} = w_{t-}(1-m_1).\ wb_1 - w_{b2}$	*the cycle network*	(10)
$w_{b1} = h_2 - h_1 = \int v.\ dp$	*the pump work 1*	(11)
$h_2 = h_1 - w_{b1}$	*the enthalpy 2*	(12)
$w_{b2} = h_4 - h_3 = \int v.\ dp$	*the work pump 2*	(13)
$\int v_{43}.\ dp = v_{43}.\ (p_4 - p_3)$	*the pump work = the specific volume. Δpressure*	(14)
$S_5 = S_6 = S_{L6} + x_6.\ S_{Lv6}$	*the entropy in 5 and 6 are equal*	(15)

$h_6 = h_{L6}+x_6 . S_{Lv6}$	*the enthalpy in 6*	(16)
$S_5 = S_7 = S_{L7}+x_7 . S_{Lv7}$	*the entropy in 5 and 7 are equal*	(17)
$h_7 = h_{L6}+x_6 . S_{Lv6}$	*the enthalpy at 7*	(18)
$h_3 = m_1 . h_6 + (1-m_1) . h_2$	*the determination fraction m1*	(19)
$w_{t=}(h_{5\_}h_6)+(1-m_1).(h_6 - h_7)$	*the enthalpy input - the extraction output enthalpy …* *+ input enthalpy- the enthalpy output, complementary to extraction*	(20)

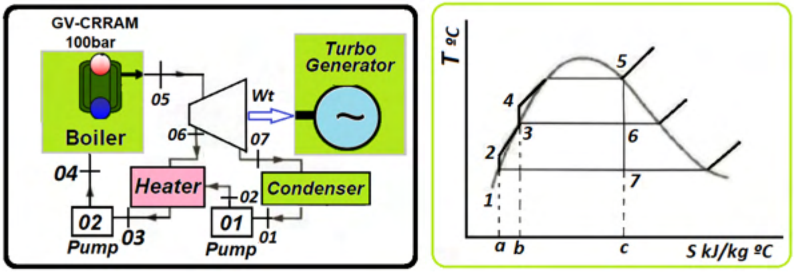


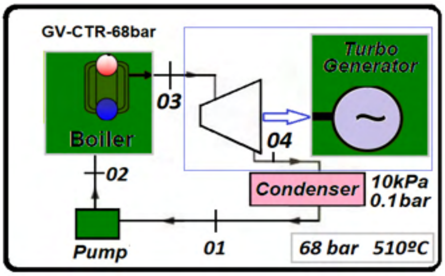
Figure 03 and 04: Regenerative Rankine Cycle with Mixing Heater and *Entropy & Temperature Curve.*

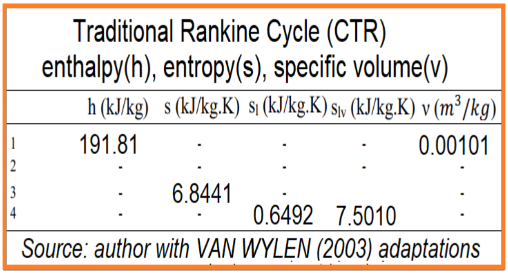
Source: author, adapted from VAN WYLEN (2003).

3 I RESULTS AND DISCUSSION

3.1 Traditional Rankine Cycle in 68 bar Sucroenergetic Steam Generator (GV-CTR68bar)

The thermal efficiency determination, as a base factor for the electric power production, by thermoelectric plants powered by sugarcane biomass was determined for a sugarcane industry standard, here called GV-CTR-68bar, as shown in figure (05).





Traditional Rankine Cycle (CTR)
enthalpy(h), entropy(s), specific volume(v)

	h (kJ/kg)	s (kJ/kg.K)	s_l (kJ/kg.K)	s_{lv} (kJ/kg.K)	$v\ (m^3/kg)$
1	191.81	-	-	-	0.00101
2	-	-	-	-	-
3	-	6.8441	-		-
4	-	-	0.6492	7.5010	-

Source: author with VAN WYLEN (2003) adaptations

Figure 05 and 06: the GV-CTR-68bar adopted model.

Source: author, adapted from VAN WYLEN (2003).

The thermal efficiency determination, as a base factor for the electric power production, by thermoelectric plants powered by sugarcane biomass was determined for a sugarcane industry standard, here called GV-CTR-68bar, as shown in figure (05).

w_{liq}/q_h 1,261.92/3,238.13 = 38.97 % (21)

$w_{liq} = w_{t} - w_b$ 1,268.69 -6,77 = 1,261.92 kJ/kg (22)

$q_h = h_{3} - h_2$ 3,436.70-198.57 kJ/kg (23)

$h_2 = h_1 + \int v.\, dp$ 198.57 kJ/kg (24)

$w_b = v.\,(p_2 - p_1)$ 6.77 kJ/kg (25)

$h_4 = h_{L4} + x_4.\, h_{Lv4}$ 2,168.01 kJ/kg (26)

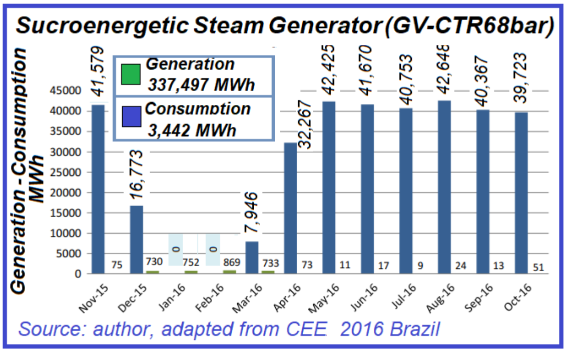
$w_t = h_3 - h_4$ 1, 268.69 kJ/kg (27)

$S_4 = S_3 = S_{L4} + x_4.\, S_{Lv4}$ 6.8441 kJ/kg°K (28)

x_4 0.8259 (29)

The GV-CTR-68bar, used as a basis in this model, with simplifications, had a performance in the excess electricity exported generation / imported in the SIN, the 2016 harvest, as shown in figure 07.

Figure 07 Electricity Excess exported / imported in SIN, 2016 harvest GV-CTR-68bar, LT 138 kV / UTE Boa Vista - SE Quirinópolis - GO.



Source: author, adapted from CEE 2016 Brazil

The UTE Boa Vista energy consumption is, as from 2017, under a free contracting regime, belonging to Group A, Subgroup A2, Blue Rate Modality, with the seasonality benefit. It has a 38.9 MW Physical Guarantee for the year 2016. (DE ABREU, 2015; CCEE, 2016).

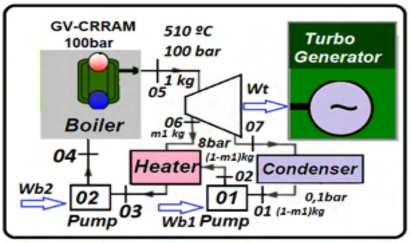
3.2 Regenerative Rankine Cycle with 100 bar Sucroenergetic Plant Steam Generator and Mixer Heater (GV-CRRAM 100bar)

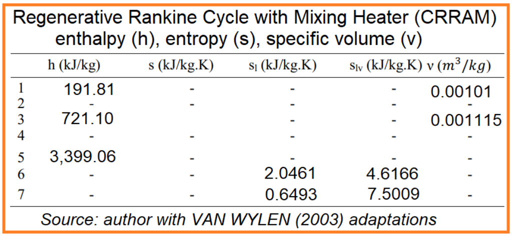
Shows up in the figure (08), the GV-CRRAM system 100 bar simplified structure, and figure (09), the parameters obtained from the steam tables, to obtain the theoretical efficiency, as shown in equations (28) to (40). Shows up in the figure 10 the excess electricity exported and imported balance in the SIN, 2016 harvest, by the UTE Boa Vista, whose is GV-CRR 100 bar generation system, which supplies the 138 kV (138 kV) electricity transmission line from UTE Boa Vista up to Electrical Substation (SE) Quirinópolis – GO (DE ABREU, 2015; CCEE, 2016).

The thermal efficiency improvement, shown in equations (19) and (28) from 38.97%

to 42.80%, was the base factor for the increase in the surplus electric energy production, as shown in figure (10). It is observed that despite a seemingly low 2.756% efficiency increase [(1.4280 / 1.3897-1) .100], an enormous a surplus energy mount was generated, in the 86,499 MWh amount, representing 25.63%, reflecting the efficiency improvement that affects all the biomass used, and the surplus electric energy generation, occurs only after meeting the energy Plant demands.

The total annual generation, after updating to GV-CRR 100 bar, resulted in 434,868 MWh, and considering net generation, including own consumption and the basic grid losses, resulted in 423,996 MWh. In order to adjust the new generation configuration due to this net generation increase, an amount to 9.87 MW in the Physical Guarantee was added to the existing 38.9 MW, totaling 48.77 MW. The proposed changes did not significantly affect the unit's own electricity consumption, and for this reason it was not considered for modeling purposes. It is important to note that UTE Boa Vista will use the same biomass amounts in the current steam generator.





Regenerative Rankine Cycle with Mixing Heater (CRRAM)
enthalpy (h), entropy (s), specific volume (v)

	h (kJ/kg)	s (kJ/kg.K)	s_l (kJ/kg.K)	s_{lv} (kJ/kg.K)	v (m^3/kg)
1	191.81	-	-	-	0.00101
2	-	-	-	-	-
3	721.10		-	-	0.001115
4	-	-	-	-	-
5	3,399.06	-	-	-	-
6	-	-	2.0461	4.6166	-
7	-	-	0.6493	7.5009	-

Source: author with VAN WYLEN (2003) adaptations

Figure 08 and 09 the GV-CRRAM 100bar, and values extracted from the steam tables.

Source: author, adapted from VAN WYLEN (2003).

For the Rankine Thermal Cycle GV-CRRAM modality the efficiency calculation, as described in (2.2), was found the value of η_t (%) = 42.80%, being:

η_t (%) = w_{liq}/q_h 1,141.76/2,667.70 = 42.80 % (30)

$w_{liq} = w_{t} - (1-m_1).\ wb_1 - w_{b2}$ 1,141.76 kJ/kg (31)

$w_{b1} = h_2 - h_1 = \int v.\ dp$ 0.00101(800-10) = 0.80 kJ/kg (32)

$w_{b2} = h_4 - h_3 = \int v.\ dp$ 0.001115(10.000-800) = 10.26 kJ/kg (33)

$h_4 = h_3 - w_{b2}$ 721.10-(-10.26) = 731.36 kJ/kg (34)

$S_5 = S_6 = S_{L6} + x_6.\ S_{Lv6}$ 6.6284 kJ/kgºK (35)

$h_6 = h_{L6} + x_6.\ S_{Lv6}$ 721.10 + 0.9832(2048) = 2,734.69 kJ/kg (36)

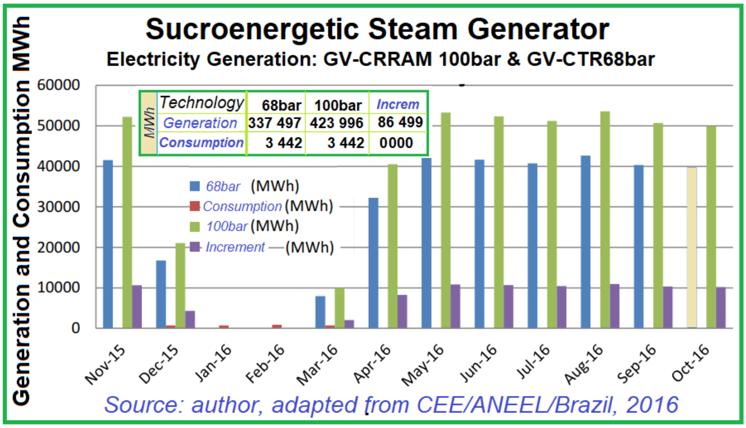
$S_5 = S_7 = S_{L7} + x_7.\ S_{Lv7}$ 6,6284 kJ/kgºK (37)

$h_7 = h_{L7} + x_7.\ S_{Lv7}$ 191.81 + 0.8051(2392.80) = 2,118.25 kJ/kg (38)

$h_3 = m_1.h_6 + (1-m_1).h_2$ m_1 =0.2079 (39)

$w_t = (h_5 - h_6). + (1-m_1).(h_6 - h_7)$	1,152.65 kJ/kg	(40)
x_6	0.9832	(41)
x_7	0.8051	(42)

Figure (10) Annual balance, Electric Energy Surplus exported / imported in SIN, GV-CTR-68bar & GV-CTR100bar, 2016 harvest, 138 kV LT / UTE Boa Vista - Quirinópolis - GO.



Source: author, adapted from CEE/ANEEL/Brazil, 2016

4 I CONCLUSIONS

Considering the technical aspects, the steam generator modernization is an extreme importance requirement, as shown in the model presented for the GV-CTR-68bar system by GV-CTR100bar system, where an 2.756% efficiency increase the electricity surplus amount was 25.63%, or 86,499 MWh / harvest, equivalent to R$ 15.57 million, for the MWh sold at CCEE at R$ 180.00 / MWh. The biomass amount for the system operation was 212.80 ton / h (sugarcane bagasse tons per hour). The 68 bar and 100 bars units' yields were modeled with 38.97% and 42.80% efficiency. When assessing the economic and financial aspects, other issues can be considered, such as the necessary cost for the appropriate substitutions, according to the different technologies systems, since more current technologies may have non-linear costs for substitution and, therefore, the analysis should be taking this question into account.

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