

Efficiency of an aquatubular boiler from the burning of four cultivars of sugar cane
Eficiência de uma caldeira aquatubular a partir da queima de quatro cultivares de
cana-de-açúcar

Eficiencia de una caldera aquatubular al quemar cuatro cultivares de caña de azúcar

Received: 11/02/2020 | Reviewed: 11/06/2020 | Accept: 11/19/2020 | Published: 11/26/2020

Marcelo Costa Dias

ORCID: <https://orcid.org/0000-0002-6507-0136>

Universidade de Uberaba, Brazil

E-mail: professorft@gmail.com

Antonio Manoel Batista da Silva

ORCID: <http://orcid.org/0000-0003-1082-7637>

Universidade de Uberaba, Brazil

E-mail: tomanel.tamanel@gmail.com

Lúcio Rogério Junior

ORCID: <https://orcid.org/0000-0002-7840-5863>

Universidade de Uberaba, Brazil

E-mail: lucio.rogerio@hotmail.com

Abstract

The growing demand for energy from renewable sources increasingly seeks to implement efficient energy production systems. Thus, the objective of this work is to determine the thermal efficiency of an aquatubular boiler that will burn the bagasse from four sugarcane cultivars: SP 80-1816, RB72-454, SP80-3280 and SP81-3250. This efficiency will be determined through the calculation methods: PCI - lower calorific value, PCS - higher calorific value and direct method. These cultivars were planted in the south-central region of Brazil where the largest sugar cane producers in the country are located. The results obtained show the importance of the energy analysis that each cultivar provides for energy cogeneration, as well as the benefits that will directly influence its production chain for controlled management. Among the benefits of controlled management are: maximizing processes and optimizing the energy use of each cultivar. The optimum efficiency of the boiler in energy production in relation to steam production depends on the intrinsic variables of each cultivar, such as bagasse and moisture content. When calculating the boiler efficiency,

the SP 80-1816 variety proved to be more advantageous in relation to the others, considering the same characteristics of the production process, planting region, harvest time and the same type of boiler used. Still related to the study, the cultivar SP 80-1816 requires a smaller amount of bagasse in the boiler feed to produce heat, which results in greater energy production considering the same amount of bagasse of the studied varieties.

Keywords: Cogeneration; Sugarcane cultivars; Energy efficiency; Boiler.

Resumo

A crescente demanda por energia de fontes renováveis busca cada vez mais a implantação de sistemas eficientes de produção energética. Assim, o objetivo deste trabalho é determinar a eficiência térmica de uma caldeira aquatubular que irá queimar o bagaço de quatro cultivares de cana-de-açúcar: SP 80-1816, RB72-454, SP80-3280 e SP81-3250. Essa eficiência será determinada através dos métodos de cálculo: PCI - poder calorífico inferior, PCS - poder calorífico superior e método direto. Essas cultivares foram plantadas na região centro-sul do Brasil onde estão localizados os maiores produtores de cana-de-açúcar do país. Os resultados obtidos mostram a importância da análise energética que cada cultivar proporciona para a cogeração energética, bem como os benefícios que influenciarão diretamente na sua cadeia produtiva para um manejo controlado. Dentre os benefícios do manejo controlado tem-se: maximização dos processos e uma otimização do aproveitamento energético de cada cultivar. O rendimento ótimo da caldeira na produção de energia em relação à produção de vapor depende das variáveis intrínsecas de cada cultivar, como teor de bagaço e umidade. Ao calcular a eficiência da caldeira a variedade SP 80-1816 mostrou-se mais vantajosa em relação às demais, considerando as mesmas características do processo produtivo, região de plantio, época de colheita e mesmo tipo de caldeira utilizada. Ainda relacionado ao estudo, a cultivar SP 80-1816 requer uma quantidade menor de bagaço na alimentação da caldeira para produção de calor, isso resulta em maior produção de energia considerando a mesma quantidade de bagaço das variedades estudadas.

Palavras-chave: Cogeração; Cultivares de cana-de-açúcar; Eficiência energética; Caldeira.

Resumen

La creciente demanda de energía procedente de fuentes renovables busca cada vez más implementar sistemas de producción energética eficientes. Así, el objetivo de este trabajo es determinar la eficiencia térmica de una caldera aquatubular que quemará el bagazo de cuatro cultivares de caña de azúcar: SP 80-1816, RB72-454, SP80-3280 y SP81-3250. Esta

eficiencia se determinará mediante los métodos de cálculo: PCI - menor poder calorífico, PCS - mayor poder calorífico y método directo. Estos cultivares fueron sembrados en la región centro-sur de Brasil donde se encuentran los mayores productores de caña de azúcar del país. Los resultados obtenidos muestran la importancia del análisis energético que cada cultivar aporta para la cogeneración energética, así como los beneficios que influirán directamente en su cadena productiva para un manejo controlado. Entre los beneficios del manejo controlado están: maximizar los procesos y optimizar el uso energético de cada cultivar. La eficiencia óptima de la caldera en la producción de energía en relación a la producción de vapor depende de las variables intrínsecas de cada cultivar, como el bagazo y el contenido de humedad. Al calcular la eficiencia de la caldera, la variedad SP 80-1816 resultó ser más ventajosa en relación a las demás, considerando las mismas características del proceso de producción, región de siembra, tiempo de cosecha y el mismo tipo de caldera utilizada. Aún relacionado con el estudio, el cultivar SP 80-1816 requiere una menor cantidad de bagazo en la alimentación de la caldera para producir calor, lo que se traduce en una mayor producción de energía considerando la misma cantidad de bagazo de las variedades estudiadas.

Palabras clave: Cogeneración; Cultivares de caña de azúcar; Eficiencia energética; Caldera.

1. Introduction

The biomass of sugarcane bagasse occupies a prominent place among the renewable energy sources in Brazil. It has a high energy potential for electricity production through cogeneration, since sugarcane processing generates energy material and has a vast area for cultivation in Brazilian soil. In addition to the cultivation area, other points to be considered in the productivity gain of the sugar-alcohol sector that brings favorable results in electricity production is the diversity of sugarcane cultivars that can be planted, the characteristics of the arable soil, the topography of the land, the improvement of planted species and the improvement of management according to each region in which sugarcane is cultivated.

Research conducted by the Brazilian Agricultural Research Company (EMBRAPA) in 2018 shows that Brazil stood out as the world's largest producer of sugarcane. This highlight is based on the amount of sugarcane processed in the harvest for the years 2017/2018, in which production reached approximately 641 million tons. In addition, data released by the Sugarcane Industry Union (UNICA) showed that 92.3% of the total processed was produced by the Central-South region, composed of the states of the South, Southeast and Midwest regions of Brazil. Based on the reports of UNICA (2019), the portion of bagasse resulting

from the processing of sugarcane used in the production of bioelectricity represented only 15% of the total potential. In this sense, if all sugarcane biomass after processing were used, bioelectricity in Brazil would have a technical potential to reach 146,000 GWh, considering the process of energy production by cogeneration in the plants. In this sense, in Brazil, the bioelectricity of origin of sugarcane has growth potential, which can exceed 50% by 2027, changing the value produced from 21,500 GWh recorded in 2018 to 33,200 GWh by the year considered (ÚNICA, 2019). Even with the growth of more than 11,700 GWh, we would still be using only 17% of the technical potential of this source, (ÚNICA, 2019).

Among the sugarcane plantation areas located in the southern central region of Brazil, the varieties analyzed in this study were planted in the municipality of Taquarituba in the State of São Paulo. The varieties of sugarcane together with their respective energy characteristics used in the calculations for the determination of boiler efficiency were SP 80-1816, RB 72-454, SP 80-3280 and SP 81-3250. For analysis, 10 stems per variety were collected in 4 random points of the plot and they were subjected to the despoite at the height of the apical yolk and the defoliation (Lima, 2009).

The four sugarcane cultivars used in this study are due to the fact that they are one of the most planted varieties in the State of São Paulo, which is the largest producer of sugarcane in Brazil. The determination of efficiency is an important factor to control the production of steam and, consequently, its use in turbines for the production of electricity in sugar and alcohol plants.

After harvest, sugarcane goes through industrial processing in mills for the removal of the broth that is used in the production of sugar and alcohol. The material resulting from this processing is bagasse, it is burned in the boilers producing necessary steam in the industrial production process and mostly in the production of electricity. The objective of this work is to identify which cultivar presents the best energy indicators to be selected as the primary source of energy for the boiler. Other points to be analyzed are: to determine, among the cultivars studied, which of them presents the best flow of sugarcane bagasse to be inserted in the combustion chamber, determine the value of the energy provided by each sugarcane cultivar and calculate the thermal efficiency of an industrial boiler of the aquatubular type when burning the sugarcane bagasse of the four cultivars (SP 80-1816 , RB72-454, SP80-3280 and SP81-3250).

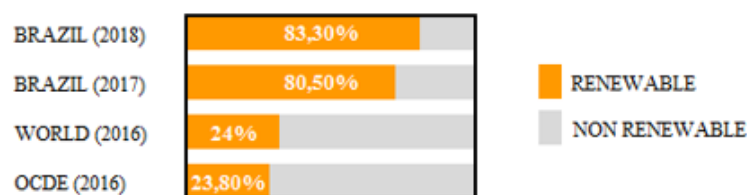
2. Methodology

This work was developed using empirical equations as a basic tool. The efficiencies analyzed in this article were estimated by authors considering their experience in processing studies of sugar production plants. This type of research can be considered quantitative, since the results are analyzed in comparative terms between the cultivars, and qualitative, since the energy efficiencies were determined by cultivar. The work was carried out based on the data determined in the laboratory by the aforementioned authors, but the knowledge of the variables necessary to obtain the results was very important for the use of mathematical equations. Therefore, it can be considered both industrial analysis and laboratory work. The basic criterion for analyzing the results was a comparison between the characteristics of the cultivars and the results found. The steps carried out in the study, the determination of the sugarcane bagasse feed, the useful energy and the boiler efficiency will be presented in the next sections.

2.1 Availability of electricity

The availability of electricity is a fundamental characteristic for the industrial development of a country. It allows the expansion of industrial activity and, at the same time, other sectors of the economy absorb the result of this activity, also contributing to the economic development of the region. The summary report of the National Energy Balance (BEN), released by the Brazilian National Electric Energy Agency (ANEEL) in 2019, based on 2018, showed that the availability of domestic energy in Brazil reached 288.4 Mtoe (equivalent to Megaton oil), representing a decrease in the availability of energy from non-renewable sources such as oil. In the analyzed period, the drop was 1.7% compared to the previous period. This fall occurred due to the increase in the use of energy from renewable sources such as water force and wind in electricity generation.

Figure 1. Percentage of renewable and non-renewable energy used in Brazil and in the world.



Source: BEN (2018).

2.2 Biomass characterization

Biomass processing in the industry generates agricultural and industrial waste. The harvesting of sugarcane in a mechanized way, that is, with machines gives rise to agricultural residue called straw, which includes straw, green leaves, grinding wheels, roots and weeds that grow within the sugarcane field and "industrial waste includes bagasse, molasses, vinasse, filter cake and ash (Silva et al., 2014). The biomass composition of the sugar-alcohol industry is basically composed of six chemical elements in its organic phase: carbon, hydrogen, nitrogen, sulfur, chlorine and oxygen. In the inorganic phase, however, ten other elements are found, such as silicon, aluminum, iron, calcium, magnesium, sodium, potassium, sulfur, phosphorus and titanium (Jenkins et al., 1998).

Bagasse originated after sugarcane grinding is a by-product of high energy value used in the sugar-alcohol industry as an insum in steam production. Its composition varies according to the type of cultivar and can contain in its constitution 45 to 55% of water, 40 to 53% of fiber, 2 to 5% of solids and 1% of dissolved ash (Van der Poel et al., 1998). It is of paramount importance to confirm the characteristics of sugarcane bagasse, because these parameters are necessary for the manufacture of auxiliary equipment for cogeneration, such as: bagasse feeding systems in the boiler, pneumatic conveyor and bagasse dryer. Regardless of the sugarcane broth extraction process, when a bagasse sample is checked, two distinct groups are observed. According to Meirelles (1984), the first group is fibers (larger particles) and the second of the medulla or powder (smaller particles).

Figure 2. Sugarcane bagasse constitution.



a) Bagasse disposal



b) Bagasse fibers



c) Marrow or bagasse powder

Source: Authors (2020).

Figure 2 shows the sugarcane bagasse and its particularities, a bagasse deposit, figure 2 (a), bagasse fibers, Figure 2 (b) and the marrow or powder 2 (c).

2.3 Calorific power

According to Cortez at al., (2008), the calorific value of any energy source is the amount of energy released in the form of heat during the complete combustion of the fuel mass unit, being measured in kJ/kg or in lime/kg. Associated with this theme, González (2015) states that the calorific value varies with the amount of moisture present in biomass and is differentiated into two types: the superior calorific value (PCS) and lower calorific value (PCI). PCS is the energy released in the form of heat in combustion when the water vapor generated during combustion is condensed. It is the sum of the energy released in the form of heat and the energy spent on the evaporation of water formed during oxidation. The PCI is only the energy released in the form of heat, and in the boiler, one of the products resulting from the combustion of sugarcane bagasse is steam.

The value of the superior calorific value (PCS) is determined by the use of an adiabatic calorimetric pump, using the standard ASTM techniques - Standard Method for the Gross Calorific Value of Solid Fuel (Cortez at al., 2008). Considering the entire cogeneration system, after burning sugarcane bagasse the temperature of exhaust gases in most cases is higher than the condensation temperature of the gases, which makes the PCI more applicable in boiler efficiency calculations. The calculations performed in this study are based on pcs and PCI of cultivars SP 80-1816, RB72-454, SP 80-3280 and SP81-32.50. The samples were collected coincidentally during sugarcane harvest in October 2007 (Lima, 2009).

Table 1. Calorific power of the researched sugarcane cultivars.

Cultivars	Volume of clown (m ³ /t)	PCS (Mcal/t)	PCI (Mcal/t)	Moisture %
SP 80-1816	7,964	4582,70	4247,90	69,04
RB 72-454	8,610	4511,34	4176,79	70,57
SP 80-3280	9,369	4426,97	4092,17	69,60
SP 81-3250	10,619	4331,77	3996,97	69,13

Source: Authors (2020).

After performing the calculations, the results found were shown in Table 1, in which it

can be seen that the SP 80-1816 variety, even with the lowest straw volume value in m³ / t, presented the highest PCS and PCI values, since the percentage of moisture did not show significant difference between the varieties.

A more complete analysis of the chemical composition of the bagasse sample is extremely important for the determination of the PCI in order to establish the relationships between the elemental composition of the bagasse and the calorific value of a fuel. The Russian scientist Mendeliev (1987) proposed an expression for the calculation of PCI in kJ/kg from the elemental composition of the fuel as evidenced by expression 1 (Cortez at al., 2008).

$$PCI' = 339C' + 1030H' - 109(O' - S') - 24W' \quad (1)$$

Still on the calorific value, equation 2 can be used to convert the PCS from dry base to work base, and to convert the superior calorific value of the dry base into lower calorific value on a work basis, equation 3 is used (Cortez at al, 2008).

$$PCS' = PCS^s (100 - W') \quad (2)$$

$$PCI' = \left\{ \left[PCS^s - \lambda(r + 0,09H^s) \right] \left(\frac{100 - W'}{100} \right) \right\} \quad (3)$$

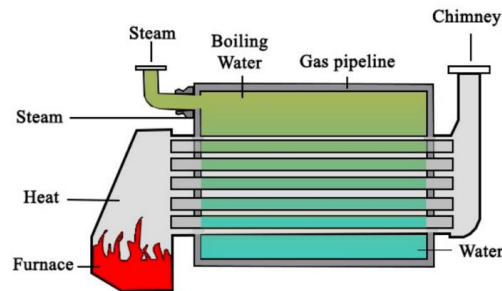
2.4 Boiler

The use of heat has been part of human life since the beginning and this energy is not restricted only to the direct use of fire. Industrially, this thermal energy is obtained through boilers resulting in steam being widely used in various industrial sectors such as sugar and alcohol factories. The availability of water near industrial parks is relatively high and, as steam has a specific high heat, it is used for heating or mechanical activation purposes. In addition, due to its easy obtaining employing boilers and the low cost lead their use on a large scale in industrial processes and facilities that require steam energy for its operation.

The boiler is a heat exchanger that works at a pressure higher than atmospheric pressure, produces steam from the thermal energy extracted from a primary fuel, which can be gaseous, liquid or solid. Thus, "heat transfer is widely used in many applications in heat exchangers, chemical process, gas and oil production, air condition, automotive or food industries" (Vahidifar & Kahrom, 2015), and there are two types: flamotubular and aquatubular boilers, which may receive different classifications for their employability and

use. The flamotubular boiler (fig. 3.) is one of the most widely used steam generators in the industry. They do not need to work with high pressure and steam flow, do not need considerable spaces, can be positioned vertically when necessary and their cost is relatively low.

Figure 3. Horizontal tube flamotubular boiler.



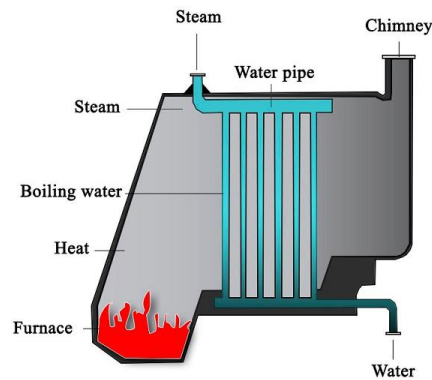
Source: Botelho (2011).

As shown in Figure 3, the principle of operation of these generators is the exchange of heat with water, so that the combustion gases circulate inside the pipes and the water around them is heated (Botelho, 2011).

An example of using this model to generate steam for small capacities, is through vertical configuration. The steam generated in this equipment is saturated or supersaturated steam type and can have a production of 160 to 50 ton/h of steam and pressures that can go from 10 to 18 bar, producing from 112 to 34,000 kW. The boilers designed in the horizontal configuration limit the flow of steam to 13 ton/h and pressures of up to 14 kgf/cm² (Botelho, 2011).

In these boiler models, after burning the fuel, the combustion gases pass through pipes heating the water that surrounds them. When the oven is built outside this type of boiler, the fuel to be used in burning is low calorific value, such as rice husk, coffee and peanuts, straw, sawdust, black liquor and heavy oils.

Figure 4. Vertical tube aquatubular boiler.



Source: Botelho (2011).

The aquatubular boiler Figure 4, works with the circulation of hot gases through the outside of the pipes and the water passes through them. The tubes in this boiler model are arranged as if they were water walls or tubular beams. This change in the configuration allows the parts where the highest pressures will be to have reduced diameter, allowing higher values in the pressure to be achieved, however, for the proper functioning of this model it is necessary to have greater control of the process variables.

This type of boiler is more difficult to build and, in the scope of its operation, generates a large amount of steam, reaching 750 ton/h. But usually the amount of steam is between 15 and 150 ton/h, with high operating pressure reaching a level between 90 kgf/cm² to 100 kgf/cm² (Botelho, 2011).

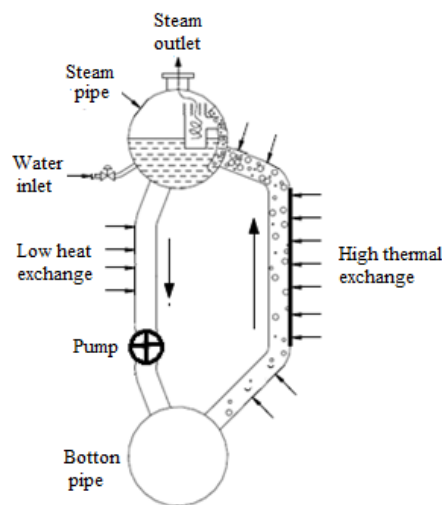
One of the operational principles of aquatubular boiler is the circulation of water through the pipe. And most of these boilers work with natural circulation caused by the difference in density when the water is heated until it reaches the water-steam mixture. The density difference causes the downward displacement of the water in the direction of the lower tube, while on the other side there is an upward flow from the mixture of water and steam to the upper tube. This cyclical movement is facilitated by the continuous supply of water, steam outlet and hot gas flow.

In boilers that work with high pressure, the density difference decreases, just as the water-steam mixture decreases greatly and natural circulation becomes slow. To maintain water circulation, a pump is installed to maintain sufficiently higher steam demand than natural circulation. This measure provides that the aquatubular boilers meet the needs of the application, such as high steam consumption, high steam pressure or overheated steam (Santini & Telhado, 2015).

The macroprocess of steam production in an aquatubular boiler begins with the supply

of low temperature water that is pumped to the economizer which has the function of heating the boiler feed water, performing the first heat exchange to increase the temperature. This allows the mixing of heated water with the steam generation system. Which is a necessary process to avoid thermal shocks and possible temperature fluctuations. Continuing the cycle, the water from the steam pipe passes into the lower tube through the pipes at low temperatures. After reaching the lower tube, the heated water passes through the hottest tubes, with the partial transformation of the water into saturated steam, following a biphasic flow until it reaches the steam nozzle.

Figure 5. Vertical tube aquatubular boiler.



Source: Santini & Telhado modified, (2015).

The design presented Figure 5 shows a simplified scheme of water circulation in an aquatubular boiler with vertical tubes. The advantages of this boiler model are: the possibility of working with pressures between 50 and 165 bar, the rapid production of steam, the fast start-up and ease of adapting to different types of fuels. Although it has the disadvantages of having large dimensions, of presenting sensitivity to sudden variations of load, high demand for quality of the feed water due to the high operational pressure, high installation cost and complexity in the assembly (Botelho, 2011).

2.5 Methodology, data and assumption

The analysis performed is based on the result of the calculations performed to determine the efficiency of an aquatubular boiler, using the data of biomass burning of

sugarcane. The PCS value of the four sugarcane cultivars SP 80-1816, RB72-454, SP80-3280 and SP81-3250 were obtained as follows: the samples of the cultivars were ground, dried, sieved in the ABNT 70 sieve according to the ABNT - NBR 8633 standard, after this process they were pressed to the form of tablets with a mass of approximately 1 g. Later they were left in a greenhouse with a temperature of 105 °C resulting in a dry sample. After this stage, an ALEMMAR KL-5 calorimetric pump was used to burn the sample and obtain the superior calorific power, the process of obtaining was based on the calorimeter instruction manual and this one was adapted according to the ABNT-NBR 8633 standard (Lima, 2009).

After the determination of the PCS of the cultivars, doat (1977) was used to determine the PCI, this method takes into account the amount of hydrogen present in the sample, the heat absorbed for the vaporization of the water contained in the sample and the proportion of water that was formed during combustion (Lima, 2009).

"Producing economical heating and cooling systems with high performances is a constant concern in the industry (Touzani et al., 2019)", and thus, the calculation of the yield of these equipments becomes quite necessary. To calculate the efficiency of the boiler are used parameters similar to those of a real boiler. The steam production of the boiler used as a model is 300,000 kg/h at a temperature of 520°C with a working pressure of 6.7 Mpa. The gas resulting from combustion has a temperature of 160°C and the estimated yield of the PCI is 90%. The feeding of sugarcane bagasse in the combustion chamber is carried out by conveyors and the consumption of bagasse necessary to maintain the operational characteristics of the boiler is determined by dividing the total heat transferred by the fuel, which in the studied model is equal to 991,858.2 MJ/h. This value is determined by the WET bagasse PCI (Sampaio, 2015).

The consumption of sugarcane bagasse in the boiler is determined by the relationship between the total heat transferred by the fuel (991,858.2 MJ/h) and the lowest calorific value of the bagasse of each variety studied (Sampaio, 2015). Boiler efficiency is achieved using the PCI method determined by equation 4 and the PCS method specified by the equation 5, respectively.

$$\eta = \left[\frac{m_s (h_{soc} - h_{wic})}{m_b PCI_b} \right] 100(\%) \quad (4)$$

$$\eta = \left[\frac{m_s (h_{soc} - h_{wic})}{m_b PCS_b} \right] 100(\%) \quad (5)$$

Another calculation to be performed to determine the efficiency of the boiler is through the inputs and outputs method, also called gross efficiency, for which expression 6 is used.

$$\eta_b = \frac{Q_u}{Q_d} 100(\%) \quad (6)$$

After the burning of the bagasse in the boiler furnace, the combustion products will be at high temperature and yielding part of their energy to the evaporative surfaces in the heater and superheater, the sum of these energies represents the useful heat of the boiler. Useful heat is the energy transferred to the working substance, considering the following data: energy consumed for the evaporation of the feed water and the overheating of the steam to the required pressure and temperature conditions and the energy contained in continuous extraction waters (Cortez et al., 2008). The calculation of useful heat (Q_u) is obtained by equation 7.

$$Q_u = \left[\frac{\dot{m}_{vs}}{C} (h_{vs} - h_{aa}) + \frac{\dot{m}_e}{C} (h_e - h_{aa}) \right] \quad (7)$$

The available heat determined per unit of fuel mass (kg) is calculated using equation 8.

$$Q_d^t = PCI^t + Q_{fc} + Q_{paa} + Q_{at} \quad (8)$$

Using the calculation parameters and to meet normative aspects, the boiler efficiency calculation for the four cultivars used was performed based on the recommendations manual published by the Institute of Technological Research (IPT) (Camargo, 1990). Where it is recommended that parameters such as PCI and PCS be used to quantify the thermal efficiency of the boiler, so that the final results calculated by different methods are interpreted and compared with the requirements of the boiler. In addition to the PCI and PCS values, other values used in the efficiency calculations are the data from the boiler that served as a model for the work, are the following: steam temperature 520 °C, flue gases 160 °C, working pressure 6.7 MPa and energy from the steam produced in the boiler of 991,858.2 MJ / h.

Table 2. Reference values for the calculation of efficiency.

Variable	Value
Calor específico médio do combustível C_{pc}	3,02
Temperatura do combustível T_C	30
Temperatura de referência T_R	25
Massa de ar seco $M_{ar\ seco}$	4,79
Calor específico da água C_{pa}	4,19
Umidade do ar ambiente W	0,019
Calor específico médio do vapor d'água C_{pv}	1,9
Temperatura do ar de combustão T_{ar}	30

Source: Authors (2020).

The data in Table 2 are reference values that are commonly used in efficiency calculations thermal power of boilers, for example, mass of dry air entering the combustion chamber, specific average heat of the fuel. The boiler efficiency calculation was performed considering the main characteristics of the studied cultivars. In this sense, the result found is directly linked, among other factors, to the rate of supply of sugarcane bagasse for burning in the boiler and the energy provided by each cultivar studied from the combustion of bagasse.

3. Results and Discussions

To determine the boiler efficiency, process variables such as humidity, lower calorific value and consumption of sugarcane bagasse in the boiler should be checked. Knowing the proportion of moisture in the sugarcane bagasse assists in determining its combustion capacity as well as in storage, handling and transport. Not being able to be quantified, the lower calorific value is found by subtracting from the higher calorific value the water condensing energy that is produced during the combustion of bagasse and the moisture present in the fuel before burning.

Table 3. Results of consumption of sugarcane bagasse in the boiler by variety.

Cultivars	PCI (Mcal/t)	Moisture %	Bagasse consumption (kg/s)
SP 80-1816	4247,90	69,04	15,52
RB 72-454	4176,79	70,57	15,78
SP 80-3280	4092,17	69,60	16,11
SP 81-3250	3996,97	69,13	16,49

Source: Authors (2020).

The consumption of bagasse for burning in the boiler is determined through the relationship between the energy of the steam in the boiler and the lower calorific value, the results obtained after the calculations are described in Table 3. Because it is a lignocellulosic material, the bagasse of the cane sugar is very hygroscopic. The moisture present in the bagasse varies according to the variety, your knowledge is important to avoid feeding in the boiler with high moisture content in the bagasse, preventing combustion from occurring unevenly and irregularly, causing imperfections in the thermal exchange of heat influencing the power generation.

Although there was no significant difference in sugarcane bagasse moisture between cultivars, the varieties SP80-3280 and SP81-3250 were the ones that resulted in the highest consumption of bagasse in the boiler to meet the technical specifications of energy production. Making a comparison of this consumption and taking into account the specifications of the boiler under study, the cultivar SP80-1816 requires less bagasse in the boiler for energy production, a value of approximately 6.25% in relation to cultivar SP 81-3250. The comparison of bagasse consumption in t / h of this variety with the SP81-3250 variety results in 3,492 t / h of bagasse consumed more than the first cultivar. To determine the efficiency of the boiler by the direct method using equation (6) it is necessary to determine the useful energy provided by the cane bagasse of each cultivar.

Table 4. Results of the energy supplied and useful through the burning of sugarcane bagasse.

Cultivars	Supplied power (kJ/kg)	Useful energy (kJ/kg)
SP 80-1816	19.272,00	15.893,21
RB 72-454	18.973,72	15.627,16
SP 80-3280	18.621,05	15.310,56
SP 81-3250	18.127,72	14.954,37

Source: Authors (2020).

Table 4 shows the values of the energy released by each cultivar in kJ / kg and the useful energy used in the generation of energy. The difference in the useful energy provided in burning the sugarcane bagasse of the cultivars SP 80-1816 and SP81-3250 is approximately 6.27% greater, justifying bagasse consumption of the last cultivar to offer the same amount of energy as the first. With magnitude values shown in Tables 3 and 4, it is possible to determine the boiler performance which was used as a model for the analysis of energy efficiency based on the characteristics of the studied cultivars. This is determined by the direct method using three parameters: useful energy for the energy supplied, higher calorific value of the basic PCS, lower base caloric PCI, whose numerical values are shown in Table 5. From the results shown in Table 4, it is possible to observe that the boiler efficiency calculated by the PCI method was higher. The efficiency determined by the PCS and the ratio between the useful energy and the energy supplied did not show any significant difference in the results.

Table 5. Results of the energy supplied and useful through the burning of sugarcane bagasse.

Cultivars	Efficiency PCI (%)	Efficiency PCS (%)	Useful energy/provided (%)
SP 80-1816	91,37	82,97	82,47
RB 72-454	92,93	82,87	82,36
SP 80-3280	94,85	82,74	82,22
SP 81-3250	97,11	82,59	82,49

Source: Authors (2020).

4. Conclusion

One of the items needed to determine the thermal efficiency of the boiler is the amount of sugarcane bagasse that must be introduced into your combustion chamber over time. This value was determined by the relationship between the steam flow produced in the boiler and the PCI of each cultivar. The lowest bagasse feed flow in the boiler was found to cultivate SP80-1816 at a rate of 15.52 kg / s, whereas cultivar SP81-3250 had the highest feed rate at 16.49 kg / s. shows that to maintain the same working conditions, the boiler combustion chamber has to be supplied with a greater amount of bagasse from the second cultivar, which reaches a level of 0.97 kg / s. Regarding the transfer of energy to steam, the highlight is again with the cultivars SP 80-1816 with energy supplied of 19,272.00 kJ / kg and the cultivar SP81-3250 with 18,127.72 kJ / kg.

This produces a difference of 1,144.28 kJ / kg between them. The useful energy results

in a lower value because it takes into account the effective values that the boiler uses in the generation of thermal energy, namely: steam flow from the boiler, water enthalpy at the boiler inlet, steam enthalpy at the boiler outlet and consumption of bagasse in the combustion chamber. The values found are: cultivar SP80-1816 with a useful energy of 15,893.21 kJ / kg and cultivar SP81-3250 with 14,954.37 kJ / kg. Once again, it is evident that the cultivar SP80-1816 is the best option for the production of thermal energy because the energy difference between the two cultivars is 938.84 MJ / ton. The method calculated taking into account the PCI presented thermal efficiency of the boiler in value above 90%.

And with the use of cultivar SP81-3250, the value obtained is 97.11%. This value is justified because the direct method was used in the calculation, disregarding the losses that occur in the system. The values found using the PCS and useful energy / supplied energy methods were smaller and closer because in these methods the values used in the calculations take into account the real requirements of the boiler operation. Thus, it demonstrates the importance of determining the thermal efficiency of a boiler when burning sugarcane bagasse for different cane cultivars, because each cultivar will provide a different amount of energy for a given boiler model. Another point to be noted in this regard is that with the determination of the energy quantities of each cultivar, there will always be an improvement in cogeneration in the plants that use sugarcane as a raw material.

Of the cultivars analyzed, the best choice for using sugarcane bagasse as a primary source of energy is the cultivar SP80-1816 because it has less bagasse consumption in the boiler and more useful energy available for steam generation. We indicated that it could be appropriate to determine the efficiency of each cultivar considering the losses that occur in the steam production process in different boilers. This can enable the identification of the efficiency provided by the cultivars in different equipment, considering the point of work of each one. That is, what would be the best cultivar to be used to produce bagasse in an industrial unit. We also claim that another important topic to be developed is the calculation of the thermal energy that steam can supply to a turbine and produce mechanical energy for the purpose of generating electrical energy when driving an electric generator.

As a suggestion for future work, we recommend determining the efficiency of each cultivar considering the losses that occur in the steam production process in different boilers. This can enable the identification of the efficiency provided by the cultivars in different equipment, considering the point of work of each one, that is, which will be the best cultivar to be used in an industrial unit. We argue that another item also as an important topic to be developed in future works is the calculation of the thermal energy that the steam will supply

to a steam turbine for the purpose of producing electric energy.

Acknowledgment

The authors would like to thank the Research Support Foundation of the State of Minas Gerais - FAPEMIG and the University of Uberaba - UNIUBE for the support provided in the development of this work.

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Percentage of contribution of each author in the manuscript

Marcelo Costa Dias – 55%

Antonio Manoel Batista da Silva – 30%

Lúcio Rogério Junior – 15%