EFFECT OF BAGASSE WASTE QUALITY AS BIOMASS FUEL ON WATER TUBE BOILER EFFICIENCY

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Submitted	Revised	Published	
10.02.2024	03.06.2024	03.09.2024	© Author 2024
PISSN 2540-8223 **EISSN 2540-8268**			Publisher: Department of Chemistry FMIPA University of Lampung

ABSTRAK
Residu pengolahan tebu, yang umum disebut sebagai limbah bagas, merupakan produk sampingan dari proses produksi gula. Limbah bagas memiliki potensi untuk dimanfaatkan sebagai bahan bakar alternatif. Limbah bagas dapat digunakan secara langsung sebagai bahan bakar boiler untuk kebutuhan industri. Namun, pengaruh kualitas limbah bagas terhadap efisiensi boiler perlu diteliti untuk menentukan potensinya sebagai bahan bakar alternatif. Dalam penelitian ini, pengaruh penggunaan bagas terhadap efisiensi boiler diamati. Data yang digunakan dalam penelitian ini diperoleh dari buku catatan harian boiler dan laboratorium. Analisis data menunjukkan bahwa nilai kalor optimal dari bahan bakar yang digunakan mencapai 2347,48 kcal/kg. Selain itu, efisiensi boiler yang paling optimal mencapai 70,34%, yang 10,6% lebih rendah dibandingkan dengan boiler berbahan bakar batu bara. Hasil penelitian ini berkontribusi pada pemahaman yang lebih luas tentang potensi bahan bakar biomassa dalam boiler industri. Dengan demikian, ini mewakili solusi alternatif yang potensial untuk pengolahan limbah tebu yang berkelanjutan dalam konteks transisi menuju energi hijau.

Kata kunci: biomassa, efisiensi boiler, limbah bagas

ABSTRACT
Sugarcane processing residue, commonly referred to as bagasse waste, is a by-product of the sugar production process. Bagasse waste has the potential to be utilized as an alternative fuel. Bagasse waste can be used directly as boiler fuel for industrial needs. However, the effect of bagasse waste quality on boiler efficiency needs to be investigated to determine its potential as an alternative fuel. In this study, the effect of using bagasse on boiler efficiency was observed. The data used in this research were obtained from the boiler daily log book and laboratory. Analysis of the data indicates that the optimal calorific value of the fuel used reaches 2347.48 kcal/kg. Furthermore, the most optimal boiler efficiency reached 70.34%, which is 10.6% lower than the coal-fired boiler. The results of this study contribute to a broader understanding of the potential of biomass fuels in industrial boilers. Consequently, this represents a potential alternative solution for the sustainable processing of sugarcane waste in the context of the transition to green energy.

Keywords: biomass, boiler efficiency, bagasse waste

INTRODUCTION

Energy plays a pivotal role in supporting life at all scales, from the household to the industrial. The energy demand of the industrial sector continues to increase (Sanzana, et al., 2022). The sustainability of an industry is highly dependent on the available energy sources. One strategy for achieving sustainability in the energy transition agenda is to utilize agricultural and plantation waste as boiler fuel. Boilers have the role of producing advanced hot steam as a steam turbine drive in power generation in the processing industry. Furthermore, the residual steam exiting the turbine can be employed as a heat source in the processing of agricultural and plantation products (Ikonen et al., 2023).

One of the agricultural and plantation wastes that can be utilized as boiler fuel is bagasse. After sugarcane is harvested and extracted for sugar production, the remaining bagasse, known as bagasse, still has a high energy potential. This bagasse is then dried and crushed for conversion into solid fuel. In boilers, bagasse is burnt to produce steam, which is used as a source of power generation in processing industries (Kumar & Arora, 2021). The conversion of sugarcane bagasse into a fuel for power generation in industry can reduce the environmental impact of plantation waste while reducing the cost of purchasing existing fuel, which generally uses coal. The calorific value of sugarcane bagasse that has been dried is 2370.5 kcal/kg (Leko et al., 2021), while that of sugarcane bagasse that has been torrefied at 275 ºC is 4838.4224 kcal/kg (Daniyanto et al., 2015).

The majority of boilers utilize coal as a fuel source. Indonesia's coal reserves are estimated to last for a further 62 years, according to the BP Energy Outlook 2023. However, the Indonesian government has committed to reducing emissions by 31.89% through Presidential Regulation No. 14 of 2024. The utilization of biomass in power generation has the potential to assist in the reduction of greenhouse gas emissions. Biomass is currently a widely utilized fuel for power generation and processing (Lee et al., 2022; Islam et al., 2021). Even the upgrading of biomass into wood pellets can be a competitive export commodity (Rahayu et al., 2021).

The potential of agricultural waste in Indonesia is considerable. In 2023, it was estimated that the power that can be generated from biomass power plants reaches 3,854 GWh (Prayitno et al., 2024). One of the potential biomass wastes that can be utilized as fuel for electricity generation is sugarcane bagasse waste. According to the Indonesian Plantation Statistics (SPI), the amount of sugarcane produced in 2018 was 2,854,300 tonnes, with a land area of 3,473,230 Ha (Ditjenbun, 2018).

Sugarcane bagasse waste is a renewable energy source. In addition to its considerable potential, bagasse waste is also easy to pretreat (Hugot, 1986). Bagasse waste is a solid fiber derived from the final grinding of sugarcane stalks following the process of milking sap. Currently, the sugarcane processing industry extensively utilizes this bagasse waste as fuel in boilers for power generation (Fioranelli, 2023). The water content of sugarcane bagasse waste varies considerably between different milling periods. The moisture content of bagasse waste affects boiler efficiency, and therefore the effect of boiler efficiency due to different bagasse fuel quality was analyzed (Marx et al., 2023).

METHOD

Tools dan Materials

This research examines the impact of fuel alterations on the efficacy of the Isgec Heavy Engineering Limited water tube boiler. This boiler has a production capacity of up to 150 tonnes per hour and operates at a working pressure of 30 kg/cm². The biomass utilized is bagasse waste, which serves as the boiler fuel.

Figure 1. Water tube isgec yipe boiler

Procedure

The sugarcane bagasse waste used as research material is a by-product of milking sap. Samples were taken, and each sample was analyzed for bagasse pol content and water content. Boiler performance was observed by monitoring the pressure and temperature of the steam produced. Boiler efficiency was analyzed by analyzing boiler performance observations from 26-29 July 2023. The work steps used in this study are as follows:

1. The collection of bagasse waste samples was conducted at the final stage of the milling process, or at the point before bagasse waste entered the combustion chamber. Samples were collected over four days at four-hour intervals.
2. Testing and determining the bagasse pol at each bagasse sampling time by conducting heat extraction testing in the laboratory to analyze the moisture content of bagasse waste.
3. Observation of the state of dry steam exiting the boiler to the turbine.

The observation of dry steam and the sampling of sugarcane bagasse waste were conducted concurrently. It is essential to establish a correlation between the state of the bagasse waste and the condition of the boiler output dry steam. The observation of dry steam is crucial for the acquisition of data on the pressure and temperature of the steam exiting the boiler.

Figure 2. Sugarcane bagasse waste

The direct method is employed for the analysis of boiler efficiency, with the calculation stages being as follows:

1. Calculation of enthalpy value

The enthalpy value per day can be calculated from known data. In order to obtain the enthalpy values of advanced hot steam (h) and feed water enthalpy (h_f) at boiler steam temperature and feed water temperature, it is necessary to consult Table A-4 Thermodynamics (Saturated water-Temperature The data from tables A-4 and A-6, Thermodynamics (Saturated water-Temperature) and Thermodynamics (Superheated water), respectively, at a pressure of 3.00 MPa (233.85 °C) were interpolated (Cengel et al., 2023). (233,85°C) melalui interpolasi (Cengel et al., 2023).

Interpolation:

$$\left(\frac{y - y_1}{y_2 - y_1} = \frac{x - x_1}{x_2 - x_1}\right) \quad (1)$$

Thus:

$$y = y_1 + \left[\left(\frac{x - x_1}{x_2 - x_1}\right) \times (y_2 - y_1)\right] \quad (2)$$

2. Calculation of calorific value of bagasse waste

The calorific value of fuel is comprised of two distinct values: NCV (Net Calorific Value) and GCV (Gross Calorific Value). NCV represents the amount of energy released when the fuel is fully burned, minus the energy required in the process of evaporating the moisture content contained in the fuel. In contrast, GCV is the total amount of energy released when the fuel is fully burned, without calculating the energy required during the process of evaporating the water contained in the fuel. The calorific value of pulp can be calculated as follows: (Hugot, 1986)

$$NCV = 4250 - 12s - 48{,}5w \quad (3)$$

$$GCV = 4600 - 12s - 46w \quad (4)$$

The pol content of bagasse, denoted by the letter s, is defined as the ratio of the mass of pol to the total mass of the sample. The moisture content of bagasse, represented by the letter w, is defined as the ratio of the mass of moisture to the total mass of the sample.

3. Calculate boiler efficiency

The calorific value of bagasse can be calculated from the enthalpy value and observation data, and the efficiency of the boiler with the direct method can be obtained as follows: (Hugot, 1986).

$$\eta = \frac{Q_{steam}}{Q_{fuel}} \times 100\% \tag{5}$$

$$\eta = \frac{\dot{Q} \times (h - h_f)}{\dot{q} \times NCV} \times 100\% \tag{6}$$

where;

η : Boiler efficiency (%)

$Qsteam$: Total heat energy absorbed by water vapour

$Qfuel$: Heat energy of combustion products

$\dot{Q}$: Boiler exit water vapour rate (kg/h)

hg : Enthalpy of steam leaving the boiler (kj/kg)

hf : Enthalpy of water entering the boiler (kj/kg)

$\dot{q}$: Fuel flow rate (kg/hour)

NCV : Net Calorific Value of fuel (kj/kg)

RESULTS AND DISCUSSION

Data Observation

The boiler log sheet daily report provides data on operational conditions. Data collection is conducted during boiler operation, spanning 24 hours. Data collection commenced on 26 July and concluded on 29 July 2023. This enabled the acquisition of essential data, including boiler pressure, steam outlet temperature, steam flow, fuel consumption, and other parameters, as presented in Table 1.

Analysis of the Enthalpy Value

The enthalpy values of advanced hot steam (h) and feed water enthalpy (h_f) at pressure P = 3.00 MPa (233.85°C) were obtained using the interpolation method (Cengel, et al., 2023) from tables A-4 Thermodynamics (Saturated Water-Temperature table) and A-6 Thermodynamics (Superheated water). From the observations, it was observed that the highest values of enthalpy of advanced hot steam and enthalpy of feed water were 3132.48 kJ/kg and 435.15 kJ/kg at the time of operation on 26 July. From the observations that have been made every day, it can be seen that the pressure and temperature of the output steam can continue to change. Further detailed observation results can be seen in Table 2.

Table 1. Parameters of Boiler Efficiency Calculation by Direct Method.

Parameter	July 26, 2023	July 27, 2023	July 28, 2023	July 29, 2023
Boiler working pressure (P) (kg/cm^2)	28.75	28.8	28.71	28.58
Steam production (W_s) (ton/hour)	122.83	123.92	79.71	110.17
Fuel flow rate ($\dot{q}$) (kg/jam)	61416.7	61916.7	39833.3	55041.7
Steam boiler temperature (T_2) (°C)	357.08	353.58	354.88	354.75
Feed water temperature (T_1) (°C)	103.8	102.54	100.54	101.83
Dregs Pol (s) (%)	1.17	1.18	1.17	1.16
Moisture (w) (%)	49.02	48.66	49.28	49.48

Table 2. Calculation results of enthalpy values

Date	Enthalpy of superheated steam (h) (kj/kg)	Enthalpy of feed water (h_f)(kj/kg)
July 26, 2023	3132.48	435.18
July 27, 2023	3124.38	429.9
July 28, 2023	3127.37	421.46
July 29, 2023	3127.08	426.91

Calorific Value Analysis of Bagasse

The calorific value is a crucial parameter for measuring the energy that a fuel can produce when fully burnt. To determine the calorific value, the formula from Hugot's book can be employed. The calorific value exerts a significant influence on the pol value of bagasse and moisture. The highest NCV and GCV values were obtained on 27 July at 7848.47 KJ/kg and 9821.86 kJ/kg, respectively. This was due to the lowest moisture content observed on the other dates. The following are the results of the calorific value calculation for bagasse:

Table 3. Calorific value calculation results of bagasse

Date	NCV (KJ/kg)	GCV (KJ/kg)
July 26, 2023	7775.92	9753.07
July 27, 2023	7848.47	9821.86
July 28, 2023	7723.16	9703.03
July 29, 2023	7683.08	9665.04

Analysis of Boiler Efficiency

The calculation of the enthalpy value and calorific value of bagasse, in conjunction with observational data, allows for the determination of boiler efficiency through a direct method. However, the resulting values may vary due to the use of actual parameter data during the boiler's operational phase. Additionally, the data obtained during direct observation may fluctuate daily. Consequently, the resulting boiler efficiency value may differ, influenced by various factors, including the quality of the boiler fuel. The calorific value of bagasse and the moisture content of the fuel will affect the enthalpy value and the boiler efficiency value.

Boiler efficiency is a crucial parameter in industry, measuring the optimal performance of a boiler in converting heat energy into high-pressure advanced hot steam that powers a steam turbine and subsequently into electrical energy. Boiler efficiency has a direct impact on operating costs and environmental impact. The highest boiler efficiency value was observed on 29 July at 70.34%, while the lowest occurred on 27 July at 68.71%, as illustrated in Figure 3. The higher the boiler efficiency, the less steam is produced per unit mass of fuel. Consequently, the cost of providing bagasse waste is more competitive. Higher efficiency signifies lower combustion emissions, which in turn reduces pollution due to burning bagasse in the boiler.

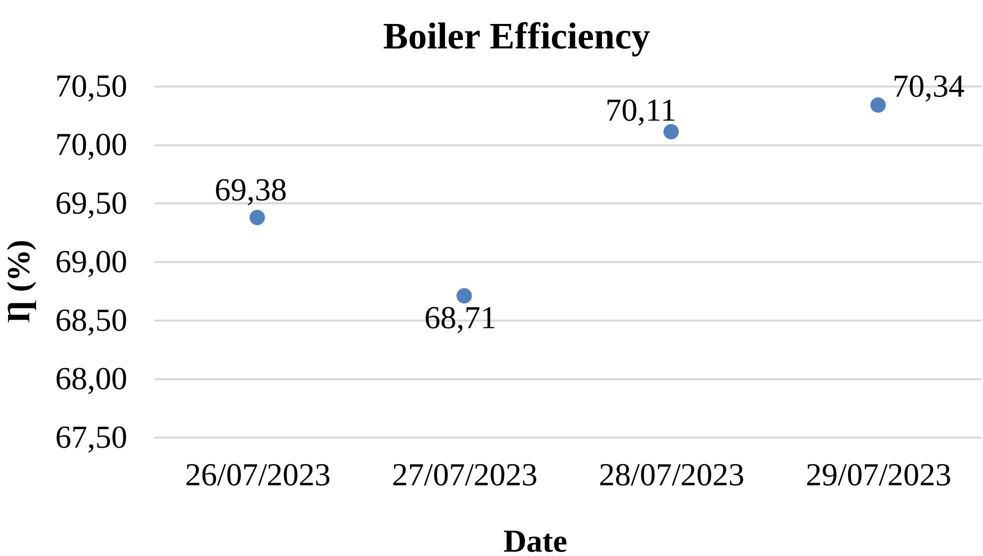

Figure 3. Comparison of boiler efficiencies

http://dx.doi.org/ 10.23960/analit.v9i01.162

Figure 3 presents a comparison of boiler efficiency at the time of observation. This is because the load on the boiler changes, which in turn causes the boiler efficiency to change daily. Furthermore, differences in the quality of biomass fuel, such as variations in moisture content and bagasse pol, must be considered. On 28 July 2023, there was a significant increase in efficiency. This is because, on 28 July 2023, a maintenance day was conducted, namely routine maintenance, which is carried out every two weeks. This routine maintenance affects all existing machines, with the sugarcane grinding mill machine being of particular significance in terms of its impact on the quality of bagasse for boiler fuel.

This bagasse waste is an alternative fuel to replace coal in power assemblies that are generally used in processing industries such as sugar cane factories. Boilers that use coal as fuel are more efficient. Boilers that use coal have an efficiency of 83.94% (Srivinas, et al., 2017), which is 10.6% higher than the boilers used in this study. It is evident that the efficiency of bagasse-fuelled boilers is indeed lower than that of coal-fired boilers. However, the utilisation of bagasse waste is free of charge, thereby reducing the accumulation of bagasse waste. Furthermore, boilers that employ biomass fuels, such as bagasse, produce lower emissions than those that utilise coal (Frandesen, et al., 2023).

CONCLUSION

The ratio of fuel usage to the advanced hot steam produced is 1:2. The average steam quality produced by the bagasse-fired boiler is 3127.83 kJ/kg with a temperature of 355.07 °C and a pressure of 28.71 kg/cm². The boiler efficiency reaches 70.34%, which is 10.6% lower than the efficiency of the coal-fired boiler. Consequently, bagasse biomass, which is a carbon-neutral fuel, can be employed as an alternative fuel for power plants with lower emissions than coal.

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