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Research Article

Thermal Characteristics of Coconut Shells as Boiler Fuel

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Abstract. Agricultural waste products, such as wood, rice husk, corn waste, and coconut shells, are abundantly available and can potentially be used as an energy source, particularly for direct combustion in boilers. Because coconut production increases every year, it would be useful to find an alternative use for coconut shells, which are a type of coconut waste. As coconut shells can be used as fuel in boilers, the aim of this study was to evaluate the thermal characteristics of coconut shells in this regard. This study used experimental results to evaluate the performance of a boiler when coconut shells were used as solid fuel. The variations in feed rate were 5, 7.5, and 10 kg/h, and the water flow rates varied between 1 litre per minute (lpm), 2 lpm, and 3 lpm. Temperature data were collected every second via data acquisition , and the mass flow rate of the flue gas was collected every 5 min using a pitot tube equation. One of the parameters evaluated in determining the success of coconut shells as boiler fuel is the thermal efficiency of the boiler. The results showed that the maximum thermal efficiency reached approximately 62.04%, and the maximum flue gas temperature was approximately 500 °C for a biomass mass flow rate of 7.5 kg/h. The maximum water temperature of the boiler was 99 °C, which was reached at a minimum water flow rate of 1 lpm. The results showed that coconut shells are suitable for use as boiler fuel.

Keywords: Agricultural waste, boiler fuel , coconut shell, thermal characteristics

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1. Introduction

Coconut is one of the agricultural products of Indonesia and is grown in many parts of the country. Coconut production in Indonesia is increasing by 1.5% annually, reaching approximately 3,000,000 tons in 2015. However, an increase in coconut production leads to an increase in their waste products. Currently, coconut waste, in the form of coconut shells, is used for handicrafts and charcoal, but the rate at which it is being used is less than that of its production. However, coconut shells have the potential to be used as a renewable energy source to generate heat and electricity.

Most of the power plants in Indonesia are steam power plants that use coal as a fuel to generate steam in their boilers. The use of coal leads to environmental pollution due to the CO_2 released from the combustion process. However, substituting solid biomass for fossil fuels in residential heating systems can help reduce CO_2 emissions (Golles *et al.* 2013).

A boiler is a type of heat exchanger that transfers energy into a working fluid, such as water. Boilers that use biomass as fuel have been built and tested by researchers worldwide, for example, biomass boilers were tested using wood biomass in 1981 (Yakima 2003). Wood has the potential to be used as a fuel for steam and power generation, but no information is currently available on the boiler efficiency. Other studies have reported on the use of boilers with various types of biomass, such as rice husk, corn waste, palm waste, wood chips, sugarcane, wood pellets, and refuse-derived fuel or RDF (Saidur *et al.* 2011). The review notes that the mentioned biomass has the potential to be used as fuel by being burnt together with coal in the boiler but lacks the information characterizing the temperature attainment and thermal efficiency.

The potential of biomass as boiler fuel has also been studied in several countries. Malaysia has the potential to use waste from oil palm production, such as empty fruit bunches (EFBs), palm shells (PSs), and mesocarp fibers (MFs) (Soh 2016). Soh's (2016) study described the proximate and ultimate analysis of oil palm waste that can potentially be used as a renewable energy source; however, there is no information on the characterization of heat production as an effect of the proximate and ultimate analysis parameters. India has published the biomass potential for the country, which includes the potential of the straw of cereals and pulses, stalks of fiber crops, seed coats of oil seed, and crop wastes, such as sugarcane trash, rice husk, and coconut shells (Kumar *et al.* 2015). Furthermore, South Tyrol (Northern Italy) has declared the possibility of using Norway spruce, willow, apple logs, and apple pruning as biomass (Prando *et al.* 2016). In Indonesia, most biomass boilers are designed to generate steam that is used in several industries for cooking processes and power plants. Biomass from the EFBs empty fruit bunches of palm oil has been studied in palm oil mill boilers (Sukiran *et al.* 2020).

In general, the moisture content affects the efficiency of the boiler, which achieves optimum efficiency when the moisture content is below 15%. Biomass fuel for palm oil kernel shell

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boilers has also been investigated as a replacement for diesel boilers (Heredia *et al*. 2019), with a boiler combustion efficiency of 99.8%. However, the temperature characteristics were not discussed in this study. The potency of palm kernel shells as fuel in the palm oil industry has already been discussed. A study by Handaya *et al.* (2022) reported that palm kernel shells are agricultural waste products with an energy potential of 5.4 MTOE per year. Coconut leaves can also be used as solid fuel via torrefaction. Pestaño and Jose (2016) concluded that the coconut leaf torrefaction process significantly improved the calorific value of the product compared with that of the untreated biomass. Another biomass that is suitable as solid fuel through the co-firing process is sugarcane bagasse. Additionally, research has shown that torrefaction can improve combustion quality (Samaksaman & Manatura 2021).

The most important parameters used to evaluate the performance of a boiler when using biomass as fuel are temperature achievement and efficiency. The temperature values consist of the flue gas (inlet and outlet boilers) and water temperatures (inlet and outlet boilers). Therefore, the efficiency of the boiler can be evaluated based on both the flue gas and water temperature (inlet and outlet). The efficiency describes the amount of heat from the flue gas absorbed by the water to increase the temperature. However, the investigations that were performed lacked information on the temperature and boiler efficiency.

Biomass used as boiler fuel, such as wood, rice husk, corn waste, palm waste (EFBs, PSs, and MFs), willow, apple logs, apple pruning remains, and coconut leaves have calorific values between 2,000–4,500 Cal/g. Meanwhile, the coconut shell has a calorific value of approximately 4,700 Cal/g, indicating its potential as a fuel in boilers to produce steam and electricity.

Coconut shells are abundant in Indonesia. To assess its potential use as a fuel for boilers, its properties, particularly the boiler flue gas and water temperature, should be evaluated. The boiler efficiency should also be calculated to ensure adequate boiler performance when using coconut shells. The performance characterization of coconut shells as boiler fuel is important for obtaining fundamental data for further development. Therefore, the objective of this study is to evaluate the thermal characteristics of coconut shells as fuel in boilers. This study contributes to the provision of data on the performance of coconut shells used as fuel in boilers.

2. Materials and Methods

2.1 Materials

The boiler was constructed using cylindrical steel with a shell diameter of 32 cm and a length of 94 cm. The diameter and amount of the tube were 2.54 cm and 17 tubes, respectively. The boiler was insulated with 5.08 cm thick ceramic wool. The working fluid of the boiler was water, and the boiler had a capacity of 67.5 kg. The fuel used in the stove was a coconut shell with approximate, ultimate, and calorific values as shown in Table 1.

2.2 Methods

The experimental data were collected by varying the fuel feed rate and water flow rates. The fuel feed rate was allowed to vary between 5, 7.5, and 10 kg/h. The water flow rate was allowed to vary between 1, 2, and 3 liters per minute (lpm) for each variation in the fuel feed rate. The experimental setup can be seen in Fig. 1. Temperature data were collected every second using a type K thermocouple and recorded using data acquisition. Furthermore, the water flow rate was calculated using a rotameter for 5 min each, whereas the flue gas mass flow rate was calculated from a pitot tube. The experiment was performed according to the matrix, as shown in Table 2.

2.3. Sample analysis

2.3.1. Proximate analysis

Proximate analysis is generally used to determine the percentages of moisture, volatiles, bound carbon, and ash. This analysis is important for studying the combustion of solid biomass. The moisture content can affect the total energy conversion because it affects the calorific value of a given solid fuel. Typically, solid fuels have a moisture content of less than 14%.

The coconut shells used in this study had a moisture content of 10.87% (Table 1). In addition to moisture, volatiles are also components of solid fuel, which are emitted as gases at high temperatures in the absence of air. Fixed carbon and volatiles increase the calorific value of any solid biomass fuel. The coconut shells used in this experiment contained approximately 18.11% fixed carbon and 70.58% volatiles; hence, this biomass has the potential to be used as a solid fuel. Ash is the non-combustible residue left after the combustion process. In the combustion of biomass, ash consists mainly of inorganic elementary oxides, which are minerals, C, O, S, and water; these are released during combustion. As shown in Table 1, coconut husk has an ash content of 0.11%, which is lower and better than that of other types of biomass, such as wood, rice husk, corn waste, palm waste (EFBs, PSs, MFs), willow, apple logs, and apple pruning remnants, which have been used by previous researchers.

Ultimate analysis is one of the most important factors when evaluating the properties of biomass fuels. It can be used to evaluate the percentages of C, H, N, O, and S to study the environmental impact of biomass. The C, H, and O contents contribute to the calorific value, and a higher O content contributes to a lower caloric value. In contrast, higher C and H levels contribute to higher caloric values. Coconut shells have C, H, and O contents of approximately 12.22%, 4.59%, and 41.54%, respectively. The N and S contents represent the amount of emissions (i.e., NOx and SOx). Both N and S contents are crucial parameters for environmental impact assessment, especially for solid fuels in combustion technology. Coconut shells have N and S values between 0.09–0.25%. The values of C, H, N, and O of coconut husk, based on Table 1, have the potential to be used as fuel, similar to the other biomass sources mentioned by other researchers, such as wood (Jangsawang 2017), rice husk (Venugopal *et al.* 2019), corn waste (Sittisun *et al.* 2019), palm waste (Sasujit *et al.* 2017), willow (Stolarski *et al.* 2020), and apple stems and apples (Gowman *et al*. 2019)

2.3.2. Calorific value analysis

This research focuses on the phenomenon in boilers, which are commonly used in steam production for generating electricity. The direct combustion of biomass for electricity production has been found to be a promising method in the near future.

One of the most important parameters when using biomass as a fuel is its calorific value. The calorific value represents the energy content or amount of heat released when biomass is burned in air. It denotes the maximum amount of energy that can potentially be recovered from a biomass source. However, the actual amount of energy recovered depends on the conversion technology. As shown in Table 1, the coconut shell has a calorific value of approximately 4,700 Cal/g. This value is relatively constant compared with the poor quality of coal and other raw biomass materials. Based on this, coconut shells can be used as solid fuel.

Table 1
Proximate and ultimate analysis of Coconut Shell

No	Proximate Analysis	Proximate as received	Unit	Method
1	Moisture	10.87	Weigh%	ASTM D 3173
2	Ash	0.44	Weigh%	ASTM D 3173
3	Volatile	70.58	Weigh%	ASTM D 3173
4	Fixed Carbon	18.11	Weigh%	ASTM D 3173
No	**Ultimate Analysis**	**Ultimate as received**	**Unit**	**Method**
1	Carbon	12.22	Weigh%	ASTM D 3173
2	Hydrogen	4.59	Weigh%	ASTM D 3173
3	Nitrogen	0.09	Weigh%	ASTM D 3173
4	Sulphur	0.25	Weigh%	ASTM D 3173
5	Oxygen	41.54	Weigh%	ASTM D 3173
No	**Analysis**	**Ultimate as received**	**Unit**	**Method**
1	Caloric Value	4728.44	Cal/gram	ASTM D5865

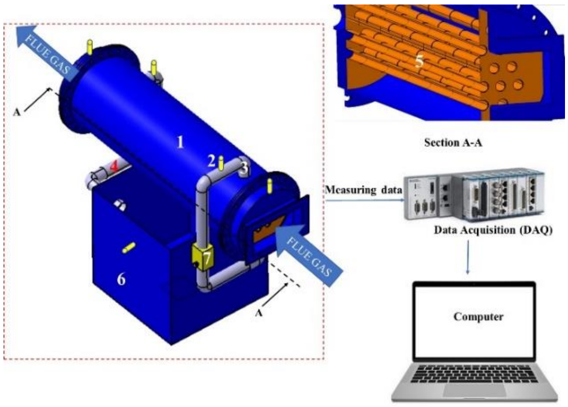

Fig. 1 Experimental Setup of Boiler. The equipment consisted of (1) shell of boiler, (2) type K thermocouple, (3) water inlet pipe, (4) water outlet pipe, (5) tube of boiler with fin, (6) water reservoir, and (7) valve and water flow meter.

Table 2
Experiment guides by matrix

No	Biomass feed rate (kg/h)	Water flow rate (Litre per minutes)
1	5	1
		2
		3
2	7.5	1
		2
		3
3	10	1
		2
		3

The analysis performed in this experiment consisted of energy balance and thermal efficiency of the boiler. As shown in Eq. 1, the amount of heat generated by the biomass is described by the flue gas temperature(Q_{fg}). The heat from the flue gas is transferred to water (Q_w) through the shell (heat exchanger) of the boiler (Q_{he}). Theoretically, the energy balance transferred by the flue gas temperature (Q_{fg}) to the water (Q_w) through heat exchanger (Q_{he}) is the same.

$$Q_w = Q_{fg} = Q_{he} \tag{1}$$

The amount of heat received by the water (Q_w) is based on the water mass flow rate $(\dot{m}_w)$, heat capacity of water (Cp_w), temperature of the water inlet (T_{win}), and temperature of the water outlet (T_{wout}). However, the amount of heat transferred from the flue gas is based on the mass flow rate of flue gas $(\dot{m}_{fg})$, heat capacity of flue gas (Cp_{fg}), temperature of flue gas inlet (T_{fgin}), and temperature of flue gas outlet (T_{fgout}). The amount of heat transferred from flue gas to water is based on the area of the heat exchanger (A_{he}), the overall heat transfer coefficient (U_{he}), and the logarithmic average of the temperature differences between the hot and cold feeds at each end of the heat exchanger (ΔT_{lmtd}).

$$\dot{m}_w.Cp_w.(T_{w\,out} - T_{w\,in}) = \dot{m}_{fg}.Cp_{fg}.(T_{fg\,out} - T_{fg\,in}) = A_{he}.U_{he}.\Delta T_{lmtd} \tag{2}$$

$$\Delta T_{lmtd} = \frac{(T_{fg\,in} - T_{w\,out}) - (T_{fg\,out} - T_{w\,in})}{\ln \dfrac{(T_{fg\,in} - T_{w\,out})}{T_{fg\,out} - T_{w\,in}}} \tag{3}$$

The overall heat transfer coefficient was calculated based on the diameter of the pipe inlet (d_{in}) and outlet (d_{in}), conductivity of the tube material (λ_t), and heat transfer coefficient of the flue gas (α_{fg}) and water (α_w).

$$U = \left(\frac{d_{out}}{\alpha_{fgin}.d_{in}} + \frac{d_{out}}{2\lambda_t} ln \frac{d_{out}}{d_{in}} + \frac{1}{\alpha_w}\right)^{-1} \tag{4}$$

The performance of the boiler was evaluated based on the thermal efficiency using the following equation:

$$\eta_{th} = \frac{Q_{out}}{Q_{in}} \tag{5}$$

$$\eta_{th} = \frac{\dot{m}_w.Cp_w(T_{wout} - T_{win})}{\dot{m}_{fg}.Cp_{fg}(T_{fg_{out}} - T_{fg_{in}})} \tag{6}$$

All data analyses were based on thermodynamic and heat-transfer phenomena (Cengel *et al.* 2005). The thermal efficiency of the boiler was the most important parameter in this experiment.

3. Result and Discussion

3.1 Characteristics of water temperature

Fig. 2. a) shows the results of the water temperature inside and outside the boiler under a coconut shell feed rate of 5 kg/h. The maximum water outlet temperature reached approximately 76 °C at a minimum water flow rate of 1 lpm. Meanwhile, the minimum temperature reached approximately 72 °C, with a maximum water flow rate of 3 lpm. Both the maximum and minimum temperatures of the water outlet were reached after 10 h of steady-state operation.

Fig. 2. b) shows the profile of the water inlet and outlet temperatures at a coconut shell feed rate of 7.5 kg/h. This condition had a maximum temperature of 99 °C for the water outlet with a minimum water flow rate of 1 lpm. The minimum temperature of the water outlet reached 87 °C, with a maximum water flow rate of 3 lpm. Both the maximum and minimum outlet water temperatures were reached after 8.5 h of steady-state operation.

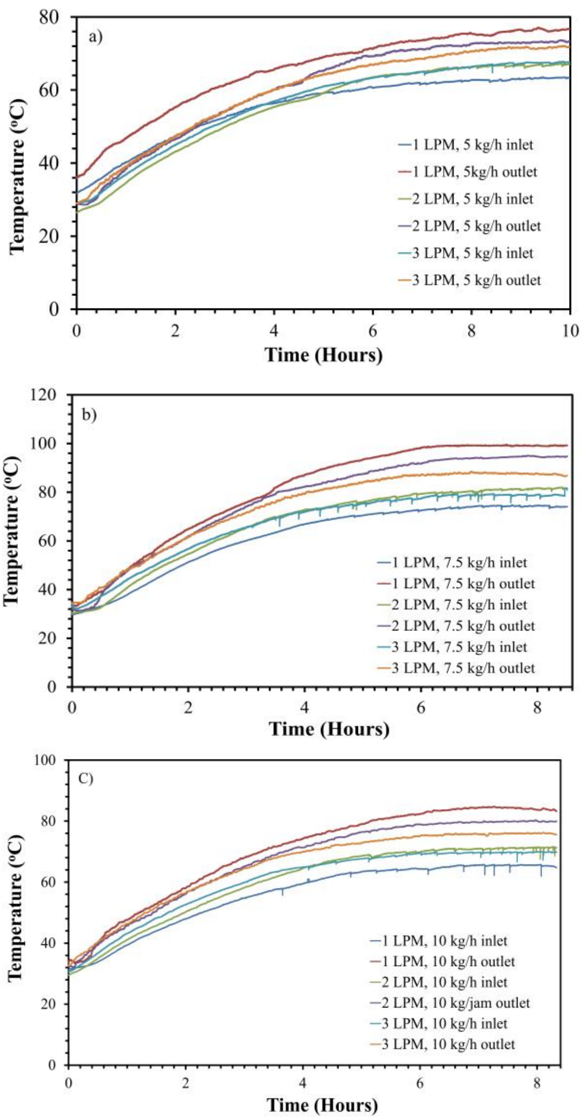

Fig 2. Profile of water temperature at a) 5 kg/h, b) 10 kg/h, and c) 15 kg/h coconut shell feed rate

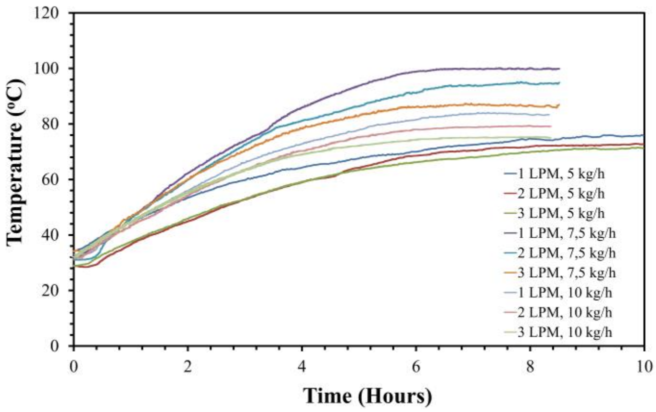

Fig. 3 Profile of water temperature inside boiler

Fig. 2. c) shows the temperature profiles of the water inlet and outlet at a coconut shell feed rate of 10 kg/h. The maximum water outlet temperature for this condition reached 83.7 °C with a minimum water flow rate of 1 lpm. The minimum temperature of the water outlet reached 75.8 °C with a maximum water flow rate of 3 lpm. Both the maximum and minimum outlet water temperatures were reached after 8.5 h of steady-state operation.

Fig. 3 shows the temperature profile of the water in the boiler. The maximum temperature inside the boiler reached 99 °C at a coconut shell feed rate of 7.5 kg/h and a water flow rate of 1 lpm. The minimum water outlet temperature reached 71 °C at a coconut shell feed rate of 10 kg/h and a water flow rate of 3 lpm.

Using Figs. 2 (a-c) and 3, it can be explained that by increasing the coconut husk feed rate, the water outlet temperature increased. However, when designing the tube in a boiler, it should be noted that increasing the feed rate of coconut shells requires more tubes to carry the flue gas from the furnace to the boiler. If the number of tubes is less than the required number, the amount of flue gas entering the boiler will decrease. This phenomenon is also evident when testing a scrubber system (Bianchini *et al.* 2016) and when studying the combination of tubular boilers (Patro 2016).

The temperature inside the boiler is higher than when using spent coffee grounds to heat water with a capacity of 40.1 kg, producing a maximum temperature of 78.5 °C (Kang *et al.* 2017). Compared with wood pellets and domestic wood pellet boiler, where the water outlet temperature was 70 °C (Euh *et al.* 2016) (Carlon *et al.* 2016) and 79 °C (Kang *et al.* 2013), respectively, a much higher water outlet temperature of 99 °C was obtained from using coconut shells. This experiment also shows that a high water flow rate reduces the temperature of the water outlet, which is caused by a reduction in the heat absorbed by the water.

3.2. Characteristics of flue gas temperature

Fig. 4 (a-c) show the profile of the flue gas temperature at the inlet and outlet at coconut shell feed rates of 5, 7.5, and 10 kg/h, respectively. The flue gas temperature at the inlet reached a maximum of 310 °C at a water flow rate of 1 lpm, whereas the outlet temperature reached a minimum of 75 °C at a water flow rate of 3 lpm for a mass flow rate of 5 kg/h.

Different patterns were observed when the mass flow rate of the flue gas was 7.5 kg/s, and the maximum temperature at the boiler inlet reached 500 °C with a water flow rate of 1 lpm. Moreover, the flue gas outlet temperature reached 87 °C with a water flow rate of 3 lpm. Both the inlet and outlet flue gas temperatures were higher than the coconut shell feed rate of 5 kg/h. Although a high temperature was reached, the heat loss of the system should be considered as well. More leaks in the system lead to higher losses and lower thermal efficiency. Furthermore, a higher flue gas temperature creates an uncertainly higher heat transfer to the fluid.

In contrast, for a mass flow rate of 10 kg/h, the maximum flue gas temperature was reached at 390 °C with a water flow rate of 1 lpm, while the minimum flue gas outlet temperature reached 75 °C with a water flow rate of 3 lpm

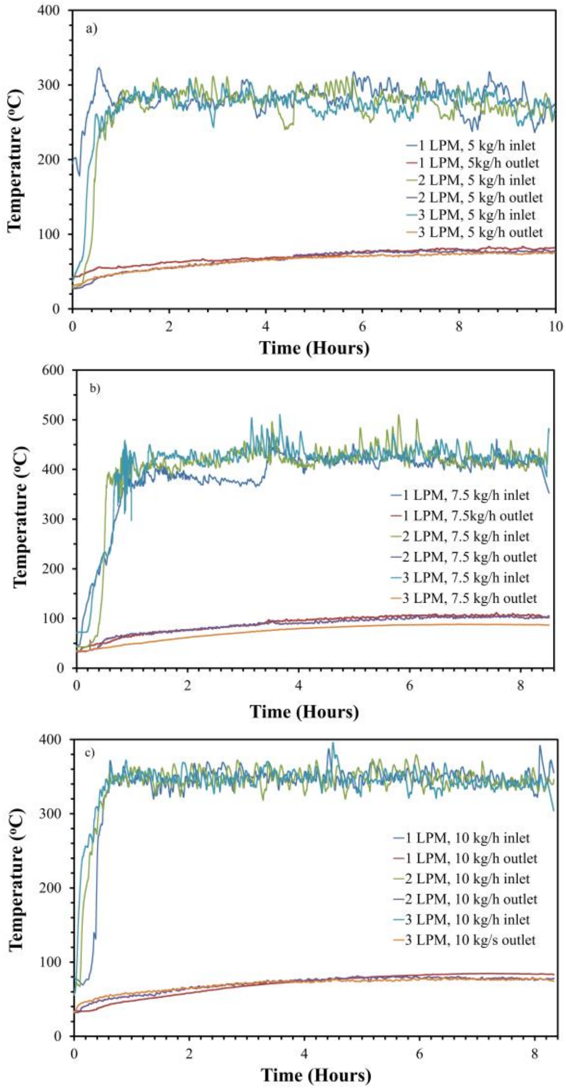

Fig. 4 Profile of flue gas temperature at a) 5 kg/h, b) 7.5 kg/h, and c) 10 kg/h

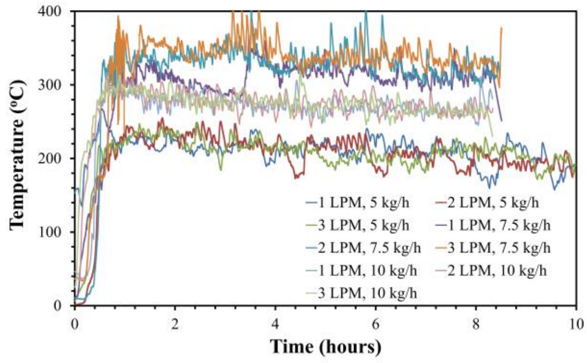

Fig. 5 Profile of temperature differences in flue gas

Fig. 5 shows the profile of the temperature difference between the flue gas inlet and outlet. The maximum temperature difference was 397 °C for the water flow rate of 2 lpm and feed rate of 7.5 kg/h. This temperature difference is the heat potential to be transferred to the water. Typically, in the combustion process, a higher feed rate requires a higher air supply to satisfy the composition of the air-fuel ratio, and a higher air-fuel ratio produces a higher flue gas temperature. In this study, the air supply was constant for all the biomass feed rates. Based on the characteristics presented in Fig. 7, it can be concluded that the best air-fuel ratio occurs when the feed rate of biomass is 7.5 kg/h

Based on the flue gas temperature characterization in Fig. 4(a-c), using the coconut shell yields a higher temperature than when using wood chips for the biomass-fire, which has a temperature heat source of 300 °C (Pezzuolo *et al.* 2016). The biomass boiler with flint corn and a power capacity of 25 kW has a flue gas temperature at the outlet of about 200 °C (Bianchini *et al.* 2016), which is higher than that when using coconut shells. This occurs because of different feed rates.

3.3. Potential of heat production

Fig. 6 shows the results of the heat analysis for each experiment. The maximum heat output from the flue gas was 2.41 kW at a conditioned coconut shell feed rate of 10 kg/h, whereas the maximum heat input to the water was 1.45 kW. Based on the heat balance, this condition resulted in a heat loss of approximately 0.96 kW. Compared with the other biomass sources, a palletized wood boiler with a mass flow of 439.2 kg/h produces 1,275 MW (J *et al.* 2013), flint corn with a mass flow rate of 3 kg/h produces 12.5 kW (Bianchini *et al.* 2016), and palletized wood with a mass flow rate of 2 kg/h produces 12 kW. Another study used coal to generate 550 MW (Yang *et al.* 2014). All the biomass sources used in these studies reported higher thermal results than coconut shells because of the different mass flow rates and heat capacities of the biomass.

Despite the advantages, using coconut shells as fuel in this experiment had the issue of the mass flow of the flue gas being uncontrollable, although the feed rate of biomass was constant and controllable, as shown in Fig. 7. This problem causes the heat generated from the flue gas to be nonlinear. It is also important to consider the excess air from the furnace creating a high temperature that is transferred to the boiler. The number of tubes should also be considered because, according to many experiments, tar can become fouled by the heat transferred to the water (Macek *et al.* 2017) (Romeo *et al.* 2009).

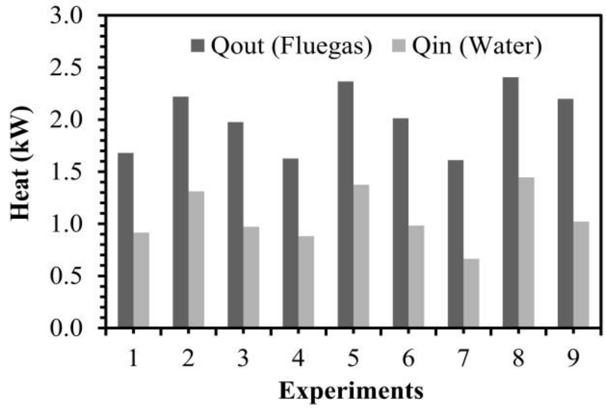

Fig. 6 Analysis of heat

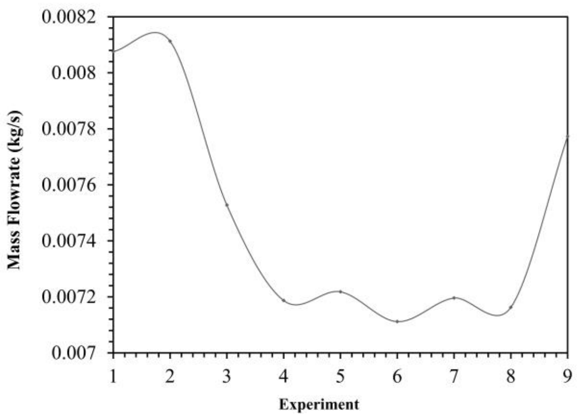

Fig. 7 Analysis of the flue gas mass flow rate

Table 3 lists the thermal efficiencies of the boilers used in this experiment. The highest efficiency of approximately 62.04% was obtained at a biomass feed rate of 7.5 kg and a water flow rate of 3 lpm. Researchers have also studied and improved the thermal efficiency of certain materials. Patro (2016) tested the combination of coal and rice husks as fuel in a boiler using a two-pass combination tube and an indirect method, resulting in a thermal efficiency of 76.12%. Other studies have described improvements in the use of fuel drying, air preheating, and air volume control for fuel combustion, which increased the thermal efficiency of the boiler by approximately 5.15%, from 76.48% to 81.63% (Suntivarakorn and Treedet 2016). Considering the load factor for boilers with wood pellets, an efficiency increase of approximately 5–15% has been reported, with the efficiency after the improvement being between 70–85% (Carlon *et al.* 2015). Improving the superheating area, excess air coefficient, and inlet and outlet gas for traditional boilers using coal as fuel has also increased the thermal efficiency from 71.2% to 83.2% (Chao *et al.* 2017). As mentioned earlier, the flue gas temperature plays an important role in boiler development. A higher temperature in the flue gas does not automatically lead to higher thermal efficiency. This phenomenon has also been described by other researchers in *Pinus halepensis* fuel boilers and *Pinus pinaster* chips. The experiment showed that the efficiency loss due to the flue gas temperature was higher than those due to unburned gases and solid residues (Serano *et al.* 2013). This experiment yielded good results for a traditional boiler.

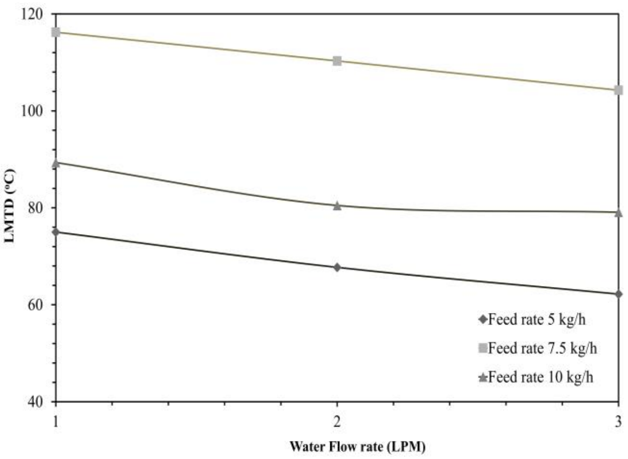

Fig. 8 Profile of water flow rate correlation

Table 3
Analysis of thermal efficiency of boiler

Feed rate of biomass (kg/h)	Water flow rate (LPM)		
	1	2	3
5	52.42	51.74	40.79
7.5	59.02	60.25	62.04
10	48.57	49.38	46.94

Fig. 8 shows the correlation between the logarithmic mean temperatures and the water flow rate. This correlation indicates that the logarithmic mean temperature, which consists of the temperature of both the flue gas and water at the inlet and outlet, affects the heat transferred to the water based on the water flow rate. Another phenomenon describes the correlation of the water flow rate using linear regression (Carlon *et al.* 2015). Using an empirical delta T approach to predict flue gas temperature (Heller 2010), it was found that a high water flow rate reduces the temperature of water at the outlet but has the potential to increase the heat transfer.

4. Conclusion

Coconut shells have been tested as fuel for boilers. The results show that the water temperature consists of three regions: the initial region from the beginning, the charge heat cycle, and the final steady-state region. The coconut shell fuel produced a maximum water temperature of 99 °C at the outlet of the boiler, with a feed rate of 7.5 kg/h and a water flow rate of 1 lpm.

The flue gas temperature profile consists of two regions, which are starting and stationary, or constant loads. The flue gas of the coconut shell boiler can reach a maximum temperature of 500 °C, even with a feed rate of 7.5 kg/h and a water flow rate of 1 lpm. Furthermore, the maximum thermal efficiency of 62.04% occurs at a biomass feed rate of 7.5 kg/h and a water flow rate of 3 lpm. The thermal efficiency depends not only on the highest temperature achieved but also on the water mass flow. Based on the abovementioned results, coconut shells can be used as fuel for boilers. This study has limitations in terms of the number of tubes used to transfer energy from flue gas to water and in the composition of the mass feed rate and the amount of air in the combustion process. In the future, the optimization of the flow rate, air volume, and number of tubes can provide better efficiency.

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Declaration of Competing Interest: The authors declared that they have no competing financial interests or personal relationships that could have appeared to influence the work reported in this paper

Nomenclature

Q_w	= Heat of Water (kW)
Q_{fg}	= Heat of flue gas (kW)
Q_{he}	= Heat of Heat Exchanger (kW)
$\dot{m}_w$	= Mass flow rate of water (kg/s)
$\dot{m}_{fg}$	= Mass flow rate of flue gas (kg/s)
Cp_w	= Heat capacity of water (kJ/kg°C)
Cp_{fg}	= Heat capacity of flue gas (kJ/kg°C)
$T_{w_{out}}$	= Temperature of water out from boiler (°C)
$T_{fg_{out}}$	= Temperature of flue gas out from boiler (°C)
$T_{w_{in}}$	= Temperature of water into boiler (°C)
$T_{fg_{in}}$	= Temperature of flue gas into boiler (°C)
A_{he}	= Area of heat exchanger (m^2)
U_{he}	= Overall heat transfer coefficient (kW/m^2°C)
d_{in}	= Diameter inlet tube (m)
d_{out}	= Diameter outlet tube (m)
α_{fg}	= Heat transfer coefficient flue gas (kW/m^{2}K)
α_w	= Heat transfer coefficient water (kW/m^{2}K)
λ_t	= Thermal conductivity of tube (kW/mK)
ΔT_{lmtd}	= Logarithmic mean temperature differences (°C)
η_{th}	= Efficiency thermal (%)
Q_{out}	= Heat out from system (kW)
Q_{in}	= Heat into system (kW)

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