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WORLD CHEMICAL ENGINEERING JOURNAL

Journal homepage: http://jurnal.untirta.ac.id/index.php/WCEJ

Performance Test of Biomass Cookstove with Torrefied Rice Husk as Fuel Using Water Boiling Test Method

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ARTICLE HISTORY

Received January 13, 2020
Received in revised form March 12, 2020
Accepted May 8, 2020
Available online May 9, 2020

ABSTRACT

One of the ways to increase effectiveness and efficiency of using biomass as fuel is through gasification cookstove technology. Gasification cookstoves is tools used to convert biomass into combustible gases via thermochemical pathways. Rice husk is a type of biomass that has a low heating value of 11-14 MJ/Kg. Therefore, it is necessary to pre-treat it through torrefaction to increase the calorific value of the fuel so that it can increase the thermal efficiency of the gasification cookstove. This efficiency is determined by the water boiling test (WBT) method. This method is a laboratory-based test that can be used to measure how efficiently a cookstove uses fuel to heat water in a cooking pot and the quantity of emissions produced while cooking. This research was conducted to obtain the optimum conditions for air flow rate, height of the bed, and fuel type of rice husk torrefied. This research was conducted by inserting rice husk torrefied as fuel with a variation of height of the bed 42.6 cm; 31.5 cm; and 21.3 cm, the secondary air flow rate openings (full open; partial open; close), and type of fuel used is the rice husk torrefied at temperature 250 ^{o}C for 60 minutes (fuel A), and temperature 300 °C for 30 minutes (fuel B). The optimum operating conditions were found at 21.3 cm of bed height, full close secondary air opening, with type A fuel. While the highest efficiency value of 18.75% was found in type A fuel, with bed height 31.5 cm, and secondary air opening is full close.

Keywords: rice husk, cookstove, gasification, torrefaction, wbt.

1. INTRODUCTION

The cookstove is a technology that has an important role as a tool in utilization of energy in the household sector. The cookstove serves as a provider of energy for cooking with fossil fuels. Along with population growth that continues to increase, causing global demand for energy to increase rapidly, including in the household sector. It is estimated that the supply of major fossil energy sources, such as coal and petroleum will be exhausted in the next three decades (Van Hung et al., 2018). This has led to an increase in the price of fuel, which in turn adds to the burden on the community, especially those with low-income groups. Energy from biomass can be an alternative energy source because of its abundant availability, renewable, inexpensive, and environmentally friendly. The main source of biomass energy in Indonesia can be obtained from rice residue such as rice husk. It is has the potential energy up to 53.7 GWe (Anshar et al., 2014).

Indonesia is one of the largest rice producer countries in the world. Based on data from the Central Statistics Agency (BPS), rice production in Indonesia in 2019 was 54.6 million tons/year (BPS, 2019). Rice production produces a waste known as husk. In general, rice mills produce 72% rice, 5-8% bran, and 20-22% rice husks (Barus, 2017). The abundant potential of rice husk waste as a byproduct of the rice production process can be a cheap and renewable energy source, especially to support energy in the household sector in rural areas.

Husk is a part of grain (*cereal*) which is a dry, scaly, inedible sheet, which protects the inside (*endospermium and embryo*). Rice husks have a heating value of 11-16.5 MJ/kg which can be used as the main source of energy for the household sector in rural areas. The characteristics of rice husk as fuel can be seen from two parameters, proximate and ultimate analysis (Table 1).

Table 1. Ultimate and proximate analysis of rice husk.

Ref	Proximate (%-wt)			Ultimate (%-wt)					HHV
	VM	FC	Ash	C	H	N	O	S	MJ/kg
(Alwan, 2019)	61.81	16.95	21.24	38.50	5.20	0.45	34.61	-	14.69
(Bich et al., 2017)	51	20.1	18	34.6	4.23	0.46	31.7	-	16.57
(Kasembe et al., 2015)	59.2	14.6	26.2	35.6	4.5	0.19	33.4	-	13.04

Traditional cookstoves usually using biomass as primary fuel for cooking in the household sector. The use of traditional cookstoves results in incomplete combustion, low thermal efficiency, and causes air pollution. One of the ways to increase the effectiveness and efficiency of biomass fuel applications is through gasifier cookstove technology.

In general, there are three pathways for thermal conversion of biomass, that is combustion, gasification and pyrolysis (Alwan, 2019). The difference between the three processes is in air supply and the main product. Gasifier cookstoves convert biomass through the gasification pathway, so that solid fuels are converted into combustible gases consisting of carbon monoxide (CO), hydrogen (H_2) and methane (CH_4). The thermal efficiency of gasifier cookstoves reaches 40%, while conventional cookstoves are only 15%. Various designs and models of gasification cookstoves have been developed, but still have various obstacles, including the gasification process that is not optimal and the combustion quality is low. One of the factors that affect the performance of the gasifier cookstove is the type of biomass (Djafar et al., 2018). Based on research conducted by Bhusal (2015) using a rice husk gasifier cookstove with a modification of two combustion chambers with different fuels, the highest thermal efficiency was found in a mixture of wood chips was 27.93%, followed by a mixture of pellets was 27.89% and then rice husk was 26.97% (Bhusal et al., 2015). The cookstove performance test showed that the efficiency of using rice husks was 20.02%, a mixture of wood chips was 25.89%, and a mixture of pellets was 26.27%. The efficiency of gasifier cookstoves with rice husk fuel shows lower quality than the other two variations. This is because rice husks have a lower heating value than other fuels. One of the efforts to increase calorific value of rice husks is through the torrefaction. Other factors that affect the performance of a gasifier cookstove are air flow rate, height of bed, and type of fuel. This research was conducted to obtain the optimum conditions for air flow rate, height of bed, and type of fuel on the performance of updraft type rice husk gasifier cookstove with torrefied rice husk as fuel.

2. METHODS

2.1 Experimental Procedure

Two kilograms (2 kg) of rice husk was put into the torrefaction reactor made of stainless steel, with variations in temperature and residence time of 250°C, 60 minutes (Fuel A) and 300°C, 30 minutes (Fuel B), respectively. The fuel is then analyzed through proximate analysis to determine changes in composition before and after being torrefaction, that is moisture content (MC), ash, volatile matter (VM), and fixed carbon (FC).

The second step is to test the performance of the gasifier cookstove, in this study using the water boiling test (WBT) method. This method is a laboratory-based test that can be used to measure how efficiently a cookstove uses fuel to heat water in a cooking pot and the quantity of emissions produced while cooking. The test is carried out with a variation of secondary air openings, that is full open; partial open; and full close. Variation of bed height was 42.6 cm; 31.5 cm; and 21.3 cm, as well as variations in the types of torrefied of rice husk as fuels, that is fuel types A and B. The testing process for cookstove performance follows the standard procedure of the International Organization for Standardization (ISO) technical committee (TC 285) (ISO Standard No. 19867-1: 2018) (ISO, 2018).

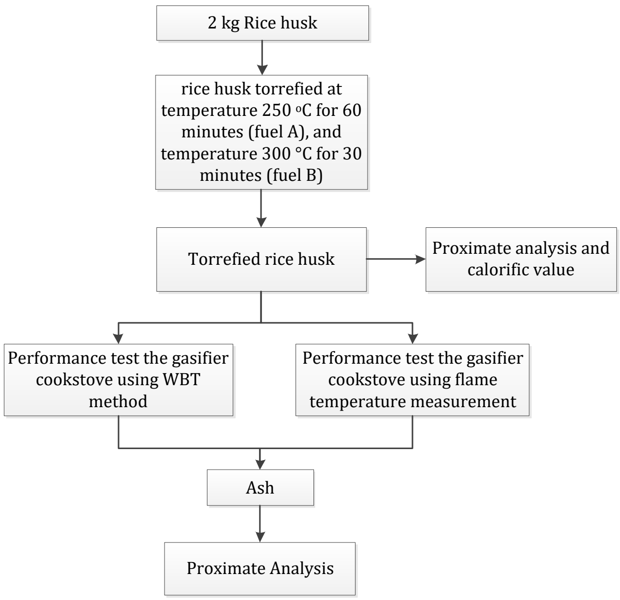


Fig. 1. Flowchart of experimental procedure.

2.2 Materials

The following are tools used in research on gasifier cookstove performance tests.

2.2.1. Torrefaction Reactor

The following is a picture of a torrefaction reactor set used in the process of making torrefied of rice husks as fuel.

2.2.2. Gasification Cookstove

The gasifier cookstove used in this study is an updraft type with the following dimensions, bed height was 60 cm, outer diameter was 20 cm and inner diameter was 15 cm, which is equipped with 9 holes of secondary air holes with each hole has diameter 1 cm, and the primary air holes at the bottom of the reactor has 39 holes with diameter of 0.5 cm. In addition, the gasifier cookstove used in this study is also equipped with a holder, fan, gas burner, and char chamber.

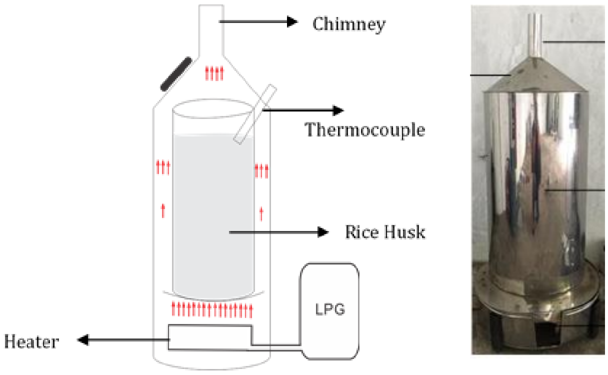


Fig. 2. Torrefaction equipment.

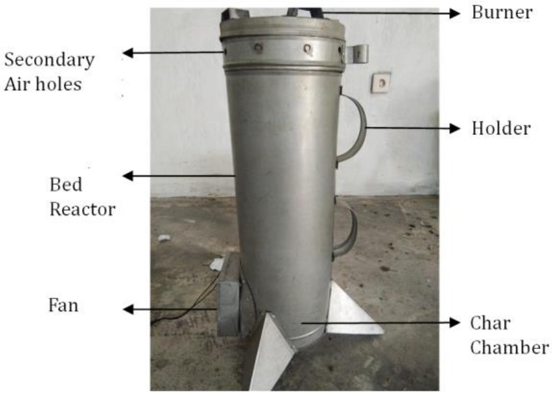


Fig. 3. Updraft gasification cookstove.

Other supporting tools used in this study were stopwatch, thermometer, thermocouple, pot, analytical balance, and 1000 mL glass beaker.

3. RESULT AND DISCUSSION

The biomass used in this study was torrefied rice husk. Torrefaction aims to improving the quality of biomass solid fuels, in terms of higher energy density, longer shelf life and hydrophobic in nature. Torrefaction is a thermal treatment for lignocellulosic waste biomass at low temperature between 200-300^oC and atmospheric pressure in the absence of oxygen. During the torrefaction process, rice husks will take place devolatilization which causes a decrease weight due to removal of water and volatile matter. The loss of mass in the process causes the energy density to increase.

Based on research conducted by Irawan, et al (2019), the best results of rice husk torrefaction occurred at temperature of 250^oC with a residence time of 60 minutes, and temperature of 300^oC with a residence time of 30 minutes. Table 2 shows the proximate analysis of rice husks before torrefaction (bulk rice husk) and rice husk after going through torrefaction process (Irawan et al., 2019).

Table 2 shows that the torrefaction process can improve the quality of rice husk. This can be seen from the water content of rice husk in condition A and B decreasing 2.62% and 2.56%. The high moisture content will reduce fuel energy during combustion, because the energy produced is partly used for the drying process.

Table 2 also shows the solid carbon content of rice husk which increased after going through the torrefaction process, that is 0.96% in condition A, and 3.08% in condition B. Solid carbon is the main component of rice husks which can produce heat in combustion process. The higher solid carbon content, that calorific value of rice husks will increase. The calorific value of torrefied rice husk increases by 109 Cal/g in condition A, while in condition B was 237 Cal/g (Table 2).

3.1 Effect of Bed Height on the Boiling Water Temperature

The height of bed indicates the mass of rice husks used as fuel. In this study, there were three variations of bed height that is 42.6 cm, 31.5 cm, and 21.3 cm. The maximum flame temperature is at starting of the operating time, this is because the available fuel has started to burn and produces a lot of combustible gases such as CO, H_2, and CH_4 which come into contact with the air so that it produces a high flame temperature and are marked with an orange flame.

Table 2. Proximate analysis result of bulk and torrefied rice husk

Fuel	MC (%, adb*)	Ash (%, adb)	VM (%, adb)	FC (%, adb)	(LHV) (Cal/g, adb)
Bulk	9.60	19.98	56.98	13.44	3,228
Type A**	6.98	21.78	56.84	14.40	3.337
Type B***	7.04	22.36	54.08	16.52	3.465

** adb = air dry basis*
*** Torrefied rice husk at temperatures of 250^oC for 60 minutes*
**** Torrefied rice husk at temperatures of 300^oC for 30 minutes.*

Table 3. Output parameters at various of bed height.

Parameter	Fuel A			Fuel B		
	42.6 cm	31.5 cm	21.3 cm	42.6 cm	31.5 cm	21.3 cm
t_{op} (min)	41.67	26.33	18.00	39.33	27.00	19.00
T ≥ 500^oC (% total t_{op})	37.84	39.92	42.58	39.17	40.64	43.86

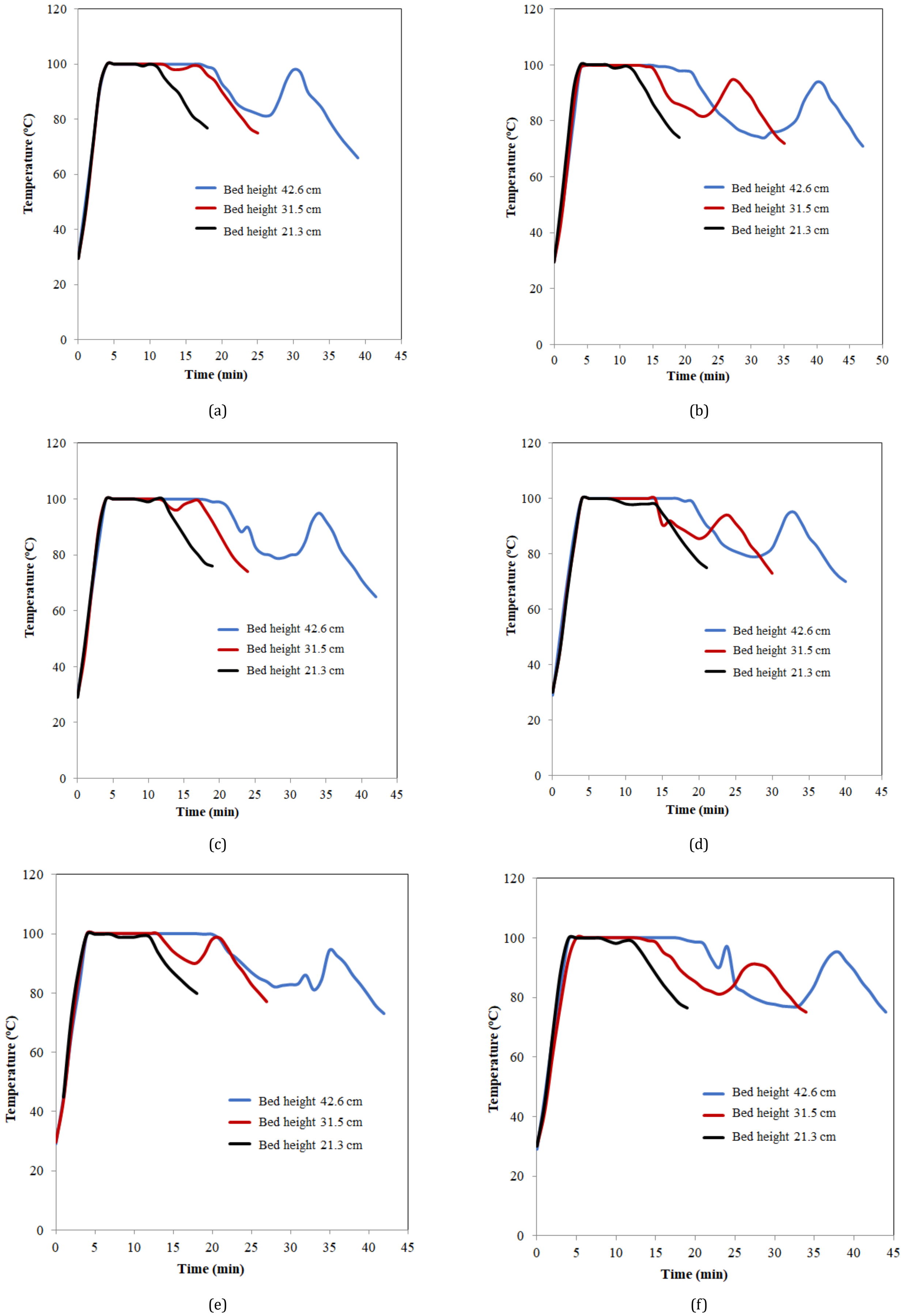


Fig. 4. Curve of boiling water temperature against time at various of bed height (a) fuel A with opening secondary air is close; (b) fuel A with opening secondary air is partial open; (c) fuel A with opening secondary air is full open; (d) fuel B with opening secondary air is close; (e) fuel B with opening secondary air is partial open; (f) fuel A with opening secondary air is full open.

Increasing the bed height will increase operating time required for gasification processes such as drying, pyrolysis, reduction and oxidation. Table 3 shows increasing the bed height, causing the operating time with a flame temperature above 500°C (> 500°C) to be smaller. This is because the air resistance to pass through the spaces of the bed is getting bigger.

The parameter used to evaluate the performance of gasification stoves using the WBT method is the water temperature during the boiling process. Water temperature data taken are initial temperature, and water temperature every minute during boiling. The boiling process will cause various phenomena, that is natural convection boiling, nucleate boiling, transition boiling, and film boiling. This phenomenon occurs very rapidly during the boiling process. The first minute there is no boiling phenomena, this happens because the heat generated by the fuel is transferred to the surface of the cooking pot (natural convection boiling), then the second minute the bubbles appear on the surface of the cooking pot (nucleate boiling). The third minute, the bubbles escape from the surface of the cooking pot and disappear into the liquid. Increasing temperature of the water will accelerate the bubbles to form a continuous column of vapor in the liquid. Bubbles rise to the surface and explode, and in the fourth minute water boils at 100°C (Cengel, 2004).

The water temperature decreased faster with a bed height of 21.3 cm compared to 31.5 cm and 42.6 cm. This shows, the operating time is faster at a bed height of 21.3 cm compared to 31.5 cm and 42.6 cm. This phenomenon is due to the different amount of fuel, so that the heat energy available in the fuel is greater at the higher bed.

3.2 Effect of Secondary Air Opening on the Boiling Water Temperature

Secondary air holes are air from the environment that can enter the gasifier cookstove, or primary air that can exit into the environment through the secondary air holes. The amount of air that enters will determine the result of temperature and quality of the flame. In this study, there are three variations of secondary air outlet openings, there are full close, partial open, and full open. Full close means that the secondary air holes are fully closed and no air from the environment enters the stove or not. Partial open meaning that only part of the air supply is used for the gasification process, some of which is discharged into the environment. Full open means that the secondary air openings are fully open for use in the gasification process.

Table 4 shows the longest operating time with a flame temperature above 500°C (> 500°C) which is the variation of the secondary air openings full close, followed by partial open, and finally full open. This is show that the more primary air that enters gasifier cookstove, gasification and combustion processes can run well.

Tabel 4. Output parameters at various of secondary air opening.

Parameter	Fuel A			Fuel B		
	Full close	**Partial open**	**Full open**	**Full close**	**Partial open**	**Full open**
t_{op} (min)	27.00	29.00	30.00	28.33	28.67	28.33
T ≥ 500°C (% total t_{op})	43.35	39.81	37.18	46.18	37.21	36.77

Figure 5 shows the effect of secondary air holes on the temperature of water boiling. The water boil in the fourth minute, then the water becomes constant after reaching temperature of 100°C. Water temperature has decreased at a relatively the same point at each variation of the secondary air outlet openings. As previously explained that the bed height affects the temperature profile of water boiling, this phenomenon occurs because the greater air resistance occurs at a bed height of 42.6 cm. The greater air resistance causes the primary air that is supplied to exit to the environment through the secondary air holes. The insufficient air supply results in the oxidation of combustible gases difficult to occur. Then the combustible gas formed in the bed will find it difficult to pass through the space in the bed and is trapped under the bed. So that at one time the water temperature decreased, this was because the amount of fuel had started to run out (Fig. 5). This condition is called the lower flammability limit, the condition of the resulting gas composition is not sufficient for combustion to occur. Then the water temperature has increased again because the fire is back on. This phenomenon is caused by combustible gas trapped in the bed accumulating at the bottom of the burner and then coming into contact with heat and air which causes the fire to start burning again. Then the water temperature decreases again more quickly as the fuel starts to run out.

3.3 Effect of operating condition of torrefied rice husk on Boiling Water Temperature

The condition of rice husk affects the temperature, height and color of the resulting flame. In this section, the highest flame temperature is found in fuel A with full close air openings and a bed height of 21.3 cm, which is 900 °C, while fuel B with the same air openings and bed height results in a lower flame temperature which is equal to 871 °C.

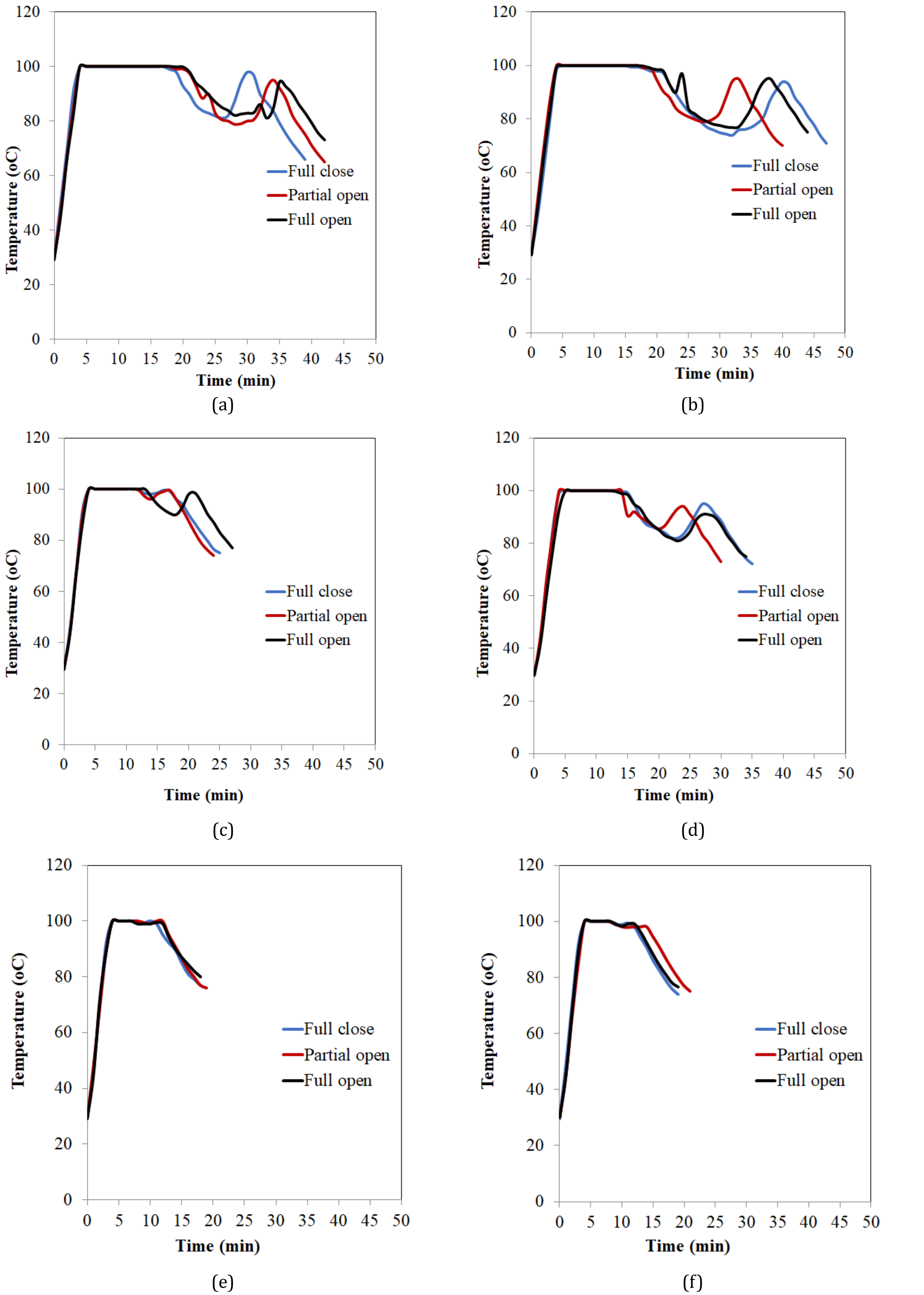
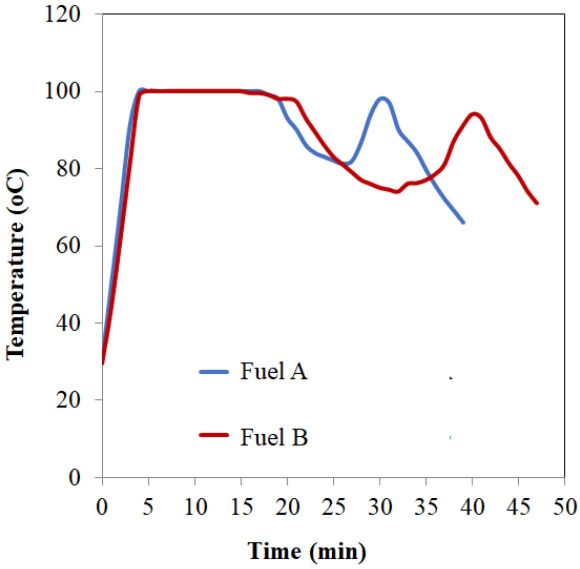


Fig. 5. Curve of boiling water temperature against time at various of secondary air opening (a) fuel A with height of bed 42.6 cm; (b) fuel A with height of bed 31.5 cm; (c) fuel A with height of bed 21.3 cm; (d) fuel B with height of bed 42.6 cm; (e) fuel B with height of bed 31.5 cm; (f) fuel B with height of bed 21.3 cm.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Temperature (oC)
Fuel A
Fuel B
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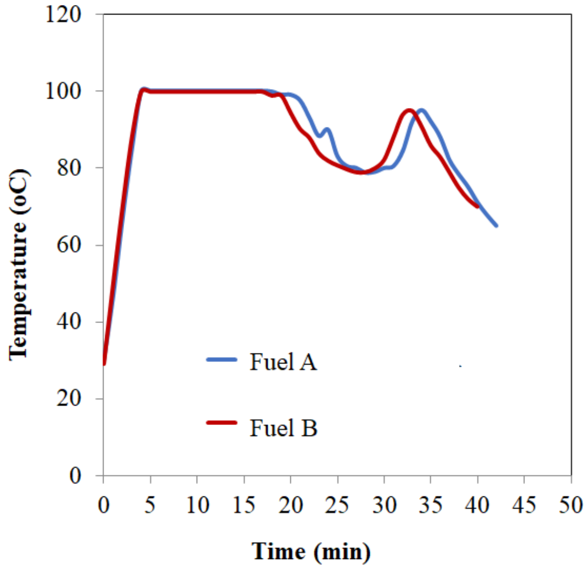
Time (min)

(a)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Temperature (oC)
Fuel A
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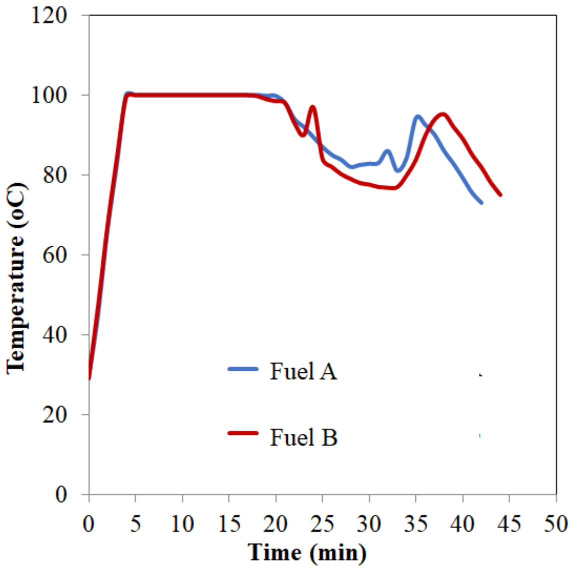
Time (min)

(b)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Temperature (oC)
Fuel A
Fuel B
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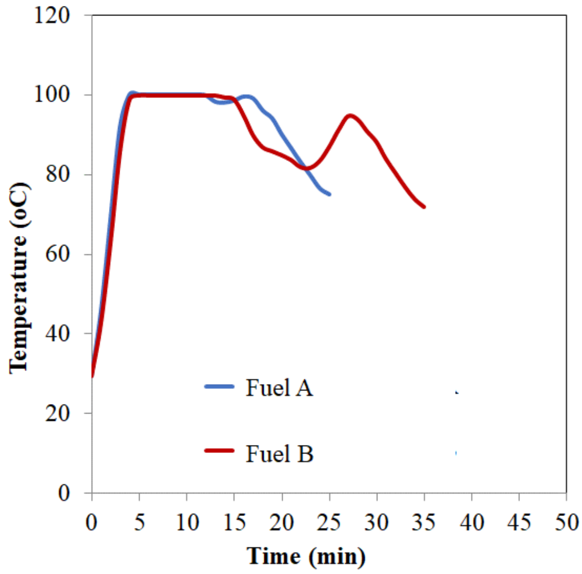
Time (min)

(c)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Temperature (oC)
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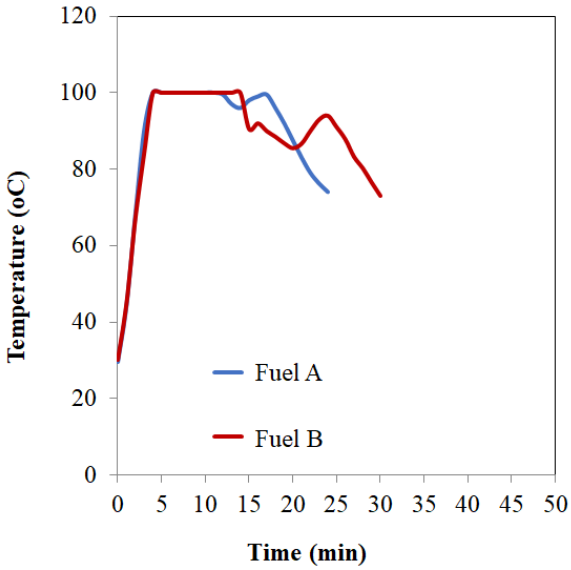
Time (min)

(d)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Temperature (oC)
Fuel A
Fuel B
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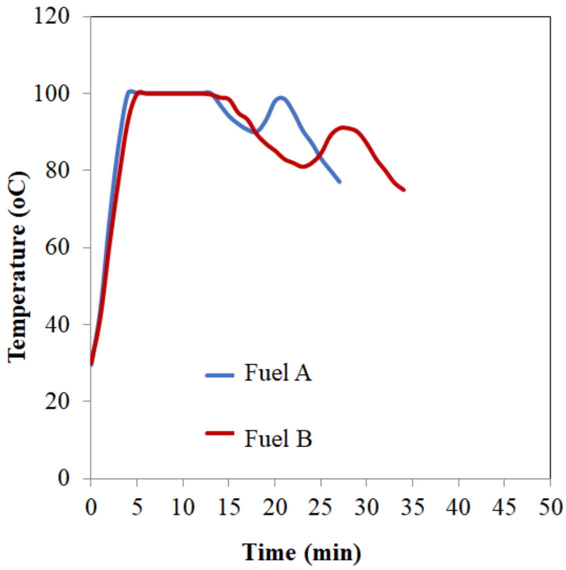
Time (min)

(e)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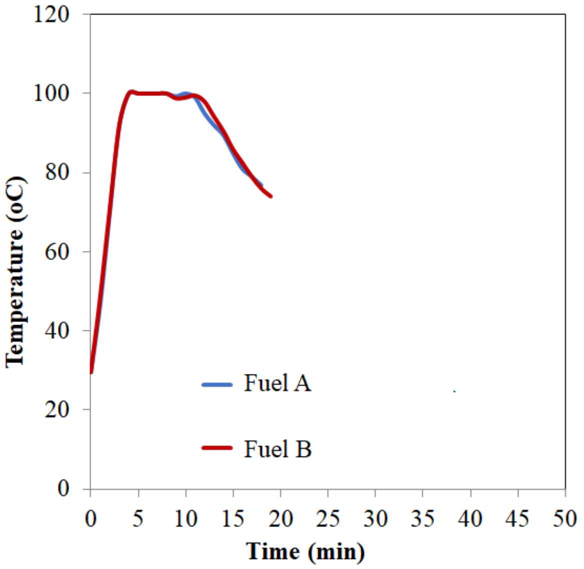
Temperature (oC)
Fuel A
Fuel B
0 5 10 15 20 25 30 35 40 45 50
Time (min)

(f)



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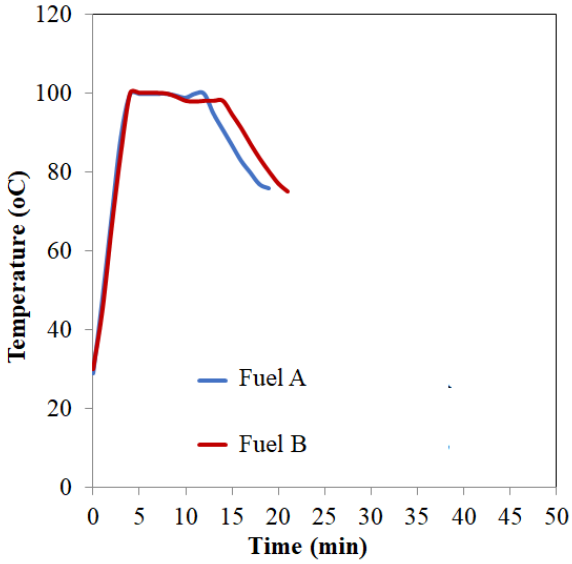

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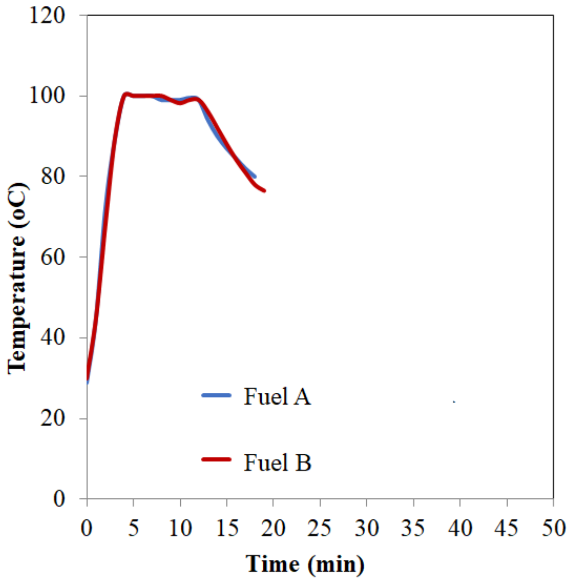


(i)

Fig. 6. Curve of boiling water temperature against time at various of fuel (a) 42,6 cm-close; (b) 42,6 cm-partial; (c) 42,6 cm-open; (d) 31,5 cm-close; (e) 31.5 cm-partial; (f) 31.5 cm-open; (g) 21.3 cm-close; (h) 21.3 cm-partial; (i) 21.3 cm-open.

Tabel 5. Output parameters at various of torrefied rice husk.

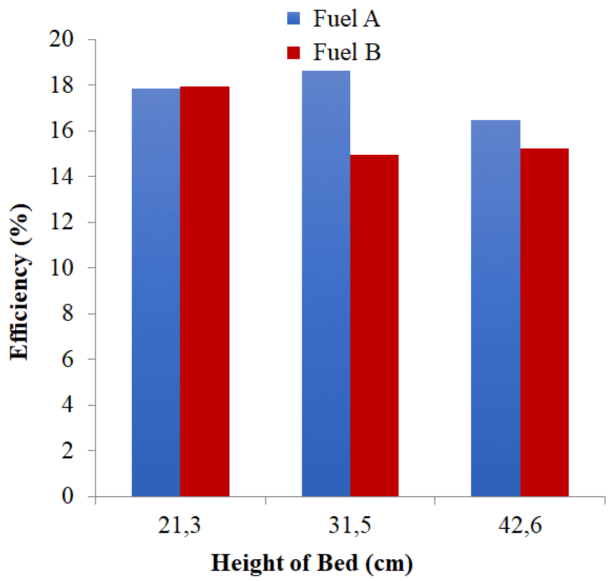
Parameter	42.6 cm		31.5 cm		21.3 cm	
	Fuel A	Fuel B	Fuel A	Fuel B	Fuel A	Fuel B
t_{op} (min)	41,67	39,33	26,33	27,00	18,00	19,00
T ≥ 500°C (% total t_{op})	37,84	39,17	39,92	40,64	42,58	43,86

The flame temperature above 500°C (> 500°C) in fuel B is higher than fuel A, which reaches 43.86%, while condition A is only 42.58% of the total operating time. This is because the calorific value fuel B is higher than fuel A, which is 3,465 Kcal/kg for fuel B, and 3,337 Kcal/kg for fuel A. This condition also shows that fuel B has a better quality of energy that can be utilized than fuel A.

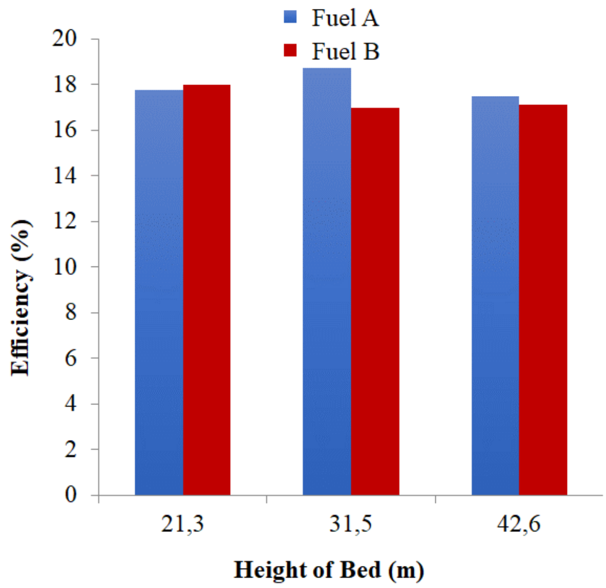
The difference that can be seen between fuel A and B is the length of time the water maintains a temperature of 100°C and the length of time it operates. Fuel B can maintain a temperature of 100°C longer than fuel A. This is because the calorific value of fuel B is greater than fuel A, where the calorific value of fuel B is 3,465 Kcal/kg and fuel A is 3,337 Kcal/kg (Table 2). This also shows that fuel B has a better energy quality than fuel A.

3.4 Thermal Efficiency of Gasification Cookstove

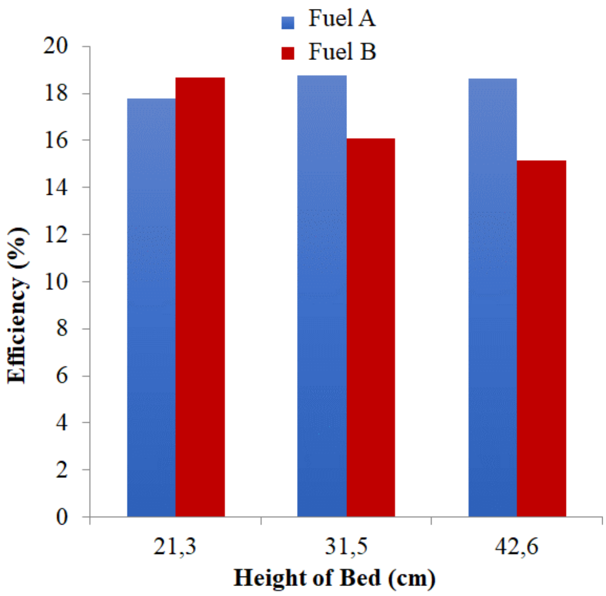
Thermal efficiency is a parameter to determine the performance of a gasifier cookstove running well or not. Thermal efficiency is determined by the water boiling test (WBT) method. This method is a laboratory-based test that can be used to measure how efficiently a cookstove uses fuel to heat water in a cooking pot and the quantity of emissions produced while cooking. The thermal efficiency at each variation is shown in Figure 7 below.



(a)



(b)



(c)

Fig. 7. Effect of bed height against thermal efficiency in fuel type A and B, with secondary air opening: (a) Full open, (b) Partial open, and (c) Full close.

Figure 7 shows the highest thermal efficiency found in fuel A with a bed height of 31.5 cm, and the secondary air inlet opening in the full close position is 18.75%. Thermal efficiency of gasification stove with fuel condition A, bed height 21.3 cm and air hole opening at full close position is 17.77%. Although the value of thermal efficiency with fuel A, the bed height of 21.3 cm and the air opening full close is smaller, the difference is relatively small, less than 1%. The small efficiency value is due to the large heat loss.

The highest thermal efficiency at fuel B is obtained at a variation of the bed height of 21.3 cm and the secondary air inlet opening in the full close position is 18.66%. The highest thermal efficiency of gasifier cookstoves at fuel B shows conformity with the previous explanation. The lowest thermal efficiency in fuel A is obtained at 42.6 cm bed height variations, full open secondary air inlet openings of 16.49%, and fuel B at 31.5 cm bed height variations full open secondary air is 14.98 %.

Based on previous research with bulk rice husk fuel using updraft type gasifier cookstoves, the highest thermal efficiency value is 12.22% (Obeng et al., 2017). The highest thermal efficiency value in this study shows an increase from previous research, so it can be noted that the performance of the gasifier cookstove type updraft with torrefied rice husk as fuel has a better performance.

4. CONCLUSION

The optimum performance of the gasifier cookstove using water boiling test (WBT) is shown by the highest thermal efficiency value, which is the variation of fuel

A, 31.5 cm bed height and the secondary air inlet opening in the full close position is 18.75%. Thermal efficiency shows the ratio between the energy provided the energy that can be utilized in the fuel.

In the future, it is necessary to improve the cookstove design, especially related to the regulation of secondary air supply and to add measuring instruments to determine the quantity of input that goes into the system.

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