Published by :
http://www.ijert.org

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 12 Issue 06, June-2023

Performance Evaluation of Rice Husk Gasifier Stove at Different Bluff Body Shapes

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Abstract*—A biomass has been used as a feedstock of a primitive biomass cook stove for centuries. Concerning high emission level and low thermal efficiency of a primitive stove, a gasifier-based biomass stove got increasing attention recently. Combustion of producer gas from biomass gasification in the gasifier stove is cleaner than direct combustion of the biomass in conventional stove. However, a problem of obtaining stable producer gas flame arises in developing gasifier stove due to low flammability limits of the producer gas. Thus, the present work aims to investigate an effect of bluff body shape on performance of rice husk gasifier stove. Four different bluff bodies (BB), i.e. BB A, BB C, BB C, and BB D are evaluated their effect on axial temperature profile of the stove, flame temperature, and thermal efficiency of the stove. The results show that the bluff body C (BB C) is the most suitable for the current design of the gasifier stove. BB C causes more stable flame and more heat transferred to the WBT unit (higher useful heat) which gives higher thermal efficiency of the gasifier stove. The thermal efficiency of the stove for using BB A, BB B, BB C, and BB D is 8.57%, 9.62%, 10.80%, and 6.73%, respectively.

***Keywords*—Bluff body; Gasifier; Performance; Flame; Stove**

I. INTRODUCTION

A biomass, one of many renewable energy resources, has been used widely all around the world as primary energy sources, especially for rural people. Biomass resource supplied about 1/7 of world energy demand [1]. The biomass mainly comes from agriculture, forestry, furniture industry, as well as municipal solid waste [2]. In developing country, biomass waste is used directly for heating as well as for cooking purposes. A traditional biomass stove is widely used for cooking purposes due to its simple construction. A traditional cook stove is used by primary world's population to burn biomass fuel [3]. Many biomass cook stoves are designed and fabricated not only for specific biomass feedstock, but also for multi biomass feedstocks, for example, Jatropha seed stove [4], corn straw cook stove [5], corn cob-pine wood stove [6], olive pomace- forest residue pellets stove [7], coffee husk-wood chips stove [8], and multi biomass stove [9]. The traditional or conventional stove has low thermal efficiency, consumes a large amount of fuels, and produces high pollutant emissions [10]. In order to achieve a low emissions and high efficiency cook stove, controllable primary air flow rate can be applied [11].

In order to reduce emission from direct combustion of biomass and to enhance stove efficiency, a newer technology of gasifier-based stove is more attractive for utilization of biomass energy resources. Working principle of the producer gas stove is that biomass is gasified in the reactor to generate producer gas and then the gas is burnt in the burner of the stove to obtain a producer gas flame. The difference of working principle between a conventional stove and a gasifier-stove is explained by schematic diagram in Figure 1. In a traditional stove, excess air is supplied to the stove either naturally or forcedly, biomass experiences direct combustion, flue gas and heat are the product. In contrast, deficient air is supplied to the stove for biomass gasification which produces a producer gas. The gas flows upward to the burner of the stove and generates a producer gas flame. The producer gas contents combustible gas (CO, H_2, and CH_4) and non-combustible gas (CO_2 and N_2) [2].

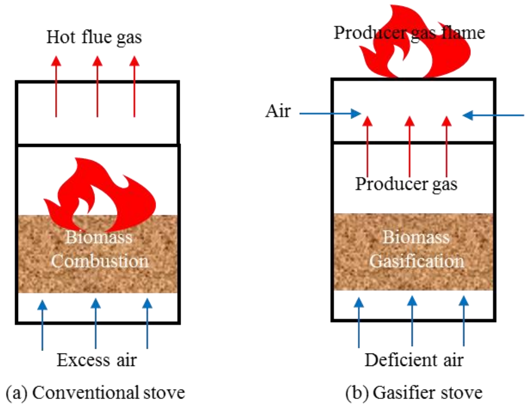


Fig. 1. Conventional biomass stove vs gasifier stove

Combustion of the producer gas results less emission than direct combustion of a solid biomass fuel [12], thus the technology has got increasing attention in biomass energy conversion recently. Generally, producer gas from biomass gasification has lower heating value within the range 3-7 MJ/kg. Low heating value fuel commonly generates low flame temperature and low-intensity thermal field which are beneficial in reducing thermal NOx [13]. However, the drawbacks of low heating value fuel like a producer gas are narrow flammability limits and the lack of flame stability [14]. Besides generates lower emission, biomass gasifier stove also has higher efficiency than conventional biomass stove. Sutar *et al.* [15], [16] developed gasifier based domestic stove having nominal capacity of 2.5 kW. The stove has maximum efficiency nearly up to 80%. Meanwhile, Tryner *et al.* [17] invented a TLUD (Top Lit Updraft) gasifier stove which has maximum measured thermal efficiency of 42%.

Due to relatively narrow flame stability limit of the producer gas, it is difficult to obtain a stable flame in the burner. The flammability limits of the producer gas fired burner was established in the range of 40–55 [18]. The peak burning rate of producer gas proved faster than those of conventional fuels, such as isooctane and methane [19]. To encounter the difficulty, a bluff body may attached on the burner to stabilize a producer gas flame in a gasifier stove. The bluff bodies with different shape (see Figure 2) have been used in flame stabilization technique, i.e. disk and tulip shape bluff body [20], and trapezoidal shape bluff body [21]. The tulip shape bluff body promoted an enlargement of the stabilization domain and emphasizes a specific region “the laminar ring flame.” On the other hand, the stabilization process is modified in the wake of the disk due to strong reverse velocities [20]. From their work, it can be known that two parameters control the stabilization process of non-premixed flames, such that the gas jet to air velocity ratio and the bluff-body shape. Bluff body’s lip thickness may affect flame length and NOx emission. Flame length increased with increasing lip thickness of the bluff body. Unluckily, increasing lip thickness of the bluff body, NOx emission level increased. Lip thickness of the bluff body effect residence time of the burner. Lip thickness of the bluff body gives positive effect on flame stability but gives negative effect on NOx emission [22].

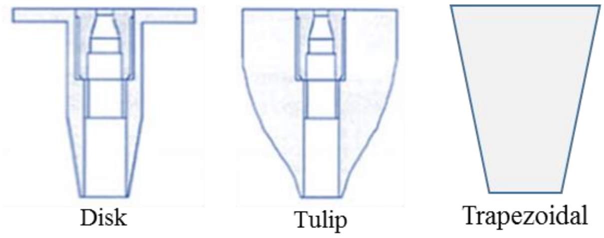


Fig. 2. Example of bluff body shape [20], [21].

II. MATERIAL AND METHOD

In the present work, performance of gasifier rice husk stove is investigated at four different bluff bodies. Fig. 3 display the experimental setup of the present work. Meanwhile Fig. 4 presents the photograph and technical drawing of the bluff bodies, namely BB A, BB B, BB C, and BB D. The setup is constructed by gasifier-stove, blower, water boiling test (WBT) unit, and measurement devices (rotameter, K type thermocouple, and Graphtec240 temperature logger). The data taken are axial temperature of the stove at location of 150 mm above a grate (T1), 300 mm above a grate (T2), 300 mm above a grate (T3), flame temperature (Tf), and water temperature (Tw). Once the data are obtained, the performance of the stove is analyzed in terms of stove’s axial temperature profile, flame and water temperatures, and thermal efficiency. Thermal efficiency of the stove is calculated by following calculation from Eq. (1) to Eq. (3).

$$Q_{in} = m_f \text{ x } HHV_f \qquad (1)$$

$$Q_{out} = (m_w \text{ x } C_{p,w} \text{ x } \Delta T) + (h_v \text{ x } m_v) \qquad (2)$$

$$\eta t = Q_{out}/Q_{in} \qquad (3)$$

where Q_{in} is the energy available due to gasification of the rice husk (kJ), m_f is the mass of the rice husk used (kg), HHV_f is the higher heating value of the rice husk (13.393 MJkg) [23], Q_{out} is the useful energy to the WBT, m_w is the mass of water in the WBT, $C_{p,w}$ is the specific heat of the water (4.2 kJ/kg.K), ΔT is the difference of final and initial temperature of the WBT (ºC), h_v is the enthalpy of vaporization of the water (2260 kJ/kg), m_w is the mass of water vapor (kg), and η_t is the thermal efficiency of the stove (%).

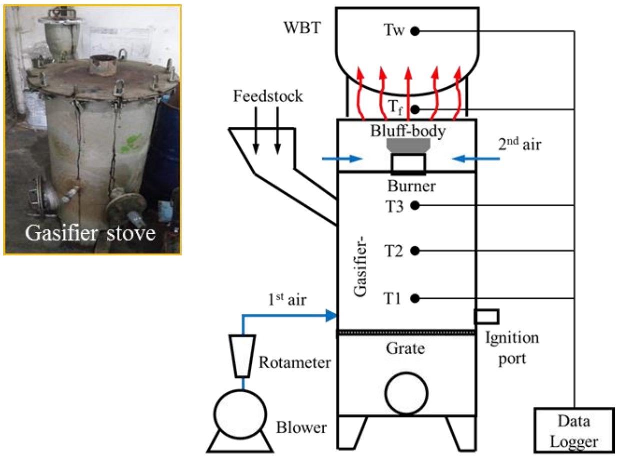


Fig. 3. Schematic diagram of experimental setup

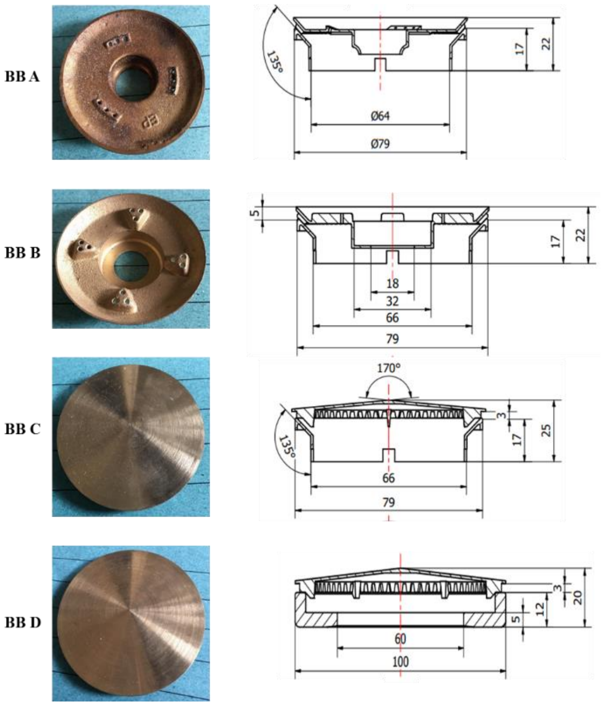
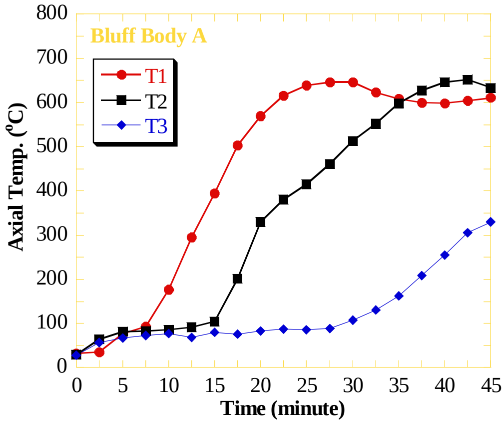


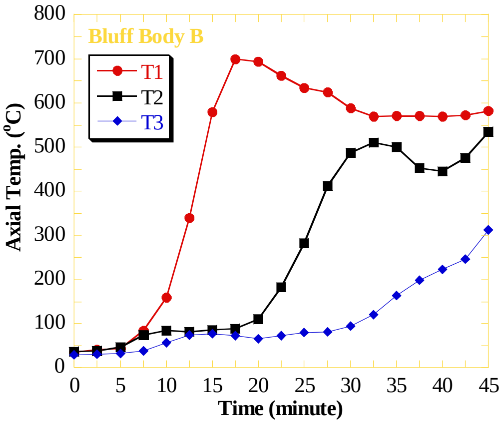
Fig. 4. Photograph and technical drawing of the bluff bodies

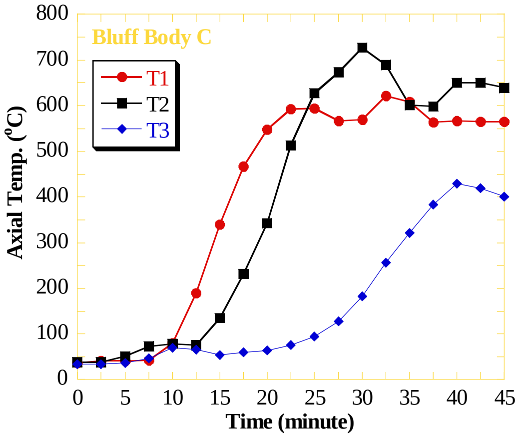
III. RESULT AND DISCUSSION

A. *Axial Temperature Profile*

Fig. 5 presents axial temperature profile of the stove during 45 minutes using different bluff bodies, i.e. BB A, BB B, BB C, and BB D. The temperature of T1 (150 mm above a grate) or the lowest part of the stove bed increases faster than temperature T2 (300 mm above a grate) and T3 (450 mm above a grate). This is due to the feedstock is ignited at the bottom part of the stove, or it is known as Bottom Lit Updraft (BLUD) gasifier stove. The feedstock experiences oxidation process at T1 location which releases heat for reduction, pyrolysis, and drying process of the feedstock at location above T1. From the graphs, it can be analyzed that a reduction and pyrolysis occur at T2 (500ºC-700ºC). Typically, rice husk gasification temperature ranges from 700ºC to 800ºC [24]. Producer gas flows upward to the burner and mixed with air, thus generates producer gas flame (See Fig. 1).







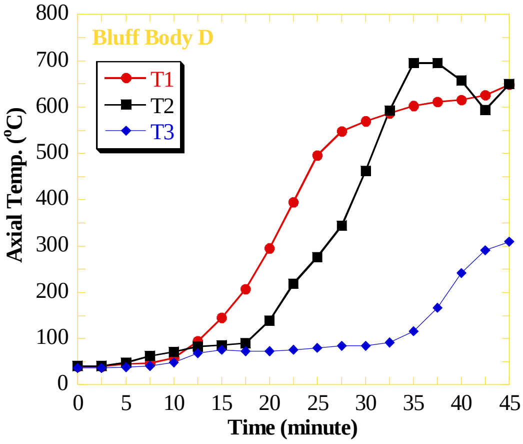


Fig. 5. Axial temperature profile of the stove

The axial temperatures of T1, T2, and T3 are then averaged as average temperature of the stove which is shown in Figure 6. It can be seen that average temperature of the gasifier stove with BB C is relatively higher than that with other bluff bodies. BB C which has only flow passage at its peripheral (see Figure 2) able to reduce excessive producer gas flow upward, thus reduces heat loss from the burner port and enhances temperature of the gasifier stove. Formation of combustible gas (CO, H_2, and CH_4) is affected by gasification temperature [25]. Higher bed temperatures favored combustible gas production as well as other gasification performance parameters [26]. Higher gasification temperature promotes producer gas with higher combustible gas content in the producer gas, result in higher heating value of the producer gas [27].

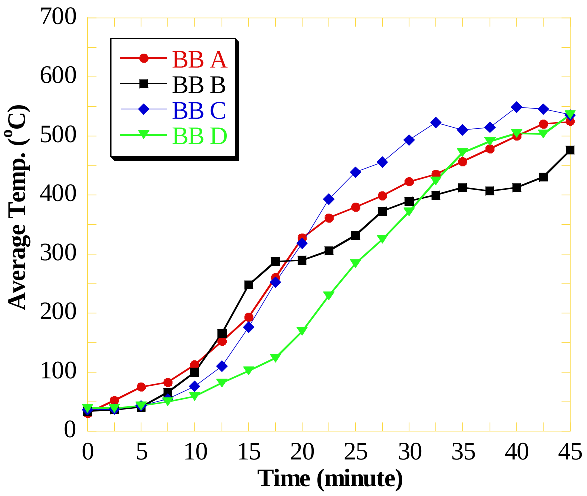
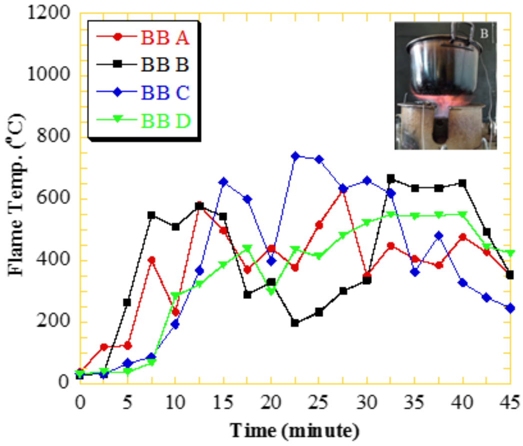


Fig. 6. Average temperature of the stove

B. *Flame and WBT Temperatures*

Meanwhile, Fig. 7 reveals temperature of the flame and water in WBT unit. Fluctuated flame temperatures are measured when using BB A, BB B, BB C, or BB D. The fluctuation is due to unsteady gasification process which affects production rate of the producer gas. This also causes producer gas flow fluctuates to the burner port, results in flame temperature fluctuation. The flame temperature graph indicates that flame temperature is relatively higher when using BB C than that using the other bluff bodies. From visualization, it is also observed that the stove with BB C produces blueish flame. This indicates that more stable producer gas flame is obtained for the use of BB C. The shape of BB C whose have only passage at its peripheral may has a suitable blockage ratio, hence able to maintain flame stability. Blockage ratio of a bluff body impacts the blow-off limits of the flame [28] and also affects a strength of vortex shedding at downstream of a bluff body [29]. Due to higher flame temperature for using BB C, the water temperature in WBT unit is also found relatively higher at the stove, particularly after 25 minutes observation as can be seen in Fig. 7.



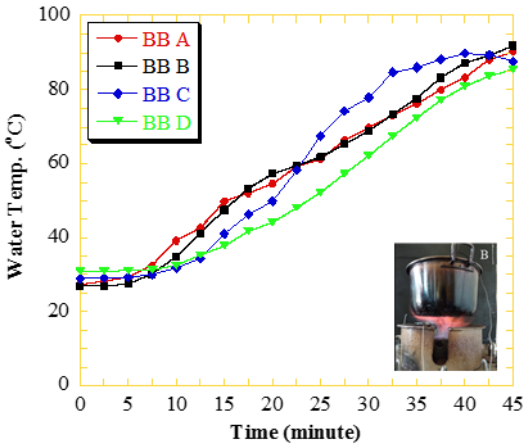


Fig. 7. Flame and WBT temperatures

C. *Thermal Efficiency*

Performance of the stove with BB A, BB B, BB C, and BB D is given in Fig. 8. The graph shows that the highest thermal efficiency of the stove is obtained when BB C is attached on the burner while in contrast the lowest thermal efficiency of the stove is analyzed when using BB D. The thermal efficiency of the stove for using BB A, BB B, BB C, and BB D is 8.57%, 9.62%, 10.80%, and 6.73%, respectively. Heat from the flame is used optimally for heating a water in WBT unit when BB C is applied on the burner, which in turn give the highest thermal efficiency. Geometry of BB C with high blocking ratio not only able to maintain flame stability of the producer gas but also leads to reduce heat loss from the flame to the surrounding.

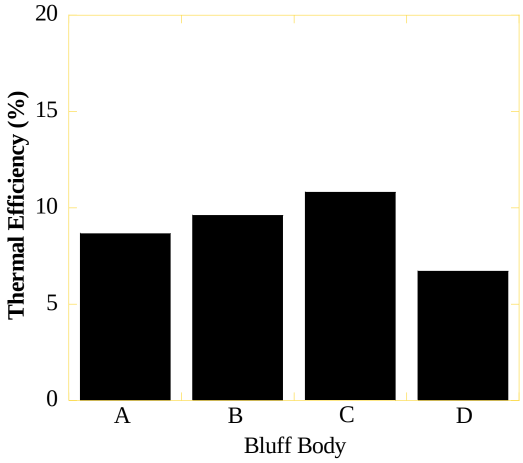


Figure 8. Thermal efficiency

IV. CONCLUSION

Four different bluff body shapes (BB A, BB B, BB C, and BB D) have been investigated their effect on axial temperature profile, flame and water temperatures, and thermal efficiency of gasifier-based rice husk stove. It can be concluded that shape of the bluff body C (BB C) is the most suitable for the current design of the gasifier stove. The BB C causes more stable flame and more heat transferred to the WBT unit (higher useful heat) which gives higher thermal efficiency of the gasifier stove. The thermal efficiency of the stove for using BB

A, BB B, BB C, and BB D is 8.57%, 9.62%, 10.80%, and 6.73%, respectively. In order to enhance thermal efficiency, it is recommended that the gasifier stove has to be well insulated to protect excessive heat lost from the stove to the surrounding.

ACKNOWLEDGMENT

The authors sincerely thank to Department of Mechanical Engineering and Laboratory of Manufacture Institut Sains & Teknologi AKPRIND Yogyakarta for the support given during the work. The first author also sincerely thanks to PT. Duraquipt Cemerlang for providing scholarship to pursue Master Program in Mechanical Engineering Institut Sains & Teknologi AKPRIND Yogyakarta.

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