



Energy Performance Analysis of B1-3.5mm Burner Model of Fasobio-15 Biodigester Biogas Cookstoves

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Authors' contributions

This work was carried out in collaboration among all the authors. Author NB designed the study, wrote the protocol, wrote the first draft of the manuscript and made all necessary corrections. Authors NB and GWS conducted the experiments at the different sites. Authors DWNK and IO managed the analyses of the study and the numerical calculation of the losses at the cookstove walls. Authors FPK and IO managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

In Burkina Faso, finding wood for cooking is still a headache for rural households due to the advancing desert. Here, we try to bring a new way for farmers who already have a biodigester and convince those who are reluctant to adopt this work to reduce their dependence on wood. For this purpose, a characterization of the energy performance of biogas stoves is carried out based on the three-phase water heating test protocol called Water Boiling Test (WBT). The fuel used in the study is the biogas produced by a batch biodigester fed with pig manure. The analysis of the produced biogas shows a methane content of 60% and maximum hydrogen sulfide of 400ppm. The heat balance shows a loss of 11% in the walls of the cookstove and about 36% in the flue gas. Thus the energy performance of the furnace is estimated at 53%, a combustion rate of 6.4 L /min and the

average boiling time is 50 minutes. Given these results, we suggest that households use biogas fuel and the B1-3.5mm burner in the cookstove as a replacement for the other burners. We intend to carry out a controlled cooking test on this stove, a modeling of the biogas production and its consumption in this type of burner.

Keywords: Pig manures; biogas; Cookstoves burners; performance analysis.

ABBREVIATIONS

<i>Cal:</i>	<i>Specific heat of aluminum vessel</i>	<i>kJ/kg/°K</i>
<i>Cw:</i>	<i>Specific heat of water</i>	<i>kJ/kg/°K</i>
<i>h</i>	<i>Global exchange coefficient</i>	<i>W/(m².s)</i>
<i>Mw:</i>	<i>Quantity of water</i>	<i>Kg</i>
<i>PC:</i>	<i>Calorific value of fuel</i>	<i>J/L</i>
λ :	<i>Thermal conductivity</i>	<i>W(m. K¹)</i>
ρ :	<i>aluminium mass density,</i>	<i>kg/m²</i>
<i>P :</i>	<i>burner power</i>	<i>kW</i>
μ :	<i>absolute viscosity</i>	<i>kg/(m.s)</i>
<i>Lw:</i>	<i>Latent heat of vaporization of water</i>	<i>KJ. Kg⁻¹</i>
<i>T1, T2 ,Tf:</i>	<i>Initials and final temperature of water</i>	<i>°C</i>
<i>F:</i>	<i>volum of biogas respectively consumed</i>	<i>L</i>
Δm :	<i>mass of water consumed</i>	<i>kg</i>
η :	<i>Oven efficiency</i>	<i>%</i>
<i>Q1, Q2, Q3, Q4:</i>	<i>Energy supplied by the burner, the load, lost by walls and lost through openings</i>	<i>kJ</i>
T_{∞} , T_w :	<i>Ambient Temperature, Walls Temperature</i>	<i>°C</i>
R_{CH_4} :	<i>percentage of methane measured in the biogas</i>	<i>%</i>

1. INTRODUCTION

West African countries in general and Burkina Faso in particular are experiencing significant deforestation due to the persistent use of wood as fuel [1]. The use of this fuel reaches a rate of 86%, of which almost 100% is in rural areas [2]. The low regeneration capacity of the forests, estimated at 10%, combined with the exploitation of firewood by the population, leads to an annual degradation of the forest of 2%, i.e. approximately 105,000 ha [3]. This energy demand will only increase, therefore, the search for other alternative and renewable energy resources becomes necessary to mitigate this rapid depletion [4].

The import of butane gas, which should undoubtedly lessen the shock of deflation, has been slowed down by its purchase price, which is out of reach of households [5], and also by regular supply disruptions [6]. In general, open cookstoves are considered to be systems with very poor thermal efficiency, because the amount

of heat used for heating is low, more than 60% of the energy supplied is dissipated by the Joule effect [7]. Given this high utilization, even a small improvement in efficiency can have a positive overall impact on fuel economy [8]. Aware of this difficult energy situation, the government of Burkina Faso has set up the National Biodigester Program to offer an alternative to the use of wood as an energy source. Thus, the optimization of the volume of biogas to be burned in a cookstove that can lead to the adoption of biodigesters is the goal. The need to save biogas consumption motivated this study to evaluate the energy efficiency of the stove. The model of the cookstove studied has an integrated burner with a nozzle. This biogas, essentially methane gas, comes from a biodigester upstream of the fireplace and is used in this work. This study aims first of all to show that biogas formed mainly of methane (CH₄) and carbon dioxide (CO₂) becomes a fuel in its own right given the potential of the organic substrate that the country has [9]. In Burkina Faso, even if the production of biogas has started since 2009

[10] there are efforts to be made for the implementation of the technology that will decrease the daily search for wood. Secondly, to show that this burner is more economical compared to the commonly used copper burners.

2. DESCRIPTION OF BIODIGESTER AND COOKE STOVE

2.1 Biodigester

The biogas comes directly from a 6m³ Fasobio-15 biodigester with a depth of 115cm and a radius of 135cm. It is fed daily with a 50kg batch of pig manures and 50kg of water. The model is a fixed dome, buried and fully bricked. It has six (06) main parts including the inlet tank, digester, dome, plumbing system, outlet tank and compost pits. The hydraulic retention time considered in the design is 35 days. The Puxing Biogas flow meter used has an error

tolerance of $\pm 0.05\%$. A Puxing Biogas desulfurizer containing iron oxide pellets is installed in the circuit to remove hydrogen sulfide (H₂S) from the biogas before it reaches the burner. The Fasobio-15 model is shown in Fig. 1.

2.2 Cookstove

The stove is a standard metal frame of cylindrical shape with a diameter of 38 cm, a height of 32 cm and a wall thickness of 8 mm. The biogas is burned by a steel burner. Type K thermocouples have been used to measure temperatures with accuracy of $\pm 0,5^{\circ}\text{C}$ and are connected to the dattalogger with a reading tolerance of 0.05%, and accuracy $\pm 1^{\circ}\text{C}$. The numerical balance has a precision of ± 1 g. The composition of the biogas produced has been determined with the biogas analyzer type Multitec 540 with an accuracy of $\pm 0,01\%$.

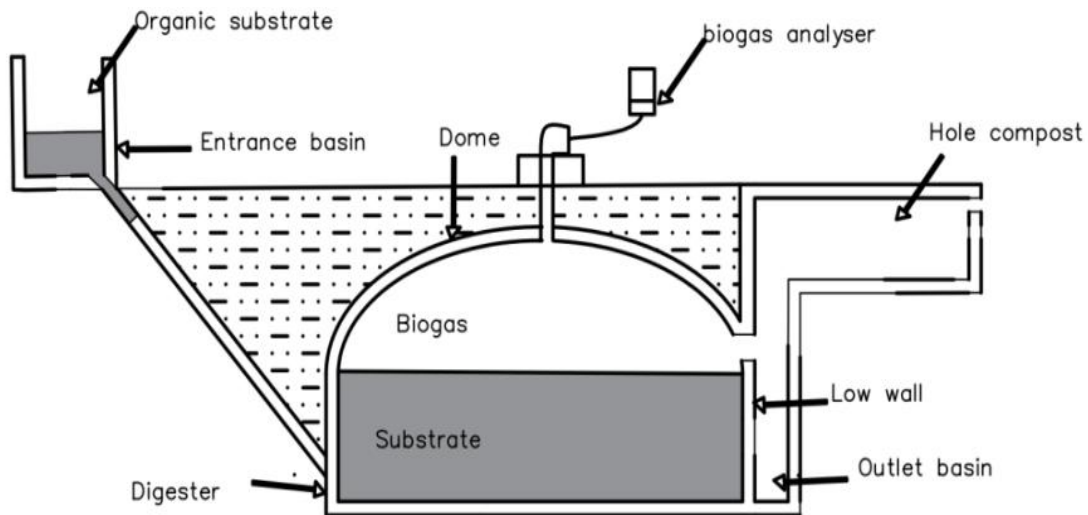


Fig. 1. Diagram of the FasoBio-15 biodigester model

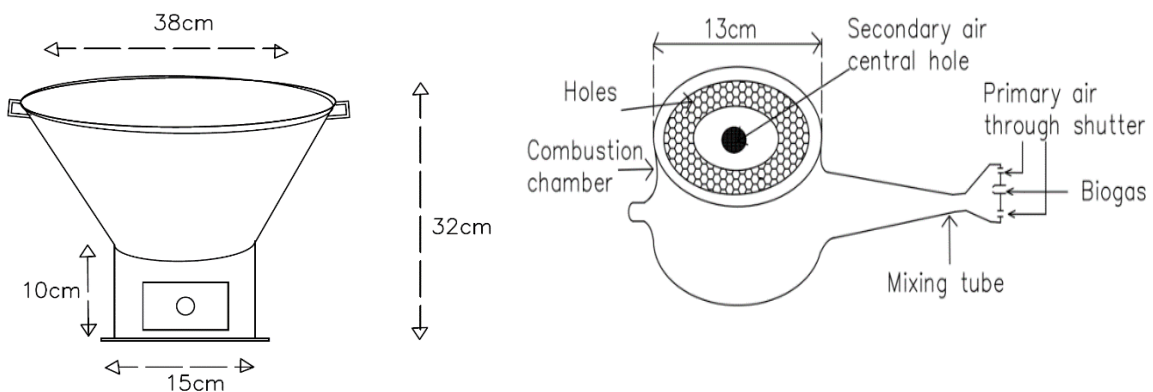


Fig. 2. Diagrams of the cookstove model and burner B1-3.5mm

3. MEASUREMENT PROTOCOL

The pressure of the biogas moves the gas up the tube to the combustion chamber. The venturi effect allows the biogas to mix with the air in the burner before combustion. Hydrogen sulphide (H_2S) is a toxic and corrosive gas for the burners and is removed from the biogas by adsorption.

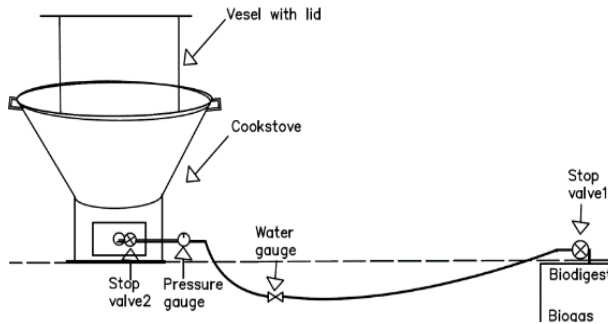


Fig. 3. Scheme of Cooke stove operation mode

Low pressure phase consists of putting a quantity of 7L of water is poured into the cooking pot. This quantity represents 2/3 of the capacity of the pot. Then we proceed to the ignition of the fire with the biogas. This phase ends when the temperature of the water reaches the local boiling point of 95°C. In the high-pressure phase, a new pot with water is changed while keeping the stove hot. The volume of water is identical to the previous phase. The water is heated to boiling point. Simmering phase where the water is now boiling and the contents are kept in this state for 45 minutes. Regular monitoring of the kettle is carried out to avoid a drop below 6 degrees below the 95°C point. The final index on the flow meter is read. This last step is essential because it allows the simmering of the meals during a real cooking

4. DESCRIPTION OF THE PHYSICAL MODEL

The heat balance in the furnace can be summarized in four forms of energy. The energy dissipated in the smoke representing the upper part is called Q_4 . The determination of this energy is necessary because it allows to establish a thermal performance of the cookstove.

The quasi-static heat balance of the stove is determined according to the input and output energy flows (fuels, air, openings, water, steam).

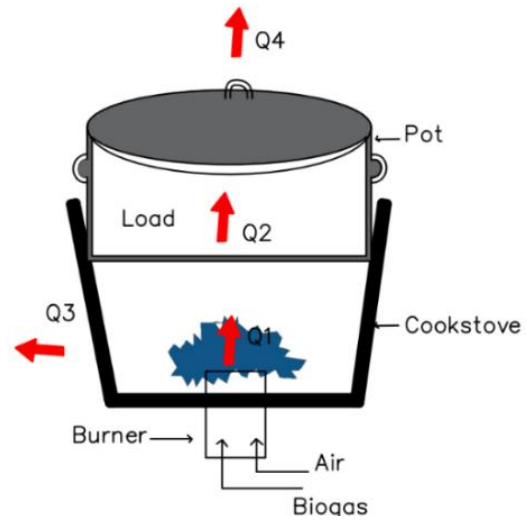


Fig. 1. Energy balance diagram

The heat balance of the system is written:

$$Q_1 + Q_2 + Q_3 + Q_4 = 0 \quad (1)$$

- Energy supplied by the fuel Q_1 :

It is evaluated from the calorific value (PC) of the biogas.

$$Q_1 = R_{CH_4} \times F \times PC \quad (2)$$

- The Inferior Calorific Value (PCI):

$$PC = R_{CH_4} \times PC_{CH_4} \quad (3)$$

The burner power is also calculated. This parameter indicates the energy savings of one burner compared to another.

$$P = \frac{R_{CH_4} \times F \times PC}{t} \quad (4)$$

- Useful energy Q_2 :

The useful energy corresponding to the one really absorbed by the load is thus obtained by the classical relation:

$$Q_2 = A \times (T_{1f} - T_{1i}) + B \times (T_{2f} - T_{2i}) + C \times (T_{3f} - T_{3i}) + D \times L_w \quad (5)$$

- Heat losses at the wall level:

Table 1. Constants used in the calculations

Mw	Cw	Lw	Cal	PC	μ	g	ρ	λ
kg	KJ/kg/°C	kJ/kg	kJ/kg/°K	kJ/L	Kg/(m.s)	N/kg	kg/m3	W(m. K ⁻¹)
7	4.185	2260	0.895	37.78	222.96	9.81	1.132	0.0270

this energy is essentially lost by convection between the wall and the surrounding environment. This method is particularly interesting to know the distribution of the heat losses and thus to concentrate on the biggest losses during the modifications allowing the improvement the cookstove performances. It is calculated by the following expression:

$$Q_3 = \int_0^t hA(T_w - T_\infty) dt \tag{6}$$

This equation is the integral of time taken for the test between the wall of the stove and the surrounding environment and is calculated by a numerical method. A, area of the outer wall surface lateral of the heating device (m²) representing our stove which is a truncated cone.

This coefficient is obtained by:

$$h = \frac{Nu \times \lambda}{D} \tag{7}$$

- Heat losses at the level of the smoke Q4:

This lost energy Q₄ is subtracted from the other energies.

$$Q_4 = Q_1 - Q_2 - Q_3 \tag{8}$$

- The energy efficiency of the boiling and simmering phases is determined.

$$\eta = 100 \times \frac{A \times (T_{1f} - T_{1i}) + B \times (T_{2f} - T_{2i}) + C \times (T_{3f} - T_{3i}) + D \times L_w}{Q_1} \tag{9}$$

With:

$$A = (m_{1i} \times C_w + m_{Al} \times C_{Al}) ; B = (m_{2i} \times C_w + m_{Al} \times C_{Al}) ; C = (m_{3i} \times C_w + m_{Al} \times C_{Al}) ; D = (\Delta m_1 + \Delta m_2 + \Delta m_3)$$

4.1 Calculation of the Different Parameters

The different constants used for the calculations are in Table 1. The aluminium pot and the air

with the thermo-physical properties of this metal are used in the calculations.

5. RESULTS AND DISCUSSION

Fig. 5 shows the composition of the biogas in methane, carbon dioxide and oxygen. As a reminder, the composition of the biogas was determined in sequences on 16 different days during two months. The biogas produced contains 60% methane which is acceptable for domestic biodigesters [11].

These pig substrates have a high potential according to the work Fikadu kumsa gemechu which find a rate of 56% [7] with the same type of substrates. Perhaps the different factors such as the high temperature of the country, the buried model of the work have favored this good result.

We compare our biogas results with other authors who have worked on different biodigester models. Thus, with our rate of 60% of methane obtained is better than those of Palestine or India [12]. The values obtained are in the order of the average values of biogas quality of those existing [13]. Also, we note a high rate of 40% of carbon dioxide that can be recovered by other processes such as methanation [14]. Nevertheless, our results are below the 68% biogas produced from food scraps which are richer in carbon [15]. The results show an absence of oxygen. This allows us to confirm the tightness of our Fasobio-15 model. The rate of CH₄ remained almost constant all the time which testifies to the stability of the digester in temperature (mesophilic operation) [12], implying a good bacterial growth [13]. The real problem of anaerobic digestion lies in this technical aspect, a depression, poor sealing, gas leakage, temperature drop leads to a production stop as predicted by the work of Michał Gaworski [14]. The CH₄ content remained almost constant all the time, which shows the stability of the digester. calorific value of the biogas is 22.67 kJ/L.

Fig. 6 shows the evolution of H₂S in the biogas over time. The presence of H₂S in the biogas remains high in the first 10 days around 400 ppm. The evolution of this rate at the beginning of the measurements means that the metal

oxides took time to adsorb this compound. Afterwards, H₂S drops and stabilizes around 100 ppm. This shows that the sorbents used were able to reduce it. The control of hydrogen sulphide is important because of its inhibiting effect on methanogenic bacteria and the diseases it causes after inhalation. These effects can appear from a level of concentration of hydrogen sulfide high around 2000 ppm [15].

Thus, our results in Fig. 6 show a maximum concentration of 400 ppm, which is lower than the corrosion value of 2000 ppm predict [16]. The level of the harmful compound decreased from 430 to 130 showing that the sorbents were able to remove 70% of this compound in the biogas showing a high mitigation potential similar to more expensive processes like activated carbon which is 78% [17].

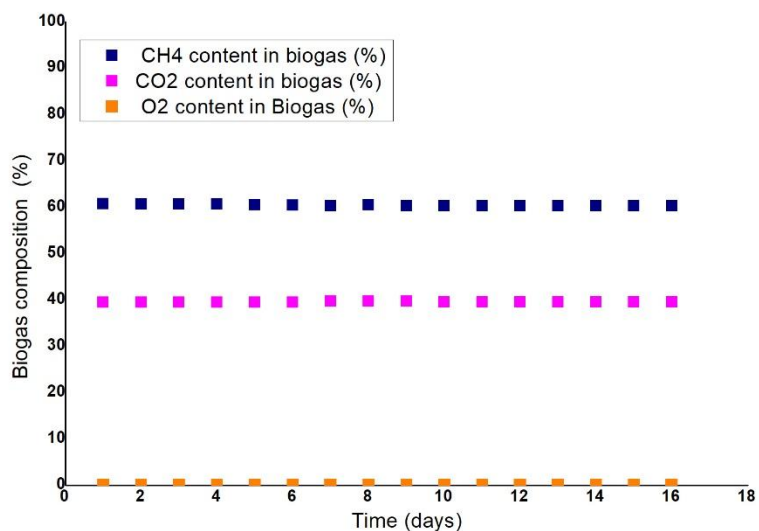


Fig. 2. Composition of the biogas

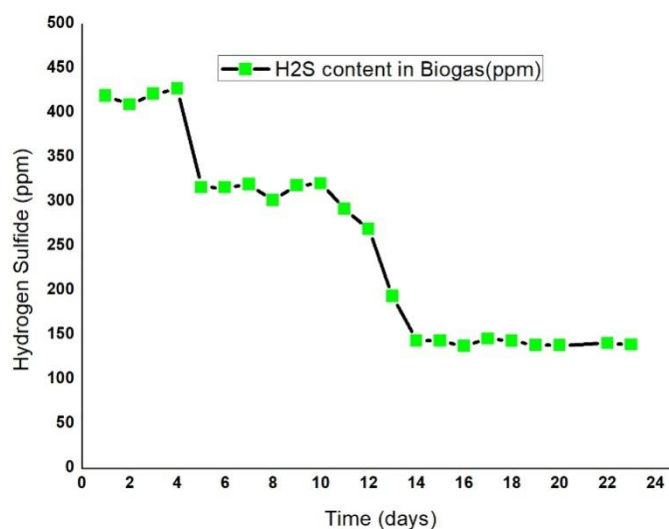


Fig. 3. Hydrogen sulphide content in biogas

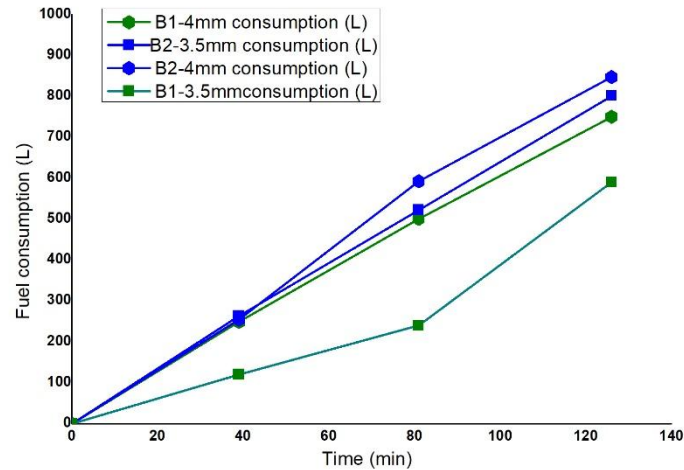


Fig. 4. Biogas consumption

The volumes of biogas consumed by two types of burners with two different nozzles 3.5 mm and 4 mm are shown in Fig. 7. The curves show that the burner model using the 3.5 mm nozzle is more economical with biogas. The B1-4mm burner consumes 750 litres or 6L/min, the B1-3.5mm burner consumes 590 litres or a consumption rate of 4.7 litres/min. The B2-3.5mm consumes 800L or 6.4L/min and the B2-5mm 847L giving a consumption speed of 6.4L/min. The burner efficiency is a function of mechanical design (nozzle diameter, diameter and number of biogas outlets, length of pipe, material). According to the work carried out in Nigeria giving a speed of 0.69 m³/min [18] compared to ours which has a speed of

6.4L min⁻¹, it is possible to say that B1-3.5mm has a very low consumption. The specification of B1-3.5 is at the nozzle diameter ($d_0 = 3.5mm < d_0 = 1.6cm$) used by this author. The consumption of the B1-3.5mm model is of the order of 120L for the first phases (40min) and 350L for the last phase (45min), making a total of around 600L for a complete test. This performance of the 3.5mm burner confirms the studies on the combustion chamber predicting that the nozzle diameter allows to regulate the fuel consumption [19]. This consumption of about two hours shows a consistent production of biogas sufficient for cooking local food [20].

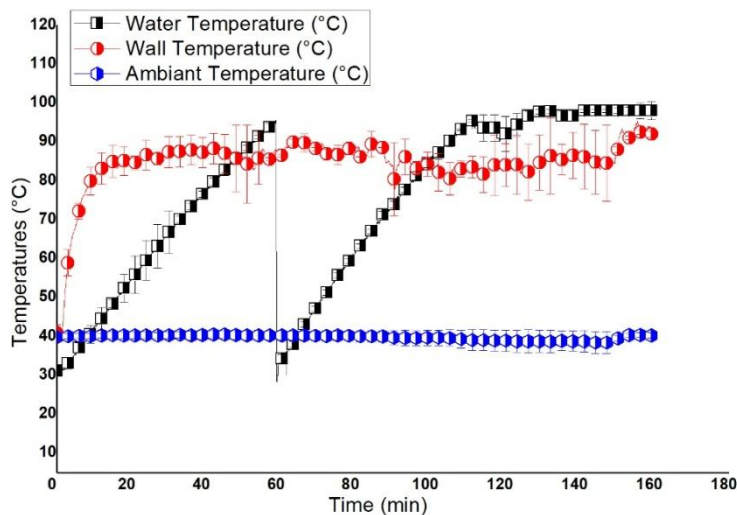


Fig. 5 Temperatures evolution in the tests

The temperatures evolution during the three-phase test is shown in Fig. 8. It can be seen that the boiling temperature of the water increases rapidly in 60 minutes to reach 95°C. The complete time for a test is 2 hours 40 minutes. Such a fast boiling time has the advantage that the meals can be cooked faster and biogas can be saved. The two phases allow to characterize the thermal inertia of the furnace during the successive cooking operations. For the first two phases, the time taken to reach boiling point is

practically identical, around 50 minutes, which explains the low inertia of the furnace, as the hot start should reach boiling point more quickly [21]. During the third phase the temperature remained constant around 98°C during the 45 minutes. This is a good indication for the simmering of the meals, as any sudden change in temperature can spoil the meals supported by several authors like Mohd. Yunus Khan finding a yield of 58% with a burner model [22].

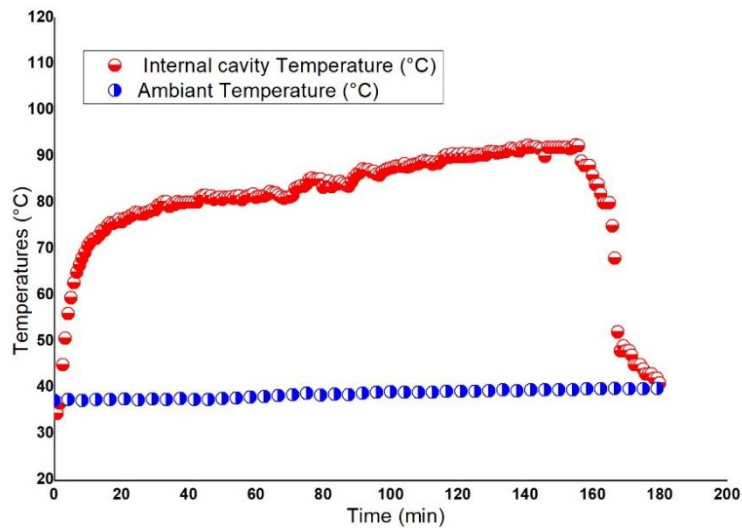


Fig. 6. Internal wall and ambient temperatures evolution

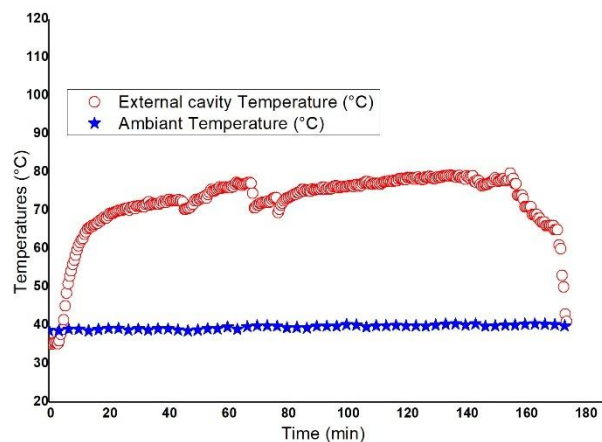


Fig. 10. External wall and ambient temperatures evolution

Table 2. Energy balance results

Energy	Q ₁	Q ₂	Q ₃	Q ₄
Energy (kJ)	10443.31	5531.28	1187.6	3724.43
Energy (%)	100	53	11	36

At the beginning of the experiment, Fig. 9 show that the temperature the stove walls is low 30°C because the cooking is done in a controlled environment. The temperatures of the firebox cavities can be reach 90°C into 2 hours when the burner is turned on. As soon as the flame is extinguished, the temperature of the firebox walls drops rapidly within 20 minutes to reach the ambient temperature (39°C). This result shows that the inertia of the stove is low. Indeed, all the heat from the burner passes by conduction through the cookstove wall. The internal and external temperature of the stove wall is almost identical. Finally, the energy performance of the stove is presented in Table 2. During the test, the initial water temperature is 31°C and the boiling temperature is 95°C. This gives an average burner efficiency of 53%, which is well above the efficiency of the charcoal stoves used in Uganda, which is 20% [23], and the solar thermal stoves, which is 15% [24]. The use of this burner made it possible to realize a gain of 10% contrary to the hearths with the burners of 4mm having generally returns of approximately 40 % [25].

The average boiling time is about 50 min. This result is similar to the efficiency of C₄H₁₀ stoves [26] and higher than that of coal stoves which is 30% [27]. This interesting result of the burner can be explained by the low powers developed during the test (total power is 1.53 kW) as shown by the work of Pankaj P. Gohil giving a power of 1.7849 kW [24]. In general, industrial burners develop powers of between 2 -3 kW [12]. However, studies conducted on the brass burner indicate a higher efficiency of 60% [18] and that conducted with the LPG based on the Indian Standard (IS) 4246:2002 which is 62% [24].

However, studies conducted on the brass burner indicate a higher efficiency of 60% [22]. Finally, we note that the energy performance of a stove depends on the fuel and the households burners [28].

6. CONCLUSION

At the end of our work, we evaluated the quality of biogas produced by a Fasobio-15 biodigester model and the energy performance of the stove. We have the WBT 4.2.3 protocol for boiling water tests. Thus, we observe that the energy losses are due to the openings of the stove. They were calculated from the heat balance equations of the system. The results at the level of the analysis of the produced biogas show a rate of 60% of methane. The results for the furnace show a

thermal performance of 53%. The integrated burners (3.5 mm) of the cookstove release a heat of 1.5 kW and this results in a better consumption of biogas. The biogas consumption is also higher when the burners are inadequate (4 mm). However, the energy performance of the cooking stove is still lower than that of kerosene stoves (60%), but it is an important step in the substitution of firewood in Burkina Faso.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Huijbregts MAJ, Hellweg S, Frischknecht R, Hendriks HWM, Hungehb K, Hendriks AJ. Cumulative energy demand as predictor for the environmental burden of commodity prodHuijbregts. M. A. J., Hellweg, S., Frischknecht, R., Hendriks, H. W. M., Hungehb??hler, K., & Hendriks, A. J. Cumulative energy demand as predictor for the environ," *Environ. Sci. Technol.*, 2010;44(6):2189–2196.
2. Grimm M. Impact evaluation of improved stove use among dolo-beer breweries in Burkina Faso – FAFASO. 2013;1–31.
3. Fullerton DG, Bruce N, Gordon SB. Indoor air pollution from biomass fuel smoke is a major health concern in the developing world. *Trans. R. Soc. Trop. Med. Hyg.* 2008;102(9):843–851. DOI: 10.1016/j.trstmh.2008.05.028
4. Russell A, et al. Using forests to enhance resilience to climate change: The Case of the Wood-Energy Sector in Burkina Faso; 2013.
5. Abdelnour S, Pemberton-Pigott C. For cook and climate: Certify cookstoves in their contexts of use. *Energy Res. Soc. Sci.*, vol. 44, no. February. 2018;196–198. DOI: 10.1016/j.erss.2018.05.014

6. Gouvernement, "communiqué BF, prix du gaz," 2021, p.02, [Online]. Available: <https://www.sig.gov.bf>
7. Boggavarapu P, Ray B, Ravikrishna RV. Thermal efficiency of LPG and PNG-fired burners: Experimental and numerical studies. *Fuel*. 2014;116:709–715. DOI: 10.1016/j.fuel.2013.08.054.
8. Ojo KD, et al. Indoor particulate matter concentration, water boiling time, and fuel use of selected alternative cookstoves in a home-like setting in rural Nepal. *Int. J. Environ. Res. Public Health*. 2015;12(7): 7558–7581. DOI: 10.3390/ijerph120707558.
9. Lin J, et al. Effects of mixture ratio on anaerobic co-digestion with fruit and vegetable waste and food waste of China. *J. Environ. Sci*. 2011;23(8):1403–1408. DOI: 10.1016/S1001-0742(10)60572-4.
10. Presentation Du Programme National De BIODIGESTEURS,"vol. 02, p. 11, 2019, [Online]. Available: www.africabiogas.org
11. Ahn HK, Smith MC, Kondrad SL, White JW. Evaluation of biogas production potential by dry anaerobic digestion of switchgrass-animal manure mixtures. *Appl. Biochem. Biotechnol*. 2010;160(4):965–975. DOI: 10.1007/s12010-009-8624-x
12. Parajuli A, Agrawal S, Tharu JK, Kamat AK, Jha AK, Darlami HB. A simplified model for understanding the performance of two-pot enclosed mud cookstoves. 2019;3(4):288–306. DOI: 10.1093/ce/zkz020.
13. Huertas JK, Quipuzco L, Hassanein A, Lansing S. Comparing hydrogen sulfide removal efficiency in a field-scale digester using microaeration and iron filters. *Energies*. 2020;13(18). DOI: 10.3390/en13184793.
14. Ohannessian A. Composés organiques volatils du silicium: Un frein a la valorisation energetique des biogaz; 2008.
15. Sawalha H, Maghalseh M, Qutaina J, Junaidi K, Rene ER. Removal of hydrogen sulfide from biogas using activated carbon synthesized from different locally available biomass wastes - a case study from Palestine. *Bioengineered*. 2020;11(1): 607–618. DOI: 10.1080/21655979.2020.1768736.
16. Chen Y, Cheng JJ, Creamer KS. Inhibition of anaerobic digestion process: A review. *Bioresour. Technol*. 2008;99(10):4044–4064. DOI: 10.1016/j.biortech.2007.01.057.
17. Wang H, Larson RA, Runge T. Impacts to hydrogen sulfide concentrations in biogas when poplar wood chips, steam treated wood chips, and biochar are added to manure-based anaerobic digestion systems. *Bioresour. Technol. Reports*. 2019;7. DOI: 10.1016/j.biteb.2019.100232.
18. Itodo IN, Agyo GE, Yusuf P. Performance evaluation of a biogas stove for cooking in Nigeria. 2007;18(3):14–18.
19. Michel SJ, Tagne K, Thierry H, Ghislain T. Prediction of radiative heat transfer in a combustion chamber. 2017;4(10):111–118.
20. Shen G, Hays MD, Smith KR, Williams C, Faircloth JW, Jetter JJ. Evaluating the performance of household liquefied petroleum gas cookstoves evaluating the performance of household liquefied petroleum gas cookstoves; 2017. DOI: 10.1021/acs.est.7b05155.
21. Sagoung JM, Tchuen G. Mathematical modelling of traditional stoves using the Thermal Network Approach; 2018. DOI: 10.14445/22315381/IJETT-V58P201.
22. Khan MY, Saxena A. Performance of LPG cooking stove using different design of burner heads. *Int. J. Eng. Res. Technol*. 2013;2(7):656–659.
23. Gandigude A, Nagarhalli M. Science direct simulation of rocket cook-stove geometrical aspect for its performance improvement. *Mater. Today Proc*. 2018; 5(2):3903–3908. DOI: 10.1016/j.matpr.2017.11.645.
24. Kahsay MB, Paintin J, Mustefa A, Haileselassie A, Tesfay M, Gebray B. Theoretical and experimental comparison of box solar cookers with and without internal reflector. *Energy Procedia*. 2014; 57:1613–1622. DOI: 10.1016/j.egypro.2014.10.153.
25. Use EE. End-use briefing a quick tutorial on an important energy end use. 1997; 1999.
26. Visser P. The testing of cookstoves: data of water-boiling tests as a basis to calculate fuel consumption. *Energy Sustain. Dev*. 2005;9(1):16–24. DOI: 10.1016/S0973-0826(08)60479-2.
27. Booker K, et al. Performance of charcoal cookstoves for haiti, Part 1: Results from the water boiling test. 2011;25. Available: <http://cookstoves.lbl.gov/haiti/lbnl-5021e.pdf>.

28. Kurchania AK, Panwar NL, Pagar SD. International Journal of Sustainable Energy Design and performance evaluation of biogas stove for community cooking application Design and performance evaluation of biogas stove for community cooking application. Int. J. Sustain. Energy. 2010;29(2):116–123. Available:<http://www.tandfonline.com/action/journalInformation?journalCode=gsol20>.

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