



Theoretical Proposal for a New Model of Cylindrical Biogas Combustion Cook Stove

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Type of Work: Peer Reviewed.

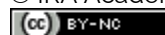
DOI : <https://dx.doi.org/10.21013/jas.v18.n2.p1>

Review history: Submitted: March 07, 2023; Revised: June 12, 2023; Accepted: June 26, 2023.

How to cite this paper:

Bagaya, N., Ouédraogo, I., Koumbem, W. N. D., Baldé, Y. M., Diop, S., Kam, S. (2023). Theoretical Proposal for a New Model of Cylindrical Biogas Combustion Cook Stove. *IRA-International Journal of Applied Sciences* (ISSN 2455-4499), 18(2), 32-42. <https://dx.doi.org/10.21013/jas.v18.n2.p1>

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ABSTRACT

The cook stove is usually constructed from black-painted sheet metal, to better absorb energy. To enhance thermal performance, a theoretical cylindrical design is proposed in this article. This article aims to study this design and compare its performance with the conical design. Theoretical modeling of the cook stove was carried out considering heat transfer by radiation, convection, and conduction based on a steady-state thermal network, and solved using the Matlab R2021b[®] platform under license (*License No*: 595687). The result of the theoretical analysis predicts a theoretical efficiency of 65% , a pot air temperature $T_f = 220^\circ\text{C}$ and a flame temperature $T_a = 900^\circ\text{C}$. Similarly, a validation with Sagouong's model on combustion chamber temperature and Kaushik's model on thermal efficiency. A maximum threshold (RMSE) of 4% is observed between the two studies. The T_c temperature stagnates rapidly within 5 minutes at 600°C and the comparison showed that the firing temperatures of the cylindrical shape are higher than those of the conical-shaped cook stove. Consequently, the performance of the cylindrical-shaped cooking stove can be improved by further experimentation and flue gas analysis.

Keywords: biogas cooker; heat transfer; thermal efficiency; energy.

Abbreviations

| Symbols | Senses | Units |
|--------------------------|--|--|
| A : | Area of the wall surface of the heating device | m^2 |
| C_d : | Burner pressure drop coefficient | – |
| $C_{pair,1}$: | Specific heat of the air in the combustion chamber | $\text{kJ} / \text{kg} / ^\circ\text{K}$ |
| $C_{pair,2}$: | Specific heat of the air in the pot | $\text{kJ} / \text{kg} / ^\circ\text{K}$ |
| Cp_i : | Specific heat of the each node | $\text{kJ} / \text{kg} / ^\circ\text{K}$ |
| m_a, \dots, m_h | Substantial weights considered in each node | kg |
| LCV : | Low Calorific Value of biogas | kJm^{-3} |
| q_a : | Biogas energy produced in the burner | kJ |
| σ : | Constant Stefan-Boltzmann constant | $\text{Wm}^2 \cdot \text{K}^{-4}$ |
| h_1 : | Combustion chamber convection coefficient | $\text{Wm}^2 \cdot \text{K}^{-1}$ |
| h_2 : | Convection coefficient in the pot | $\text{Wm}^2 \cdot \text{K}^{-1}$ |
| h_3 : | Convection coefficient in ambient air | $\text{Wm}^2 \cdot \text{K}^{-1}$ |
| T_a, T_b, \dots, T_k : | Different nodes temperatures | $^\circ\text{C}$ |
| F : | Form factor | |
| η : | Instantaneous energetic efficiency of the cooker | % |
| q_{ij} | Energy flow between two node points | kJ |
| U_{a-h} : | Conduction energy between node a and node h | $^\circ\text{C}$ |
| s_{biogas} | Biogas density | $\text{Kg} \cdot \text{m}^{-3}$ |
| p_{biogas} | Biogas pressure | Pa |
| d_{jet} | Nozzle diameter | m |

1. Introduction

The growing energy demand has prompted the government of Burkina Faso to diversify its energy sources, with a particular focus on renewable energies. These include measures to facilitate access to other energy sources, such as butane gas. However, in 2020, the butane subsidy was cut by 10%, leading to an increase in the price per bottle, and the product became scarce for the population due to its unaffordable price and distribution shortages in rural areas (Service d'Information du Gouvernement (SIG) du Burkina Faso, 2022). With butane in short supply and electricity unstable on the national grid, the adoption of waste gas (biogas) for cooking in the country has proved attractive. The emergence of a national program has enabled the development of domestic digesters. The results of the 2022 national livestock survey show a total of 9,720,615 head of cattle, 11129114 sheep, 10750406 goats, 1416342 pigs, 1509159 donkeys, 166,289 horses, 28365 camels, and 35803843 poultry. However, according to the latest IPCC report (2022), this important sector generates waste (*Synthèse Du Rapport AR6 Du GIEC Publié*, 2022). The country's energy situation is largely dependent on imported fossil fuels. According to Burkina Faso's fifth general population and housing census, published in 2022, the total population is 20,505,155, with 3,488,258 households (Bagaya et al., 2021). According to this census, 83.5% of households use firewood and coal in rural areas, and only 16.1% of Burkina Faso's population uses gas or biogas. (Faso, 2022). An alternative energy solution is therefore needed. As the production of animal waste is significant, its valorization will not only provide a waste management system but also solve the problem linked to the consumption of wood biomass. Thus, biogas production is proving to be an interesting solution for more than half of Burkina Faso's population. The promotion of biogas offers energy autonomy and diversification of energy sources, especially in peri-urban areas. The number of mini biodigester units in Burkina Faso rose from 9,000 to 16,000 installations between 2017 and 2022 (Bagaya et al., 2023). It has also been established that biogas is an energy source used for cooking with expected health, economic, environmental, and social benefits. Inefficient cooker design often leads to incomplete combustion. The thermal efficiency of open fires available on the market has shown an efficiency of 30-49% shown in the work of Khan et al., 2018 (Khan & Saxena, 2013). To solve this problem, it is important to choose the right material for the right design of the cooker-burner pair. The quality of a gas cooker depends on the size of the burner, which facilitates air-fuel mixing before burning in the combustion chamber, and also on the shape and height of the cooking stove, enabling the heat produced to be retained for as long as possible (Augustin et al., 2022). According to Jasper Okino's work, an open cooker is said to be efficient if, above all, harmful emissions are reduced and thermal efficiency is increased. (Okino et al., 2021). These factors are the concern of the cook stove manufacturer (Gandigude Aashish, 2018). The main objective of using a cooking stove is to produce the maximum possible heat when burning the fuel. Studies have also shown that it is possible to increase the efficiency of cooking systems by modifying the optimal shape of the cook stove. The calorific value of fuel, which varies according to its chemical composition, is an important factor in calculating the efficiency of a cooking stove. Various studies have been carried out to determine the calorific value of biogas, taking methane as the main component. According to Itodo (Itodo et al., 2007), the calorific value of pure methane was 37.78 MJ.m^{-3} . The development of a theoretical study provides details on the residence time required for cooking, the thermal efficiencies of furnaces, high temperatures, and the most suitable furnace model. (Parajuli et al., 2019). The use of biogas cooking stoves in Burkina Faso is increasing due to interest in biodigester technology, which will have an impact on its thermal efficiency, and the implications for the benefits of its adoption compared with wood-burning cookers during domestic cooking need to be assessed.

This study aims to propose a model for a high-performance cook stove. To achieve this, we present the work after the introduction, with the theoretical characterization of the cooker model by establishing the equations in section II. The results obtained are then discussed in section III, and the article concludes. This procedure will enable us to assess the energy performance of a household using biogas as an energy source for cooking multiple meals.

2. Theoretical Study

2.1. Physical Model of the Cook Stove

The steel hearth is cylindrical (Fig. 1a), with a radius of $r_{cooker} = 19cm$ and a combustion chamber height of $hc = 10cm$. This new model is different from the old one used by households, being conical in shape (Fig. 1b). This chamber acts as a tunnel leading hot gases to the cooking pot. The hearth in our study is constructed from sheet steel, thickness $ep = 14mm$, and the cooking pot is made from aluminum, wall thickness $ep = 2cm$. The height of the cooker is $h_{cooker} = 30cm$ from the floor. It is designed in two levels, the first being the combustion chamber with a diameter of 10 cm and the second allowing the pot to be nested. The pot, with a radius of $R_{pot} = 15 cm$, fits snugly into the firebox to prevent leaks. It is fitted with a lid made of the same material as the pot, which has a radius of 17 cm. The cook stove system's $d_{jet}=3.4mm$ diameter nozzle is fed with biogas from the biodigester. The biogas pressure pushes the gas up the tube to the burner. Its venturi effect facilitates the mixing of biogas and air during combustion. A total of eight temperatures across the nodes are to be determined according to conduction, convection, and radiation in the furnace. The system is subdivided into two subsystems (a, b, c and d) and (e, f, g and h). The heat source (a) reacts with the nodes ($N\text{œud}_a: q_a+q_{ba}+q_{ca}+q_{ha}+q_{da}=0$), ($N\text{œud}_b: q_{ab}+q_{bc}+q_{cd}=0$), ($N\text{œud}_c: q_{ca}+q_{cb}+q_{cd}=0$) and ($N\text{œud}_d: q_{da}+q_{bd}+q_{cd}+q_{ed}+q_{fd}+q_{gd}=0$). Subsequently, node (d) becomes the point of convergence of these energies, interacting with nodes ($N\text{œud}_f: q_{df}+q_{ef}+q_{gf}=0$), ($N\text{œud}_e: q_{fe}+q_{gf}+q_{de}+q_{ke}=0$) and ($N\text{œud}_g: q_{dg}+q_{eg}+q_{fg}+q_{kg}=0$). The base temperature of the focus is marked by the point ($N\text{œud}_h: q_{hk}=0$).

The heat balance in the system, which is necessary to establish performance, was carried out based on the following simplifying assumptions:

- The geometry of the cooking stove is similar to that of a vertical cylindrical chimney;
- The flow is considered to be laminar, uniform (stable), one-dimensional and symmetrical;
- The heat spreads gradually over the height of the cook stove;
- The thermodynamic properties of fumes are the same as those of air;
- Heat transfer by flue gas radiation is negligible.

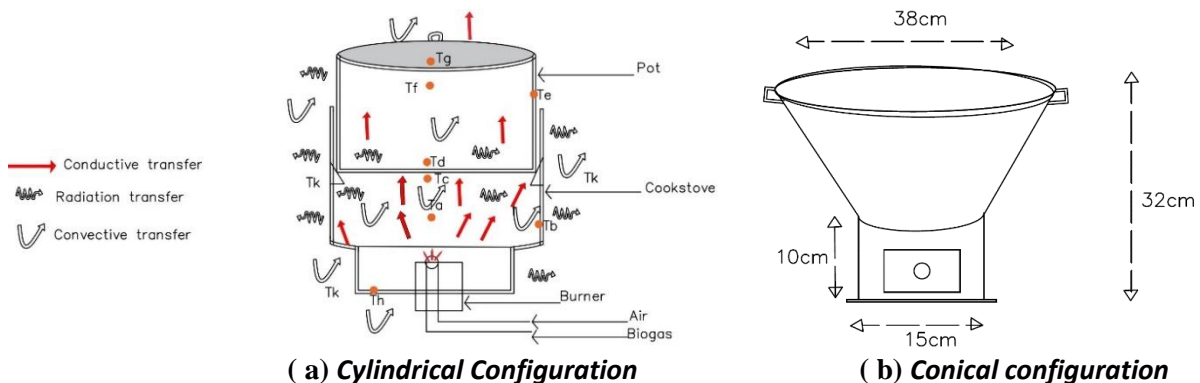


Fig.1. Physical model cylindrical shape (left) and conical shape (right)

2.2 Temperature Equations

2.2.1. Energy Produced by the Cooker

Heat balance analysis for the zone (a) of the cook stove

Combustion of the biogas feed rate in the burner produces a heat balance from the heat source (flame) in the cooking stove equivalent to the heat transfer between the walls and from the kettle and biogas evaporation. The gas flow through the burner according to Fulford's recommendation (Fulford, 1996)(Kurchania et al., 2010). The heat balance of the system is given by Equation 1.

$$m_a C_p \frac{dT_a}{dt} = A_1 \dot{q}_{rad} ba + A_1 \dot{q}_{conv} ca + A_1 \dot{q}_{rad} da + A_1 \dot{q}_{cond} ha + q_a \quad (1)$$

The biogas flow, $q_a = 0,0361.Cd.d_{jet}^2 \sqrt{\frac{p_{biogas}}{s_{biogas}}}.LCV$ whose Cd , d_{jet} respectively the pressure drops and the burner diameter as a function of time. The LCV is biogas Low Calorific Value.

In addition i, j represent the different nodes, T = the temperature, A = the surface and \dot{q} = the energy between the nodes. In the C_p , the i goes from a to k and on the surfaces A from 1 to 10.

Heat balance analysis for the zone (b) of the cook stove

Similarly, the heat produced by the vertical wall of the cook stove is given by equation 2.

$$m_b C_p \frac{dT_b}{dt} = A_2 \dot{q}_{rad} ab + A_2 \dot{q}_{conv} cb + A_3 \dot{q}_{rad} kb + A_2 \dot{q}_{rad} db + A_3 \dot{q}_{conv} kb \quad (2)$$

Heat balance analysis for the zone (c) of the cooking stove

The heat carried by the hot gases in zone c interacts with the pot and the focus is shown in equation 3.

$$m_c C_p \frac{dT_c}{dt} = A_1 \dot{q}_{conv} ac + A_2 \dot{q}_{conv} bc + A_4 \dot{q}_{conv} dc \quad (3)$$

Analysis of heat balance for the zone (h) of the cooking stove

The heat lost by the furnace to the surrounding environment through radiation and convection is given by equation 4.

$$m_h C_p \frac{dT_h}{dt} = A_1 \dot{q}_{conv} kh + A_{10} \dot{q}_{rad} kh \quad (4)$$

2.2.2. Energy Balance of the Kettle

Heat balance analysis of zone (d) at the base of the kettle

The flame in contact with the base of the pot stores a quantity of energy which is then transmitted to the contents of the pot by equation 5.

$$m_d C_p \frac{dT_d}{dt} = A_4 \dot{q}_{rad} ad + A_4 \dot{q}_{conv} cd + A_4 \dot{q}_{rad} bd + A_5 \dot{q}_{rad} ed + A_5 \dot{q}_{conv} fd + A_5 \dot{q}_{rad} gd \quad (5)$$

Heat balance analysis of zone (e) of the kettle's thickness

The vertical thickness of the aluminum pot results in losses mainly due to convection and radiation between the wall and the surrounding environment. Its observation is of particular interest in determining the distribution of heat losses, so that we can concentrate on the greatest losses when making modifications. It is calculated by equation 6.

$$m_e C_{p_e} \frac{dT_e}{dt} = A_6 \dot{q}_{rad} de + A_6 \dot{q}_{conv} fe + A_6 \dot{q}_{rad} ge + A_7 \dot{q}_{rad} ke + A_7 \dot{q}_{conv} ke \quad (6)$$

Heat balance analysis of zone (g) of the pot lid

The aluminum lid of the cooking pot also represents a loss for the furnace. Its thickness and the material used could lead to energy savings. This is calculated by equation 7.

$$m_g C_{p_g} \frac{dT_g}{dt} = A_8 \dot{q}_{conv} fg + A_8 \dot{q}_{rad} eg + A_9 \dot{q}_{rad} kg + A_8 \dot{q}_{rad} dg + A_9 \dot{q}_{conv} kg \quad (7)$$

2.2.3. Balance of the Useful Energy Produced by the Cooker-Pot Couple

The useful energy corresponding to that absorbed by the load to heat its contents is thus obtained by conventional equation 8.

$$m_f C_{p_f} \frac{dT_f}{dt} = A_5 \dot{q}_{conv} df + A_6 \dot{q}_{conv} ef + A_8 \dot{q}_{conv} gf \quad (8)$$

2.3 Thermal Efficiency Equation

The energy efficiency of the cook stove is a function of the calorific value of the biogas, the cooker-pot material, and the characteristics of the burner. It is calculated during the cooking time Δt and i here represents the different nodes at the kettle level only and $\theta = (T_i - T_{ambient})$ by equation 9.

$$\eta_{inst} = \frac{m_i \cdot cp_i \cdot \theta}{q_a \cdot \Delta t} \quad (9)$$

The definitions of the various surfaces involved in the calculations are given in Table 1. The cooking stove is made of steel and the kettle of aluminum, and the thermophysical properties of these metals are used in the calculations. Areas of the inner base surface (IBS), the inner vertical surface of the heating device (IV), the outer vertical surface (OV), the outer base surface of the heating device (OBS), inner cover surface (IC) and the outer cover surface (OC). The radiation exchange coefficient between two surfaces i and j is $hr_{i-j} = \sigma \varepsilon (T_i^2 + T_j^2)(T_i + T_j)$. The Nusselt number in the combustion chamber taken as a chimney $Nu_1 = 0.023 Re^{0.8} (1 + (D/L))^{(0.7)} 0.685^{(1/3)}$ and inside the kettle $Nu_2 = 0.54 (Gr \cdot Pr)^{(0.25)}$. The specific heat of the air is a function of the heating temperature $Cp_{air} = 0.9362 + 0.0002T(i)$.

Table 1. Definition of the various surfaces

| Areas | IBS | IV | OV | OBS | IC | OC |
|------------|-----|----|----|-----|----|----|
| Cook Stove | A1 | A2 | A3 | A10 | - | - |
| Pot | A5 | A6 | A7 | A4 | A8 | A9 |

The three transfer modes whose convection is calculated by the equation 10.

$$\dot{q}_{conv} = h_{air, fuel} (T_j - T_i) \quad (10)$$

Then the radiation is determined by the equation 11.

$$\dot{q}_{rad} = F_{ij} h_{i-j} (T_j^4 - T_i^4) \quad (11)$$

Finally, conduction along the thickness x is determined by the equation 12.

$$\dot{q}_{cond} = \frac{k_{iron}}{x} \quad (12)$$

With $h_{air, fuel}$ = the convection coefficient at the air-fuel level, h_{i-j} = the radiation coefficient and k_{iron} = the conduction coefficient. T = is the temperature and F_{ij} = the form factor between two areas i and j .

2.4. Resolution Method Protocol

Differential equation iteration algorithms are named after Carle Runge and Martin W. Kutta, who invented them in 1901 and represent a predictor-corrector technique between two-time intervals. The discretized equations are compiled using the RUNGE KUTTA 4th-order method at *Matlab*[®] (*LicenseNo*: 595687). The program inputs are the focus geometry and the physical properties of the cook stove. The temperature value and thermal efficiency at order $(i+1)$ are determined explicitly as a function of the previously calculated starting order (i) and so on, with the program running over multiple numbers of steps. A total of eight temperatures are determined using the "for" loop algorithm. When the program starts, all temperatures are taken to be equal to the ambient temperature T_k . As calculations progress, new values for the various temperatures are obtained up to the final time $n-1$. Regular corrections are necessary when the outputs show abrupt or very slow variations in a region. For validation, the author's data are written as a polynomial whose output is $y = a_5x^5 + a_4x^4 + a_3x^3 + a_2x^2 + a_1x^1 + a_0$, which we add to the Matlab code for comparison. In this way, the model developed can be used to vary important input parameters to determine the performance of homes.

3. Results and Discussion

3.1. Different Temperatures in the Cylindrical Cook Stove and Kettle

For simplicity's sake, single air is heated to maximum temperature in a completely closed kettle, as shown in the physical model in Fig. 1. The phase changes that the air in the burner may reach have been ignored in the simulation. From the theoretical results in Fig. 2, we can see that the highest temperature is T_a followed by T_c representing the flame and the combustion chamber. This is due to the energy input at node a, which is the heat source, and the conduction heat losses obtained between the two nodes (a) and (h). In the latter part, we doubled the cook stove thickness by creating a void between the two linings. In addition, the CH₄ content of the biogas used is 60%, giving the biogas a net calorific value (NCV) of 22.67 kJ/L, which means a high energy content compared with wood fuels. Consumption of the cooker-burner during time $t = 3$ h is around 500L, with daily biogas production of around 1900L. Flame temperature is in the order of literature for good insulation. Shankar B. Kausley (Shankar B. Kausley, 2010) used a wood-fired furnace with a thickness of 60mm and obtained a temperature of 800°C after 1000 seconds of combustion. A good furnace design will regulate fuel consumption and remove doubts about biogas insufficiency, as recommended in the work of A. O. Godwin (Godwin et al., 2015). The same energy produced by the walls of the furnace enabled a high combustion chamber temperature to be achieved. It is

also clear from these figures that the temperatures of the cooker walls and the horizontal kettle are equally high (500°C), and this is because this node exchanges directly with the flame produced (in Fig. 2a).

The temperatures of the cooker thicknesses (lid, vertical thickness) reached 400°C due to heat losses in the ambient air (by convection and radiation). The desired temperature (useful energy) is around 200°C , well above the boiling temperature of water at atmospheric pressure, testifying to good transfer between the various nodes with this node f (in Fig. 2b). The lowest temperature is at the bottom of the furnace $T_h = 60^{\circ}\text{C}$, due to the thermos effect (vacuum-separated insulation).

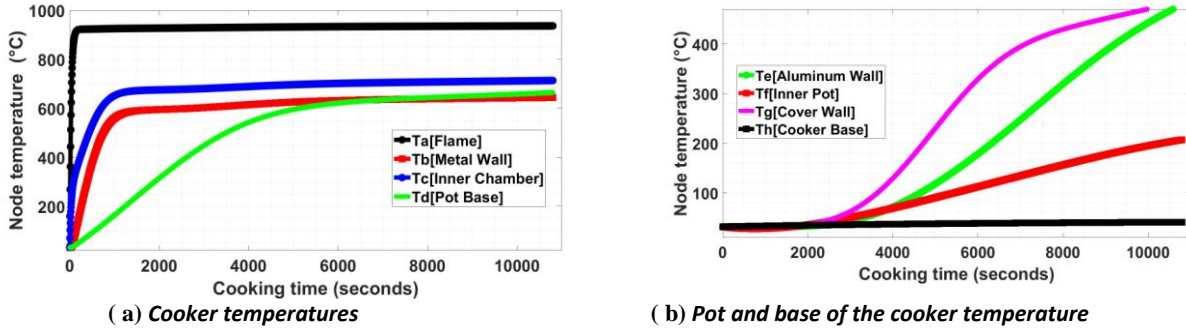


Fig. 2: Temperatures in the cook stove and the cooking pot

Fig. 2a shows that after a certain simulation time, no significant change in the temperature profile is observed. This indicates that the steel cooker has rapidly reached a quasi-stable state. Our study also showed a similar result to the flame obtained by Lucia M. Petro (2020) (Petro et al., 2020) with a 2.5 mm nozzle burner $T_{a,Lucia} = 900^{\circ}\text{C}$.

3.2 Impact of Shape on the Energy Performance of the Cook Stove System

The conical shape of the cook stove is made up of a combustion chamber at an angle $\alpha = 30^{\circ}$ to the horizontal. The difference equations taken with the conical shape in the Matlab implementation gave the curves in Fig. 3. For $t = 0.5h$ we have $T_c = 150^{\circ}\text{C}$ and for $t = 2.5h$, $T_c = 300^{\circ}\text{C}$. For, $t = 0.5h$ $T_b = 100^{\circ}\text{C}$ and $t = 2.5h$, $T_b = 320^{\circ}\text{C}$. The maximum temperature obtained in the combustion chamber (Fig. 3a) and on the wall in contact with the flame is 300°C (Fig. 3b). These results are due to the regular renewal of the air in the cook stove. The flared shape of the firebox cooker creates an air intake in the upper part of the firebox, as the cooking pot doesn't fit properly. We can therefore say that the cylindrical shape brought a gain ($T_{C,cylinder} = 600^{\circ}\text{C}$ and $T_{C,cone} = 300^{\circ}\text{C}$).

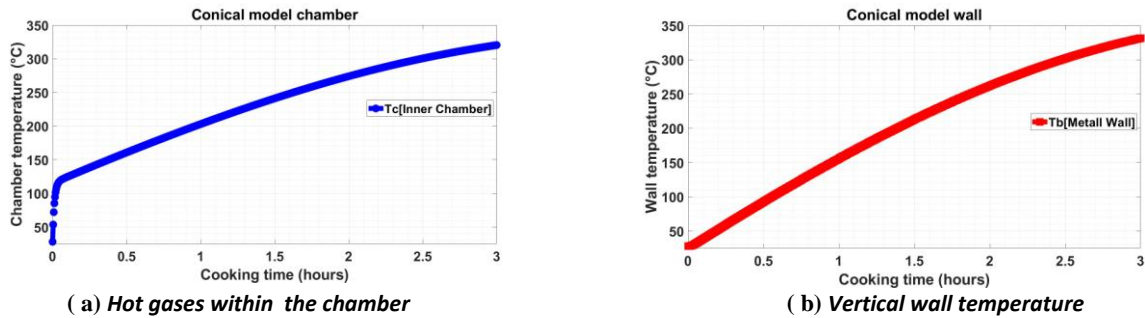


Fig. 3: Temperatures reached by the cook stove of conical configuration

The difference in temperatures between the models shows that there is a significant difference between the two designs in terms of heat production. This theoretical modeling predicts that the cylindrical design can perform much better than the conical design.

3.3 Energy Efficiency of the Cooking Stove of Cylindrical Configuration

Fig. 4 shows the evolution of the instantaneous thermal efficiency of the furnace as a function of time over 03 hours. It can be seen that at time $t = 0s$, the $\eta = 0$ because, no energy has yet been consumed or produced. At time $t = 6000 \text{ seconds}$ for the $\eta = 40\%$. After that, we observe a maximum efficiency of 65%. This is because the thermal gradient transferred to the pot at this height (10cm) and thickness (14mm) remains high. The cook stove's efficiency of 65% is already an advance (Bagaya et al., 2021) with an empty pot whose air renewal is not controlled. So, we're saying that cooking a dish under the same conditions will produce faster results. Households will save more time and energy, as this result is well above the 30% efficiency of the charcoal cookers used in Uganda (Gandigude Aashish, 2018) and solar thermal at 15% (Kahsay et al., 2014). A close look at Fig.4 shows that the energy efficiency of the cook stove is highest with cylindrical shapes and with thicker cook stoves and pots.

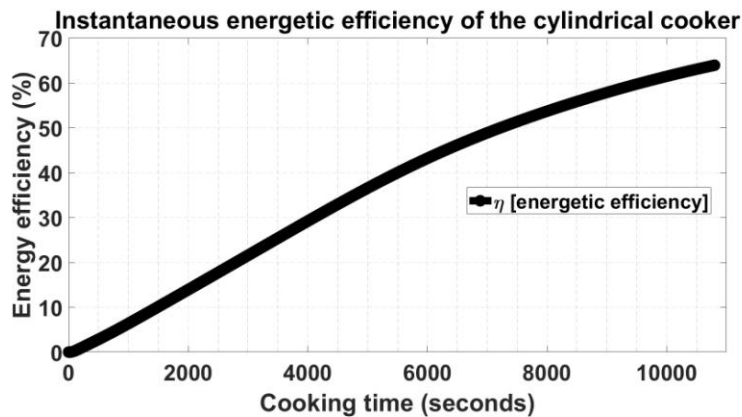


Fig. 4. Cook Stove energy efficiency

Finally, the energy performance of the cylindrical cook stove is shown in Table 2.

Table 2. Maximum values reached by cook stove parameters of cylindrical configuration

| Features | T_a | T_b | T_c | T_d | T_e | T_f | T_g | T_h | η |
|----------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|---------------|--------|
| Values | $900^{\circ}C$ | $580^{\circ}C$ | $650^{\circ}C$ | $590^{\circ}C$ | $400^{\circ}C$ | $200^{\circ}C$ | $450^{\circ}C$ | $60^{\circ}C$ | 65% |

3.4. Validation of the Result of the Cylindrical Biogas Cooker

Our theoretical results are compared with those obtained by Sagouong (Sagouong Jean Michel, Kamdem Tagne Hervé Thierry, 2017) and Kaushik L.K (Kaushik, 2019) using the polynomial to obtain a code. Such a numerical method enabled us to reproduce the heat transfers of the combustion chamber and the energy efficiency of the furnace. The comparative curves shown in Fig. 5 allow us to conclude that there is a coincidence. The figure shows that at time 0, both temperatures $T_{c, \text{Our Study}} = T_{c, \text{Sagouong}} = 300K$. At times $t = 600s$, our approximation is superior to that of the author $T_{c, \text{Our Study}} = 450K$. In the end, our study converges with the author's numerical code. This good result for the similarity of the two furnace shapes allows us to obtain more gain $T_{c, \text{Our Study}} = T_{c, \text{Sagouong}} = 440K$ (again in Fig. 5a). The temperature of the combustion chamber remains stable, which is not the case for carbon according to the work of Tanvir Sowgath (Sowgath et al., 2015).

It should be noted that the determination of emissive powers. Moment zero our model is underestimated compared to that of the author $\eta_{\text{Our Study}} = 2\%$, $\eta_{\text{Khausik}} = 15\%$. At 8000 seconds, the two yields are identical, before diverging slightly at 10000 seconds ($\eta_{\text{Our Study}} = 65\%$ and $\eta_{\text{Khausik}} = 72\%$) (again in Fig. 5b). This performance is due to the insulation added by the author to the furnace. Similarly, the author's kettle is made of 20 mm-thick steel, which is a good insulator compared with the aluminum material used to reduce radiative energy. The two figures confirm that the results of our approximation and those of the authors' numerical method are the same.

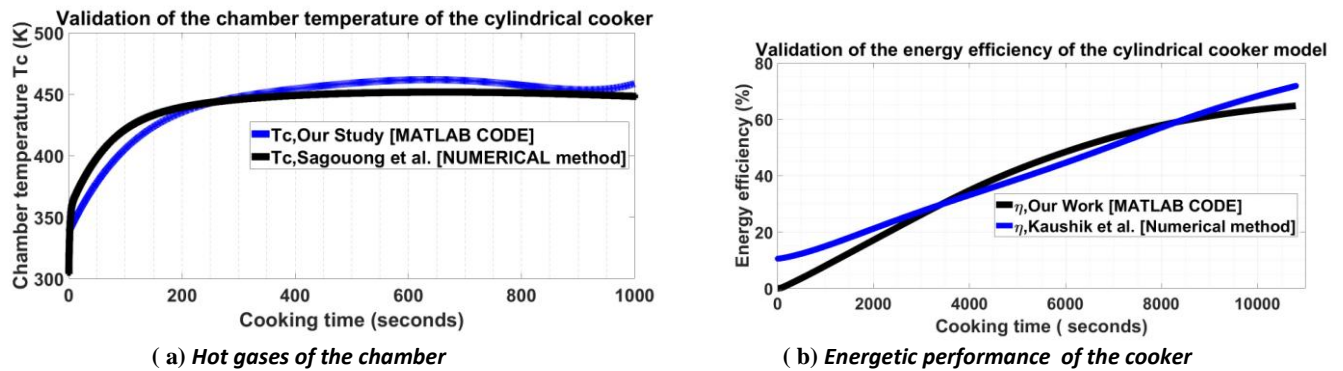


Fig. 5: Combustion chamber temperature and energy efficiency validation

4. Conclusions

This paper presents heat transfer models for biogas combustion in a cylindrical biogas cook stove. The different temperatures and thermal efficiencies within the furnace were carried out. The study clearly showed a good theoretical prediction of cylindrical cook stove performance compared with the conical model. The cylindrical shape of the cooker and the height of 10 cm are important parameters for good heat distribution, so a large amount of the heat generated is efficiently transferred to the pot ($T_f = 200^\circ\text{C}$ and $\eta = 65\%$) by the flame $T_a = 900^\circ\text{C}$. Overall cooking stove temperatures stabilize very quickly (around 20 minutes after combustion), confirming good cooking stove stability. However, losses in the kettle remain enormous (400°C). As a result, the system's performance can be improved by increasing the thickness of the kettle or incorporating insulation. In addition, the energy performance of the furnace can be improved by experimenting to validate the study, and by analyzing the stability and control of biogas combustion with a model in future research studies, as used in Diop's work. (Mone et al., 2020). This practice will undoubtedly lead to a reduction in harmful combustion gases, with a direct impact on human health and environmental pollution, as well as a reduction in fuel consumption.

Acknowledgements

The authors thank the Embassy of France in Burkina Faso for its financing of Bagaya Noufou's research stay at Paris Saclay University through the Service for Cultural Action and Cooperation (SCAC). The authors also acknowledge the financial support of the International Science Program (ISP) through the BUFO1 project.

Competing Interests: The Authors have declared that no competing interests exist.

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