

Natural Convection and Thermal Stratification in a Biomass Oven Fueled by Non-Carbonized Kesambi Leaf Briquettes: An Experimental Study

Jemmy Jonson Sula Dethan^{1,✉}, Fredrik Julius Haba Bunga¹, Erich Umbu Kondi Maliwemu²

¹ Department of Agricultural Engineering, Faculty of Agriculture Technology, Artha Wacana Christian University, Kupang, INDONESIA.

² Department of Mechanical Engineering, Faculty of Science and Engineering, Nusa Cendana University, Kupang, INDONESIA.

Article History:

Received : 20 November 2025

Revised : 25 November 2025

Accepted : 21 February 2026

Keywords:

Biomass oven,
Kesambi leaf briquettes,
Natural convection,
Thermal efficiency,
Vertical temperature distribution.

Corresponding Author:

✉ johnson@ukaw.ac.id
(Jemmy Jonson Sula Dethan)

ABSTRACT

This study investigates the vertical temperature distribution, natural convection behavior, and thermal performance of a biomass oven fueled by non-carbonized Kesambi leaf briquettes. Temperature measurements were conducted at multiple vertical positions inside the oven to characterize heat distribution and buoyancy-driven airflow during operation. The results show a clear vertical temperature stratification, indicating that heat transfer within the oven is dominated by natural convection without external airflow assistance. Dimensionless analysis revealed Rayleigh numbers on the order of 10^8 – 10^9 , confirming the prevalence of buoyancy-induced convection, while the Nusselt number varied dynamically in response to changes in temperature difference and operating conditions. The middle region of the oven (50–60 cm from the base) consistently exhibited the most stable thermal conditions, identifying it as the most effective zone for heat utilization and smoking applications. The thermal efficiency of the oven ranged from 32% to 38%, with variations primarily influenced by combustion intensity and transient heat losses through uninsulated walls and the chimney. These findings demonstrate that non-carbonized Kesambi leaf briquettes can provide stable heat output for biomass ovens and offer practical insights for optimizing oven height, heating zones, and design improvements in small-scale food processing applications.

1. INTRODUCTION

Biomass ovens are widely used in households and small industries for smoking and drying food due to their low cost, simplicity, and renewable energy utilization. Several previous studies have evaluated the efficiency and performance of wood- and briquette-based biomass ovens (Kole *et al.*, 2022; Marigo *et al.*, 2022; Njenga *et al.*, 2023). However, studies specifically examining vertical temperature distribution and heat transfer mechanisms through natural convection within a closed oven chamber are relatively limited, even though these aspects play a crucial role in process stability and energy efficiency.

One of the main drawbacks of biomass ovens is uneven heat distribution, which can potentially reduce product quality and increase energy consumption. This unevenness is influenced by airflow dynamics, burner configuration, material thermal properties, and heating chamber geometry (Álvarez-Bermúdez *et al.*, 2021; Hiron *et al.*, 2025; Kilinç & İskender, 2020). Therefore, analyzing temperature distribution and heat transfer patterns is crucial for understanding oven performance and providing a basis for design improvements.

Meanwhile, the use of alternative fuels from kesambi (*Schleichera oleosa*) leaves and branches is gaining ground. Various studies have shown that torrefaction-treated kesambi leaves possess potential biomass characteristics.

Residence time affects thermal properties and carbon content, and branch particle size influences density, combustion rate, and briquette performance. These findings demonstrate kesambi's potential as a competitive renewable briquette fuel compared to other biomasses and are relevant for application in biomass ovens (Abineno *et al.*, 2024; Dethan, 2024b, 2024a).

However, despite the increasing use of biomass ovens, the understanding of internal heat transfer mechanisms under real operating conditions remains limited. In particular, experimental studies focusing on vertical temperature stratification and natural convection behavior in closed biomass ovens fueled by non-carbonized briquettes are still scarce. Therefore, this study aims to fill this gap by providing an experimental investigation of temperature distribution and dimensionless heat transfer characteristics in a real biomass oven system. This research focuses on analyzing vertical temperature distribution, spatial-temporal visualization of internal temperature, and heat transfer characteristics through Nusselt and Rayleigh numbers in a biomass oven fueled by non-carbonized kesambi leaf briquettes. In addition, the empirical correlation of $Nu-Ra$ was also developed to describe the natural convection mechanism and its thermal efficiency was evaluated, so that it can provide a real contribution to the optimization of small-scale biomass oven design.

2. MATERIALS AND METHODS

This study was conducted to analyze natural convection behavior and thermal performance of a biomass oven using non-carbonized Kesambi leaf briquettes as fuel. The experiment focused on measuring temperature distribution, combustion duration, and fuel consumption to evaluate heat transfer efficiency under semi-controlled indoor conditions.

2.1. Materials

This study used a closed-type biomass oven constructed from mild steel sheet with an internal combustion chamber designed to support natural convection (Figure 1a, 1b). The oven body was made of mild steel plate (0.8 mm thickness) and designed as a cylindrical chamber with an inner diameter of 57 cm and height of 88 cm. A lateral air inlet (5 cm diameter) was located at the lower section, while a vertical exhaust chimney (20 cm height) at the top allowed natural airflow circulation. Non-carbonized kesambi leaf briquettes (Figure 1c, 1d) were used as fuel, produced by drying, grinding, and compressing the leaves into a cylindrical shape. The Kesambi leaf briquettes were produced from dried and ground leaves, molded under compression into cylindrical shapes with uniform size and density. The average higher heating value (HHV) of the briquettes was 15.9 MJ/kg (Dethan & Lalel, 2024), determined using a bomb calorimeter following ASTM D5865 standards.

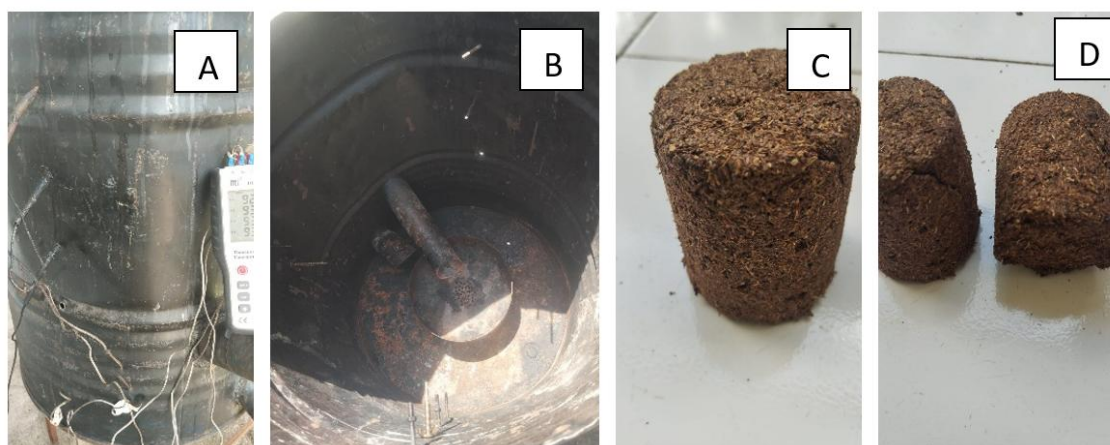


Figure 1. Schematic of the biomass oven showing briquette placement, A. Temperature sensor positions at vertical distances of 0.4–0.7 m; B. Combustion chamber view; C. Front view of the briquette; D, Briquette diameter

2.2. Experimental Procedure

Heat was supplied indirectly through combustion of briquettes in a separate chamber. The combustion of non-carbonized kesambi leaf briquettes occurred at the bottom chamber, physically separated from the smoking chamber. No direct flame contact occurred between the heat source and the product. Thermal energy generated from combustion was transferred upward into the oven chamber mainly by natural convection, driven by buoyancy forces due to temperature differences between the lower and upper regions. In addition, secondary thermal radiation from the heated oven walls contributed to the overall heat transfer inside the chamber.

Each combustion test used 0.5 kg of briquettes with an initial moisture content below 10%, achieved by oven-drying at 105°C for 24 h. To monitor the temperature, a K-type thermocouple (accuracy $\pm 0.1^\circ\text{C}$) was used, connected to a digital data logger. Digital data logger to record temperature every 15 min during a 135-min combustion period. Additional instruments included a digital scale to measure fuel mass and a stopwatch to record combustion duration, as well as ambient thermometer for measuring room temperature before and during the test.

2.3. Dimensionless Number

The heat transfer inside the oven was characterized using dimensionless parameters, including the Nusselt number (Nu), Grashof number (Gr), and Rayleigh number (Ra), which are commonly applied in natural convection analysis. These parameters were calculated based on experimentally measured temperature differences and thermophysical properties of air evaluated at the film temperature. The convective heat transfer coefficient (h) was not assumed to be constant but was estimated dynamically at each measurement interval based on the experimentally measured temperature difference (ΔT) between the oven air and the ambient environment. In this study, Nu and h was estimated using an empirical correlation for natural convection (Bergman *et al.*, 2017):

$$h = 1.42 \left(\frac{\Delta T}{L} \right)^{0.25} \quad (1)$$

$$Nu = \frac{h \cdot L}{k} \quad (2)$$

where L is the characteristic length of the oven, and k is the thermal conductivity of air. Since L and k remain constant, variations in the Nusselt number arise exclusively from changes in h , which are governed by the experimentally measured temperature difference ΔT . Therefore, the variation of Nu reflects the dynamic response of convective heat transfer to changing thermal driving forces, rather than an imposed or assumed relationship. In this study, Nu was obtained from experimentally derived convective heat transfer coefficients (h), which were estimated based on measured temperature differences between the oven air and the ambient environment.

The Grashof number (Gr) is a measure of the ratio of buoyancy to viscous forces in a fluid and represents the ratio of buoyancy forces generated by temperature differences to viscous forces resisting fluid motion. In the context of this biomass oven, Gr quantifies the intensity of buoyancy-driven air movement within the oven chamber. Equation (3) was used to calculate Gr .

$$Gr = \frac{g \beta (T_s - T_\infty) L^3}{\nu^2} \quad (3)$$

The Rayleigh number characterizes the overall strength of natural convection by combining buoyancy effects and fluid properties and is defined by Equation (4). In this study, Ra was calculated independently from temperature differences and thermophysical properties of air. This separation ensures that the Nu – Ra relationship reflects the physical behavior of buoyancy-driven convection within the oven rather than a direct mathematical dependency.

$$Ra = Gr \cdot Pr \quad (4)$$

Within the operating temperature range of 80–100 °C, air behavior closely approximates that of an ideal gas. Therefore, $\beta = 1/T$ is considered valid with negligible error for the Grashof and Rayleigh number calculations, consistent with the Boussinesq approximation commonly applied in natural convection analysis (Bejan, 2013; Incropera & DeWitt, 2007). Thermophysical properties of air (ρ , C_p , k , ν , β , α , and Pr) were evaluated at representative mean temperatures within this range and are summarized in Table 1.

Table 1. Air property data used in the calculations

Parameter	Symbol	Value (80-100 °C)	Unit	Reference
Air density	ρ	1.2	kg/m ³	(Holman, 2010; Incropera & DeWitt, 2007)
Specific heat capacity	C_p	1.005	kJ/kg·K	(Incropera & DeWitt, 2007)
Thermal conductivity	k	0.026	W/m·K	(Holman, 2010)
Kinematic viscosity	ν	16.96×10^{-6}	m ² /s	(Incropera & DeWitt, 2007)
Thermal expansion coefficient	β	$1/350 \approx 0.00286$	1/K	(Bejan, 2013)
Thermal diffusivity	α	23.9×10^{-6}	m ² /s	(Holman, 2010)
Prandtl number	Pr	0.71	-	(Incropera & DeWitt, 2007)

Note: Thermophysical properties were evaluated at a representative film temperature of approximately 350 K.

Based on experimental measurements, the film temperature ranged between approximately 345 and 355 K; therefore, a constant value of 350 K was adopted as a reasonable approximation. This simplification introduces only a minor deviation in the calculated Grashof and Rayleigh numbers and does not affect the identification of the convection regime or the overall interpretation of heat transfer behavior.

2.4. Thermal Efficiency

The thermal efficiency (η) of an oven is estimated by comparing the useful heat energy absorbed by the air inside the oven with the total energy input from the fuel:

$$\eta = \frac{Q_{output}}{Q_{input}} \times 100\% \quad (5)$$

where $Q_{input} = m_{fuel} \cdot HHV$ and $Q_{output} = Q_{air} \cdot C_p \cdot \Delta T$ with HHV = 15.9 MJ/kg as the higher heating value of kesambi briquettes.

3. RESULTS AND DISCUSSION

The heat transfer process inside the biomass oven was governed by natural convection. No mechanical ventilation or forced airflow was applied during the experiments. Air circulation occurred solely due to buoyancy forces generated by temperature differences between the hot combustion gases and the surrounding ambient air. As the air inside the oven was heated, its density decreased, causing it to rise vertically, while cooler air entered naturally from the lower openings. The calculated Rayleigh numbers ranged from the order of 10^8 to 10^9 , which is significantly higher than the critical Rayleigh number for the onset of natural convection. This confirms that buoyancy-driven flow dominated the heat transfer mechanism. Therefore, the application of dimensionless parameters such as the Nusselt, Grashof, and Rayleigh numbers is appropriate for evaluating the convective heat transfer characteristics of the oven.

3.1. Vertical Temperature Distribution

Temperature measurements were taken at four vertical points (40 cm, 50 cm, 60 cm, and 70 cm from the base of the oven) to understand the dynamics of heat distribution during the smoking process. Figure 2 shows the temperature variation over time at four height points in the biomass smoking oven. In the initial minutes (0–15 min), all points show relatively uniform low temperatures, indicating that the oven is still in the preheating phase. After 15 min, the heating pattern begins to differ across heights: the sensor at 40 cm experiences the fastest temperature increase, followed by 50 cm, 60 cm, and 70 cm slowest.

The faster temperature increase in the lower zone of the oven (40–50 cm) is clearly related to its proximity to the heat source (kesambi briquettes). This zone reaches a temperature range of 85–100 °C earlier than the upper layer. Conversely, the sensor at 70 cm shows a significant delay in reaching the peak temperature, indicating a vertical gradient due to limitations in natural convection and heat loss through the walls and chimney. After 60 minutes, the temperature profile tends to stabilize. The 40–60 cm zone forms a relatively homogeneous thermal layer at 90–100 °C, while the upper 70 cm zone remains cooler by about 5–10 °C. Small fluctuations occurring around the 105th to 135th min can be attributed to decreased fuel consumption and heat loss to the environment.

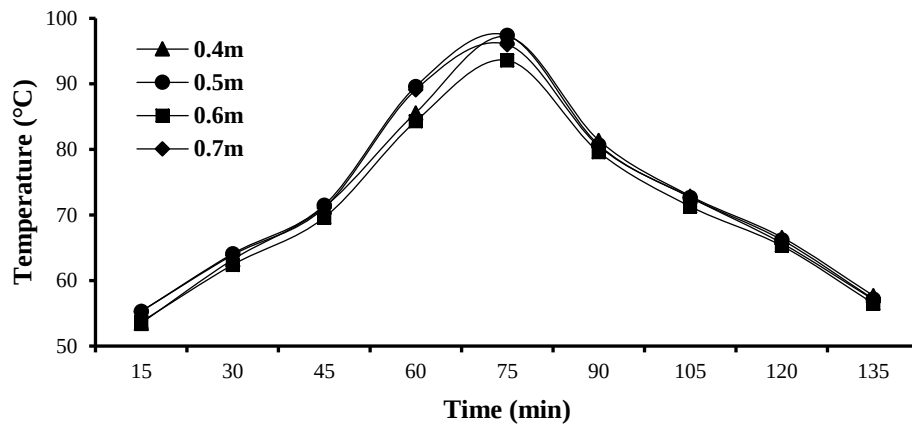


Figure 2. Temperature change over time at various heights in the smoking oven

This stratification phenomenon aligns with the characteristics of natural convection systems: hot air is pushed upward by buoyancy, but some energy is lost before reaching the highest layer. Therefore, the 40-60 cm zone can be identified as the optimal area for smoking, as it offers a stable and consistent temperature suitable for traditional smoked meat cooking.

3.2. Nusselt Number Analysis

The dynamics of convective heat transfer during the smoking process are presented in Figure 3, which displays the change in Nusselt number over time at various vertical positions within the oven. The Nu values obtained were in the range of 80–103, reflecting the effectiveness of natural convective heat transfer throughout the heating cycle. Figure 3 shows the variation in Nusselt number over time at several vertical positions inside the biomass oven. Nu values ranged from 80 to 103 and exhibited a fluctuating pattern throughout the heating process. In the initial minutes until approximately 60 minutes, Nu tended to increase as the temperature gradient increased due to the intensification of kesambi leaf briquette combustion. After passing the peak phase, Nu values began to decrease at most positions, indicating a weakening of buoyancy and convective heat transfer as the energy supply from the fuel decreased.

The middle height of the oven (0.5–0.6 m) consistently showed higher Nu values than the lower and upper positions, indicating that the middle zone is the region with the most effective convection. This pattern aligns with the natural convection theory explained by (Incropera & DeWitt, 2007), which states that heat transfer intensity reaches an

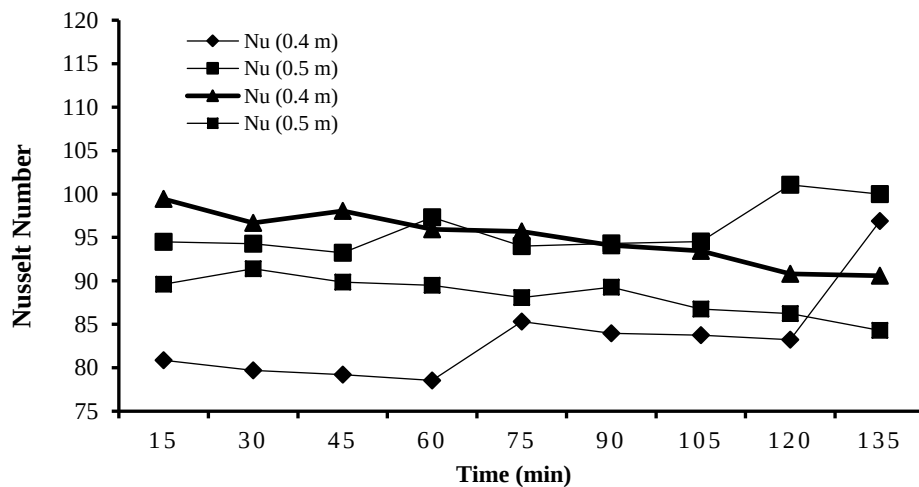


Figure 3. Nusselt Number over Time at Each Vertical Position

optimum at a certain Rayleigh value before decreasing due to a diminishing temperature gradient. This behavior is consistent with classical natural convection theory, where the strength of convection is strongly influenced by the magnitude of the temperature gradient and fluid flow dynamics (Fan *et al.*, 2021; Wang *et al.*, 2021).

The enhanced convection in the lower zone is further supported by the formation of thermal jets and stratified layers that promote vertical heat transfer (Wang *et al.*, 2021). Although convection remains the dominant heat transfer mechanism, radiation can also influence Nu scaling under certain boundary conditions, albeit to a lesser extent (Urban *et al.*, 2020).

3.3. Nusselt-Rayleigh Number Correlation

Figure 4 presents the log–log relationship between the Nusselt number (Nu) and the Rayleigh number (Ra) obtained during the biomass oven operation. At first glance, the near-perfect linearity observed in the plot may appear unusual. However, it should be clearly emphasized that the Nu – Ra relationship presented in this study is not intended to establish a new empirical correlation, but rather to verify that the experimentally derived parameters follow the expected scaling behavior of natural convection systems.

In the present study, the Nusselt number was not measured directly but calculated from the convective heat transfer coefficient derived from temperature measurements and fluid properties. Similarly, the Rayleigh number was computed using the same temperature difference and thermophysical parameters of air. As a result, Nu and Ra are inherently linked through their governing equations, which naturally leads to a strong power-law relationship when plotted in logarithmic form. This behavior is consistent with classical natural convection theory, where $Nu \propto Ra^n$ with $n \approx 0.25$ for laminar buoyancy-driven flow (Bejan, 2013; Holman, 2010).

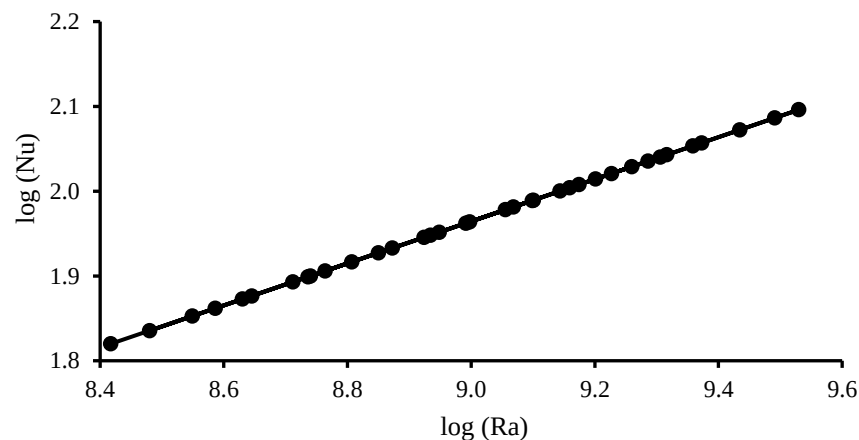


Figure 4. Log-log relationship between Nusselt Number (Nu) and Rayleigh Number (Ra)

Therefore, the excellent linear fit observed in Figure 4 does not imply a flawless experimental correlation, but rather confirms that the calculated parameters follow the expected theoretical scaling for natural convection. Similar approaches have been reported in previous studies where dimensionless analysis was used to verify flow regimes and dominant heat transfer mechanisms rather than to establish new empirical correlations (Fan *et al.*, 2021; Incropera & DeWitt, 2007). To address this limitation and provide a more physically meaningful interpretation, the present study places greater emphasis on experimentally driven relationships, such as the variation of Nu with heating time and characteristic length (Figure 5), where Nu is derived from measured temperature gradients and system response. These plots better reflect the actual thermal behavior of the oven and the influence of geometric parameters on convection intensity.

Figure 5 illustrates the variation of the experimentally derived Nusselt number (Nu) with heating time for four characteristic lengths ($L = 0.4, 0.5, 0.6,$ and 0.7 m). All curves exhibit a similar trend, where Nu increases during the initial heating period, reaches a peak at approximately 60–75 minutes, and subsequently decreases toward the end of

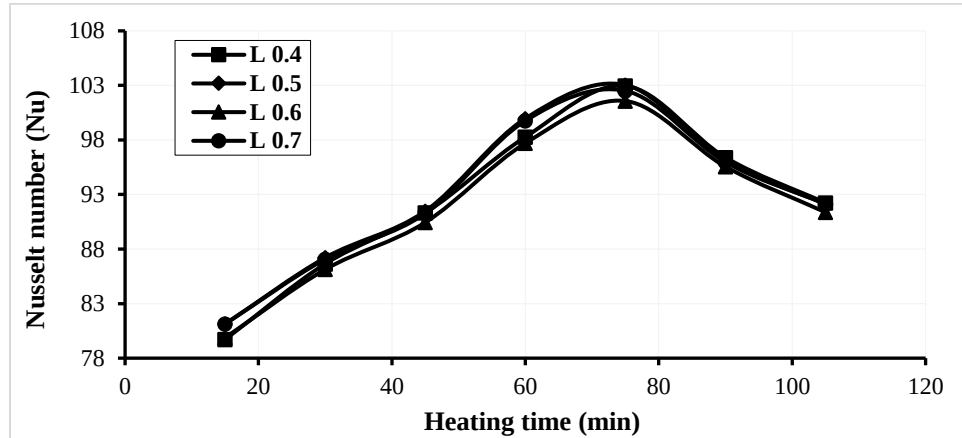


Figure 5. Variation of experimentally obtained Nusselt number with heating time at different vertical positions

the combustion cycle. This behavior reflects the dynamic nature of natural convection inside the biomass oven, which is strongly influenced by the temporal evolution of temperature gradients generated by briquette combustion.

At the early stage of heating, the increase in Nu corresponds to the intensification of buoyancy forces as the temperature difference between the hot air and the surrounding environment becomes larger. During this phase, stronger convective motion enhances heat transfer, resulting in higher Nu values. The maximum Nu observed in the mid-heating period indicates the point at which the convective flow is most effective, coinciding with stable combustion and sustained thermal stratification inside the oven chamber. Similar transient convection behavior has been reported in natural convection enclosures and biomass-fueled systems, where peak heat transfer occurs before fuel depletion reduces the driving temperature gradient (Fan *et al.*, 2021; Incropera & DeWitt, 2007).

Although the same temporal pattern is observed for all characteristic lengths, slight differences in magnitude can be identified. The $L = 0.7$ m configuration generally shows marginally higher Nu values compared to shorter characteristic lengths, suggesting that a larger vertical scale promotes stronger buoyancy-driven circulation. Conversely, the $L = 0.4$ m and $L = 0.6$ m cases display slightly lower Nu values, indicating more limited convective development. These variations are consistent with natural convection theory, which states that characteristic length directly influences the strength of buoyancy forces and flow structure within an enclosure (Bejan, 2013).

As heating progresses beyond the peak period, Nu decreases for all configurations. This decline can be attributed to the reduction in heat release rate as the briquettes are consumed, leading to weaker temperature gradients and diminished convective intensity. The convergence of Nu values among different characteristic lengths during the cooling phase suggests that convection becomes less sensitive to geometric differences once the driving force weakens.

Taken together, the results shown in Figure 5 demonstrate that heat transfer in the biomass oven is governed by transient natural convection that evolves with heating time and is moderately affected by characteristic length. These findings confirm that the mid-heating period represents the most effective operating window for heat utilization, while also providing experimental evidence that geometric scaling influences convection performance. This insight is particularly valuable for optimizing oven height and loading position in practical smoking and cooking applications.

3.4. Oven Thermal Efficiency

The thermal efficiency of the oven, defined as the ratio of useful energy absorbed by the oven air to the total energy released by the fuel, was found to vary between 32% and 38%. This variation is primarily attributed to temporal changes in combustion intensity, temperature gradients, and heat losses during the smoking process. At the early stage of operation, part of the supplied energy is consumed for heating the oven structure and establishing buoyancy-driven airflow, resulting in lower instantaneous efficiency. As the combustion stabilizes and a more uniform temperature distribution develops, particularly within the 40–60 cm zone, the fraction of energy effectively transferred to the oven air increases, leading to higher efficiency values.

Fluctuations in fuel combustion rate and briquette degradation over time also contribute to efficiency variation. As the Kesambi leaf briquettes gradually burn, the heat release rate decreases, increasing relative heat losses through the oven walls and chimney, especially in the absence of thermal insulation. Consequently, efficiency tends to decline toward the later stages of operation. Similar efficiency ranges (25–40%) have been reported for uninsulated passive biomass ovens, where heat losses exceeding 60% due to convection and radiation are common (Falciano *et al.*, 2022).

In this study, the total energy input was approximately 7.95 MJ, derived from 0.5 kg of briquettes. Heat transfer inside the oven was dominated by natural convection and thermal radiation, which together accounted for a substantial portion of energy transport to the oven air (Nguyen *et al.*, 2022). The presence of a stable thermal zone between 40 and 60 cm enhanced heat absorption and retention, contributing to higher efficiency during steady-state operation. Previous studies have shown that improving airflow distribution, combustion chamber geometry, and secondary air supply can further increase thermal efficiency while reducing emissions and heat losses (Astete *et al.*, 2021; He *et al.*, 2022; Motyl *et al.*, 2020). Therefore, the observed efficiency range reflects the combined effects of combustion dynamics, natural convection development, and unavoidable thermal losses in an uninsulated biomass oven system.

4. CONCLUSIONS

This study confirms that heat transfer in the biomass oven is dominated by natural convection, as evidenced by Rayleigh numbers on the order of 10^8 – 10^9 and distinct vertical temperature stratification. The middle zone (50–60 cm) was identified as the most thermally stable and effective region for heat utilization. The Nusselt number varied dynamically with combustion conditions, indicating transient convection behavior, while the thermal efficiency ranged from 32% to 38%, consistent with typical uninsulated biomass ovens. These results highlight the importance of chamber geometry and thermal zoning in improving oven performance and provide a basis for design optimization in small-scale biomass-based applications. From a practical perspective, these findings suggest that simple biomass ovens fueled by locally available Kesambi leaf briquettes can be effectively used for smoking and cooking applications, particularly when the load is placed within the identified optimal vertical zone.

Future work should focus on incorporating wall insulation and secondary air control to improve thermal efficiency and reduce emissions. In addition, coupling temperature measurements with direct gas velocity or heat flux measurements would allow a more comprehensive assessment of convective mechanisms. The integration of numerical simulations with experimental data is also recommended to further clarify the interaction between buoyancy, radiation, and oven geometry under different operating conditions.

AUTHOR CONTRIBUTION STATEMENT

Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
JJSD	✓	✓		✓	✓	✓			✓	✓			✓	
FJHB			✓			✓	✓	✓		✓				
EUKM					✓					✓	✓			
C: Conceptualization			Fo: Formal Analysis			O: Writing - Original Draft			Fu: Funding Acquisition					
M: Methodology			I: Investigation			E: Writing - Review & Editing			P: Project Administration					
So: Software			D: Data Curation			Vi: Visualization								
Va: Validation			R: Resources			Su: Supervision								

REFERENCES

- Abineno, J., Dethan, J., Bunga, F.J.H., & Bunga, E.H. (2025). Characterization and performance analysis of Kesambi branch biomass briquettes: A study on particle size effects. *Journal of Ecological Engineering*, *26*(1), 213–222. <https://doi.org/10.12911/22998993/195643>
- Álvarez-Bermúdez, C., Chapela, S., Varela, L.G., & Gómez, M.Á. (2021). CFD simulation of an internally cooled biomass fixed-bed combustion plant. *Resources*, *10*(8), 77. <https://doi.org/10.3390/resources10080077>
- Astete, R.B., Gutiérrez-Cáceres, N., Muñoz-Catalán, M., & Mora-Chandia, T. (2021). Direct improvement in the combustion chamber and the radiant surface to reduce the emission of particles in biomass cooking stoves used in Araucanía, Chile. *Sustainability*, *13*(13), 7205. <https://doi.org/10.3390/su13137205>

- Bejan, A. (2013). *Convection heat transfer*. John Wiley & Sons. <https://doi.org/10.1002/9781118671627>
- Bergman, T.L., Lavine, A.S., Incropera, F.P., & DeWitt, D.P. (2017). *Fundamentals of Heat and Mass Transfer* (8th ed.). John Wiley & Sons.
- Dethan, J., & Lalel, H. (2024). Optimization of particle size of torrefied kesambi leaf and binder ratio on the quality of biobriquettes. *Journal of Sustainable Development of Energy, Water and Environment Systems*, 12(1), 1120490. <https://doi.org/10.13044/j.sdewes.d12.0490>
- Dethan, J.J.S. (2024a). Evaluation of an empirical model for predicting the calorific value of biomass briquettes from candlenut shells and kesambi twigs. *Advances in Food Science, Sustainable Agriculture and Agroindustrial Engineering (AFSSAAE)*, 7(3), 253–264. <https://doi.org/10.21776/UB.AFSSAAE.2024.007.03.6>
- Dethan, J.J.S. (2024b). Statistical models for predicting the higher heating value of torrefied kesambi leaves. *Journal of Water and Land Development*, 63, 86–90. <https://doi.org/10.24425/jwld.2024.151793>
- Dethan, J.J.S., Bunga, F.J.H., Ledo, M.E.S., & Abineno, J.C. (2024). Characteristics of Residence Time of the Torrefaction Process on the Results of Pruning Kesambi Trees. *Jurnal Teknik Pertanian Lampung (Journal of Agricultural Engineering)*, 13(1), 102. <https://doi.org/10.23960/jtep-l.v13i1.102-113>
- Falciano, A., Masi, P., & Moresi, M. (2022). Performance characterization of a traditional wood-fired pizza oven. *Journal of Food Science*, 87(9), 4107–4118. <https://doi.org/10.1111/1750-3841.16268>
- Fan, Y., Zhao, Y., Torres, J.F., Xu, F., Lei, C., Li, Y., & Carmeliet, J. (2021). Natural convection over vertical and horizontal heated flat surfaces: A review of recent progress focusing on underpinnings and implications for heat transfer and environmental applications. *Physics of Fluids*, 33, 101301. <https://doi.org/10.1063/5.0065125>
- He, Z., Liu, S., Wang, S., Liu, W., Li, Y., & Feng, X. (2022). Reduced pollutant emissions and slagging rate of biomass pellet combustion by optimizing the multilayer distribution of secondary air. *ACS Omega*, 7(33), 28962–28973. <https://doi.org/10.1021/acsomega.2c02587>
- Hiron, N., Busaeri, N., Nursuwars, F.M.S., Sambas, A., & Wulandana, R. (2025). Thermal optimization with CFD analysis and real-time performance identification in briquette ovens using Modbus-based communication. *Journal of Advanced Research in Numerical Heat Transfer*, 28(1), 27–42. <https://doi.org/10.37934/arnht.28.1.2742>
- Holman, J.P. (2010). *Heat transfer* (10th ed.). McGraw-Hill Education.
- Incropera, F.P., & DeWitt, D.P. (2007). *Fundamentals of heat and mass transfer* (6th ed.). John Wiley & Sons.
- Kılınç, C., & İskender, Ü. (2020). Yüksek sıcaklık fırınlarının hesaplamalı akışkanlar dinamiği ile modellenmesi. *Politeknik Dergisi*, 23(1), 241–247. <https://doi.org/10.2339/politeknik.656066>
- Kole, A.T., Zeru, B.A., Bekele, E.A., & Ramayya, A.V. (2022). Design, development, and performance evaluation of husk biomass cook stove at high altitude condition. *International Journal of Thermofluids*, 16, 100242. <https://doi.org/10.1016/j.ijft.2022.100242>
- Marigo, M., Zulli, F., Bordignon, S., Carnieletto, L., Emmi, G., & De Carli, M. (2022). Energy analysis of a wood or pellet stove in a single-family house equipped with gas boiler and radiators. *Building Simulation*, 15, 1577–1593. <https://doi.org/10.1007/s12273-022-0884-1>
- Motyl, P., Wikło, M., Bukalska, J., Piechnik, B., & Kalbarczyk, R. (2020). A new design for wood stoves based on numerical analysis and experimental research. *Energies*, 13(5), 1028. <https://doi.org/10.3390/en13051028>
- Nguyen, P.-D., Nguyen, H.-T., Domingo, P., Vervisch, L., Mosca, G., Gazdallah, M., Lybaert, P., & Feldheim, V. (2022). Flameless combustion of low calorific value gases, experiments, and simulations with advanced radiative heat transfer modeling. *Physics of Fluids*, 34(4), 045123. <https://doi.org/10.1063/5.0087077>
- Njenga, M., Sears, R.R., & Mendum, R. (2023). Sustainable woodfuel systems: A theory of change for sub-Saharan Africa. *Environmental Research Communications*, 5(5), 051003. <https://doi.org/10.1088/2515-7620/acd0f3>
- Urban, P., Králík, T., Hanzelka, P., Musilová, V., Věžník, T., Schmoranz, D., & Skrbek, L. (2020). Thermal radiation in Rayleigh–Bénard convection experiments. *Physical Review E*, 101(4), 043106. <https://doi.org/10.1103/PhysRevE.101.043106>
- Wang, Q., Liu, H.-R., Verzicco, R., Shishkina, O., & Lohse, D. (2021). Regime transitions in thermally driven high-Rayleigh number vertical convection. *Journal of Fluid Mechanics*, 917, A7. <https://doi.org/10.1017/jfm.2021.211>