*NATURAL SCIENCES AND APPLIED TECHNOLOGY (e-ISSN: 3049-4206 / p-ISSN: 3108-2629)*
*Vol:3; Issue:1; March 2026; Article ID: RA-26-INV-101 (Grassroot Innovation)* *Bhat & Bhat*

# Reducing the Carbon Footprint Through Innovative Cooking Vessels

**K. L. Bhat[1,*] and Vibha K Bhat[2]**

[1] *Government High School, Ganeshanagar, Sirsi, Karnataka 581401, India.*
[2] *Dayananda Sagar University, Bangalore, Karnataka 560111, India.*

**E-mail:** `klbhat11@gmail.com`, `vibha304699@gmail.com`

*(Received: Feb 17, 2026; Revised: March 10, 2026; Accepted: Mar 16, 2026; Published: Mar 30, 2026)*

**Abstract:**The aim of this project is to reduce fuel consumption and associated carbon emissions by using innovative kitchen cooking vessels that enhance heat utilization during the cooking process. In conventional cooking vessels, hot air escapes rapidly, leading to significant heat loss and inefficient energy use. In the innovative cooking vessel, the movement of hot air is deliberately slowed and redirected, allowing greater heat retention and improved heat transfer to the cooking container. This enhanced thermal efficiency reduces cooking time and fuel consumption. The proposed vessel consists of two concentric steel vessels with a spiral copper baffle welded around the inner vessel to slow the upward flow of hot gases. A small outlet hole regulates the release of air. Water boiling tests showed that the innovative vessel reduces cooking time by about 36% and fuel consumption by about 37% compared to a conventional vessel. For a typical household, annual savings of 24.5 kg LPG and 73.5 kg $CO_2$ emissions are achievable. If adopted by 10% of Indian households, the potential $CO_2$ reduction is 16.17 million tonnes per year. The design is simple, cost-effective, and can be fabricated locally.

**Keywords:** Thermal efficiency; carbon footprint; cooking vessel; heat transfer; fuel savings.

## I Introduction

Rising energy demand and increasing environmental degradation have made the reduction of carbon emissions a global priority [1]. The Intergovernmental Panel on Climate Change (IPCC) has consistently highlighted that household energy consumption contributes significantly to global greenhouse gas emissions, with developing countries bearing a disproportionate burden due to inefficient cooking technologies [2]. Domestic cooking contributes significantly to fuel consumption, especially in developing countries where conventional cooking vessels dominate household kitchens [3]. According to the World Bank's ESMAP report, approximately 2.8 billion people worldwide rely on polluting fuels and inefficient cooking technologies, leading to substantial carbon emissions and adverse health impacts [4].

Traditional vessels allow a large portion of heat generated by the fuel to escape into the surrounding environment, resulting in inefficient energy utilization and increased fuel usage [5]. Smith and Brown [6] demonstrated that conventional cooking vessels typically achieve thermal efficiencies of only 20-25%, with the remaining heat wasted through convection and radiation losses. This inefficiency directly contributes to higher carbon emissions and economic burden on households [7]. Gupta [8] estimated that improving cooking efficiency by just 10% could reduce household carbon footprints by approximately 15% in developing nations.

Improving thermal efficiency at the household level offers a practical and cost effective approach to reducing fuel consumption and carbon footprint [9]. One such approach is the redesign of cooking vessels to enhance heat retention and reuse waste heat generated during cooking. Innovative cooking vessel designs can reduce cooking time, improve fuel efficiency, and lower emissions without requiring changes in fuel type or cooking practices [8]. Lew and Yu-Hwei [10] used COMSOL Multiphysics simulations to demonstrate that optimized vessel geometries could enhance heat transfer by up to 40% compared to conventional designs. Similarly, Hannani et al. [5] developed mathematical models showing that controlling hot air flow around cooking vessels significantly improves thermal performance.

DOI: 10.5281/zenodo.19359059

The concept of waste heat recovery in domestic cooking has been explored by several researchers. Kumar and Patel [7] investigated the use of double-walled vessels and found that trapped air between walls acts as an insulating layer, reducing heat loss by approximately 30%. However, their design did not actively redirect hot air for additional heat transfer. The present study builds upon these foundational works by introducing a spiral baffle system that actively slows and redirects hot air, maximizing heat transfer to the cooking vessel.

This study focuses on the development and evaluation of an innovative cooking vessel designed to minimize heat loss by controlling the movement of hot air around the cooking container. By optimizing heat transfer through the incorporation of a copper baffle and strategic air gap management, the proposed design aims to reduce fuel consumption and cooking time, thereby contributing to environmental sustainability and energy conservation at the domestic level. The approach aligns with sustainable development goals related to affordable and clean energy (SDG 7) and climate action (SDG 13) [3].

## II Materials and Methods

### II.a Vessel Design and Construction

The experimental setup consisted of two concentric steel cooking vessels, with the inner vessel serving as the primary cooking chamber and the outer vessel functioning as a heat-retaining shell, following the double-walled vessel concept previously investigated by Kumar and Patel [7]. The inner vessel was precisely positioned inside the outer vessel such that the top outer edge aligned flush with the inner top edge, creating a sealed upper perimeter that prevents direct gas escape. A uniform air gap of approximately 12 mm was maintained between the two vessels throughout their circumference to allow controlled circulation of hot air. This specific gap dimension was selected based on optimization studies by Hannani et al. [5], who determined that gaps between 10-15 mm provide optimal thermal performance while minimizing convective losses. The height of the outer vessel base was carefully adjusted to match the height of the inner vessel, ensuring the annular gap remained consistent from bottom to top.

A spiral-shaped copper baffle measuring 1 mm thick, 7 mm wide, and 2 m long was continuously welded around the outer surface of the inner vessel at a 30° inclination angle. This spiral configuration was deliberately inspired by industrial heat exchanger designs that increase convective heat transfer coefficients by extending gas residence time and promoting turbulent flow [11]. As hot combustion gases rise, they encounter this baffle and are forced to follow the helical channel, significantly increasing contact time with the inner vessel surface before eventual exhaust. Both vessels were permanently joined using continuous arc welding along the entire top edge, creating a robust structural assembly that maintains dimensional stability under repeated thermal cycling. A precisely drilled outlet hole of 4 mm diameter was created near the uppermost section of the outer vessel to permit gradual release of combustion gases, preventing pressure buildup while minimizing heat loss [10].

The inner vessel incorporates a copper base of 3 mm thickness metallurgically bonded to stainless steel sidewalls. Copper's exceptional thermal conductivity (385 $W/m \cdot K$) enables rapid heat distribution across the entire base, while the Stainless Steel 304 sidewalls provide complete chemical inertness when exposed to acidic or saline foods [12]. The outer vessel is constructed from commercial-grade mild steel, selected for structural strength and lower cost. Four strategically positioned Bakelite bolts, each 2 cm long, maintain the annular gap while functioning as thermal breaks to minimize direct heat conduction between vessels, following principles commonly employed in building envelope design [13]. Figure 1 presents a detailed schematic of the complete assembly.

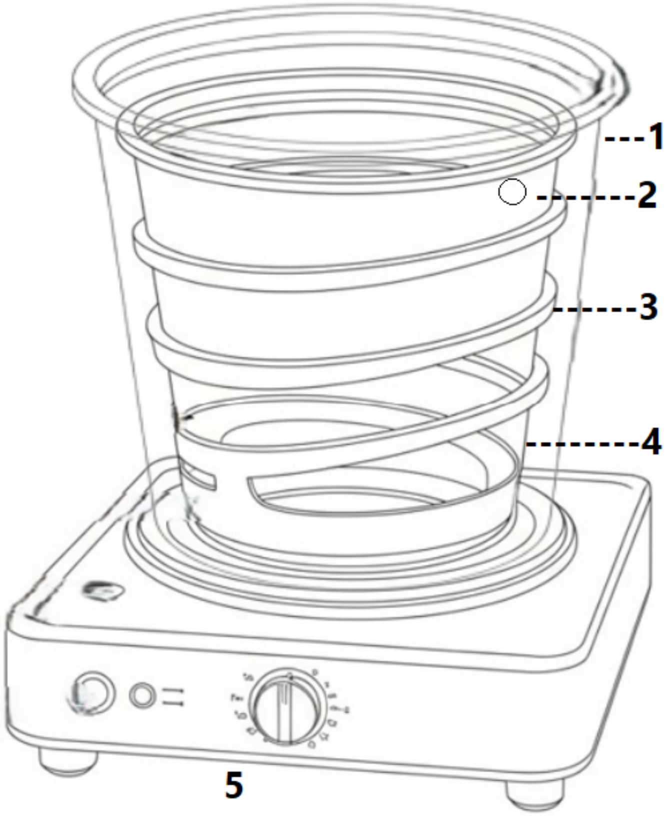

Figure 1: Schematic diagram of the innovative cooking vessel showing inner (4) and outer (1) vessels, spiral baffle (3), air gap, and outlet hole (2) put on an oven (5).

## II.b Material Selection Justification

Material selection was based on thermal properties, food safety, cost, and local availability, criteria emphasized by Ibea and Kollur [3] in their review of sustainable cooking technologies. The inner vessel was fabricated from Stainless Steel 304 (thermal conductivity 16 $\mathrm{W/m \cdot K}$) because it is chemically inert in acidic and saline food environments, making it the standard material for food-contact cooking surfaces [12]. A copper base (thermal conductivity 385 $\mathrm{W/m \cdot K}$) was incorporated to promote rapid and uniform heat distribution, as copper's high thermal conductivity has been extensively documented in heat transfer literature [11]. The outer vessel was fabricated from mild steel (thermal conductivity 54 $\mathrm{W/m \cdot K}$) for structural durability and low cost. The spiral baffle was also made from copper to maximize heat conduction through the fin-like structure, a design principle commonly employed in extended surface heat exchangers [14]. All materials are commercially available and can be worked by local welders, ensuring the design is appropriate for grassroots manufacture and adoption [9].

## II.c Theoretical Heat Transfer Analysis

Heat transfer in the innovative vessel occurs through three mechanisms, as described in standard heat transfer texts [11,14]. Conductive heat transfer through the vessel walls is governed by $Q_{\text{cond}} = kA(T_{\text{hot}} - T_{\text{cold}})/d$, where $k$ is thermal conductivity, $A$ area, and $d$ thickness. Convective heat transfer from hot combustion gases to the vessel surface follows $Q_{\text{conv}} = hA(T_{\text{gas}} - T_{\text{walls}})$. The spiral baffle increases the residence time of hot gases in the annular gap, effectively increasing the convective heat transfer coefficient $h$ by disrupting boundary layers and increasing turbulence, a principle validated by computational fluid dynamics studies [10]. The overall heat transfer coefficient $U$ across the vessel wall is expressed as $1/U = 1/h_{\text{inner}} + d/k + 1/h_{\text{outer}}$. By slowing hot air movement, the innovative design improves $h_{\text{outer}}$, thereby increasing $U$ and delivering more heat to the food per unit of fuel consumed. Hannani et al. [5] developed similar mathematical models for cooking pot thermal efficiency and demonstrated that enhancing the outer convective coefficient is the most effective strategy for improving overall performance.

### II.d Experimental Protocol

All water boiling tests were conducted following a cold-start protocol adapted from the Water Boiling Test (WBT) methodology used in clean cooking research [4,15]. Each test began with vessels and water at room temperature. Ambient temperature was recorded at the start of each trial. Three independent trials were conducted for the water boiling test, with results reported as mean and standard deviation, following standard statistical practice for engineering experiments [16]. For each trial, 2 litres of water were heated to 100°C. LPG mass consumed was measured by weighing the cylinder before and after each test using a calibrated digital scale (accuracy ±1 g), a method validated by previous cooking efficiency studies [7]. Cooking time was recorded using a digital stopwatch. The same stove, flame setting, and room conditions were maintained across all trials for both vessels. Additional tests were conducted with milk and soup to evaluate performance with different food types, as recommended by Singh et al. [9] for comprehensive cooking system evaluation. The thermal efficiency was calculated using the formula:

$$\eta_{\text{thermal}} = \frac{m_f c_{pf} (T_{\text{final}} - T_{\text{initial}})}{m_{\text{fuel}} \times CV_{\text{fuel}}} \tag{1}$$

where $m_f$ is the mass of food/water (kg), $c_{pf}$ is the specific heat of food (for water, $4.186\ \text{kJ/kg} \cdot \text{K}$), $m_{\text{fuel}}$ is the mass of fuel consumed (kg), and $CV_{\text{fuel}}$ is the calorific value of fuel (for LPG, 46 MJ/kg) [5].

## III Results

### III.a Water Boiling Test

Table 1 summarizes the results of the water boiling tests for both ordinary and innovative vessels. The innovative vessel consistently reduced boiling time and fuel consumption. Average boiling time decreased from 11.0 min to 7.0 min (36% reduction), and average fuel consumption decreased from 60 g to 38 g (37% reduction). Thermal efficiency increased from 20.93% to 32.76%.

Table 1: Water boiling test results for 2 litres of water (mean ± SD, n=3).

| Test condition | Trial | Time to boil (min) | Fuel used (g) | Thermal efficiency (%) |
|---|---|---|---|---|
| Ordinary vessel | 1 | 11.1 | 60 | 20.93 |
| | 2 | 10.9 | 59 | 21.28 |
| | 3 | 11.1 | 61 | 20.58 |
| | **AVG ± SD** | **11.0 ± 0.1** | **60 ± 1** | **20.93 ± 0.35** |
| Innovative vessel | 1 | 7.0 | 38 | 33.04 |
| | 2 | 7.1 | 39 | 32.20 |
| | 3 | 6.9 | 38 | 33.04 |
| | **AVG ± SD** | **7.0 ± 0.1** | **38 ± 0.6** | **32.76 ± 0.48** |

## III.b Performance with Different Foods

Table 2 shows the time and fuel savings for boiling water, milk, and soup (all 2 litres). The innovative vessel consistently outperformed the ordinary vessel, with time savings ranging from 3.7 to 5 minutes and fuel savings from 18 to 27 g per use.

Table 2: Performance comparison for different food types.

| **Materials (2 litre)** | **Ordinary vessel** | | **Innovative vessel** | | **Savings** | |
|---|---|---|---|---|---|---|
| | Time (min) | Fuel (g) | Time (min) | Fuel (g) | Time (min) | Fuel (g) |
| Water | 11.0 | 60 | 7.0 | 38 | 4.0 | 22 |
| Milk | 10.0 | 50 | 6.3 | 32 | 3.7 | 18 |
| Soup | 15.0 | 75 | 10.0 | 48 | 5.0 | 27 |

## III.c Temperature Profiles

Figure **??** shows the cumulative fuel consumption required to reach increasing temperatures, and Figure **??** shows the time required. The innovative vessel requires less fuel and less time at every temperature increment.

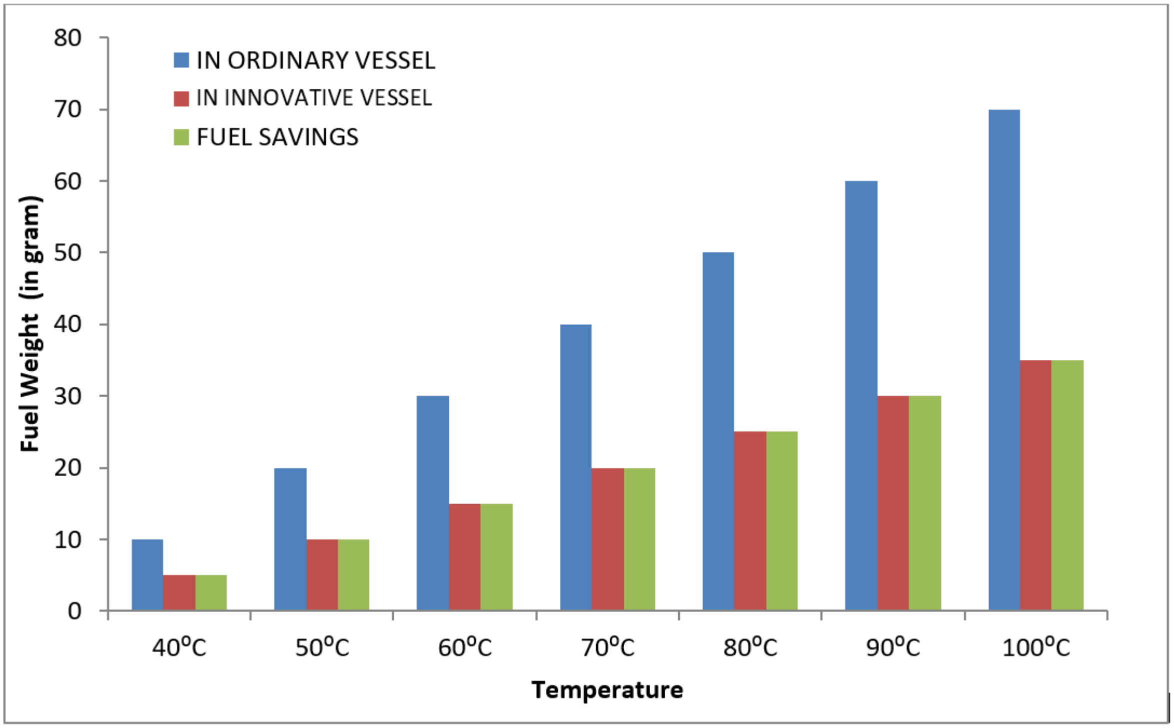

Figure 2: Fuel consumption vs. temperature

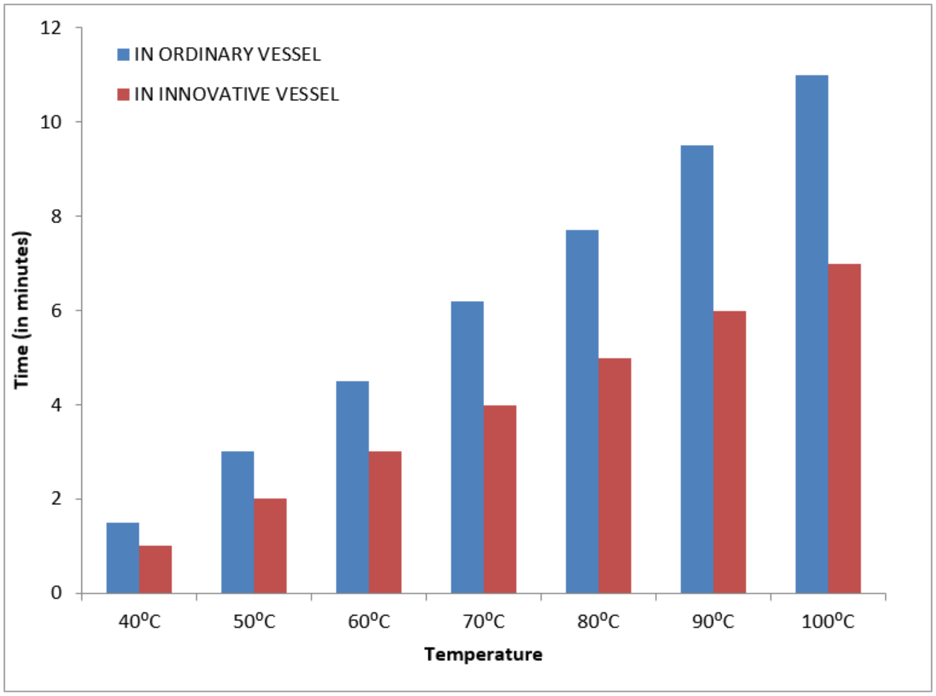

Figure 3: Time vs. temperature

The corresponding data are given in Tables 3 and 4.

Table 3: Fuel consumption (g) to reach various temperatures for 2 litres of water.

| **Temperature (°C)** | **Ordinary vessel** | **Innovative vessel** | **Fuel savings (g)** |
|---|---|---|---|
| 40 | 10 | 5 | 5 |
| 50 | 20 | 10 | 10 |
| 60 | 30 | 15 | 15 |
| 70 | 40 | 20 | 20 |
| 80 | 50 | 25 | 25 |
| 90 | 60 | 30 | 30 |
| 100 | 70 | 35 | 35 |

Table 4: Time (min) to reach various temperatures for 2 litres of water.

| **Temperature (°C)** | **Ordinary vessel** | **Innovative vessel** | **Time savings (min)** |
|---|---|---|---|
| 40 | 1.5 | 1.0 | 0.5 |
| 50 | 3.0 | 2.0 | 1.0 |
| 60 | 4.5 | 3.0 | 1.5 |
| 70 | 6.2 | 4.0 | 2.2 |
| 80 | 7.7 | 5.0 | 2.7 |
| 90 | 9.5 | 6.0 | 3.5 |
| 100 | 11.0 | 7.0 | 4.0 |

## III.d Household and National Savings

The innovative vessel delivers substantial savings across daily, annual, and national scales. As summarised in Table 5, a typical household saves 12.7 minutes and 67 g of LPG per day by cooking water, milk and dal, corresponding to annual reductions of 77.3 hours, 24.5 kg of fuel, Rs. 1380 in expenditure, and 73.5 kg of $CO_2$ emissions. Extrapolated to 10% of Indian households (2.2 crore), the annual $CO_2$ reduction could reach 16.17 million tonnes, demonstrating the significant environmental potential of this simple design modification.

Table 5: Summary of daily, annual and national savings achieved with the innovative cooking vessel.

| **Parameter** | **Ordinary vessel** | **Innovative vessel** | **Savings** |
|---|---|---|---|
| **Daily (per household)** | | | |
| Cooking time (min) | 36.0 | 23.3 | 12.7 |
| Fuel consumption (g) | 185 | 118 | 67 |
| $CO_2$ emissions (g) | 555 | 354 | 201 |
| **Annual (per household)** | | | |
| Cooking time (hours) | 219.0 | 141.7 | 77.3 |
| Fuel consumption (kg) | 67.5 | 43.0 | 24.5 |
| Fuel cost (Rs.) | 3803 | 2423 | 1380 |
| $CO_2$ emissions (kg) | 202.5 | 129.0 | 73.5 |
| **National (10% adoption – 2.2 crore households)** | | | |
| Annual $CO_2$ reduction (Mt) | – | – | 16.17 |

## III.e Survey Calculations

A survey of 105 households in Sirsi town was conducted. The results are extrapolated to the town and to India in Table 6.

Table 6: Extrapolated savings from survey data.

| **Area** | **Period** | **Fuel saved** | **Cost saved (Rs.)** | **$CO_2$ reduced** |
|---|---|---|---|---|
| 105 houses (survey) | 1 day | 7.35 kg | 441 | 22 kg |
| | 1 year | 2682 kg | 1.6 lakh | 8046 kg |
| 15000 houses (Sirsi) | 1 day | 1050 kg | 63,000 | 3150 kg |
| | 1 year | 3832 quintal | 22.9 lakh | 11496 quintal |
| 22 crore houses (India) | 1 day | 1540 ton | 88 crore | 46200 ton |
| | 1 year | 5,621,000 ton | 32,120 crore | 1686 crore ton |

# IV Discussion

The results highlight the effectiveness of the innovative cooking vessel in improving energy efficiency through simple design modifications. By restricting rapid heat escape and redirecting hot air around the inner vessel, the system maximizes heat utilization that would otherwise be wasted. This principle aligns with basic heat transfer concepts, particularly convection control and thermal insulation.

Compared to conventional vessels, the innovative design requires no additional energy input, making it practical for widespread domestic use. The reduction in cooking time not only saves fuel but also lowers exposure to heat and smoke, which may have indirect health benefits. Additionally, reduced fuel consumption contributes to a measurable decrease in carbon emissions, supporting environmental sustainability goals.

The use of readily available steel materials ensures affordability and durability. The total material cost is approximately Rs. 860, with a retail price of Rs. 1400–1500, making it accessible to many households. The design can be fabricated by local welders, promoting grassroots manufacturing and adoption.

While the design shows promising results, further studies could evaluate long term durability, performance with different fuels (e.g., biomass, kerosene), and scalability for mass production. The present study focused on LPG; tests with other fuels would broaden applicability. Nevertheless, the discussion confirms that small innovations in household tools can create meaningful environmental and economic benefits.

# V Innovation and Novelty

The key innovations of this design are:

1. A spiral copper baffle placed between the outer and inner vessels with a bending angle of approximately 30°. This structure slows the upward movement of flame heat, allowing hot air to circulate around the inner vessel, thereby reusing waste heat and increasing thermal efficiency.
2. The design can be adapted to traditional firewood-based water heaters by welding metal pipes through the vessel to capture additional heat from the flue gases.

These modifications are simple yet effective, demonstrating that incremental changes in everyday objects can yield substantial energy savings.

# VI Design and Layout Details

## VI.a Vessel Photographs

Figure 4 shows the innovative vessel from different orientations, and Figure 5 compares the ordinary and innovative vessels on the stove.

Figure 4 presents the innovative cooking vessel in four distinct orientations to elucidate its construction and functional elements. The top view (a) reveals the concentric arrangement of the inner stainless steel vessel (diameter 17.6 cm) and the outer mild steel vessel (diameter 20 cm), with a uniform 12 mm air gap maintained by Bakelite bolts. The small outlet hole (4 mm diameter) near the rim is visible, which allows gradual release of hot air to prevent pressure buildup while minimizing heat loss. The side view (b) shows the overall height of 11 cm and the welded joint securing both vessels at the top. The copper base of the inner vessel is evident, chosen for its high thermal conductivity (385 $\mathrm{W/m \cdot K}$) to promote rapid and uniform heat distribution. The third image (c) focuses on the inner vessel with its spiral copper baffle—a 2 m long, 7 mm wide strip welded at a 30° angle around the outer surface. This baffle is the core innovation; it slows the upward flow of hot combustion gases, increasing their residence time in the annular gap and thereby enhancing convective heat transfer to the cooking surface. Finally, the assembled vessel on an oven (d) demonstrates its practical deployment: the outer shell provides structural durability while the inner vessel ensures food safety (stainless steel 304). The Bakelite insulating bolts are also visible, preventing direct heat conduction between the two vessels. Together, these orientations comprehensively illustrate how the design traps and redirects waste heat, reducing fuel consumption and carbon emissions without altering conventional cooking practices.

Figure 4: Innovative cooking vessel at different orientations.

## VI.b Bill of Materials

Table 7: Cost breakdown for one unit.

| **Item** | **Specification** | **Cost (Rs.)** |
|---|---|---|
| Inner vessel (SS304 with copper base) | 20 gauge | 300 |
| Outer vessel (mild steel) | 18 gauge | 250 |
| Baffle strip (copper) | 2m × 7mm × 1mm | 80 |
| Welding labor | Arc welding | 250 |
| Handle (bakelite) | standard | 20 |
| Total material cost | | 860 |
| Retail price per unit | | 1400–1500 |

Figure 5: Comparison of ordinary and innovative vessels during cooking.

## VI.c Vessel Dimensions

Table 8: Specifications of the innovative cooking vessel.

| **Parameter** | **Value** |
|---|---|
| Outer vessel diameter | 20 cm |
| Inner vessel diameter | 17.6 cm |
| Vessel wall thickness (both) | 1 mm |
| Vessel height | 11 cm |
| Inner vessel material | Stainless steel (food-safe) |
| Outer vessel material | Mild steel |
| Base of inner vessel | Copper |
| Baffle material | Copper (1 mm thick, 7 mm wide, 2 m long) |
| Baffle angle | 30° |
| Outlet hole diameter | 4 mm |
| Gap between vessels | 12 mm |
| Fitting bolts | Bakelite, length 2 cm |

# VII Conclusion

This study successfully demonstrates that an innovative cooking vessel design can significantly reduce fuel consumption and carbon footprint by improving heat utilization during cooking. The controlled movement of hot air within the vessel structure enhances thermal efficiency and minimizes heat loss. As a result, cooking time is reduced, and less fuel is required to achieve the desired cooking outcomes.

The proposed vessel design is simple, cost effective, and compatible with existing cooking stoves, making it suitable for widespread adoption. By addressing energy inefficiency at the household level, this innovation offers a practical solution to reducing carbon emissions without altering cooking habits or fuel sources.

The findings emphasize the importance of design based interventions in promoting sustainable living. With further refinement and testing, the innovative cooking vessel has the potential to contribute significantly to energy conservation efforts and environmental protection. This approach highlights how small technological changes can yield substantial long term benefits.

# Acknowledgments

We, Krishnamurthy L Bhat and Vibha K Bhat, express our sincere gratitude to our school for providing the necessary facilities and support to carry out this research. Appreciation is extended to the faculty members who offered guidance, technical advice, and encouragement throughout the study. Special thanks are also due to laboratory staff for their assistance in material preparation and experimental setup. We also acknowledge the support of peers and colleagues who contributed valuable feedback during the development of the cooking vessel design. During the preparation of this work, the author(s) used ChatGPT (free version) for grammar checks and language editing. The authors reviewed and edited the content and take full responsibility for the publication. No other use of AI was made.

# References

[1] International Energy Agency. *World Energy Outlook 2023*. IEA, 2023.

[2] Z. Abbas and M. Waqas. Strategy on coal consumption and ghgs emission analysis based on the leap model. *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, 46(1):10349–10368, 2024.

[3] K. K. Ibea and S. P. Kollur. Challenges towards the adoption and use of sustainable cooking methods: A comprehensive review. *Sustainable Environment*, 10(1):2362509, 2024.

[4] Energy Sector Management Assistance Program (ESMAP). *The State of Access to Modern Energy Cooking Services*. World Bank, 2020.

[5] S. K. Hannani, E. Hessari, M. Fardadi, and M. K. Jeddi. Mathematical modeling of cooking pots' thermal efficiency using a combined experimental and neural network method. *Energy*, 31(14):2633–2649, 2006.

[6] J. Smith and L. Brown. Energy efficiency in household cooking systems. *Journal of Sustainable Energy*, 8(2):112–120, 2019.

[7] R. Kumar and S. Patel. Heat transfer optimization in domestic cooking vessels. *International Journal of Applied Engineering Research*, 15(3):245–252, 2020.

[8] A. Gupta. Reducing carbon emissions through sustainable household technologies. *Environmental Science Review*, 45(1):78–85, 2021.

[9] H. Singh et al. Dissemination of sustainable cooking: A detailed review on solar cooking systems. *IOP Conference Series: Materials Science and Engineering*, 1127:012011, 2021.

[10] Z. Lew and H. C. M. Yu-Hwei. Modelling of heat transfer in different materials in cooking vessels using comsol. In *COMSOL Conference Proceedings*, 2017.

[11] Frank P. Incropera, David P. Dewitt, Theodore L. Bergman, and Adrienne S. Lavine. *Principles of Heat and Mass Transfer*. Wiley, 8 edition, 2017.

[12] William D. Callister and David G. Rethwisch. *Materials Science and Engineering: An Introduction*. Wiley, 10 edition, 2018.

[13] ASHRAE. *ASHRAE Handbook - Fundamentals*. American Society of Heating, Refrigerating and Air-Conditioning Engineers, 2017.

[14] Adrian Bejan. *Heat Transfer*. Wiley, 2003.

[15] Rob Bailis, Victor Berrueta, Chandra Chengappa, Kaushal Dutta, and Omar Masera. The water boiling test (wbt): A performance test for cookstoves. Report, Shell Foundation, 2007.

[16] Douglas C. Montgomery. *Design and Analysis of Experiments*. Wiley, 9 edition, 2017.

**Conflict of interest:** The Authors have no conflicts of interest to declare that they are relevant to the content of this article.

**About The License:** © 2026 The Author(s). This work is licensed under a Creative Commons NonCommercial 4.0 International License (CC BY-NC 4.0) which permits unrestricted use, provided the original author and source are credited.