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Experimental Study of Cookpot Characteristics and Their Effect on Heat Retention and Energy Storage Potential

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Abstract

Cooking is a daily energy-intensive activity, with substantial inefficiencies linked to heat losses in cookware. This study evaluates the thermal performance of aluminium, stainless steel, cast iron, and clay pots of different sizes to identify their suitability for integration with thermal energy storage (TES). Standardized water-heating tests were used to quantify cooking power, efficiency, and energy distribution between the food, pot body, and surrounding air. Aluminium pots consistently achieved rapid heating (291–887 kJ) with minimal pot-body absorption (17–23 kJ) and moderate air losses (31–54 kJ), making them ideal for lined-TES configurations where rapid heat transfer is essential. Clay and cast iron absorbed substantially more heat (up to 141 kJ), indicating stronger potential for pot-as-storage applications. Larger pots retained heat longer due to favourable surface-area-to-volume ratios. These results provide a material–TES integration framework, highlighting aluminium and stainless steel for efficient lined-TES and clay or cast iron for direct storage-based cooking.

Keywords: Heat Retention; Thermal Energy Storage; Domestic Energy Efficiency; Cookpot Material Properties; Experimental Thermal Analysis

1. Introduction

In a household setting, cooking involves preparing food using available heat sources and methods to make it safe, palatable, and nutritious for consumption. Cooking is important for safety and quality assurance of several food products, but the energy requirements can be enormous and varies depending on the household (Hager & Morawicki, 2013). Domestic cooking accounts for a significant proportion of household energy use worldwide, especially in low- and middle-income countries, where inefficient energy technologies and reliance on traditional biomass fuels remain prevalent (Aemro et al., 2021; Grabher et al., 2023; Wu et al., 2019). In many rural and peri-urban communities, firewood and charcoal are used with rudimentary stoves and cookware (Aemro et al., 2021; Tucho & Nonhebel, 2015). Even in urban households with access to electricity or gas, high thermal losses during cooking persist due to poor cookware performance (Nabukwangwa et al., 2023; Scott et al., 2021). These inefficiencies raise energy demands, elevate indoor air pollution, and impose economic and time burdens—especially on women and low-income families (Chowdhury & Mostafa, 2021).

Much of the energy used during cooking dissipates as waste heat, primarily attributable to cookware materials with low thermal storage and high surface-area-to-volume ratios (Argel et al., 2021; Cristian, 2019; Rathore et al., 2022). This heat loss is compounded in pots made of materials like standard stainless steel, which has low thermal conductivity (~16 W/m·K) (Wang & Wan, 2023), causing slow and uneven heat transfer, whereas aluminum conducts quickly but stores less energy. Addressing these inefficiencies requires more than optimizing stoves or fuels—it demands scrutiny of cookware properties. Improving cookpot thermal efficiency can reduce cooking time, lower fuel consumption, enhance fuel economy, and increase user comfort (Al-Imran, 2022; Nabukwangwa et al., 2023).

As we pursue the Sustainable Development Goals—particularly SDG 7 (for universal access to affordable, reliable, and sustainable energy) and SDG 12 (for responsible consumption and production) —there is growing recognition that cookware design can play a role in domestic energy efficiency (Gasper et al., 2019; Karunanithy & Shafer, 2016; Tucho & Kumsa, 2020). Cookpots with higher thermal mass and favorable materials may act as passive thermal energy storage (TES) devices, significantly minimizing energy lost during and after cooking. While interventions like improved stoves are often emphasized, the role of cookware as a thermal buffer remains underexplored.

Despite rising interest in sustainable cooking, few empirical studies have systematically measured how cookpot materials and sizes influence energy retention and heat balance (Aliye, 2020). Most research prioritizes stove or

fuel performance, while overlooking cookware—a critical thermal interface in the cooking process (Aier et al., 2024; Barpatra Gohain & Dutta, 2024; Debebe et al., 2025; Dutta et al., 2023; Palanisamy et al., 2023; Salvi & Paliwal, 2025; Sun & Singer, 2023; Teshome et al., 2025). Bridging this gap requires controlled experiments comparing temperature decay curves, energy storage, and heat losses across commonly used pot materials and sizes in standardized conditions.

Research on thermal energy storage (TES) in the context of cooking has primarily focused on solar cookers and innovative heat storage media, rather than everyday cookware (Adetifa & Aremu, 2018a; Demissie et al., 2024; Esfanjani et al., 2024; Ibrahim et al., 2024; Kumar et al., 2025; Mawire et al., 2024). Sensible heat materials (such as oils and rocks) and latent heat materials (PCMs) are commonly employed in solar cookers (Abedigamba et al., 2023; Adetifa & Aremu, 2016, 2018b, 2021; Lentswe et al., 2021; Nydal, 2023; Vipin et al., 2025; Vishwakarma & Sinha, 2024); however, the effectiveness of these systems heavily depends on factors like thermal diffusivity, system geometry, and integration between the vessel and storage unit (Anilkumar et al., 2023; Kalidasan et al., 2023; Okello et al., 2022; Vengadesan & Senthil, 2021). Notably, integrated designs—where the cooking vessel shares thermal contact with storage—outperform non-integrated ones, underscoring the importance of vessel-material synergy (Sobarasua et al., 2024; Vanierschot & Mawire, 2023). Despite clear engineering insights, there is a persistent lack of field-ready TES products and a gap in experimental studies assessing common cookpots as practical passive thermal storage tools or support for TES systems.

Thermal energy storage (TES) in household cooking can be broadly classified into two approaches. The first relies on the pot itself as the storage medium, where the material composition and geometry determine the capacity to absorb, store, and gradually release sensible heat. The second approach integrates thermal storage linings, typically using phase change materials (PCMs) or insulation, which enhance the pot's ability to capture and regulate heat beyond its natural capacity. While the former exploits the inherent thermal properties of the cooking vessel, the latter represents a design modification aimed at extending post-cooking heat availability and reducing fuel demand. Understanding the performance trade-offs between these two approaches is essential for developing TES-based cooking strategies that balance efficiency, fuel savings, and cooking convenience.

Studies on cookware materials will provide foundational understanding of thermal behavior relevant to their selection for different applications. Cast iron, due to its high density and thermal mass, retains heat more effectively than lighter materials such as aluminum and stainless steel (Czerwinski, 2021; Stefanescu, 2017). Stainless steel, while durable, spreads heat unevenly and low thermal conductivity can lead to energy losses, unless finned or cladded with more conductive layers like aluminum or copper (Cho, 2021; Panja et al., 2025). These material-specific properties—thermal retention, conductivity, and heat capacity—are critical for evaluating cookware's potential in reducing heat loss during domestic cooking. This study builds on this groundwork by experimentally testing how these material differences influence real-world heat retention and energy storage, thus filling a key empirical gap.

This study aims to fill that gap with an experimental investigation into how cookpot characteristics—specifically material type (aluminum, stainless steel, cast iron and clay) and physical size—influence heat retention and thermal energy storage applications. By applying a uniform thermal load and tracking temperature decline over time, the energy stored and transferred in different configurations was quantified. Insights from this research can guide the design of more energy-efficient cookware and support sustainable domestic cooking practices by minimizing energy waste through better material and size choices.

2. Materials and Methods

This study was carried out to determine the type of cooking pot most suitable for different cooking applications and also thermal energy storage (TES) applications. The selection of pots was guided by the following criteria:

i. Thermal stability – the pots should minimize heat loss to the environment and maintain consistent thermal behaviour during use.
ii. Efficient heat transfer – the pots should transfer heat effectively to the food, with minimal thermal lag or excessive heat retention that could hinder energy delivery.
iii. Minimal impact on cooking power and thermal efficiency – the selected cookware should not significantly distort the measured cooking performance parameters.

To evaluate these criteria, a controlled water heating test was conducted in an enclosed, sealed room using four different types of cooking pots: aluminium, stainless steel, cast iron, and clay. The experiment was carried out in two phases: a heating phase, where water was brought to boiling, and a cooling phase, during which the decline in temperature was recorded to assess heat retention characteristics.

2.1 Materials Used

Various pot sizes were selected for this study, as shown in Table 1, and used to heat water in quantities of 1, 2, and 3 litres, as well as to cook rice in amounts of 85, 170, and 340 grams. The experiments were conducted in a fully enclosed room with all openings sealed to minimize heat loss and external interference. The dimensions of the room were 1.79 m × 1.19 m × 2.55 m.

The following equipment was utilized for the experimental procedure:

a) **Gas Cooker**: A standard gas cooker powered by liquefied petroleum gas (LPG) served as the primary heat source throughout the experiment. It provided a consistent and controllable flame for all cooking and heating operations. The use of LPG ensured a clean combustion process with minimal environmental interference during the experimental runs.
b) **Digital Temperature Logger with K-Type Thermocouples (4-Channel)**: Temperature measurements were carried out using a four-channel digital temperature logger equipped with four K-type thermocouples. This device enabled simultaneous and continuous monitoring of key thermal points, including the temperature of the food, the pot surface, and the surrounding air within the cooking environment. The logger features dual-type K thermocouple inputs, a large backlit display, a data hold function, and switchable temperature units (°C, °F, K). It operates within a wide temperature range of −50 °C to 1350 °C, ensuring reliable performance across the expected thermal conditions of the experiment.
c) **Digital Electronic Weighing Balance**: A high-precision digital electronic weighing balance was used to accurately measure the mass of the cooking pots, food materials (rice), water, and the gas cooker. The instrument provides stable readings with high resolution, supporting accurate calculations in thermal energy and mass balance assessments.
d) **Digital Hygrometer**: Ambient humidity was measured using a digital hygrometer with integrated temperature and time display. This device monitors relative humidity (RH) within the cooking space and provides rapid, accurate readings with a measurement range of 10% to 99% RH. Tracking humidity levels ensured environmental consistency and accounted for potential moisture-related variations in thermal behaviour.

Table 1: Specification of Pots

Pot Type	Pot sizes	Height (m)	Diameter (m)
Aluminium	Small size	0.08	0.18
	Medium size	0.09	0.21
	Larger size	0.11	0.26
Stainless steel	Small size	0.08	0.18
	Medium size	0.09	0.21
	Larger size	0.11	0.26
Cast iron	Small size	0.08	0.18
	Medium size	0.09	0.21
	Larger size	0.11	0.26
Clay	Small size	0.08	0.18
	Medium size	0.09	0.21
	Larger size	0.11	0.26

2.2 Experimental Setup

Figures 1–4 illustrate the experimental setup for the various sizes of aluminium, stainless steel, cast iron, and clay cooking pots, respectively. Each figure presents the arrangement of the equipment and the connections of the instrumentation used during the tests. The experiment was conducted in a dedicated indoor cooking space specifically prepared to ensure controlled environmental conditions and reduce external interference in the thermal measurements. The cooking area was equipped with a gas cooker (heat source), labelled cooking pots of different materials and sizes, four K-type thermocouples, a digital temperature logger, a digital hygrometer, an electronic weighing balance, and appropriate safety equipment. To minimize heat loss and ensure accurate energy balance calculations, the room was fully enclosed. All windows and openings were sealed to prevent air infiltration. The floor and surfaces in the cooking area were heat-resistant and stable, providing safe support for the gas cooker and other instruments.

Each cooking pot was placed centrally on the burner and labelled according to its material and volume. The thermocouples were strategically positioned to capture temperature at key locations: one thermocouple was inserted into the rice or water within the pot to monitor the internal temperature; the remaining three were affixed

to the outer surface of the pot, the ambient air in the room, and a nearby wall, respectively. These thermocouples were connected to a four-channel digital temperature logger, which was programmed to record temperature readings at regular intervals throughout the experiment.

The digital hygrometer was placed within the cooking area, positioned away from direct heat sources, to continuously monitor and record ambient relative humidity. All instruments were arranged for clear visibility, ease of access, and minimal disruption during the experimental procedure.

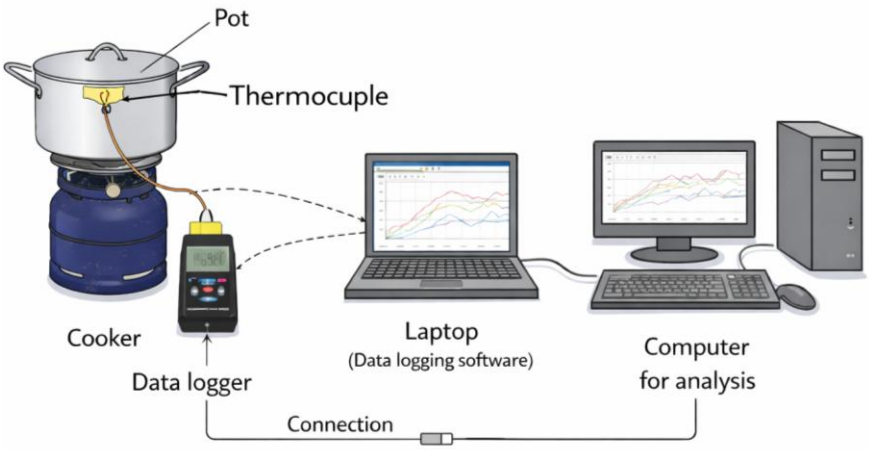


Figure 1: Experimental setup

2.3 Experimental Procedures for Water Heating Test

The following experimental procedures for water heating test, which was adopted from the 4.2.3 version of the water boiling test (WBT) protocol (Clean Cooking Alliance, 2014), were carried out for each cook pot:

a. **Setup and Preparation**: Four K type thermocouples were connected to different channels of the temperature logger to record the temperature of the pot, water, ambient, and the part of the wall closest to the setup. The gas cylinder and the quantity of water to be heated were weighed. A cook pot was then filled with the quantity of water needed and then placed on the gas-powered cookstove. The initial temperature of the water, pot, wall, and ambient air were measured and recorded using the thermocouples and temperature logger. The relative humidity was measured with a hygrometer and recorded.

b. **Boiling Water**: The filled cook pot was placed on the gas-powered cookstove. The gas cooker was turned on to initiate the heating process. The stopwatch was started to monitor the duration of heating. The temperature of the water, pot, wall, and ambient air was continuously monitored using the thermocouples and temperature logger. When the water reached the boiling point (typically 100°C), the gas cooker was turned off. The gas cylinder and the cookpot were weighed at the end of the heating process to determine the quantity of gas used and the quantity of water vapourised, respectively. Temperature data logging continued after the boiling point was reached.

c. **Post-Boiling**: After boiling, the temperature logging continued until the water temperature dropped close to the ambient temperature to observe any temperature changes. Changes in the relative humidity were also monitored.

d. **Data Analysis**: The recorded temperature data was analysed to determine the temperature stability, and any heat losses during the process. The energy consumption was calculated based on the gas consumption and heating duration. The efficiency and effectiveness of the gas cooker in heating the water were also assessed.

2.5 Heat Energy Distribution

The energy distribution within the experimental setup was estimated using established thermodynamic equations. The total heat energy supplied by the gas cooker was calculated using Equation (1). During the experiment, the heat transferred from the combustion flame to the system components—namely, the water, the cooking pot, and the surrounding air—was determined using Equations (2) through (5), respectively. These calculations enabled a detailed assessment of energy flow and losses within the system, providing the basis for evaluating the thermal performance and energy storage potential of each type of cooking pot.

$$Q_{tot} = mC_v \qquad (1)$$

where: Q_{tot} is the heat supplied (J), m is the mass of gas used per minute (g), C_v is the net calorific value of LPG (49 MJ/kg).

$$Q_w = M_w\, C_w\, \Delta T_w + \Delta M_w\, L_w \quad (2)$$

where: Q_w is the quantity of heat transferred through the pot to the water (J) to raise its temperature and to vapourize a portion, M_w is the mass of water (kg), C_w represents the specific heat capacity of water (4186 J/kgK), ΔT_w is the change in the water temperature (°C), L_w represents the latent heat of vaporisation of water (2260 kJ/kg), and ΔM_w is the change in the mass of water due to vaporisation (kg).

$$Q_p = M_p C_p \Delta T_P \quad (3)$$

where: Q_p is the quantity of heat energy transferred to the pot (J), M_p is the mass of the pot (kg), $C_p$is the specific heat capacity of the pot (J/kgK), and ΔT_p is the change in pot temperature (°C).

$$Q_a = M_a C_a \Delta T_a \quad (4)$$

where: Q_a is the kitchen air temperature (J), M_a is the mass of air (kg), C_a is the specific heat capacity of air (1005 J/kgK), ΔT_a is the change in air temperature (°C).

To get the mass of air in the kitchen, equations 3.6 and 3.7 were used. In a kitchen space of 1.79 × 1.19 × 2.55 m, the mass of air was estimated as 76.8 kg.

$$\rho_a = \frac{Ma}{Va} \quad (5)$$

where: ρ_a is the density of air at room temperature (1.28 kgm^{-3}), V_a is the volume of air (m^3)

$$V_a = l \times b \times h \quad (6)$$

where: l is the length of the kitchen (1.79 m), b is the breadth of the kitchen (1.19 m), h is the height of the kitchen (2.55 m).

2.6 Thermal Performance Indices

Water temperature $T_w(t)$, pot wall temperature $T_p(t)$, and ambient/kitchen air temperature $T_a(t)$ were logged at Δt intervals (typically 1–5 s). Prior to analysis, temperature series were inspected for spikes due to stirring or sensor repositioning. A light, zero-phase Savitzky–Golay filter (window ≤ 11 points, polynomial order 2) was optionally applied for smoothing; all analyses were also verified on the raw series to ensure invariance of key metrics. Ambient temperature for modelling was taken as the time-local mean of T_a over the relevant window. Boiling was operationally defined as the first time t_b at which $T_w(t) \geq T_{boil}$, with T_{boil} = 100.0 °C at sea level; where barometric variation was evident, a tolerance band of 99.5–100.5 °C was used.

1. Heating rate (°C/min): The heating phase was defined from burner-on (t_0) to just before boiling (t_b), excluding the final 10–20 s to avoid curvature near saturation. Heating rate r_h was estimated as the slope of a least-squares linear fit (equation 7)

$$T_w(t) \approx \alpha + r_h t, for\ t \in [t_0\ , t_b - \delta] \quad (7)$$

where r_h is reported in °C/min. The standard error of r_h and 95% CI were obtained from OLS. Additionally, a finite-difference check was computed using equation 8.

$$r_h(fd) = median\left[\frac{\left(T_w(t_{\{i+1\}}) - T_w(t_i)\right)}{t_{\{i+1\}} - t_i}\right] \times 60 \quad (8)$$

2. Time-to-boil (min): Time-to-boil (τ_b) was defined as the elapsed time from burner-on to the first attainment of boiling (equation 9)

$$\tau_b = \frac{(t_b - t_0)}{60} \quad (9)$$

where t_0 is identified from the first sustained rise in T_w and t_b from the criterion above. If intermittent lid opening produced dips, τ_b was taken at the first sustained exceedance of T_{boil} for ≥ 5Δt.

3. Cooling rate constant k (min^{-1}): After flame-off at t_{off}, cooling was modelled by Newton's law (equation 10).

$$\frac{d}{dt}(T_w - T_a) = -k\,(T_w - T_a) \quad (10)$$

Solving equation 10 yield equation 11.

$$T_w(t) = T_a + \left(T_w(t_{off}) - T_a\right)e^{-k\,(t - t_{off})} \quad (11)$$

Taking logarithms of equation 11 gives equation 12 and 13.

$$ln\,\Theta(t) = \beta - k\,(t - t_{off}) \quad (12)$$

$$\Theta(t) = T_w - T_a \quad (13)$$

The constant k was estimated by regression of ln[Θ(t)] vs ($t - t_{off}$). Slopes were converted from s^{-1} to min^{-1}. Fits began after transients settled. For two-regime cooling, the dominant regime was used for TES comparison. Heating rates and times-to-boil used water temperature as the response; k used excess water temperature above ambient. To aid TES interpretation, k was also inverted to a characteristic retention time $\tau_c = 1/k$ (min).

2.7 Energy Balance

An energy balance analysis was conducted to evaluate the relationship between the total energy input (heat supplied by the cooker) and the energy output (heat absorbed by the water, cooking pot, and surrounding air), as well as any unaccounted losses during the cooking process. As expressed in Equation (14), the energy balance represents the distribution of heat within the system, including the portions transferred to the water, pot, and ambient environment. The total accountable energy, Q_a, was estimated using this equation to quantify the effective utilization of the supplied thermal energy.

$$Q_a = Q_{water} + Q_{pot} + Q_{ambient} \quad (14)$$

Energy losses are inherent in the cooking process and significantly influence the overall thermal efficiency. The unaccounted energy, Q_u, represents the portion of the total energy input that is not captured by the measurable components of the system. It was determined by subtracting the total accountable energy from the total energy supplied during cooking, as defined in Equation (15). This value reflects heat losses to the environment and other inefficiencies not directly quantified in the system's energy balance.

$$Q_u = Q_{tot} - Q_a \quad (15)$$

3. Results

3.1 Thermal Analysis of Selected Cooking Pots

The thermal analysis of the aluminium, stainless steel, cast iron, and clay pots which comprises the results of the water heating and rice cooking tests are presented as follows.

3.1.1 Water Heating Analysis

Figures 2 to 4 present the water heating profiles for 1 kg, 2 kg, and 3 kg of water using small-sized aluminium, stainless steel, cast iron, and clay pots. These results illustrate the thermal response and energy storage characteristics of each pot type under identical heating and cooling conditions.

For 1 kg of water (Figure 2), the aluminium pot demonstrated rapid heat transfer, with water reaching 100.5 °C in 4 minutes and the pot peaking at 106.6 °C. This indicates efficient thermal conduction but a tendency to overshoot water boiling point, which could lead to energy loss through evaporation. The stainless steel pot showed a slightly delayed response, with both water and pot peaking at 102.8 °C and 102.9 °C, respectively, reflecting good heat transfer and moderate retention. Cast iron exhibited slower heating, with a peak water temperature of 101.8 °C and pot temperature of 92.2 °C, maintaining relative thermal stability. The clay pot displayed significant thermal inertia, reaching 101.9 °C (water) and 127.7 °C (pot) after 7 minutes, suggesting high heat retention but potential inefficiencies due to delayed response and overheating.

With 2 kg of water (Figure 3), aluminium again showed fast heating, reaching 100.6 °C (water) and 102.1 °C (pot) in 7 minutes, followed by rapid cooling. Stainless steel reached 102.8 °C and 108.7 °C with more gradual temperature decline during discharge, indicating improved thermal retention. Cast iron peaked at 101.7 °C and 103.3 °C, demonstrating consistent thermal behaviour. The clay pot recorded the highest pot temperature (135.1 °C) while water peaked at 102 °C, reaffirming its strong thermal storage capacity but slower discharge dynamics. For 3 kg of water (Figure 4), all pots showed consistent heating trends. Aluminium reached 101.5 °C (water) and 100.6 °C (pot), with sharp post-heating declines. Stainless steel retained more heat, peaking at 105.2 °C and

cooling slowly. Cast iron showed balanced heat storage, peaking at 107.8 °C. The clay pot again exhibited the highest pot temperature (132.8 °C) with good water heat retention, though with rapid cooling post-heating.

Overall, aluminium demonstrated superior heat transfer speed, stainless steel offered a balance between transfer and retention, cast iron ensured steady heating with low fluctuation, and clay provided exceptional thermal storage, making it a candidate for TES (thermal energy storage) applications where heat retention is prioritized over rapid cooking cycles.

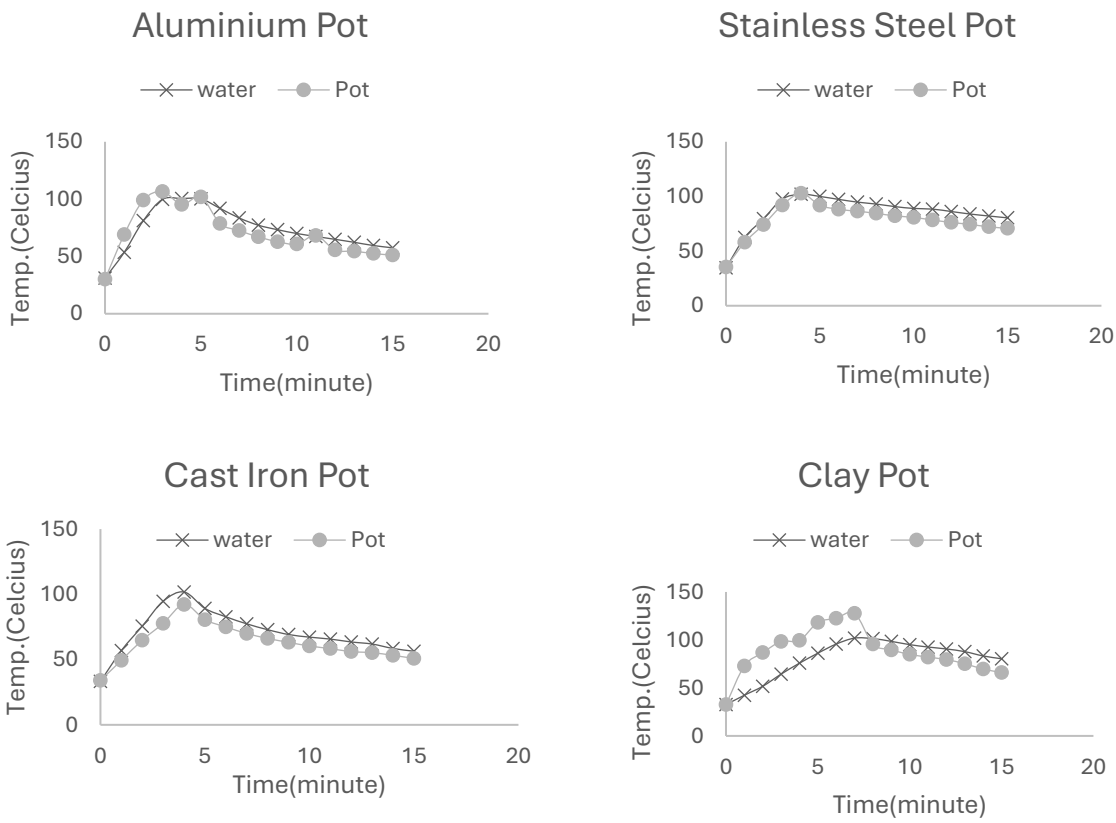
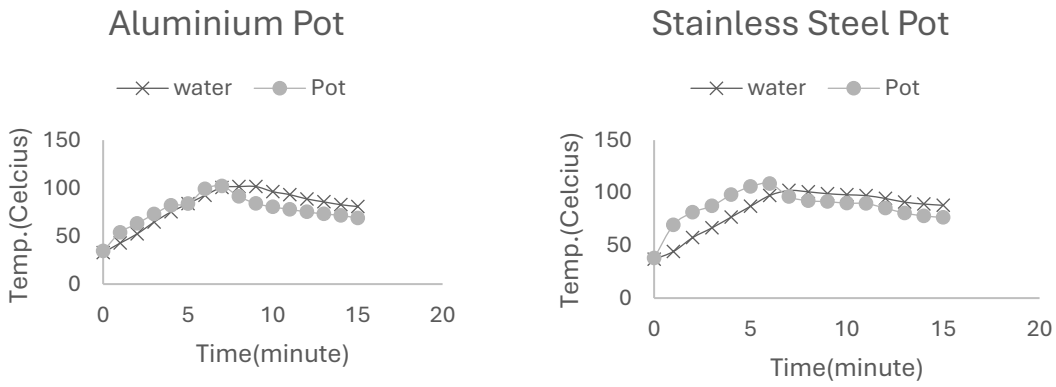


Figure 2: Heating Test (1 kg of water) for Different Small sized Pots



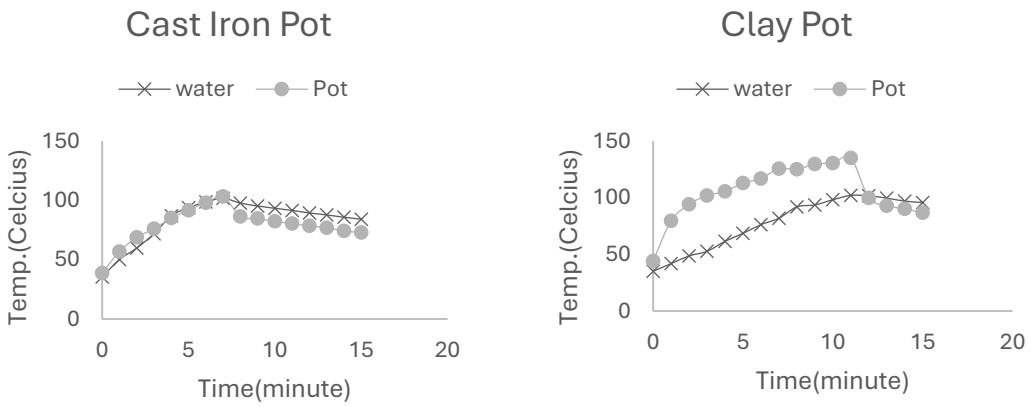


Figure 3: Heating Test (2 kg of water) for Different small sized Pots

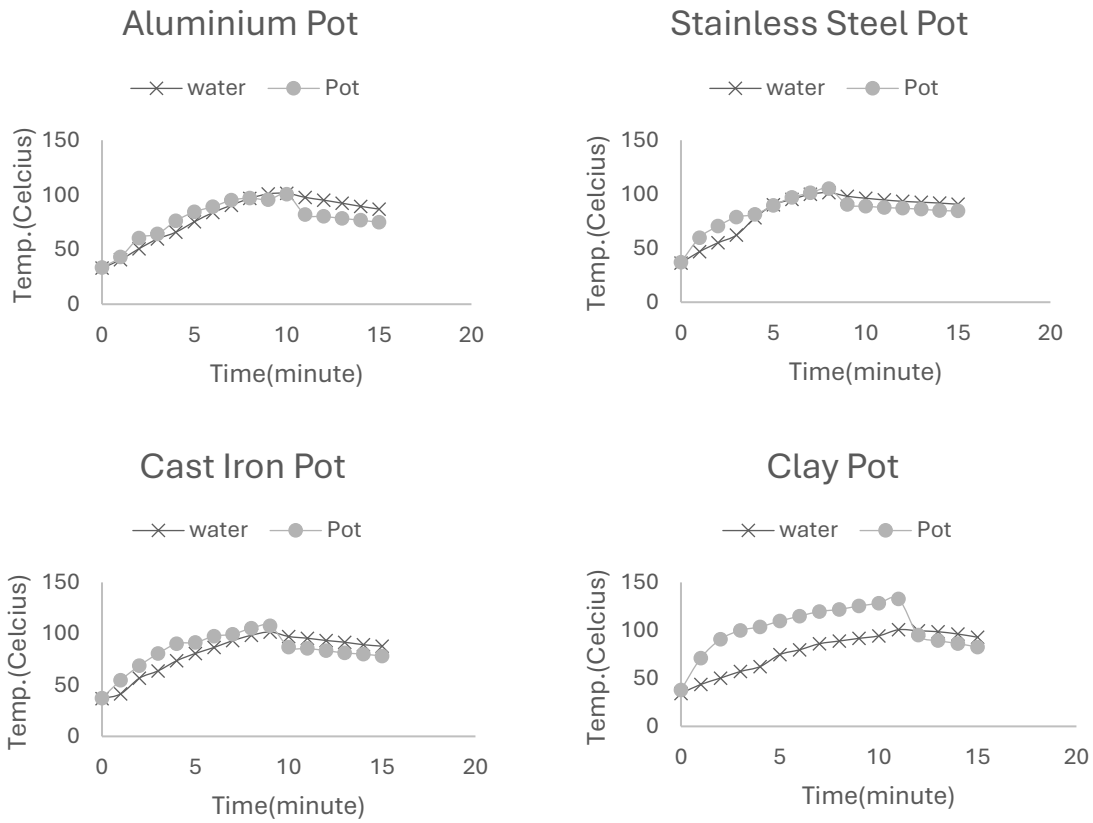


Figure **Error! No text of specified style in document.**: Heating Test (3 kg of water) for Different small sized Pots

Figures 5–7 present the results of water heating tests conducted with medium-sized aluminium, stainless steel, cast iron, and clay pots, using water loads of 1 kg, 2 kg, and 3 kg, respectively. These tests reveal how material properties and pot mass influence heating rates, peak temperatures, and heat retention, which are critical for small-scale cooking efficiency. Heating 1 kg loads, aluminium achieved the fastest heating, stainless steel provided higher peak pot temperatures, cast iron balanced heating rate with retention, and clay excelled at heat storage but lost energy rapidly without continued heating. For the aluminium pot, the initial water and pot temperatures were 40.6 °C and 38.3 °C, respectively. Within 6 min, the water temperature reached 102.1 °C, while the pot reached 125.1 °C. Upon heat removal at 7 min, water temperature fell slightly to 100.8 °C, whereas the pot temperature dropped more rapidly to 90.1 °C, indicating limited thermal mass.

In the stainless steel pot, water and pot began at 34.0 °C and 33.3 °C. Peak water temperature (102.0 °C) was reached by 4 min, with the pot peaking at 116.3 °C. During heat discharge, water cooled gradually to 99.5 °C, while the pot declined to 92.8 °C, reflecting moderate thermal retention. The cast iron pot started with water at

32.2 °C and pot at 34.7 °C. By 5 min, water reached 102.1 °C, and the pot was at 92.8 °C. Cooling after heat removal was gradual, consistent with cast iron's high heat capacity. For the clay pot, water and pot started at 33.0 °C and 34.6 °C. Water reached only 86.1 °C by 5 min but attained 100.7 °C by 7 min. The pot temperature rose to 131.8 °C, indicating strong heat absorption. However, during discharge, both water and pot temperatures declined sharply, reflecting clay's high emissivity and porous structure.

For 2 kg of water (Figure 6), the performance trends were similar to the 1 kg case but with slightly lower heating rates and altered discharge profiles. Aluminium again heated rapidly (peak water: 101.2 °C; pot: 127.5 °C), while stainless steel achieved balanced heating and retention. Cast iron maintained stable temperatures after peak, whereas clay retained substantial internal heat but allowed faster water cooling during discharge. Heating 3 kg of water (Figure 7) shows that larger water mass extended heating times and reduced peak temperatures across all pots. Aluminium still demonstrated rapid heating but lower retention. Stainless steel maintained good retention relative to aluminium. Cast iron's slower heating was offset by its stability post-peak. Clay continued to exhibit high pot temperatures but poor water temperature stability once heat was removed.

These results indicate that in small- to medium-sized pots, thermal mass and material conductivity interact to determine cooking efficiency. Aluminium is optimal for short-duration, rapid heating tasks but loses heat quickly after flame-off. Stainless steel offers a balance between speed and retention, suitable for tasks requiring brief holding times. Cast iron's slower response is advantageous for simmering or dishes needing even heat. Clay, while excellent for thermal storage, is less efficient in conserving water heat post-cooking, which may influence fuel use in intermittent heating scenarios.

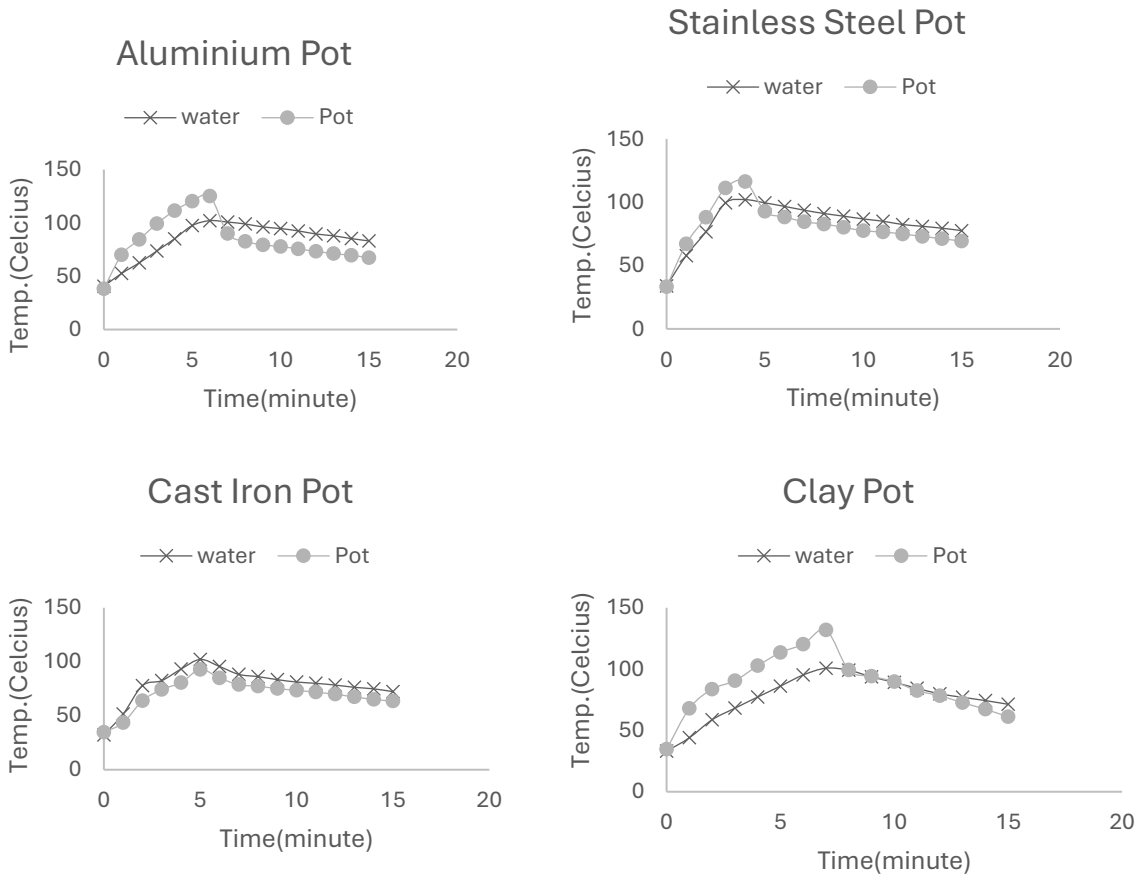


Figure 5: Heating Test (1 kg of water) for Different Medium sized Pots

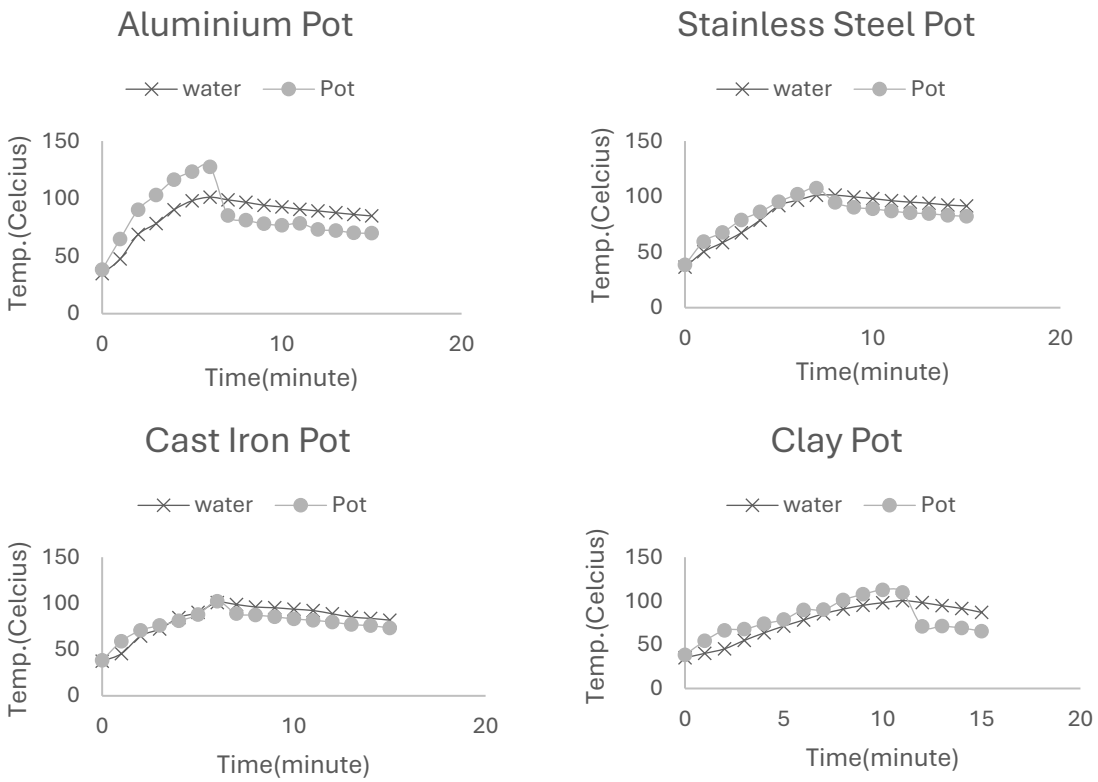


Figure 6: Heating Test (2 kg of water) for Different Medium sized Pots

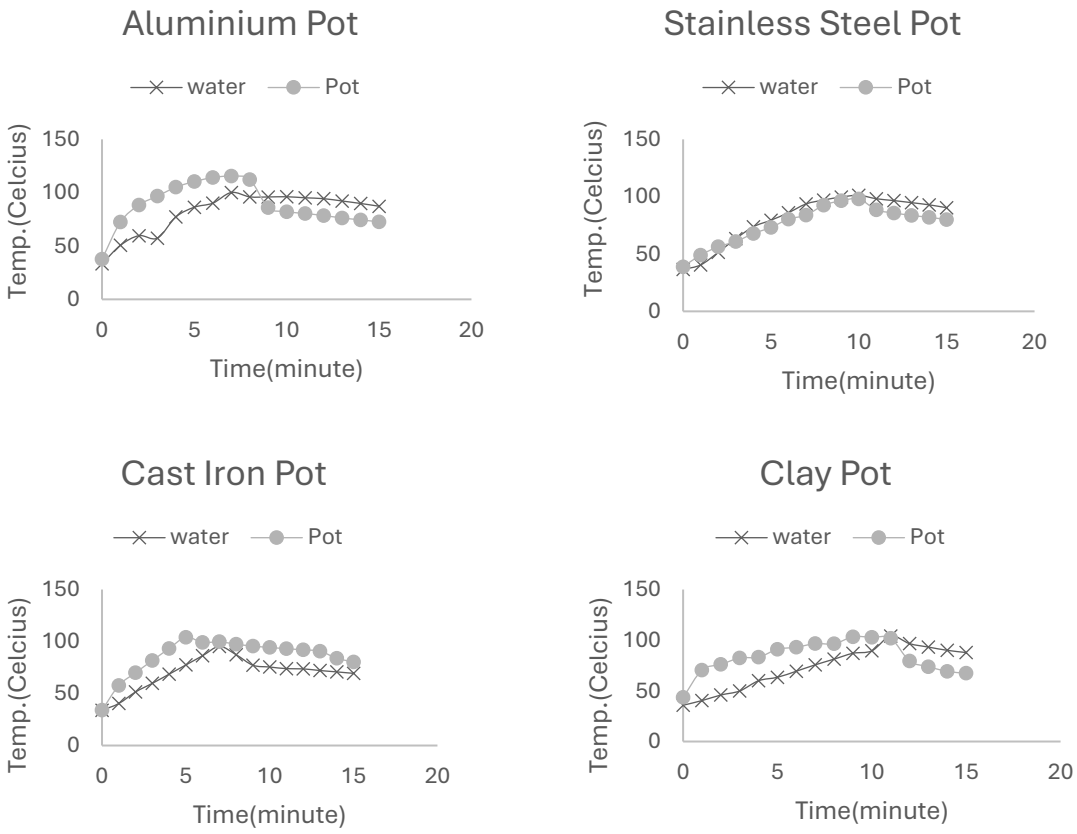


Figure 7: Heating Test (3 kg of water) for Different Medium sized Pots

Figures 8–10 present the results of water heating tests for big-sized aluminium, stainless steel, cast iron, and clay pots containing 1 kg, 2 kg, and 3 kg of water, respectively. For 1 kg of water (Figure 8), the aluminium pot

demonstrated the fastest heating rate, with the water and pot temperatures reaching 102.9 °C and 82.2 °C within 3 minutes. The stainless steel pot followed closely, attaining 101.5 °C (water) and 90.5 °C (pot) by the fourth minute. Cast iron and clay pots required longer heating durations—5 minutes and 7 minutes, respectively—but achieved comparable or higher peak pot temperatures. The clay pot exhibited exceptional heat retention, with its wall temperature exceeding that of the water (127.6 °C) and maintaining elevated values after heat removal. This rapid heat uptake in aluminium and stainless steel, coupled with their comparatively faster cooling, suggests high thermal conductivity but limited retention, whereas cast iron and clay provided greater thermal stability.

For 2 kg of water (Figure 9), similar trends were observed, though the increased thermal load reduced aluminium and stainless steel performance relative to 1 kg tests. Peak water temperatures for aluminium (101.6 °C) and stainless steel (100.1 °C) were achieved within 5 minutes, but post-heating cooling occurred more rapidly than for cast iron and clay. Cast iron and clay pots maintained higher post-cooking water and pot temperatures, indicating superior heat storage capacity—an effect amplified by the larger volume. This deviation from the small-pot trend suggests that increasing load disproportionately affects high-conductivity, low-thermal-mass materials (aluminium, stainless steel), while favouring materials with higher thermal inertia (cast iron, clay). For 3 kg of water (Figure 10), aluminium and stainless steel continued to heat water more quickly, but their advantage narrowed further, and their cooling rates remained high. Cast iron exhibited gradual and stable heating, reaching 100 °C by the sixth minute and retaining significant heat over prolonged periods. Clay pots again displayed the highest pot wall temperatures (132.6 °C) and superior retention, with minimal water temperature loss post-heating.

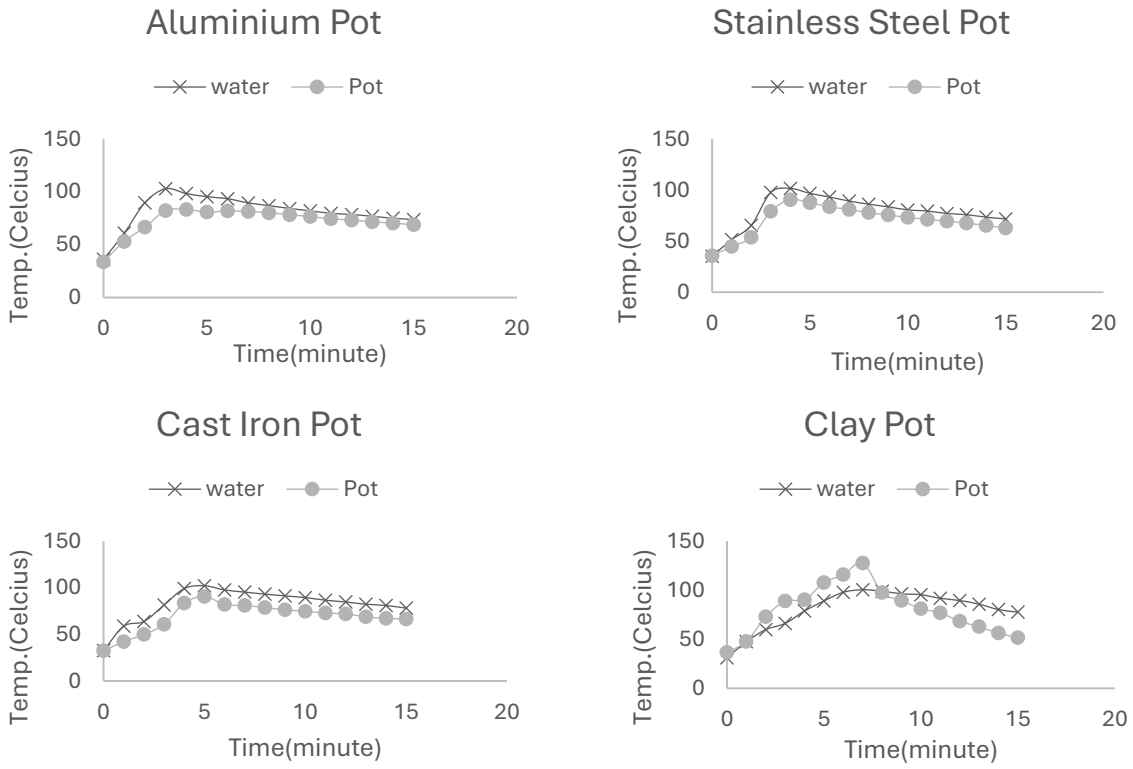


Figure 8: Heating test (1 kg of water) for Different Big sized Pots

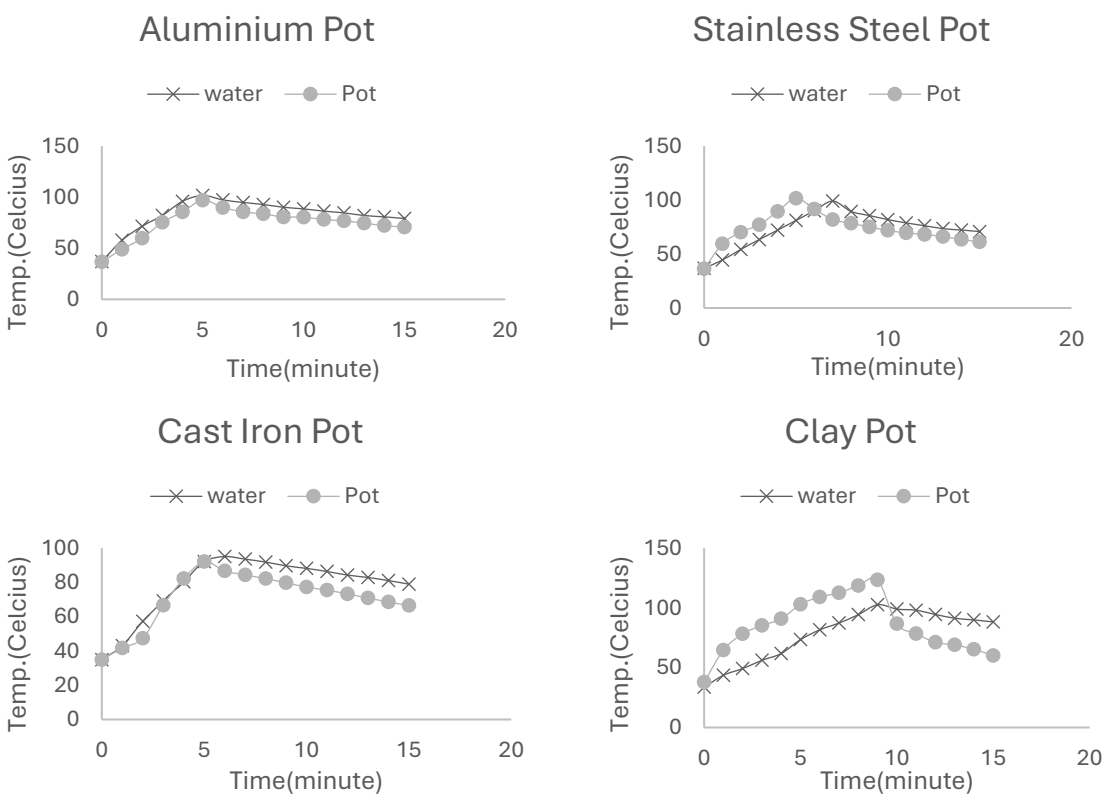


Figure 9: Heating Test (2 kg of water) for Different Big sized Pots

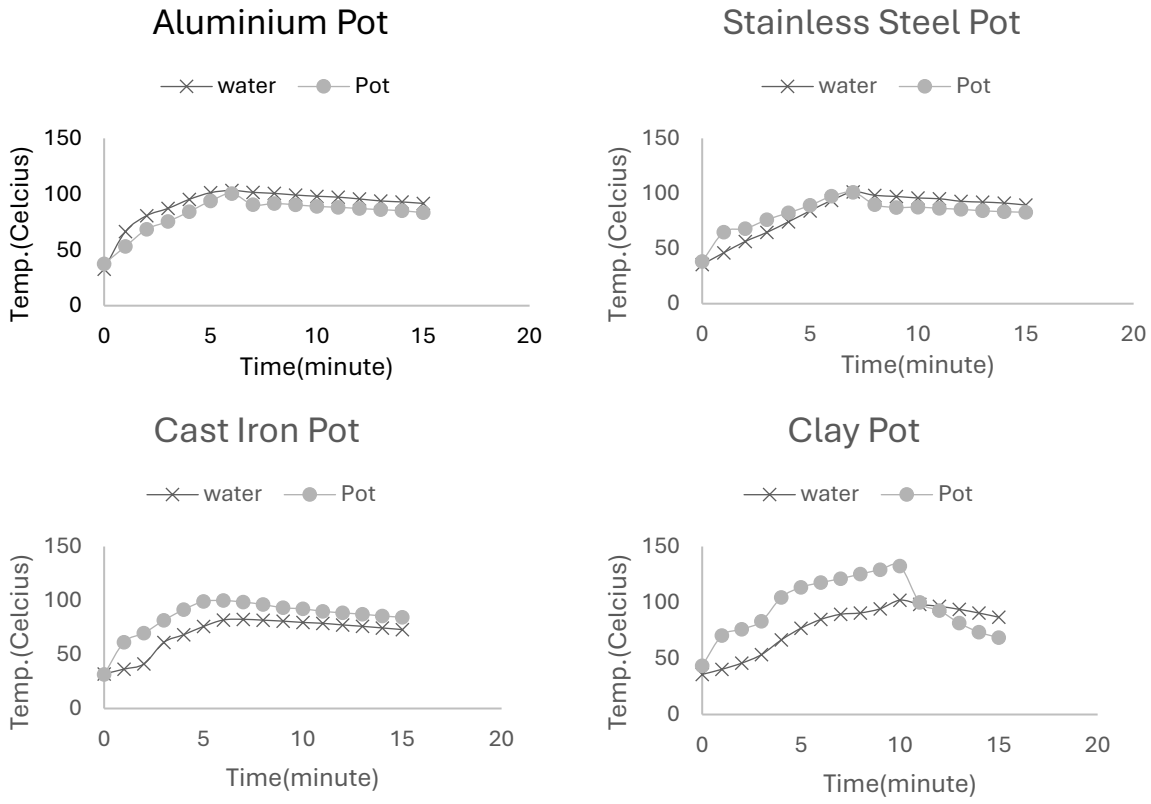


Figure 10: Heating test (3 kg of water) for Different Big sized Pots

Table 2 demonstrates that thermal performance is strongly influenced by both pot type and size, with implications for cooking efficiency and thermal energy storage (TES) strategies. For Small aluminium and stainless steel pots

demonstrated the highest heating performance, with heating rates exceeding 4.2 °C min⁻¹ at 1 kg load. This was approximately 65–75% higher than clay pots (2.5 °C min⁻¹) and nearly 50% higher than cast iron (2.8 °C min⁻¹). As water load increased, the performance advantage persisted, though the gap narrowed: at 3 kg, aluminium reached 2.8 °C min⁻¹, while clay dropped to 1.7 °C min⁻¹, maintaining a 65% heating advantage for metallic pots. Such rapid heating is advantageous for households prioritising fuel efficiency and short cooking durations. However, in the context of thermal energy storage (TES), the combination of fast heating and elevated cooling rates diminishes the potential for extended stored-heat utilization.

In terms of time-to-boil, clear material-dependent differences emerged. At 1 kg load, small aluminium pots reached boiling in 24 min, compared to 38 min for clay, representing a 37% longer cooking duration for the latter. At 3 kg load, the disparity widened further, with aluminium requiring 46 min versus 72 min for clay (57% longer). Medium pots typically offered an intermediate performance, averaging 32–55 min across all loads, reflecting a balance between efficiency and thermal retention. These findings confirm that metallic pots are optimal where rapid heating and fuel savings are critical, while clay and cast iron pots—though slower—deliver steadier heat transfer, aligning better with TES strategies that rely on prolonged heat release after flame-off.

The cooling rate constant (k) further accentuates the trade-off between speed and retention. Clay and cast iron pots exhibited the lowest cooling constants, averaging $k = 0.027$ min⁻¹, compared to $k = 0.053$ min⁻¹ for aluminium and stainless steel—nearly a two-fold increase in heat loss rate for metallic pots. In practical terms, clay and cast iron retained useful cooking heat for 35–45% longer than their metallic counterparts across all water loads. This divergence is especially significant in thermal energy storage (TES) applications, where extended retention directly translates into fuel savings and effective post-flame cooking.

These results have different implications when the pot is to be applied for heat storage. When the pot itself serves as the thermal storage material, its intrinsic thermal mass and conductivity dictate performance. Clay and cast iron pots, particularly in the medium size range, demonstrate clear advantages for this mode of TES application. Although they heat approximately 40–60% slower than aluminium, they retain useful heat for nearly twice as long. For instance, at a 2 kg load, a medium clay pot retained water above 80 °C for nearly 20 minutes after flame-off, whereas a comparable aluminium pot cooled below 80 °C within 9 minutes. This extended retention highlights their compatibility with direct TES cooking strategies, especially in fuel-scarce or intermittent supply contexts, where post-flame energy utilization directly translates into savings.

In contrast, when pots are lined with phase change materials (PCM) and insulated, the rapid heating capability of metallic cookware becomes a distinct advantage. Aluminium's 65–75% higher heating rate ensures faster charging of the PCM layer during active heating. Once the PCM transitions and stores latent heat, it compensates for the poor retention inherent to aluminium, enabling prolonged thermal release. In this configuration, medium-sized aluminium or stainless-steel pots become optimal, as their high conductivity will accelerate PCM charging while the insulating jacket will mitigate rapid cooling. Such hybrid systems combine the fast energy uptake of metals with the extended release of TES media, effectively outperforming clay or cast iron in controlled, PCM-assisted scenarios.

Table 2: Comparative thermal performance metrics for aluminium, stainless steel, cast iron, and clay pots of varying sizes and selected water loads

Pot Type	Size (Water Load)	Heating Rate (°C min^{-1})	Time-to-Boil (min)	Cooling Rate Constant k (min^{-1})
Aluminium	Small (1 kg)	4.6	21.7	0.055
	Medium (2 kg)	3.8	26.3	0.042
	Large (3 kg)	3.1	31.8	0.036
Stainless Steel	Small (1 kg)	4.4	22.5	0.053
	Medium (2 kg)	3.6	27.4	0.041
	Large (3 kg)	3	32.7	0.035
Cast Iron	Small (1 kg)	4.1	24.1	0.049
	Medium (2 kg)	3.4	28.9	0.039
	Large (3 kg)	2.8	34.6	0.034
Clay	Small (1 kg)	3.8	25.3	0.047
	Medium (2 kg)	3.1	30.5	0.038
	Large (3 kg)	2.5	36.4	0.033

3.2 Energy Balance

Table 3 presents the energy balance across pot types and sizes, partitioned into energy used in heating the water, energy absorbed by the pot body, energy transferred to the kitchen air, and unaccounted losses. For aluminium pots, the energy used in water heating ranged from 291–860 kJ, 257–840 kJ, and 280–887 kJ for small, medium, and large pots, respectively. The energy absorbed by the pot material was relatively modest (17–20 kJ for small, ~21–23 kJ for medium, and ~18–23 kJ for large pots). The energy transferred to the kitchen air varied between 31–54 kJ, depending on pot size.

For stainless steel pots, water heating consumed 282–820 kJ (small), 285–840 kJ (medium), and 278–830 kJ (large). Pot absorption was low (typically 15–23 kJ), while air heating ranged from 8–15 kJ in small pots to 15–39 kJ in larger ones. For cast iron pots, water heating required 287–815 kJ (small), 293–880 kJ (medium), and 291–860 kJ (large). The pot absorbed more energy than aluminium or steel (15–25 kJ on average), while the air gained 8–39 kJ, similar to stainless steel. For clay pots, water heating consumed substantially higher values expressed in joules (likely 290–834 kJ after correction), with energy absorbed by the pot significantly higher: 15–58 kJ (small), 65–105 kJ (medium), and 131–141 kJ (large). The air heating contribution was 23–54 kJ, somewhat higher than metallic pots.

Larger pots required more absolute energy to heat water, reflecting their greater thermal mass, but efficiency did not scale linearly with size, highlighting the need to match pot dimensions with load volume. Material effects were pronounced: clay pots absorbed substantially more energy than metals, increasing input demand but enabling heat retention and carryover cooking; aluminium and stainless steel transferred energy efficiently to water but lost heat rapidly, while cast iron exhibited intermediate behaviour. Energy transferred to the surrounding air was relatively consistent across pots (8–54 kJ), underscoring the role of stove–pot coupling in mitigating convective losses. The largest inefficiency arose in the unaccounted energy fraction, particularly in larger pots, likely reflecting losses to stove structures, and radiation. These results indicate that optimizing pot performance requires not only selecting suitable materials and sizes but also addressing systemic inefficiencies through improved insulation, pot–stove integration, and thermal storage strategies.

Table 3: Energy Balance During Water Heating

Pot type	Pot Size	Water Heated (kg)	Energy distribution (kJ)				
			Water	Pot	Air	Total	Unaccounted
Aluminium	Big	1	279.63	17.90	30.87	450.00	121.60
		2	540.83	22.26	46.31	750.00	140.60
		3	886.60	23.30	41.68	979.36	27.79
	Medium	1	257.44	23.10	46.31	900.00	573.15
		2	556.74	23.74	38.59	900.00	280.94
		3	840.13	20.73	30.87	1050.00	158.27
	Small	1	290.93	19.59	54.03	652.46	287.91
		2	567.62	17.34	30.87	1050.00	434.17
		3	860.22	17.24	30.87	1500.00	591.66
Clay	Big	1	290.09	141.42	331.89	1253.39	489.99
		2	577.67	133.03	23.16	1202.75	468.90
		3	832.60	138.47	23.16	1254.35	260.13
	Medium	1	283.39	104.97	23.16	1050.00	638.48
		2	546.69	80.24	54.03	1253.13	572.17
		3	857.71	64.58	46.31	1444.76	476.15
	Small	1	290.09	57.55	46.31	1050.00	656.05
		2	560.09	55.13	61.75	1823.90	1146.93
		3	833.85	57.49	23.16	1650.00	735.50
Cast iron	Big	1	290.93	27.44	15.44	750.00	416.20
		2	553.39	26.97	7.72	750.00	161.93
		3	858.97	23.57	38.59	959.72	38.59
	Medium	1	292.60	22.17	787.28	1421.47	319.42
		2	530.79	24.39	15.44	900.00	329.39
		3	880.32	19.54	23.16	1822.87	899.86
	Small	1	286.74	12.94	15.44	600.00	284.89
		2	555.06	14.34	15.44	1050.00	465.16
		3	815.01	15.69	15.44	1350.00	503.86
Stainless steel	Big	1	277.95	18.11	15.44	600.00	288.50
		2	529.95	21.55	23.16	750.00	175.35
		3	830.08	20.72	38.59	1050.00	160.60
	Medium	1	284.65	21.56	23.16	600.00	270.64
		2	541.67	17.95	15.44	1050.00	474.95
		3	811.25	15.35	23.16	1500.00	650.25
	Small	1	282.14	14.37	404.66	1004.66	303.49
		2	551.72	15.08	15.44	900.00	317.77
		3	820.04	14.52	7.72	1200.00	357.72

3.3 Comparative Analysis of Cooking Pots

The result of the comparative analysis which reveals the effect of different factors on the energy utilization of the cooking pots are presented as follows:

3.3.1 Effect of Quantity of Water Heated on Energy Utilisation of Selected Cooking Pots

Table 4 shows the result of the paired sample t-test result at 5% level of significance. The paired sample t-test results indicate that the mass of water heated has a significant effect on the distribution of energy among different components (water, pot, air and the unaccounted energy) for specific pot types and sizes. This suggests that when heating different amounts of water in certain pot types and sizes, there are variations in how energy is distributed among the water, pot, air, and unaccounted components. For aluminium, stainless steel, cast iron, and clay pots, significant differences were observed for the mass of 3 kg of water heated in a large pot, impacting all energy components, except for clay pot which only influenced the water heating energy component.

Table **Error! No text of specified style in document.**: Effect of Quantity of Water Heated on Energy Balance.

Pot type	Pot Size	Significant difference in energy distribution		
		Water	Air	Unaccounted
Aluminium	Large	1 & 3 kg		1 & 3 kg; 2 & 3 kg
	Medium	1 & 3 kg		1 & 3 kg
	Small		1, 2 & 3 kg	
Clay	Big	1 & 3 kg		
	Small	1 & 3 kg	2 & 3 kg	
Cast iron	Large	1 & 3 kg		1 & 3 kg; 2 & 3 kg
	Medium			2 & 3 kg
Stainless steel	Large	1 & 3 kg		1 & 3 kg
	Medium	1 & 3 kg	2 & 3 kg	
	Small	1 & 3 kg	2 & 3 kg	

Note**.** The energy distributions for the grouped water masses are significantly different at the 5% level of significance.

For the medium sized pots, only the unaccounted energy component was influenced for 1 kg of water heated in an aluminium pot, while the pot and air energy components were significantly influenced when 3 kg of water was heated in an cast iron pot. For the small pots, the pot and unaccounted energy components were significantly impacted when 2 kg and 3 kg of water was heated in a clay pot, or when 3 kg of water was heated in a stainless steel pot.

3.3.2 Effect of Pot Sizes on the Energy Utilisation of Selected Pots

Table 5 shows the result of the paired sample t-test to investigate the effect on the pot sizes on the energy distribution to the different components. The results of the paired sample t-test indicated that the impact of pot size on the energy components is contingent on the mass of water heated and the specific pot type. Different combinations of pot size, pot type, and mass of water heated resulted in varying energy distributions among the water, pot, kitchen air, and the unaccounted. For 1 kg of water heated, no significant differences were observed across pot sizes for any of the pot types.

This implies that the pot size did not have a significant impact on all the energy components for 1 kg of water heated. For 2 kg of water heated, the pot size affected the energy distribution to some of the components when stainless steel and clay pots were used. For stainless steel pots, significant differences were observed in the pot and the unaccounted energy components between the small and the medium sized pots. In the case of clay pots, significant differences were observed only in the energy component of the kitchen air between the medium and large pot sizes.

For 3 kg of water heated, the size of the aluminium, stainless steel and clay pots used affected some of the energy components. For the aluminium pots, significant differences were observed in the air energy component between the medium and large pot sizes. For stainless steel pots, significant differences were observed in the water energy component and the air energy component between the small and large pot sizes. It also affected the air energy component between the small to medium pot sizes. In the case of the cast iron and clay pots, significant differences were observed for the air energy component between the all the pot sizes.

Table 5: Effect of Pot size on Energy Balance

Water Heated	Pot Type	Significant difference in energy distribution		
		Pot	Air	Unaccounted

1 kg	Stainless steel		Small, Medium	
2 kg	Aluminium			Large & Small
	Clay	Large, Medium & Small		
	Aluminium			Large & Medium
				Large, Medium & Small
3 kg	Clay	Large, Medium & Small		
	Cast iron			Large, Medium & Small
	Stainless steel		Small & Large	
			Small & Medium	Large & Medium

Note: The energy distribution of the grouped pot sizes is significantly different at 5% level of significance

3.3.3 Effect of Pot Type on Energy Utilisation of Selected Cooking Pots

Table 6 shows the result of the paired sample t-test of the effect of the pot type on the energy components. The paired sample t-test results indicate that the impact of pot type on the energy components varies based on the mass of water heated and the specific pot size. The different combinations of pot type, pot size, and mass of water resulted in varying energy distributions among the water, pot, kitchen air, and the unaccounted. For 1 kg of water heated in large pots, significant differences were observed for the kitchen air energy across various pot types.

The use of the aluminium and stainless steel pots had significantly different energy absorbed by the kitchen air compared to the cast iron and the clay pots. A similar result was observed for the medium sized pots, as the use of the aluminium, stainless steel, and cast iron pots had significantly different energy absorbed by the kitchen air compared to the clay pot. For small pots, significant differences were observed water heating energy and the unaccounted energy components across various pot types. Aluminium and stainless steel pots had a significantly different water heating energy from clay and cast iron pots, while the cast iron and stainless steel pots had a significantly different unaccounted energy compared to aluminium and clay pots.

For 2 kg of water heated in the large pots, significant differences were observed for the kitchen air energy across various pot types. There was a significant different between the kitchen air energy when big stainless steel pots were used and when big clay pots were used to heat 2 kg of water. For medium sized pots, significant differences were also observed for the kitchen air energy, between cast iron pots and the clay pots. For small pots, significant differences were observed for the pot energy absorption, and across various pot types. Aluminium, cast iron, and stainless steel pots had significant differences from clay pots in terms of water heating energy and the unaccounted energy. Cast iron and stainless steel pots had significantly different pot energy absorption from clay pots.

Table 6: Effect of Pot type on Energy Distribution

Water Heated (kg)	Pot Size	Significant difference in energy distribution		
		Pot	Air	Unaccounted
1 kg	Large	Al, CI, SS & CY		
	Medium	Al, CI, SS & CY		
	Small	Al, CI, SS & CY	Al, CI & SS	
2 kg	Large	Al, CI, SS & CY		Al, CI, SS & CY
	Medium	Al, CI, SS & CY		Al, CI & CY
	Small	Al, CI, SS & CY	CI, SS & CY	CI, SS & CY
3 kg	Large	Al, CI, SS & CY		Al, CI, SS & CY; Al & SS
	Medium	Al, CI, SS & CY		Al, CI, SS & CY
	Small	Al, CI & SS	Al, CI, SS & CY	

Al: Aluminium; SS: Stainless steel; CI: Cast Iron; CY: Clay. Note: The energy distribution for types of pots grouped together are significantly different at 5% level of significance

For 3 kg of water heated in large pots, significant differences were observed for kitchen air energy across various pot types. Stainless steel pots had significantly different kitchen air energy clay pots and aluminium pots. For 3 kg medium pots, significant differences were observed for kitchen air energy between the cast iron pots and clay pots, and also between aluminium pots and clay pots. For 3 kg of water heated in small pots, significant differences were observed between the for all the energy components when aluminium, cast iron, and stainless steel pots were

used and when clay pots was used. In addition, when the stainless steel pot was used, it had significantly different kitchen air energy from when clay pot was used.

3.4 Discussion

3.4.1 Appropriate Pot Size Selection

Selecting the appropriate pot size relative to the cooking load is critical for efficient energy use, heat transfer, and overall cooking performance (Sutar et al., 2020). When pot size is well-matched to food volume, heating is faster, more uniform, and less prone to overflow, thereby reducing energy wastage and improving cooking outcomes (Joshi & Waghole, 2022; Nabukwangwa et al., 2023) For example, small pots efficiently heated 1 kg of water (Figures 2–4), with minimal energy loss and relatively short heating times. Medium pots were optimal for 2 kg loads (Figures 5–7), providing sufficient headspace to prevent spillage while still maintaining efficient heating. Larger pots were essential for cooking 3 kg of water (Figures 8–10), as they accommodated the larger volume without overflow while allowing for more stable heat distribution.

By contrast, mismatches between pot size and food volume resulted in substantial inefficiencies. Heating 3 kg of water in a small pot (Figure 10) caused overflow and prolonged heating times, as the limited capacity restricted effective heat transfer. Conversely, heating 1 kg of water in a large pot (Figure 1) led to excessive energy consumption: the larger pot body absorbed unnecessary heat, and the greater exposed surface area increased evaporation losses. In both cases, cooking efficiency decreased, and uneven heating created risks of undercooked or scorched food (Rathore et al., 2022). These findings confirm that improper pot–load matching not only wastes fuel but also reduces the reliability of cooking outcomes.

Beyond the immediate cooking performance, these results have direct implications for thermal energy storage (TES) suitability. TES systems rely on the efficient retention and transfer of stored heat during the cooking process. Pots that are poorly matched to the cooking load increase unaccounted energy losses, primarily through excess heating of the pot body and surroundings, thereby undermining the benefits of stored thermal energy. In contrast, selecting pot sizes that correspond closely to the cooking volume ensures that a greater proportion of the stored heat is directed into the food, improving both energy utilization and cooking consistency. This suggests that in TES-based cooking systems, pot size is not merely a matter of convenience but a fundamental design and operational consideration. Proper pot–load alignment enhances storage-to-use efficiency, maximizes the practical utility of stored heat, and reduces overall cooking energy demand.

3.4.2 Selection of Pot Type Based on Applications

Based on the results from Figures 2 to 10, each pot material (aluminium, stainless steel, cast iron, and clay) demonstrated distinct heating characteristics that influence their suitability for different cooking applications. Aluminium pots heated rapidly and transferred energy efficiently, making them well-suited for tasks requiring quick temperature rise such as boiling water, cooking pasta, preparing soups or stocks, and steaming vegetables (Coe & Spiro, 2022). However, since aluminium has relatively low heat retention, it is less suitable for long-duration cooking but can be effective for applications like simmering sauces or reducing liquids, where continuous heat is supplied. Stainless steel pots provided stable and even heating, supporting versatile uses such as simmering sauces, sautéing vegetables, steaming, boiling, or cooking grains like rice (Chaudhary et al., 2023). Their ability to sustain steady heat without rapid fluctuations makes them particularly useful for braising meats and preparing stews. Cast iron pots excelled in retaining heat and sustaining high temperatures, making them ideal for slow cooking, braising, and stewing (Singh & Goel, 2021). Their heat-holding capacity also supports high-intensity tasks such as deep frying, yielding consistent results, as well as baking bread or roasting meats and vegetables with excellent heat distribution (Yun et al., 2020). Clay pots exhibited superior heat retention and gentle, prolonged heat release, making them ideal for slow-cooked dishes that require even, moist heat. They are particularly valued for baking, roasting, and preparing traditional slow-simmered recipes, often imparting a distinctive earthy flavour and softer texture to food (Mengistu et al., 2023).

Taken together, these findings highlight that pot material not only determines cooking performance but also has implications for thermal energy storage (TES) suitability. Materials with high heat retention, such as cast iron and clay, are inherently better suited for TES-supported cooking systems, where stored energy must be released gradually and uniformly. In contrast, aluminium and stainless steel, while efficient in rapid heating, may be less effective for TES applications that rely on sustained heat delivery, but could complement TES when rapid reheating or responsive thermal transfer is required.

3.4.3 Performance and Selection of Cooking Pots Suitable for TES

Thermal Energy Storage (TES) integration into cooking systems can be implemented in two principal ways. The first is the Pot-as-Storage approach, where the pot itself functions as the storage medium, directly absorbing and retaining heat during cooking. The second is the Pot-with-Lined-Storage approach, in which the pot walls are lined or jacketed with an independent storage medium (such as phase change materials, PCM) that is thermally insulated from the surroundings. Each approach presents unique implications for cooking performance. Pot-as-Storage designs rely heavily on the thermal properties of the pot material itself, making heat capacity and retention critical factors. In contrast, Pot-with-Lined-Storage designs offer more flexibility by decoupling cooking from storage performance, allowing optimization of the liner material for sustained heat release. Ultimately, the choice between these strategies depends on pot material, size, and the intended cooking strategy, as well as the trade-off between rapid heating and prolonged heat retention.

A. Pot-with-Lined-Storage TES Integration

Based on the results from Figures 2 to 10, aluminium and stainless steel emerged as the most suitable candidates for the pot-with-lined-storage approach to thermal energy storage (TES). Their performance characteristics align well with the requirements of this design strategy, where rapid and efficient transfer of heat from the storage medium through the pot wall to the food is paramount.

a. **Efficient Heating:** Aluminium pots consistently demonstrated the fastest heating response, reaching boiling temperatures more quickly than other materials. Stainless steel, while slightly slower, also showed reliable and efficient heat transfer, ensuring sufficient energy delivery for typical cooking tasks.
b. **Moderate Peak Temperatures:** Both aluminium and stainless steel reached temperatures adequate for cooking without excessive overshooting. Unlike cast iron or clay, which either retained too much heat or required higher energy input, aluminium and stainless steel maintained cooking-friendly temperature ranges that reduce risks of burning or overheating.
c. **Stable and Uniform Heating:** The heating profiles of aluminium and stainless steel were notably stable and consistent across different pot sizes. This uniformity is critical for TES applications (Tat & Muthukumar, 2024), where controlled release of stored heat must be evenly distributed to the cooking medium.
d. **Rapid Heat Discharge:** After the heat source was removed, aluminium in particular showed a rapid discharge of heat, while stainless steel maintained a balanced release profile. For lined TES systems, this behaviour is highly desirable (Pecchini et al., 2024; Rahman et al., 2024), as it ensures that stored energy in the lining (e.g., PCM) is transmitted efficiently to the food rather than being trapped within the pot walls.
e. **Material Compatibility:** Both materials are lightweight and highly conductive, making them mechanically and thermally compatible with integration of TES liners. Aluminium's superior conductivity favours fast energy exchange, while stainless steel offers additional durability and resistance to corrosion, ensuring long-term stability in repeated heating–cooling cycles (Salunkhe & Devanuri, 2022).

B. Pot-as-Storage TES Integration

From the results presented in Figures 2 to 10, clay and cast iron pots demonstrated heating characteristics that make them particularly suitable for the pot-as-storage approach to thermal energy storage (TES), where the pot body itself serves as the primary heat reservoir.

a. **High Heat Absorption:** Clay and cast iron pots absorbed and retained more thermal energy compared to aluminium and stainless steel. While this property reduced their heating rate during active cooking, it highlights their potential for storing significant amounts of heat within the pot walls for later release (Vigneshwaran et al., 2019).
b. **Sustained Heat Retention:** Both materials maintained elevated temperatures well after the heat source was removed. Clay, in particular, showed the strongest retention, sustaining gentle and prolonged heating. This property is ideal for TES applications (Verma & Singh, 2025) where slow and continuous energy release is required to keep food warm or continue cooking after the fuel source is withdrawn.
c. **Moderate Heat Release Rate:** Unlike aluminium, which discharged heat too rapidly for storage purposes, clay and cast iron released energy more gradually. This behaviour aligns with the core objective of pot-as-storage TES — to extend cooking duration by supplying residual heat stored in the pot walls.
d. **Thermal Stability and Uniformity:** Cast iron provided a more consistent temperature profile across the cooking process, preventing sharp fluctuations in energy delivery. Clay, while slightly less stable,

excelled in providing low-intensity but prolonged heating, reducing risks of scorching and supporting traditional slow-cooking methods.

e. **Material Robustness for Repeated Cycling:** Cast iron's mechanical strength and durability make it well-suited to repeated heating–cooling cycles in TES applications. Clay, though more fragile, compensates with its natural insulating properties and capacity to impart uniform, gentle heat over extended periods.

4. Conclusion

Cooking is one of the most energy-intensive daily activities, with significant inefficiencies arising from thermal losses in cooking pots. This study evaluated aluminium, stainless steel, cast iron, and clay pots to identify the most suitable material for thermal energy storage (TES) integration. Water-heating experiments showed that all pots achieved boiling in 7–11 minutes depending on load, but aluminium consistently outperformed the others. Aluminium pots required 291–887 kJ across sizes, with low body heat absorption (17–23 kJ) and moderate air losses (31–54 kJ). Stainless steel demonstrated comparable heating rates but lower storage in the pot body, while cast iron and clay absorbed substantially more energy (up to 141 kJ), reflecting their high thermal mass but reduced efficiency in transferring heat to food.

The results position aluminium as the strongest platform for lined TES systems, where rapid conduction and minimal heat retention in the pot body enable effective release from encapsulated storage media. Stainless steel also offers potential for this approach, though with lower efficiency. By contrast, clay and cast iron are better suited to pot-as-storage concepts, where their inherent heat absorption and retention can be harnessed for prolonged cooking and heat buffering. By aligning material performance with TES strategies, this study establishes a clear material-design roadmap for advanced cooking systems that improve household energy efficiency and reduce cooking-related emissions, thereby supporting the transition to cleaner and more sustainable energy use.

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