UNIABUJA Journal of Engineering and Technology

https://ujet.uniabuja.edu.ng/

ISSN: 2714-3236 (Online); 2714-3228 (Print)

Volume 2, Issue 2, 2025; 253-264

Development of a Mobile Multipurpose Cooking System Integrated with A Cooling Storage and Washing Sink

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Abstract
The increasing need for clean, efficient, and mobile cooking solutions for street food vending and small-scale food processing in developing countries motivated the design, fabrication, and evaluation of a mobile, multipurpose cooking system integrating roasting, boiling, and frying functionalities. The system was developed using locally sourced materials, with the roasting unit powered by charcoal and the cooking unit by liquefied petroleum gas (LPG), both insulated with a gypsum plaster–wood dust mixture to enhance thermal efficiency and safety. Water Boiling Tests (WBT) and roasting tests were conducted to evaluate thermal performance, fuel consumption, and operational efficiency. Results showed a thermal efficiency of 14.78% for the LPG-powered cooking unit and 5.42% for the charcoal-powered roasting unit. The firepower of the cooking system was recorded as 37.3 kW with a specific fuel consumption of 0.518 kg fuel per kg of water evaporated during testing. These results demonstrate the system's potential in providing a cleaner and more efficient cooking alternative while ensuring mobility and ease of use for street vendors and small-scale processors. The system promotes improved hygiene, reduced environmental pollution, and enhanced user safety, aligning with the goals of clean energy utilization under Sustainable Development Goal 7 (SDG 7).

Keywords: *Thermal efficiency, mobility, fuel consumption, cooking, fabrication.*

1.0 Introduction

Cooking is a vital domestic activity that requires energy in different proportion (Bhave & Kale, 2020; Datta et al., 2021). The required energy for cooking is obtained by burning fuel such as firewood, charcoal, agricultural waste and liquefied petroleum gas (LPG). Concerning this, over 3 billion people on the surface of the earth uses these solid fuels for cooking (Datta et al., 2021; Pratiti et al., 2020). This has however; led to the increase in deforestation, forest desolation and extinction. The secondary effects of using solid fuels such as wood include soil degradation and erosion which has direct effect on the ecological system leading to climate change (Dagnachew et al., 2020). In Nigeria, the energy consumed domestically and industrially using biomass ranges from 80-90% (Oyejide et al., 2019).

Due to poverty, the main source of energy used for cooking is wood (Jewitt et al., 2020). With this, about 120 million Nigerians are estimated to be exposed to different illnesses and deaths as a result of their contact with smoke, with an average of 4 million deaths associated with this kind of air pollution recorded annually. The biomass stoves that use firewood charcoal over the years have been improved upon to Rocket, forced-draft, and more efficient and clean charcoal stoves with fewer emissions compared to the three-stone fire method. The World Health Organization (WHO) has affirmed that only one biomass stove that uses Biogas, liquefied petroleum gas (LPG), electricity, ethanol, and natural gas as fuels meets these strict health and emissions standards (Gill-Wiehl et al., 2021). Today, clean cooking fuels and technologies are beginning to have direct social and environmental benefits as indicated in Sustainable Development Goal 7 (SDG 7) (Tucho & Kumsa, 2020; Zahno et al., 2020). As asserted by authors in Tucho & Kumsa and Zahno *et al.*, it is forecast that by 2030, energy should be affordable, dependable, and available for use. However, for the sake of man's health, it is important to access this clean energy so as to reduce the risk of illness due to exposure to a polluted environment.

However, health and safety issues are paramount; the problems do not stop once the firewood is obtained. Smoke from the open fire method of cooking can create a dirty and unhealthy environment that has led to eye and respiratory problems, which are widely spread, burns and scalds, especially where children are numerous. Even without this danger, a smoke-filled, soot-blackened cooking area is neither a pleasant nor a healthy environment to work. Clean cooking practice helps to prevent emissions from the solid fuel biomass, thereby reducing the pollution and providing better, healthier environment and slowing down the rate of climate change (Aberilla et al., 2020). By this research people who are into cooking that entails roasting, frying,

Received: 24-06-2025 / Accepted: 10-07-2025 / Published: 26-07-2025

https://doi.org/10.70118/ujet.2025.0202.24

and boiling, will be less exposed to harmful cooking emissions, thereby providing a cleaner and more efficient cooking environment. By integrating cooking, cooling, and washing functions, the system reduces the risk of contamination and promotes better hygiene and healthier cooking process.

2.0 Materials and Methods

The materials used for the fabrication include mild steel sheet, stainless steel sheet, square pipe, angle bar, rivet pins, screws, hinges, fiber glass, kitchen sink, cooler, universal joint, stainless steel rod, wheels, and other used for the design are; industrial gas burner, gas cylinder, car trailer hitch.

2.1 Materials Selection

The selection of materials for the construction of the mobile is easily made due to the availability of locally sourced materials. The materials selected can withstand engineering properties like heat, strength, corrosion, toughness, strain, vibrations, fatigue, and stress without undergoing failure during operation. The materials selected for the construction of the mobile kitchen include the following:

i. Stainless steel sheet, which is used for the combustion chamber and the roasting chamber to withstand heating from the gas burner and charcoal for a long period without rusting, and the roasting mesh was made from stainless steel to avoid contamination with the product.
ii. Mild steel sheet is used for the construction of the body because of its high weldability properties and ease of riveting.
iii. Pipes are made from mild steel and used for forming the frame of the mobile kitchen.
iv. Angle iron made from mild steel is used to form the support of the wheels to give rigidity.
v. Fiber glass and the mixture of Gypsum plaster (Plaster of Paris) and wood dust were used, and this serves as a lagging material to reduce thermal conductivity.

2.2.1 The insulation

The proper insulation of the cooking and roasting unit holds significant importance in preventing or minimizing heat loss to the surroundings. In addition to conserving heat within the combustion chamber, the insulation also serves to prevent the roasting and cooking chamber from reaching excessive temperatures, thereby reducing potential hazards to users. Essential attributes of an insulation material include low thermal conductivity, the ability to withstand high temperatures, and good durability, density, and strength.

2.2.2 Choice of insulating material

The insulation used for the combustion chamber in this study consists of a mixture of gypsum plaster (plaster of Paris) and wood dust due to their favourable thermal properties and availability. Gypsum plaster was selected primarily for its low thermal conductivity of approximately 0.22 W/m K, making it an energy-efficient insulating material for reducing heat loss in combustion systems [13]. Its high-water uptake during mixing, which is nearly 50% by weight, allows it to release moisture when exposed to high temperatures, contributing to a cooling effect that retards heat loss within the system. Additionally, gypsum plaster is lightweight, supporting the mobility requirements of the developed cooking system. The incorporation of wood dust further reduces the thermal conductivity of the insulation mixture, enhancing its insulating properties while utilising locally available, low-cost materials. To prepare the insulation, gypsum plaster and wood dust were manually mixed with water, allowed to dry, and subsequently sieved to obtain uniform particle sizes for effective application in the combustion chamber insulation.

2.3 Design description of the mobile kitchen

The mobile kitchen integrates a cooking unit and roasting unit within a compact, towable frame to support efficient, clean, and mobile street food vending. The cylindrical cooking unit consists of a combustion chamber with a diameter of 302 mm and a height of 568 mm, insulated with a mixture of agglomerated gypsum plaster (plaster of Paris) and sawdust to reduce heat loss. A feeder tube of 20 mm diameter is positioned at 460 mm height with an opening for the seat of the industrial gas burner. A pot skirt of 320 mm diameter accommodates varying pot sizes, while a chimney made from a rectangular mild steel pipe, 760 mm in height with a 45 mm outlet, is attached for smoke dissipation, positioned 425 mm above the pot skirt. The overall unit height is 1205 mm. The body is fabricated from 18-gauge mild steel for durability, ease of fabrication, and cost-effectiveness using locally available materials, with mild steel angle bars for the frame. The cylindrical structure ensures even heat distribution, while the insulation conserves energy and reduces fuel consumption. The chimney height ensures smoke is safely dissipated above head level, enhancing operator comfort during operation.

The well-insulated rectangular roasting unit has a roasting chamber measuring 739 mm by 739 mm with a depth of 570 mm and a height of 743 mm. An air vent door measuring 345 mm by 425 mm controls

Received: 24-06-2025 / Accepted: 10-07-2025 / Published: 26-07-2025

https://doi.org/10.70118/ujet.2025.0202.24

combustion, while a removable ash collector of 184 mm diameter with a chamber height of 320 mm ensures easy ash disposal during continuous operation. The heating chamber, made from perforated stainless steel, ensures even heat distribution around the food items while maintaining hygiene and easy cleaning. Fiber glass insulation retains heat within the roasting chamber, reducing charcoal consumption while maintaining roasting temperatures, while the mild steel external structure provides strength and longevity. The air vent allows precise combustion control to improve roasting efficiency, while the ash collector keeps the workspace clean and organized during operations.

The unit is mounted on a towable trailer frame with a clearance of 425 mm from the ground, equipped with a car trailer hitch and a universal joint that allows smooth towing and maneuverability on various terrains. The structural frame uses 50 mm diameter mild steel hollow pipes for strength and stability. The mobility feature allows easy relocation for street vending and event catering, with the universal joint ensuring compatibility with different transport means.

The design supports efficient energy use with effective insulation while maintaining durability and low fabrication costs using locally available materials. Safety and hygiene are achieved with stainless steel contact surfaces and a smoke dissipation system, and the compact integration of the cooking and roasting functions within a single mobile unit enables hygienic, flexible, and environmentally friendly street food vending.

2.4 Methods

The method used for developing the mobile multipurpose cooking system involves designing, fabricating, and evaluating the cooking and roasting unit. Charcoal is used as the energy source for the roasting unit while LPG is used for the cooking unit, with both units insulated to enhance thermal efficiency. The system uses readily available materials in Nigeria, including mild steel sheets, stainless steel, square pipes, angle iron, fiberglass, kitchen sink, cooler, universal joint, wheels, an industrial gas burner, and a gas cylinder. The design prioritizes ease of assembly and user operation through a modular structure that allows straightforward installation without specialized tools, while the industrial gas burner and gas cylinder are plug-and-use for convenience. The kitchen sink, cooler, and universal joints are pre-mounted, and wheels enable easy mobility without disassembly. The arrangement of the roasting unit, washing sink, and cooling chamber allows for intuitive operation with minimal training, and all parts are accessible for maintenance using common tools.

2.5 Design Analysis and Calculations

2.5.1 For roasting unit

Heat Absorbed by the Corn (**Qheat**)

The quantity of heat absorbed during the roasting process can be estimated using the specific heat formula, as expressed by equation 1:

$Q_{heat} = M_{before}C_c\Delta T$ (Das et al., 2022) (1)

Where:

Q_{heat} = Quantity of heat absorbed (in joules, J)

M_{before} = Mass of the corn before roasting (in kilograms, kg)

C_c = Specific heat capacity of corn (in joules per kilogram per degree Celsius, J/kg·°C)

ΔT = Change in temperature during roasting (final temperature minus initial temperature, in °C)

Given Parameters from the Roasting Experiment;

Mass of corn before roasting (M_{before}) = 1.002kg = 1002g (average mass of 9 corn cobs before roasting)

Mass of corn after roasting (M_{after}) = 0.866kg = 8660g

Initial temperature = 27℃

Final temperature = 470℃

Specific heat capacity of corn = 1.8J/g℃ = 1800J/kg℃

Weight of charcoal before roasting ($M_{charcoal\_before}$) = 2.338 kg

Weight of charcoal after roasting ($M_{charcoal\_after}$) = 1.702 kg

Latent heat of vapourisation ($L_{vapourisation}$) = 2,260,000 J/kg

The change in the mass of charcoal used during the roasting process is calculated as the difference between the initial mass of the charcoal before roasting and the final mass after roasting, as expressed in the equation:

$\Delta M_{charcoal} = M_{charcoal\_before} - M_{charcoal\_after}$ (2)

$= 2.338 - 1.702 = 0.636$ kg

Mass of corn before roasting (M_{before}) = 1.002kg = 1002g

Mass of corn after roasting (M_{after}) = 0.866kg = 8660g

2.5.1 Useful Heat Absorbed by Corn

$Q_{heat} = M_{after}C_c\Delta T$ (3)

Received: 24-06-2025 / Accepted: 10-07-2025 / Published: 26-07-2025
https://doi.org/10.70118/ujet.2025.0202.24

$= 0.8660 \times 1800 \times 443$
$= 691, 174$ J
$= 691.17$ kJ

Latent heat:

$M_{\text{evaporated}} = 1.002 \times 0.8660 = 0.136$ kg

Latent heat of vapourisation ($L_{vapourisation}$) = 2,260,000 J/kg

$Q_{\text{latent}} = 0.136 \times 2{,}260{,}000 = 307{,}360$ J = 307.36 kJ

Total Useful Heat:

$$Q_{\text{useful}} = Q_{\text{heat}} + Q_{\text{latent}} \quad (4)$$
$= 691.17 + 307.36$
$= 998.53$ kJ

2.5.2 Heat Supplied by Charcoal (Q_{input})

$$M_{\text{charcoal consumed}} = 2.338 - 1.702 = 0.636 \text{ kg} \quad (5)$$

Calorific value of charcoal

$CV_{\text{charcoal}} = 29{,}000$ kJ/kg

Total Heat Supplied

$$Q_{\text{input}} = M_{\text{charcoal consumed}} \times CV_{\text{charcoal}} = 0.636 \times 29{,}0000 = 18{,}444 \text{ kJ} \quad (6)$$

2.5.3 Thermal efficiency, (ŋ)

The thermal efficiency of the roasting unit is calculated as the ratio of the heat energy utilized by the corn to the total heat energy supplied by the charcoal, multiplied by 100 to express it as a percentage, as shown in the equation:

$$ŋ = \frac{Q_{heat}}{Q_{input}} \times 100\% \quad (7)$$

$$ŋ = \frac{998.53}{18{,}444} = 5.42\%$$

2.6 Fabrication of the Mobile Kitchen

The mobile kitchen is equipped with a cooking unit, roasting unit, cooling storage, and a kitchen sink. The cooking unit consists of a combustion chamber and chimney, while the roasting unit features a well-insulated roasting chamber. These components have been meticulously fabricated and interconnected in a single unit, forming an inverted U-shape. The fabrication process involved a range of precise techniques such as cutting, welding, filing, drilling, rolling, bending, painting, and riveting to ensure the highest quality and durability of the mobile kitchen.

2.6.1 Fabrication of the frame

This is the main body that houses all the other components of this project. The frame is made from a 76.2 mm × 38.1 mm × 2 mm pipe. It was accurately measured, cut, and welded together as shown in Plate I below.

Plate I: Frame of the mobile kitchen

2.6.2 Fabrication of the combustion chamber

The combustion chamber is fabricated as a square container with dimensions of 20 × 20 cm and a height of 25 cm, where heat energy is generated. It has a riser tube made from a 76.2 mm × 38.1 mm × 1 mm pipe, which directs the heat flow. The combustion chamber is fully insulated using a mixture of Gypsum plaster (plaster of Paris) and wood dust.

Received: 24-06-2025 / Accepted: 10-07-2025 / Published: 26-07-2025

https://doi.org/10.70118/ujet.2025.0202.24

Plate II: Combustion chamber and gas burner stand

2.6.3 Fabrication of the roasting chamber

The roasting chamber is made with a 1 mm stainless steel plate with dimension that measures 50 cm long, 23 cm wide, and 7 cm high, and the roasting top is made with a 6mm stainless steel rod in the form of a mesh size of 30 cm × 57 cm. For air inflow, the stainless-steel base plate is perforated, and the external body is a mild steel plate, which is also covered with a fiber glass, which helps to retain the heat in the roasting chamber unit.

Plate III: Roasting Chamber unit

2.6.4 Installation of the kitchen sink and cooling storage

Attached to the frame is the kitchen sink and cooling storage. During the design of the frame, the size for the kitchen sink and cooling storage was considered in order for ease of installation.

Plate IV: Washing sink and the cooling storage

2.6.5 Fabrication of the air inlet door

As a way of improving the design and allowing for a self-fanning system, an inlet door is made to accommodate the inflow of air, and this door serves as a way of regulating the air flow during roasting. The door is just below the roasting chamber. The inlet door is made from 0.8mm mild steel plate as shown in the Plate V below:

Received: 24-06-2025 / Accepted: 10-07-2025 / Published: 26-07-2025

https://doi.org/10.70118/ujet.2025.0202.24

Plate V: Air inlet door

2.6.6 Fabrication process

The joining processes for the construction of the mobile kitchen were electric arc welding, riveting, drilling, folding, bending, bolt and nuts. The components were all assembled based on the fabrication process outline in Table 1.

Table 1: Fabrication process

Component	Materials	Process Description	Equipment Used
Support frame	Mild steel pipes (76.2 mm x 38.1 mm x 2 mm)	Measurement, cutting, and electric arc welding	Measuring tape, Square rule, hack saw and gauge 12 electrodes
Roasting chamber	1 mm Stainless steel sheet and 0.8 mm mild steel plate, fibre glass	Measurement, cutting and electric arc welding and riveting	Measuring tape, cutting machine, gauge 12 electrodes, riveting gun and rivet pins
Combustion chamber	1.5 mm stainless steel sheet, 1mm mild steel	Measurement, cutting, and electric arc welding	Measuring tape, cutting machine, electric arc welding machine and gauge 12 electrodes
Riser Tube	1.5 mm stainless steel sheet	Measurement, cutting, and electric arc welding	Measuring tape, cutting machine, electric arc welding machine and gauge 12 electrodes
Roasting Mesh	6 mm stainless steel rod	Measurement, cutting and arc welding	Measuring tape, cutting machine and gauge 12 electrodes
Chimney	Mild steel pipes (76.2 mm x 38.1 mm x 2 mm)	Measurement and cutting	Measuring tape, cutting machine, and gauge 12 electrode
Washing Sink	Stainless steel	Purchased	
Cooling Storage	Foam	Purchased	
Umbrella	Nylon	Purchased	
Wheel	Rubber	Purchased	

Received: 24-06-2025 / Accepted: 10-07-2025 / Published: 26-07-2025
https://doi.org/10.70118/ujet.2025.0202.24

Plate VII: Developed mobile kitchen

2.7 Performance Test of the Cooking Machine (Water Boiling Test)

To evaluate the performance of the cooking unit, a water boiling test was conducted. This test provides reliable information on the efficiency and effectiveness of the cooking machine during operation. The Equipment used for the Water Boiling Test includes the following:

i. A 40kg digital Camry weighing scale
ii. Thermometer
iii. Timer
iv. Gas cylinder
v. Industrial gas burner
vi. Pot
vii. Heat resistant gloves viii. 10 liters of clean water

All the required equipment for the experiment is assembled, and a data sheet is prepared for recording observations. The following measurements are taken and systematically recorded on the data sheet:

i. Weight of empty pot
ii. Weight of the gas cylinder
iii. The timer is prepared and ready to take readings
iv. Clean water is poured into the pot, and the weight of the pot with water in it is measured.
v. A thermometer is placed in the center of the pot to measure the initial water temperature
vi. The water pot is placed on the industrial gas burner
vii. When the water in the pot reached its boiling point, the following is done rapidly: The time at which the water in the Pot reached a boiling point and the temperature were both recorded. The pot was weighed with the water left in it, and the result was documented. The gas cylinder was weighed and the result documented.

2.8 Project Cost Evaluation for Mobile Kitchen Fabrication

Listed in Table 2 are the different materials used in the course of the manufacturing of the mobile kitchen as well as their corresponding costs.

Table 2: Bill of Engineering Measurement and Evaluation (BEME)

S/N	Items	Quantity	Unit Price (₦)	Amount (₦)
1.	3″ x $1^{1}{}_{2}$" x 2mm pipes	5 Length	18,000	90,000
2.	$1^{1}{}_{2}$" Angle Iron	1 Length	9,500	9,500
3.	18-gauge mild steel plate	2 sheets	32,000	64,000
4.	24-gauge mild steel plate	2 sheets	17,500	35,000
5.	6 mm stainless steel rod	2 length	18,000	36,000
6.	0.8 mm stainless steel	½ *sheet*	54,000	27,000
7.	Fiber glass insulation	4kg	1200	4,800
8.	1.5 mm stainless steel	¼ *sheet*	96,000	24,000
9.	Cooling storage (Cooler)	1	12,000	12,000
10.	Kitchen sink	1	13,000	13,000
11.	Wheels	2	15,000	30,000
12.	Cone and shaft	2	3,000	6,000
13.	13″ bolt and nut	12	60	720

Received: 24-06-2025 / Accepted: 10-07-2025 / Published: 26-07-2025

https://doi.org/10.70118/ujet.2025.0202.24

S/N	Items	Quantity	Unit Price (₦)	Amount (₦)
14.	Universal joint	1	3,000	3,000
15.	Paint	4 liters	4,500	18,000
16.	Thinner	2 liters	3,000	6,000
			Total	379,020

Table 3: Summary of evaluation

Category	Cost (₦)
A. Material Costs	379,020
B. Labour Costs	60,000
C. Fabrication & Finishing	18,000
D. Transport & Logistics	17,000
E. Miscellaneous/Contingency	24,200
Total Project Evaluation	₦ 498,220

3.0 Results and Discussion

3.1 Results

The Table 4 presents the constant variables utilized in the Water Boiling Test. These constants include the higher heating value (HHV) and lower heating value (LHV) of LPG, as well as the weight of the empty pot (P), which are critical for accurately determining the energy input and efficiency during the test.

Table 4: Constant variables for the water boiling test

S/N	Variables	Values
1	HHV	50 MJ/kg (typical for LPG)
2	LHV	45.5 MJ/kg (typical for LPG)
3	P	1.572 kg

The variables are defined as follows:

HHV - Gross calorific value LPG (MJ/kg)

LHV - Net calorific value of LPG (MJ/kg)

P - Weight of empty Pot (kg)

3.2 Performance Evaluation Test Description

The data presented in Table 5 below were obtained through a practical Water Boiling Test (WBT) conducted to evaluate the thermal performance of the developed cooking system. The test involved heating a known quantity of water using the cooking system while recording relevant parameters such as the initial and final weights of the gas cylinder and cooking pot, the initial and final water temperatures, and the time taken for the water to reach boiling point. Additional measurements, including water evaporated and fuel consumption, were also recorded. These directly measured variables serve as the basis for subsequent calculations of energy utilization, fuel efficiency, and overall system performance.

Table 5: Directly measured variables for the water boiling test

S/N	Variables	Description	Values
1	f_i	Initial weight of empty pot (kg)	5.010
2	P_i	Initial weight of gas cylinder (kg)	11.284
3	T_i	Initial water temperature (°C)	27
4	t_i	Start time	4:20 pm
5	f_f	Final weight of empty pot (kg)	4.981
6	P_f	Final weight of gas cylinder (kg)	10.881
7	T_f	Final water temperature (°C)	100
8	t_f	End time	4.29pm
9	W_e	Weight of water used (kg)	3.994
10	W_{1kg}	Volume equivalent of 1 kg LPG	1.016 (m^3)
11	W_a	Weight of water evaporated (kg)	0.778

Received: 24-06-2025 / Accepted: 10-07-2025 / Published: 26-07-2025
https://doi.org/10.70118/ujet.2025.0202.24

S/N	Variables	Description	Values
12	P_{1kg}	Price of 1 kg LPG (₦)	1100
13	P	Price of LPG used during test (₦)	1.572

3.3 Analysis of Test Results

3.3.1 Change in weight of gas cylinder (Δf)

The change in the weight of the gas cylinder during the test is calculated using the following formula:

$\Delta = f_i - f_f$ [12] (8)

where Δf is the change in weight of the gas cylinder, f_i is the initial weight of the gas cylinder before the test, and f_f is the final weight of the gas cylinder after the test (Shaisundaram et al., 2020).

= 5.010 – 4.981

= 0.029 kg

3.3.2 Mass of fuel consumed (mw)

The mass of water heated during the test is determined using the difference in the weights of the pot with water before and after heating, as expressed by the equation:

$m_w = P - P_f$ (9)

m_w = 11.284 – 10.881

= 0.403 kg

3.3.3 Water remaining at end of test (wr)

The amount of water remaining at the end of the test is calculated by subtracting the weight of evaporated water from the final weight of the pot with water, given by:

$w_r = P_f - P$ (10)

w_r = 10.881 – 1.572

= 9.309 kg

3.3.4 Change in water temperature (ΔT)

The change in water temperature during the test is calculated by subtracting the initial water temperature from the final water temperature, expressed as:

$\Delta T = T_f - T_i$ (11)

= 100 – 27

= 73°C

3.3.5 Duration of the test (Δt)

The duration of the test is determined by calculating the time difference between the end and start times of the test, as given by:

$\Delta t = t_f - t_i$ (12)

= 16:29 – 16:20

= 9 minutes = 9 × 60 = 540 $seconds$

3.3.6 Energy used (Q)

The energy used to heat the water during the test was calculated based on the mass of water heated, its specific heat capacity, and the temperature change, expressed as:

$Q_{heat} = m_w \times c \times \Delta T$ (13)

Where,

Q_{heat} is the energy used to heat the water (in joules or kilojoules),

m is the mass of water heated (kg) = 3.994 kg

c is the specific heat capacity of water (typically 4186 J/kg°C)

ΔT is the change in water temperature = 73°C

Q_{heat} = 3.994 × 4186 × 73 = 1,220,978.2 J = 1.221 MJ

Energy to vaporize the water:

The energy required to vaporize the water during the test is calculated using the mass of water vaporized and the latent heat of vaporization, given by:

$Qvapourize = mw \times L$ (14)

Where,

$Q_{vapourize}$ is the energy used to vaporize the water (in joules or kilojoules)

m_w is the mass of water vaporized (kg)

L is the latent heat of vaporization of water (typically 2,260,000 J/kg).

Received: 24-06-2025 / Accepted: 10-07-2025 / Published: 26-07-2025
https://doi.org/10.70118/ujet.2025.0202.24

$Q_{vapourise}$ = 0.778 × 2,260,000 = 1,757,080.8 J = 1.757 MJ

Total energy used (Q)

The total energy used during the test is calculated as the sum of the energy required to heat the water and the energy required to vapourize part of the water, expressed as:

Q = $Qheat + Qvapourize$

Where,

Q is the total energy used

Q_{heat} is the energy used to heat the water

$Q_{vapourie}$ is the energy used to vaporize the water.

= 1.221 + 1.757 = 2.978 MJ

3.3.8 Specific fuel consumption (SFC)

The specific fuel consumption was calculated by dividing the mass of fuel consumed by the mass of water evaporated, as given by:

SFC = $\frac{m_w}{w_a}$ = $\frac{0.403}{0.778}$ = 0.518 kg fuel/kg water evaporated (15)

3.3.9 Firepower (FP)

The firepower of the cooking system was calculated by dividing the total energy used by the duration of the test, as expressed in the following equation:

FP = $\frac{Q}{\Delta t}$ (16)

= $\frac{20.15\ MJ}{540\ s}$ = 0.03731 MJ /s = 37,314.8 W = 37.3 kW

3.3.10 Efficiency (ŋ)

Efficiency is the ratio of useful energy output to the total energy input.

Efficiency (ŋ) = $\frac{Q}{Total\ Energy\ Input}$ (Oyejide et al., 2019) (17)

$Total\ Energy\ Input$

Total Energy Input = $\boldsymbol{mw}$ × $HH\ V$

Where,

Q = 2.978 MJ

$HH\ V$ = 50 MJ/kg

$\boldsymbol{mw}$ = 0.403 kg

Total Energy Input = 0.403 × 50

= 20.15 MJ

Efficiency (ŋ) = $\frac{Q}{Total\ Energy\ Input} \times 100$

= $\frac{2.978}{20.15} \times 100$

= 14.78 %

Table 6: Calculated variables for the water boiling test

Variables	Values for phase 1
Δf	0.029 kg
m_w	0.403 kg
ΔT	73°C
w_r	9.424 kg
Δt	540 seconds
SFC	0.072
FP	37,314.8 W
ŋ	14.78 %

3.4 Discussion of Results

The performance evaluation of the developed mobile multipurpose cooking system revealed insightful outcomes when compared with existing studies. The thermal efficiency of the LPG-powered cooking unit was determined to be 14.78%, which aligns with reported practical field values for LPG stoves typically ranging between 10–25% under real operating conditions (Bhave & Kale, 2020; Oyejide et al., 2019). Additionally, Lubis et al., 2024 reported LPG stove thermal efficiencies ranging from 17–33% under Water Boiling Test (WBT) conditions, depending on stove design, pot type, and operational factors, confirming the

Received: 24-06-2025 / Accepted: 10-07-2025 / Published: 26-07-2025
https://doi.org/10.70118/ujet.2025.0202.24

reasonableness of the efficiency values obtained in this study while indicating potential for further optimization of the system.

The roasting unit powered by charcoal achieved a thermal efficiency of 5.42%, which falls within the lower bounds of efficiency reported for traditional charcoal stoves, typically ranging from 5–15% depending on design and operating conditions (Gill-Wiehl et al., 2021). The lower efficiency underscores the inherent limitations of natural draft charcoal stoves and highlights the potential for further improvement through enhanced insulation, advanced combustion chamber geometry, and the incorporation of forced draft or improved combustion air supply systems to increase combustion efficiency and reduce charcoal consumption.

The firepower of 37.3 kW recorded for the LPG-powered cooking unit demonstrates the system's capability for high-capacity, rapid cooking—ideal for street food vending and small-scale processing operations. This output aligns with documented firepower levels for commercial-scale LPG cook-stoves, which operate at substantially higher power input rates than domestic systems to achieve similar values (20–40 kW) designed for robust performance (Palanisamy et al., 2023). The high firepower enables reduced cooking times and improved productivity, crucial for meeting the demands of commercial food preparation

The specific fuel consumption (SFC) of 0.518 kg fuel/kg water evaporated for the LPG unit indicates efficient fuel utilization when compared with traditional methods. In related studies, similar systems have reported SFC values within this range, emphasizing the role of system design and insulation in reducing fuel requirements (Bhave & Kale, 2020; Oyejide et al., 2019).

Furthermore, the system's design, which integrates clean cooking with LPG and more efficient charcoal utilization, aligns with the objectives of Sustainable Development Goal 7 (SDG 7), which aims to ensure access to affordable, reliable, sustainable, and modern energy for all by 2030 (Tucho & Kumsa, 2020; Zahno et al., 2020). It also supports the recommendations of the World Health Organization (WHO, 2016) in promoting clean household energy to reduce indoor air pollution, thereby enhancing environmental sustainability and public health outcomes.

By integrating cooking, roasting, washing, and cooling functionalities within a single mobile unit, the system addresses health and hygiene challenges typically associated with street food vending. It also reduces exposure to harmful emissions while providing an energy-efficient cooking environment, consistent with previous findings emphasizing the importance of clean cooking practices in reducing pollution and slowing the rate of climate change (Aberilla et al., 2020; Datta et al., 2021).

4.0 Conclusion

A mobile, multipurpose cooking system integrating roasting, boiling, and frying units was successfully designed, fabricated, and evaluated using locally sourced materials to address the challenges of clean cooking for street food vending and small-scale food processors in developing contexts. The system demonstrated a thermal efficiency of 14.78% for the cooking unit and 5.42% for the roasting unit, with a firepower of 37.3 kW and effective heat utilization during cooking and roasting operations. The use of LPG and charcoal with appropriate insulation materials ensured fuel efficiency while reducing harmful emissions, promoting a cleaner and healthier cooking environment. The system's mobility, ease of operation, and hygienic design provide practical benefits to street vendors, enabling them to prepare food efficiently while minimizing exposure to smoke and environmental pollutants. By promoting the adoption of clean energy and efficient cooking technologies, the developed system contributes to achieving Sustainable Development Goal 7, fostering energy sustainability and improved public health outcomes. Future research may explore the integration of smart control features for fuel monitoring and emissions management to further enhance system performance and environmental impact.

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Received: 24-06-2025 / Accepted: 10-07-2025 / Published: 26-07-2025
https://doi.org/10.70118/ujet.2025.0202.24