Construction and Performance Evaluation of a Dual Powered Mini Baking Oven

*,[1a] Omoyi C.O., [2b] Ana. R. R. [3c] Ushie, D.O. [4d] Imhade P. Okokpujie

[1,2,3] Department of Mechanical Engineering, University of Calabar, Nigeria
[4]Department of Mechanical and Mechatronics Engineering, Afe Babalola University, Nigeria
[1]cordeliaochuole@unical.edu.ng |[2]anaraymond@unical.edu.ng |[3]davidogarushie@unical.edu.ng | [4]ip.okokpujie@abuad.edu.ng

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Abstract-- This paper describes designing, constructing, and testing a dual power baking oven prototype with combined electric and gas heating proficiencies. The oven permits users to select an electric (120V, 2000W) or gas (20,000 BTU/hr) heating system to optimize baking across dissimilar foods. Oven testing was conducted by baking homogeneous meat pies and cake recipes using electric and gas modes. Heating profiles, bake times, weight loss and internal temperatures were measured to evaluate and compare performance. The electric mode baked at 120°C for 8 minutes, while the gas mode baked at 150°C for 6 minutes. Weight loss after baking was 0.9 kg (16.2%) with electricity versus 0.95 kg (24.2%) with gas, showing increased moisture removal with gas heating. Temperature profiles demonstrated faster preheating with gas (250°C in 3 minutes) than electric (250°C in 4 minutes) under no load conditions. However, under load, electric heats up faster and reaches a higher temperature of 160°C, the gas within the same 10-minute timeframe at 140°C. According to the results, a dual-fuel small oven is achievable where the gas produces greater temperatures and faster preheating than electric, while electric offers precise, progressive heating. A Smart regulator enabled this hybrid systems to maximize benefits.

Keywords: Baking oven, Dual-fuel, Heating profiles.

1.0 INTRODUCTION

Baking is a dry heat cooking method that uses hot, dry air to cook food in an enclosed space opined by (Ayigun, et al., 2022). According to Singh. and Heldman (2001), baking is a process that has been used for thousands of years across numerous cultures to produce staple foods and delicious treats from ancient civilizations using wood-fired clay ovens for baking bread to modern kitchens with electric ovens for baking cakes and cookies. Some of the health benefits of oven-baked food include low in fat, a little oil is required to cook food in an oven, as opposed to immersing it in oil when frying it. In the study of Kutlu, et al (2022), baked foods have a richer taste and a better texture as well as retain more nutrients. The most common baked item is bread, but many other types of foods can be baked. Nwosu and Okeke (2022) elucidae on the Performance evaluation of a biomass-fueled baking oven for rural applications. Baking ovens are essential appliances in the snack food industry that use thermal insulation and fuel-generated heat to transform ingredients into edible products (Ilesanmi & Akinnuli, 2019; Adeyinka et al., 2018). The complex baking process requires precise control over simultaneous heat and mass transfer (Ilesanmi & Akinnuli, 2019; Genitha et al., 2014; Purlis, 2012). Ovens are typically powered by heat-producing fuels like gas, oil, charcoal or coal (Chukwuneke et al., 2018). Practical baking relies on an oven's ability to generate and maintain proper temperatures over time. Snack food companies depend on reliable, high-performance ovens to bake quality products at commercial scales. Advances in oven technologies that improve temperature regulation, efficiency, and uniform heating continue to benefit the industry. Thermal efficiency of a solar-powered baking oven was discussed by Adeyemi and Oladikpo (2021), while Eze and Uche (2020) gave a comparative study of electric and gas baking ovens in terms of energy consumption. Bello et al (2019) Designed an optimization of a hybrid baking oven using computational fluid dynamics.

*Corresponding Author: **cordeliaochuole@unical.edu.ng**

Section C- MECHANICAL/MECHATRONICS ENGINEERING & RELATED SCIENCES
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Baking ovens have historically relied on either gas or electric heating, each with inherent advantages and limitations (Khater & Bahnasawy, 2014). While gas provides rapid, high heat output, electricity enables more precise temperature control (Olugbade & Ojo, 2018; Akinnuli & Basil, 2019). Dual-fuel ovens combining both energy sources have been widely studied for industrial-scale baking to optimize different stages of the process (Suryanto & Armunanto, 2015). However, minimal research has explored applying hybrid gas/electric systems in a miniaturized format tailored for small-batch baking applications Specialized miniature ovens aim to address the constraints of standard ovens. With cavity volumes under 1 cubic foot, mini-ovens require less energy and preheat more rapidly thanks to the heated smaller area. Compact miniature ovens offer portability, reduced power demands, and concentrated heat for single servings (Devaraju et al., 2011). But current mini ovens are restricted to either gas or electric, lacking flexibility. This presents opportunities to address knowledge gaps around interchangeable gas and electric capabilities in specialty mini baking ovens (Chukwuneke et al., 2018).

Prior work studying pilot-scale dual-fuel ovens shows the approach is feasible but challenging to implement for home or commercial use. Adebayo, & Adekunle (2021), Developed and tested an energy-efficient electric baking oven. The work of Chukwuneke et al., (2018) developed and tested a prototype dual-fuel oven using kerosene and electric heating, demonstrating the potential but also difficulties in engineering an effective hybrid system. Another research by Chukwu & Nwankwo, (2020). Analysed heat distribution in a convection baking oven using finite element method and Okoronkwo et al (2022). Designed and characterized a gas-powered baking oven fabricated with local engineering materials shows that combining gas and electric heat for large industrial baking ovens can optimise different baking stages and improve efficiency, speed, and product quality (Other researchers has focused on optimizing industrial batch oven designs using combined gas and electric heating for different baking stages (Suryanto & Armunanto, 2015). The potential advantages of optimizing mini ovens for precision, rapid heating, or efficiency with gas/electric flexibility warrant further research. More applied experiments focused explicitly on constructing and testing integrated dual heating systems in miniaturized formats are needed to characterize performance trade-offs and demonstrate effective designs (Suryanto & Armunanto, 2015). Intelligent controllers enable these hybrid systems to maximize benefits. CFD modelling has also helped optimize gas burner designs for more uniform heating in tunnel ovens. This developed prototype is suitable for home use, potable, and affordable with limited maintenance costs.

2.0 DESIGN PARAMETERS

The isometric, part list and working diagram of the dual fuel source oven are presented in Figures 1 and 2

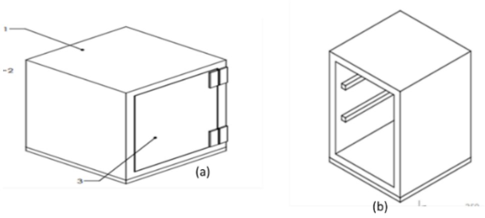
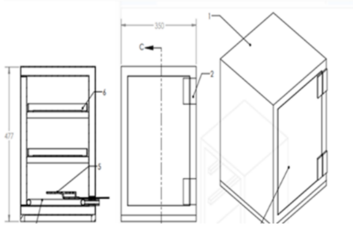


Figure **1:** Technical drawings showing (a) exterior housing (b) interior cavity and components



ITEM NO	PART NUMBER	QTY
1	Body	1
2	Hinges	2
3	DOOR	1
4	Burner	1
5	Spiral element	1
6	Tray	2

Figure 2: Part List of the Oven

- Inner cavity dimensions: 350 mm x 350 mm x 350 mm (0.42 cubic ft)
- Target temperature range: 150°C to 200 °C (Chukwuneke et al., 2018)
- Power supply: 120V, 60Hz, 15A electric
- Gas supply: 1/2 in NPT, 0.5 psi natural gas line

3.0 METHODOLOGY

Principle of Operation of the dual-fuel baking oven applies dry heat within an insulated stainless-steel cavity to transform raw dough and batters into baked agoods. A thermostat and selector switch allow the user to choose electricity or gas heating and set the target temperature. The oven chamber is designed to distribute heat evenly for uniform baking. The insulated walls minimize heat loss. Racks allow the positioning of the baked goods at different heights as needed. A viewing window permits monitoring without opening the door. Dual-fuel functionality provides both precise, adjustable electrical heat for gentle baking and intense gas heat for faster preheating or cooking at higher temperatures. This flexibility optimises the oven for a wide range of baking needs with maximum efficiency. The custom mini oven provides a compact, energy-efficient baking solution. Standardized Baking Trials: Conducted using both heating modes on various baked goods like meat pies and cakes. Data Collected: Included heating profiles, bake times, weight loss, colour, texture, and internal doneness. Performance differences Provided gradual heat ramping with precision control, ideal for delicate baking tasks. higher temperatures and faster preheat, suitable for items needing searing.

3.1 DESIGN CALCULATIONS

Oven capacity in the number of loaves of bread it can process per batch using the dimension shown in Figure. 2. Equation (1) is used for the design application

Size of tray = $= L_t \times B_t$ (1)

where:

L_t = length of tray;

B_t = breath of tray;

Capacity of oven = $\frac{size\ of\ tray}{size\ of\ bread} = n$

But the oven has a double tray;

Therefore, the number/volume of substances to be baked is 2n

3.2 REQUIRED HEATING POWER

The inner cavity volume is obtained using Equation (2)

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Volume to be heated = $length \times breadth \times width$ (2)

where;

Length, Breadth and Width = 0.350 m respectively,

$Volume\ to\ be\ heated = 0.35^3$ = 0.042875 m^3

Using the heat capacity of air as 0.456 Ws/m³/K and the desired temperature increase of 468 °C from room temperature to 500°C, the heating power (Q) can be calculated using Equation (3) as given according to Singh and Heldman (2001):

$$Q = mCp\Delta T \quad (3)$$

where;

m = mass or volume,

Cp = specific heat capacity of air, = 0.456 Ws/m³/K and

ΔT = temperature change; ΔT = 500 °C – 32 °C= 468 °C

$$Q = 0.042875 m^3 \times 0.456\ Ws / m^3 / K \times 468\ K$$

Q = 9.15 kW

Therefore, the estimated heating power for the 0.042875 m³ mini oven to reach baking temperatures is 9.15 kW.

3.3 ELECTRIC HEATING POWER

The electric heating system needs to be sized to provide sufficient power to heat the cavity volume to the target 500°C baking temperature.

The required heating power was calculated to be 9.15 kW. Adding a 25% safety factor gives:

9.155 kW x 1.25 = 11.45 kW

Therefore, the electric heating system should have a power rating of approximately 11.45 Kw.

For a 120V AC supply voltage, this 11.45 kW equates to as shown in equation (3) and (4):

P = IV (4)

$$I = \frac{P}{V} \quad (5)$$

$$I = \frac{11450}{120}$$

I = 95.4 A

Using standard 120V, 95A residential wiring, a heating element of 2000 – 3000 W is recommended. This heating element combined rating of the electric resistors satisfies the required heating load with overhead. A thermostat and relay will control the elements. Also, the coil heaters powered by a 120V/95A circuit provide adequate electric heating capacity for the mini baking oven design.

3.4 GAS HEATING POWER

The required thermal load for the gas heating system is 11.45 kW as determined previously.

Assuming the gas burner has an efficiency of 85%, the required gas input heating power would be:

$$\text{Required input} = \frac{11.45\ kW}{0.85} = 13.47\ \text{kW}$$

Converting this to common gas units:

1 kW ≈ 1,000,000,000,000 Pa/hr

Or, 1 kW = 10,000 BTU/hr

Therefore, required gas heat input = 13.47 kW x 10,000 BTU/kW = 13,4700 BTU/hr

Rounding up, a standard 20,000 BTU/hr gas burner would suffice for heating needs.

The natural gas supply is 0.5 psi line pressure feeding a 1/2-inch NPT inlet. For a 20,000 BTU/hr burner, the required gas flow rate is:

$$= \frac{20,000\ BTU / hr}{24,500\ BTU / ft^3}$$

= 0.82 ft³/hr of natural gas

4 RESULT AND DISCUSSION

The performance of the dual-fuel mini baking oven was assessed by testing its electric and gas heating systems to bake various food items. Standardized recipes and procedures were used in experimental baking tests the result shows all criteria. Both electricity and gas modes were used in the baking trials to compare the heating system performance.

The empirical baking data provides insights into the real-world functionality and optimization of the dual-fuel oven design.

4.1 BAKING OVEN PERFORMANCE ANALYSIS

The performance analysis of the dual-fuel oven was evaluated by carrying out a no-load temperature test and an On-load temperature test. The following chart for the calibration of the thermostat was obtained for analysis.

4.2 NO LOAD TEMPERATURE OVER TIME

The no-load temperature data in Figure 3 shows. The gas heating curve has a steeper slope, indicating faster heating and preheat times. The gas reaches 250 °C in approximately 3 minutes, while the electricity is approximately about 4 minutes under no load. Early Phase (0-3 minutes), Both Electric and Gas Loads shows a similar rate of temperature increase, reaching about 200°C by the 3rd minute.

Later Phase (3-7 minutes), The Gas Load's temperature increases more rapidly than the Electric Load. By the 7th minute, the Gas Load reaches around 500°C, while the Electric Load is at about 400° though slower, provides a steady and

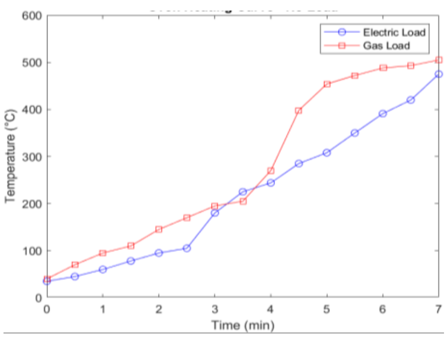
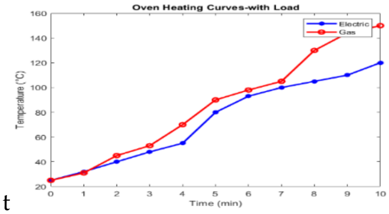


Figure 3: No Load Temperature Profile

4.3 ON–LOAD TEMPERATURE OVER TIME

With a baking load inserted in the oven cavity, the temperature profiles change significantly, as shown in Figure 4. Electric heats up faster and reaches a higher temperature of 160°C, than gas within the same 10-minute timeframe. Electricity process-controlled increase in temperature. Whereas the gas system heats up more quickly. It burns the propane to produce heat, which is then distributed through the system. The combustion process generates a lot of heat rapidly, making the gas system faster at reaching the desired temperature. (Around 140°C) by the end of the 10 minutes



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` **Figure 4:** On – Load Temperature Profile

4.4 WEIGHT LOSS DATA COMPARISON BETWEEN THE DUAL FUELS

A batch of 6 meat pies was baked using dual power. The average starting dough weight was 1 kg per,

Table 1: weight loss in the dual Oven

Electric heating:	Gas heating
Baked for 8 minutes at 120 °C *The average initial weight was 5.55 kg.* *Average weight after baking = 4.65 kg* *Weight loss = 5.55 kg – 4.65 kg = 0.9 kg* *Weight loss percentage =* $\left(\frac{0.9}{5.55}\right)kg \times 100$ *= 16.21%*	Baked for 6 minutes at 150 °C Average initial weight was 5.58 kg Average weight after baking = 4.23 kg Weight loss = 5.58 kg – 4.23 kg = 0.95 kg Weight loss percentage = $\left(\frac{0.95}{5.58}\right)kg \times 100$ = 24.2%

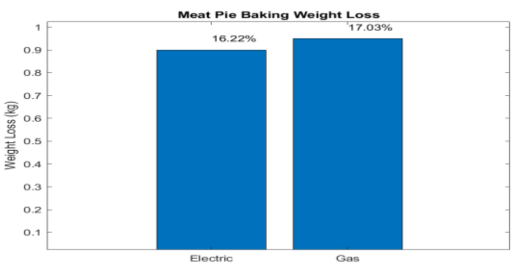

Figure 5: Weight Loss comparison between the Dual Fuels

Figure 5 provides insights into the moisture removal differences similar to that of (Ojo et al., 2021; Akinfaloye, 2018; Ologunye et al., 2020). Gas heating resulted in a 24% reduction. While faster baking can be an advantage of gas ovens, too much moisture removal can negatively impact end-product quality by causing dryness or hardening (Kutlu et al., 2022

5.0 CONCLUSION

The study successfully designed and tested a prototype mini baking oven with both electric and gas heating systems. This dual oven offers flexibility and allows users to choose between precise electric heating or high-heat gas baking for optimal results. Constructed from stainless steel and commercially available components, the oven is compact and efficient. It demonstrated the feasibility of a hybrid gas/electric system in a mini baking oven and provided detailed data on how each heating mode impacts moisture removal, browning, and overall bake quality. This helps in selecting the appropriate heating method based on the food item and desired outcomes.

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