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Performance Assessment of Dual-Powered Baking Oven Developed from Locally Sourced Materials

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Abstract: In this study, a dual-powered baking oven (electric and gas) was developed using locally available materials with the aim of investigating the performance of the constructed oven using standard test procedure. The performance of the constructed baking system was assessed by investigating the quantity of heat supplied, gas expended, moisture content and drying rate. The experimental results revealed that more heat is supplied during the baking of bread using electrical part of the system while high moisture content and drying rate was recorded during the roasting of fish using electricity. However, the highest (39.742kJ) and lowest (0.334kJ) heat supplied was obtained in the 15th and 6th minutes respectively during the baking of bread with electricity and gas respectively. Hence, it can be concluded that the use of electricity in baking or roasting is capable of enhancing an efficient and effective baking processes.

Keywords: Baking oven, temperature, time, fish, bread

1. Introduction

The growth and success of any industry depend on the quality of products and energy efficient processes [1]. However, food processing such as frying, roasting, boiling and baking are some of the most energy intensive unit operations [2]. Though, roasting and baking are considered as a universal cooking methods consisting of heating food inside an oven at a uniform temperature as a result, heat is transferred to the load mainly by means of radiation and convection [2]. Also, the demand for baked products is significantly on the increase with over 94 million tons of breads consumed each year [3]. Baking is one of the most heat sensitive processes in which the heating has a significant influence on quality (chemical, physical and sensory qualities) and cost of the final product, [3]. An oven is a thermally protected and enclosure device used for drying and heating of a substance. Baking oven is widely used appliance in food service industry [4]. However, before the invention of modern baking oven, people had adopted several methods of cooking and baking but some of these methods had led to the destruction of lives and properties [3]. According to [1,3], they have evaluated the performance of different types of oven by predicting the air temperature in an industrial biscuit baking oven and revealed that getting precise samples for specific combinations of baking load and heating methods is a necessity for optimal performance. Also, solar ovens are used in situations base on the necessity, Hence, Zeleke and Sameer [5] evaluated the performances of a double-glazed box type solar oven with three reflectors and a vapour wiper mechanism fabricated using locally available materials. The authors revealed that double-glazed box type solar oven was best suitable for domestic use and may not be appropriate for commercial purposes. Hence, there is need for researchers to developed

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alternative indigenous baking oven which is efficient, safe to use and can be applied for commercial purposes [6]. Therefore, in this study, an oven which works on dual and alternate power sources was developed by incorporating electric heating element and gas burner to the interior of the oven with the need of promoting the development of high-performing indigenous dual baking oven (gas/electric-baking oven) which incorporate a temperature regulator.

2. Materials and Methods

2.1 Materials

The material selected for this study include a mild steel (2mm metal sheet), 2mm pipe, gas burner, control valves. gas burner, control valve, electric heating element of 2.4 kW capacity, a thermostat for temperature regulation, hose (3 yards), gas cylinder (2kg), drill bits, dimmer switch, connecting wires (3 yards), rice husk, baking dish, rack and aluminium sheet. Other test equipment includes; thermometer, voltmeter, ammeter and stop watch. All materials were locally purchase from various commercial shops in Jalingo-Nigeria.

2.2 Methods

2.2.1 Design Consideration

The factors considered during the construction of the oven include; ease of assembly of the oven parts by simplifying the structure of product components, size of the oven to create interesting dynamics within a design, size and geometry of bread loaves, bread baking temperature since, may temperature since temperature may differ depending on what is being baked and the type of oven constructed, and time is taken to bake the bread loaves and fish since baking time depends variables such as ingredients used, pan size, height and size of the oven, and type of oven used. In addition, size and geometry of bread loaves was considered because heat transfer in baking is often influenced by the size and geometry of the baked product [7]. Also, in order to achieve high efficiency, reliability and cheaper method of developing the oven, the design consideration include principles of operation of the oven, convenience of operation, rate of heat transfer during baking to meet the needs and ease of producing the system. The design processes adopted in this study comprises of Mass and energy balances, design drawing**,** equipment sizing (the calculation of the size and characteristics of the oven according to process specifications), Equipment rating (the calculation and selection of the operating conditions given process specifications, equipment size and characteristics and equipment costs.

2.2.2 Design Drawings

Design drawings were carried out using AutoCAD 2019. The orthographic Design of the dual powered oven is shown in Fig. 1 while the cut away section of the oven as well as the assembly drawing (isometric view) are shown in Fig. 2 and 3 respectively.

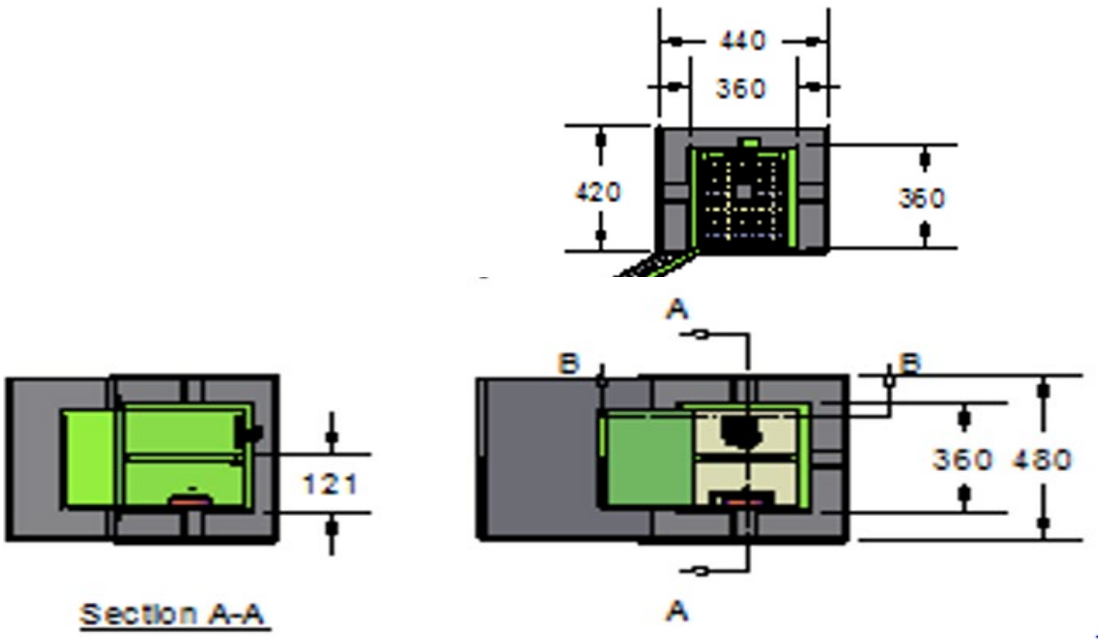

Fig. 1 - The orthographic view of the dual powered oven

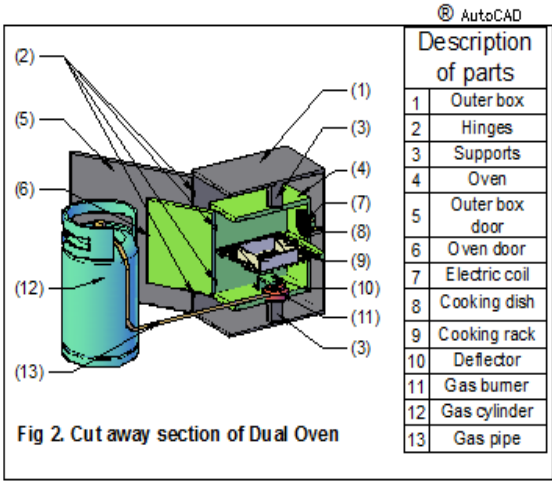

Fig. 2 - Cut away section of dual powered

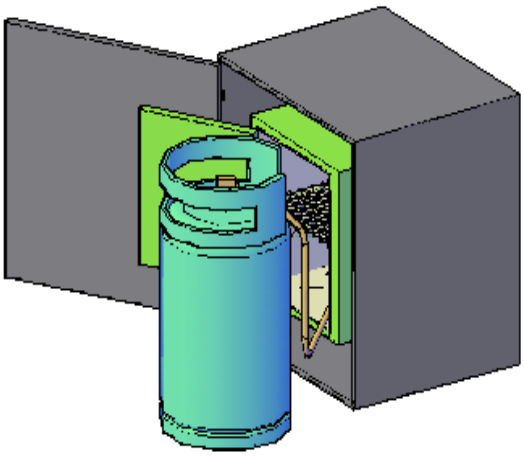

Fig. 3 - Assembly drawing (Isometric view)

2.2.3 Fabrication and Assembling of parts

The fabrication of the oven parts was conducted at the Mechanical Engineering workshop of Taraba State University. The fabrication of the oven framework was initiated by constructing the frame using locally sourced mild steel which were cut to the desired size stipulated in Fig. 1 and welded together, making provisions for the installation of other components. The square rod of mild steel material (20mm²) was clamped, measured and cut to the dimensions of 420x440x 480 mm and welded to the body frame. Thereafter, the parts were assembled together using try square and arc welding apparatus. The base of the baking chamber consisting of two partition (gas and electric) was bolted together for easy coupling and dismantling. Thereafter, a vent (20mm) was introduced at the top center for the continuous removal of the hot and humid air from the inner baking chamber during baking [8]. In the assembling of the parts of the baking oven, the gas burner was installed at the base of the baking chamber beneath the deflector plate while the heating element was attached to the side of the baking chamber close to the base of the oven. Also, external part of the oven was coated with emulsion paint, while the internal part was made of aluminum sheet. However, in between the inside and outside of the oven, rice husks and clay were used as insulating material for lagging. In addition, an electric heating element was fixed at the upper side of the baking chamber to generate heat in the baking chamber. Also, a gas cylinder, gas tap, hose and control valve were thereafter installed in the system as an alternative source of power when there is no electric power supply. In the installation of the gas burner, a round hose, control valve and a tap were fixed properly while the thermostat (0-300ºC), power switch and indicator light were fitted using nuts and bolts. To eliminate contours and irregular areas on the body of the oven, grinding machine was used and thereafter, painted with black colour paint. The operating temperature of the oven is 110^{O} C-300^{O} C. The assembled parts of the baking oven are shown in Fig. 4.

(a) Inner view of the baking oven

(b) Outer view of the baking oven

(c) Baking oven with test sample

Fig. 4 - Constructed dual-powered baking oven

2.2.4 Performance Evaluation

Performance evaluation of the developed oven was carried out using fresh fish and bread. Experiment was performed at different temperature and time interval of three (3) minutes using three test specimens each from fish and bread. Thereafter, the maximum temperature (250°C) of the oven was divided into 5 in order to get the calibrated mark for the thermostat. Hence, experiments were conducted for each of the calibrated thermostats while measurements were taken with respect to the corresponding temperature and time-taken for particular turning level of the thermostat knob. For each test sample, experiment was conducted at 3 minutes' interval by recording the weight of test sample and temperature of oven chamber. The baked samples are shown in Fig. 5. In addition, the results obtained were used to determine the drying rate (Eqn. 1) and moisture content (Eqn. 2) of test samples.

(a) Baked fish

(b) Baked bread

Fig. 5 - Experimental test samples

$$\text{Drying Rate} = \frac{m_w - m_d}{t} \quad (1)$$

$$\% \text{ Moisture Content} = \frac{m_w - m_d}{m_w} \times 100 \quad (2)$$

Where,

m_w = mass of wet sample (g)

m_d = mass of dried baked sample (g)

t = drying time (hours)

Also, the quantity of heat required (Q) to bake bread or fish was calculated using Eqn. 3 while the mass (M_g) of gas used for baking or roasting fish was calculated using Eqn. 4. However, the change in baking temperature was calculated using Equ. 5.

$$Q = M_b \text{ x } C_b \text{ x } \Delta T \quad (3)$$

$$M_g = M_f - M_c \quad (4)$$

$$\Delta T = T_2 - T_1 \quad (5)$$

Where;

ΔT= change in baking temperature, T_2 and T_2 = temperature of oven before and after three minutes of baking respectively, M_b = Mass of fish or bread and C_b = Specific heat capacity of fish or bread. M_f =Mass of gas cylinder after use and M_c = Mass of gas cylinder before use. According to [9], the C_b for fresh fish = 3.6kJ/kg^{o}C and C_b for bread = 2.72kJ/kg^{o}C.

3. Results and Discussion

The experimental results for the performance assessment of the developed dual-powered baking oven using bread and fish is presented in Table 1-4. The highest heat supplied (39.742kJ) was obtained in the 15th minutes during the baking of bread with electricity while the lowest heat supplied (0.334kJ) was achieved in the 6th minutes during the baking of bread with gas. This results are represented in Fig. 6-8. Based on the results presented in Fig. 6, it can be revealed that more heat was supplied to the baking oven during the baking of bread with electricity compared to when gas was used and vice versa. In addition, Fig. 7 and 8 showed that higher moisture content and drying rate was recorded using electricity compared to using gas as source of power. However, high moisture content and drying rate was recorded during the roasting of fish with electricity. In addition, more gas was expended during the baking of the bread compared to the roasting of the fish. This may be attributed to the weight differences between the two experimental samples.

Table 1 - Experimental results for bread baking using gas

Run	Time (mins)	Sample weight M_b (g)	Oven temperature T_1 (^{o}C)	ΔT (^{o}C)	Quantity of heat (kJ)	Mass of gas used (g)	Moisture content (%)	Drying rate (g/mins)
1	0.00	413.60	34.70	-	0	0.00	-	0.000
2	3.00	412.10	37.70	3.00	3.367	11.10	0.363	0.500
3	6.00	409.27	38.00	0.30	0.334	11.20	0.687	0.472
4	9.00	402.00	42.50	4.50	4.921	11.60	1.776	0.808
5	12.00	400.00	51.20	8.70	9.466	10.80	0.498	0.167
6	15.00	393.00	61.70	10.5	11.22	11.50	1.750	0.467

Table 2 - Experimental results for fish roasting using gas

Run	Time (mins)	Sample weight M_b (g)	Oven temperature (^{o}C)	ΔT (^{o}C)	Quantity of heat (kJ)	Mass of gas used (g)	Moisture content (%)	Drying rate (g/mins)
1	0.00	291.93	32.11	-	0.000	0.00	-	0.000
2	3.00	287.81	35.89	3.78	2.959	9.80	1.411	1.373
3	6.00	276.18	37.23	1.34	1.007	9.90	4.041	1.938
4	9.00	241.31	47.11	9.88	6.485	10.10	12.626	3.874

5	12.00	223.71	52.72	5.61	3.414	10.40	7.294	1.467
6	15.00	217.22	59.33	6.61	3.905	10.20	2.901	0.433

Table 3 - Experimental results for bread baking using electricity

Run	Time (mins)	Sample weight M_b (g)	Oven temperature (°C)	ΔT (oC)	Quantity of heat supplied (kJ)	Moisture content (%)	Drying rate (g/mins)
1	0.00	391.20	96.10	-	0.0000		0.000
2	3.00	387.50	107.20	11.1	11.699	0.946	1.233
3	6.00	376.00	127.30	20.1	20.557	2.968	1.917
4	9.00	364.90	153.90	26.6	26.401	2.952	1.233
5	12.00	353.00	183.10	29.2	28.037	3.261	0.992
6	15.00	344.60	225.50	42.4	39.742	2.380	0.560

Table 4 - Experimental results for fish roasting using electricity

Run	Time (mins)	Sample weight Mb (g)	Oven temperature (°C)	ΔT (oC)	Quantity of heat supplied (kJ)	Moisture content (%)	Drying rate (g/mins)
1	0.00	292.90	49.99	-	0.000		0.000
2	3.00	254.90	58.21	8.22	7.543	12.974	12.667
3	6.00	172.10	66.72	8.51	5.272	32.483	13.800
4	9.00	122.90	73.35	6.63	2.933	28.588	5.467
5	12.00	97.33	82.17	8.82	3.090	20.806	2.131
6	15.00	72.47	91.81	9.64	2.515	25.542	1.657

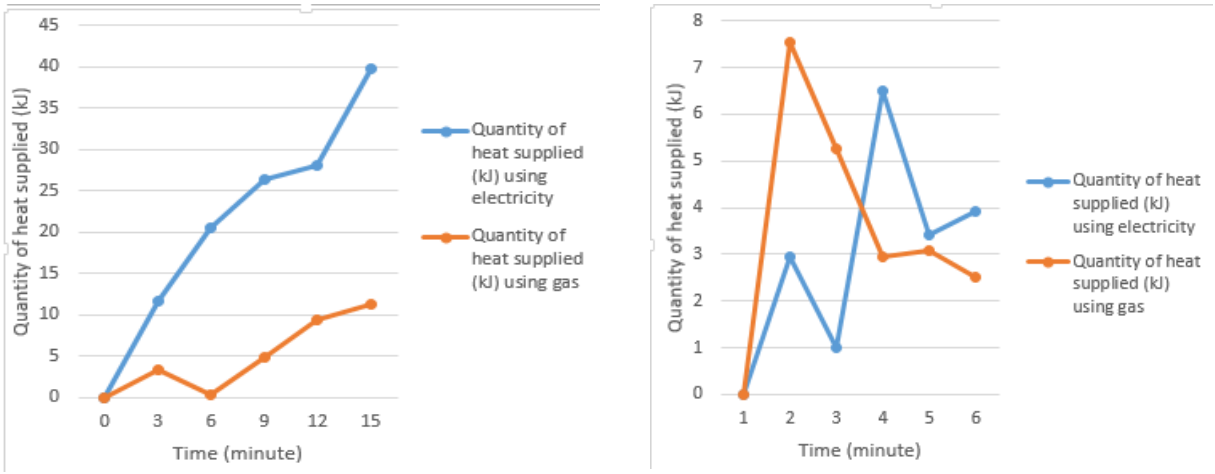

Fig. 6 - Quantity of heat supplied in (a) baking bread; (b) roasting fish

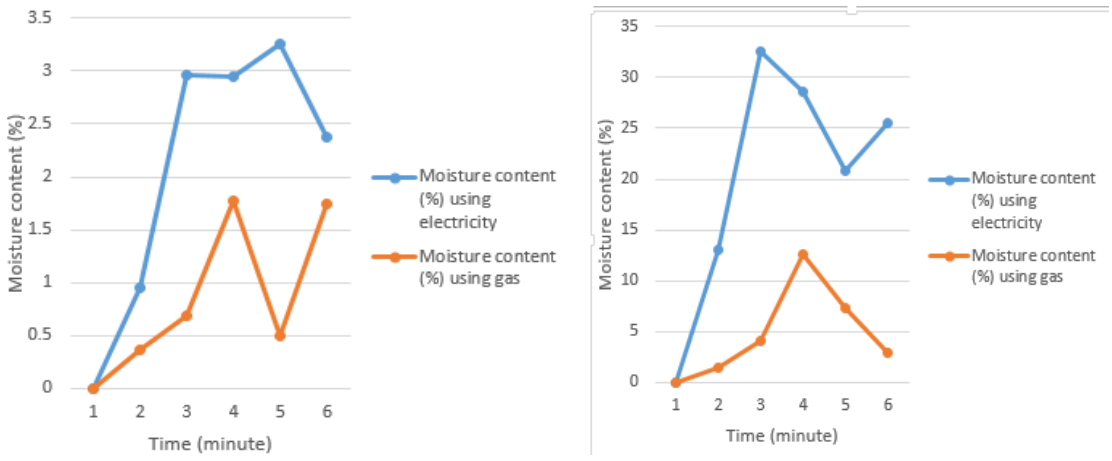

Fig. 7 - Moisture content in (a) baking bread; (b) roasting fish

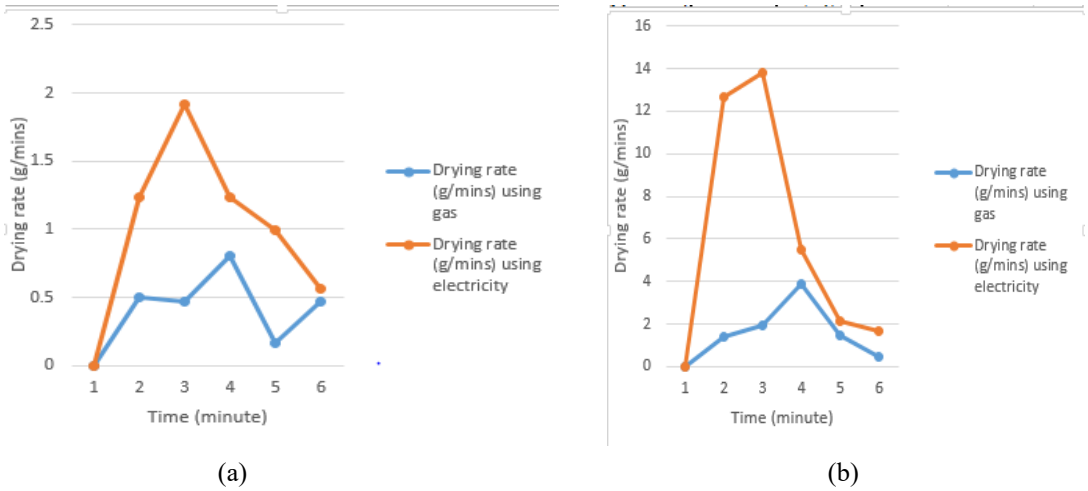

Fig. 8 - Drying rate in (a) baking bread; (b) roasting fish

4. Conclusion

Baking is one of the most heat sensitive processes in which the heating has a significant influence on quality (chemical, physical and sensory qualities) and cost of the final product. In this study, a dual powered baking oven has been developed from locally sourced materials and the performance was evaluated. Based on the results obtained, the following conclusions can be drawn;

i. More heat is supplied during the baking of bread using electrical part of the system while high moisture content and drying rate was recorded during the roasting of fish using electricity.

ii. The highest heat supplied (39.742kJ) was obtained in the 15th minutes during the baking of bread with electricity while the lowest heat supplied (0.334kJ) was achieved in the 6th minutes during the baking of bread with gas

iii. Higher volume of gas was expended during the baking of the bread compared to the roasting of the fish. Hence, weight difference affects the quantity of gas expended during baking processes.

iv. The mass of the test samples reduces as baking time increases and vice versa.

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