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**Original Research Article**

# DEVELOPMENT OF A LOW COST DUAL ELECTRIC/SOLAR OVEN FROM LOCALLY AVAILABLE MATERIALS

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**ABSTRACT**

*In this study, a low cost cooking oven capable of using electric and solar energy was developed from locally available materials. The effectiveness of each compartment of the oven was tested with respect to the source of energy, temperature and time taken to bake a sample of food item. The result showed that as the temperature increases, the food takes lesser time to dehydrate and bake.*

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## 1. INTRODUCTION

Baking is the oldest and most popular food processing technique that uses the prolonged dry heating by convection (Adegbola et al., 2012). It is a complex simultaneous heat and mass transfer process commonly applied in food industries. A baking oven is one of the most widely used appliances in food service industry (Ozilgen and Heil, 1994). An oven can be simply described as a fully enclosed thermally insulated chamber use for the heating, baking or drying of a substance. In a baking oven, the hot air flows over the baking material either by natural or forced convection (Mercer, 2014). The moisture in the food material simultaneously diffuses toward the food surfaces, then, it transfers from the surface by convection. The material being baked thus loses moisture with the continuous movement of the ambient air in the oven. Commercially, ovens are available in various configurations and examples include electric ovens, microwave ovens and wood ovens etc. (Genitha et al., 2014).

Drying and baking of food are major recurrent food processing activities in Nigeria which have been done in various forms. These include the traditional outdoor wood drying which is characterized by carbon emission, extended drying time, and lack of hygiene (Shaw, 2005). The need to reduce greenhouse gas emissions all over the world has necessitated the need to develop baking devices as the electric oven which is electrically powered with no fossil gas emission. One of the major energy sources of Nigeria is electricity, however, the epileptic nature of electric power supply in Nigeria has made the use of electricity for powering cooking equipment almost impossible (Genitha et al., 2014). The need for the use of renewable source of energy has become highly necessary to mitigate these shortcomings; hence the shift towards the utilization of energy sources like solar energy which do not have adverse effect on the environment.

The aim of this study was to use locally available materials to construct an oven which is simple to operate and uses electric and solar energy.

## 2. MATERIALS AND METHODS

### 2.1. Material of Construction

Following a careful review of the concepts and design of the dual electric/solar oven, the following materials were used for its fabrication; sheet metal, paint, angle bar and rods, regulator, insulator (used fibre glass), rivets and screws, blower (fan), heating element, indicator lights, glass (transparent).

### 2.2. Proposed Design

The electric oven consisted of a structural frame made of 2inch rectangular pipe to which galvanized mild steel plate of 2 mm gauge was wrapped and firmly welded externally and internally to form a void between the widths of the rectangular pipe. The void was filled with an insulator material (fiber glass) to prevent heat loss from the oven to the external environment. The oven consisted of two compartments. The upper compartment is solar powered and consisted of an absorbing thick glass which collects the incident sun rays and impinges them on a black perforated absorbing plate placed underneath the glass. The lower compartment is electrically powered and consisted of heating elements and food holding plates. A thermostat was included for temperature regulation. A fan was included in the upper compartment to cause a forced draft of air through the black plate perforators to enhance the convective and uniform heat supply. A natural draft is created through the incorporation of chimney holes made of 1 inch pipe. Figure 1 shows the proposed design.

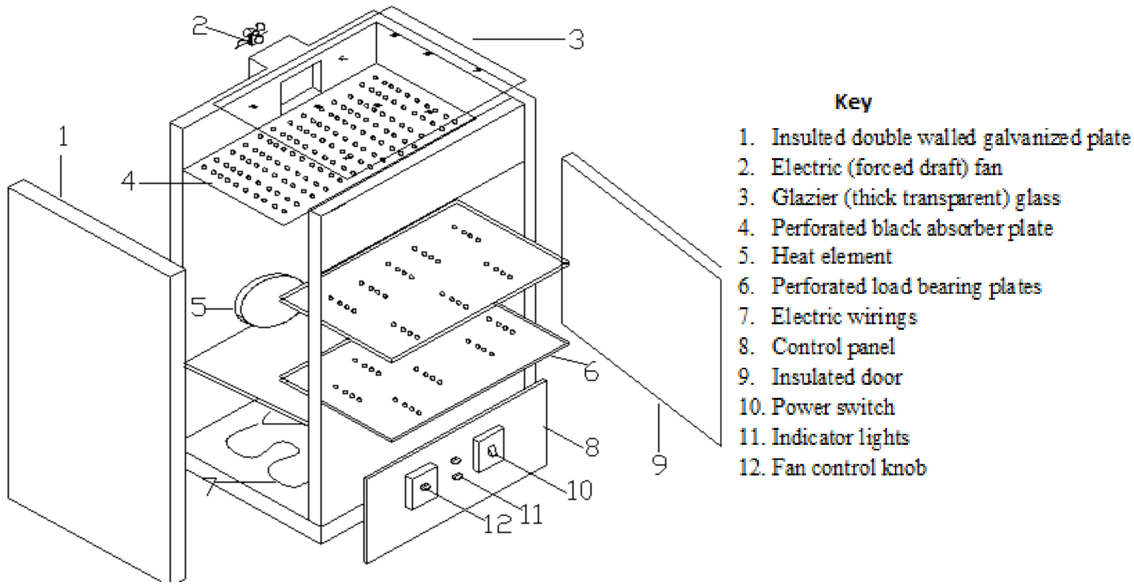


**Figure 1:** Isometric drawing of the oven (ssembly of components)

## 2.3. Design Calculations

### 2.3.1. The sheet metal casing estimation

This is the main sheet metal covering of the oven consisting of the internal and external face of the oven. From existing design we assume the following dimensions (Adegbola et al. 2012):

Dimensions of outer box = 35cm by 30cm by 25cm
Dimensions of inner box = 25cm by 22cm by 17cm
Therefore total surface area (TSA) of sheet material was obtained as the sum of the TSA of outer box and that of the inner box as shown in Equation (1).

$$= (2lh + 2lw + hw)_o + (2lh + 2lw + hw)_i \tag{1}$$

Where l= length, h = height, w = width, o = outer, i = inner

$$= [2(35\times30) + 2(35\times25) + 2(30\times25)] + [2(25\times22) + 2(35\times17) + 2(22\times17)]$$

i.e TSA $= [2100 + 1750 + 1500] + [1100 + 1190 + 748] = 8388cm^2$

### 2.3.2. Baking power

This is defined as the rate of useful energy available for baking during heating period. It may be determined as a product of the change in water temperature for each interval and mass and specific heat capacity of the water contained in the baking (Carvalho et al., 1993). It was computed using Equation (2) (Okafor, 2014).

$$P = (M_w C_w)\left(\frac{T_{wb} - T_{wa}}{\gamma_{ab}}\right) \quad (2)$$

Where:

M = mass of water (kg)
C = specific heat capacity of water J/(kgK)
$T_{wb}$ = initial temperature of water (K)
$T_{wa}$ = final temperature of water (K)
$\Upsilon_{ab}$ = time duration (s)

### 2.3.3. Heat transfer analysis

The heat transfer in the oven was analyzed by considering the conduction, convection and radiation heat transfer which occur independently or simultaneously in the system (Ozilgen and Heil, 1994).

#### 2.3.3.1. *Conductive heat transfer*

This is mathematically expressed as:

$$Q = \left(\frac{KA\Delta T}{\Delta X}\right) \quad (3)$$

Q = the rate of heat flows in Kw (kJ/s)
K = Thermal conductivity of the material (W/mK)
$\Delta T$ = Temperature difference between the surfaces of metal (K)
$\Delta X$ = Thickness of the material (m)
A = Area of the section at right angle ($m^2$)

#### 2.3.3.2. *Convective heat transfer*

This is mathematically, expressed as (Ozilgen and Heil, 1994):

$$Q = LA(T_2 - T_2) \quad (4)$$

Where:

L = Coefficient of convective heat transfer W/($m^2$.K)
A = Area of surfaces not perpendicular to direction of heat flow ($m^2$)
$T_2 - T_1$ = change in temperature (K)

The rate at which heat is transferred across the enclosed space (oven) is calculated from Equation (4).

#### 2.3.3.3. Radiation heat transfer

The total heat flux via radiation throughout the internal surface of the oven and absolute temperature T is given by the Stefan- Boltzman law (Okafor, 2014).

$$Q = A\sigma T^4 \quad (5)$$

Where:

Q = Heat flux, (J/s)
$\sigma$ = Stefan Boltzman constant = 5.6703 $10^{-8}$($W/m^2K^4$)
A = Area of the emitting body ($m^2$)

T = absolute temperature (K)

**2.3.3.4.** ***Energy conservation within the system***

The energy conservation within the system is given by Equation (6) (Solihin and Wisnoe, 2014).

$$mc\Delta T = hA\Delta t(T_1 - T_\infty) + \frac{kA\Delta s}{L}(T_1 - T_\infty) + A\sigma T^4 \quad (6)$$

Where:

M = mass of the heating element (kg)
C = specific heat capacity J/(kgK)
K = Thermal conductivity of the material (W/mK)
A = Area of surfaces not perpendicular to direction of heat flow ($m^2$)
L = Coefficient of convective heat transfer W/($m^2$K)
$\Delta s$ = change in entropy (J/K)
$\Delta T$ = change in temperature (K)
*h*= specific enthalpy (J/kg)

Assuming that the system is perfectly insulated and there are no losses due to conduction in the system, Equation (6) will be a total energy conversion from electrical to heat, hence Equation 7 is obtained i.e Heat generated = electric power generated

$$mC_p\Delta T = IV \quad (7)$$

Where:

I = current (A)
V = voltage (V)

**2.3.3.5.** ***Energy losses***

Considering the energy balance for the oven heat system, ideally, the heat losses can be represented in terms of temperature change of the sample (Solihin and Wisnoe, 2014), energy into the sample, conductive losses, radiation and convective losses as shown in Equation (8)

$$mC_p(T - T_\infty) - \frac{kA\Delta s}{L}(T - T_\infty) - h_{air}A\Delta t(T - T_\infty) - A\sigma T^4 = 0 \quad (8)$$

**2.3.3.6.** ***Concentration factor***

Where reflecting mirrors are incorporated, the concentration factor (CF) can be defined as the ratio of sum of the projections of the mirrors on the plane of the concentrator and the width of the aperture of the cooker to the width of the absorber (Solihin and Wisnoe, 2014). This is presented in Equation (9).

$$CF = \frac{D' + W_1\cos(\alpha_1 + \phi) + W_2\cos(\alpha_2 - \phi)}{D} \quad (9)$$

Where:

$D'$ = width of the aperture of the cooker (m)
D = width of the absorber (m)

$W_1$ = focal distance for mirror 1 (m)
$W_2$ = focal distance for mirror 2 (m)
$\alpha$ = receptor angle
$\phi$ = aperture angle

## 2.4. Construction of Oven

The various manufacturing method utilized in the production of the machine setup include the followings; cutting and pairing, milling and machining, boring, welding and painting.

## 2.5 Performance Evaluation

The performance of the oven was evaluated by using it to process some food items such as cake, egg, fish etc. The performance test was carried out using each of the compartment of the oven and their sources of energy. Measurements were taken with respect to the temperature and time-taken for the food items to get properly processed.

# 3. RESULTS AND DISCUSSION

Results of the experiment will aid in the calibration of timer for processing various food items. The timer was set to specific temperature value and the food item was put into the oven. The machine was switched on while the timer was set to the expected marked point gradually. At intervals of time in minutes, the food item was check and tested. The following results as shown in Tables 1, 2 and 3 were obtained during the various experiments conducted.

**Table 1:** Time-taken and temperature attained by the electric baking oven for an egg roll

| Experiments | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Time (minutes) | 50 | 37 | 25 | 20 | 13 |
| Temperature (°C) | 120 | 150 | 170 | 200 | 230 |

**Table 2:** Time-taken and temperature attained by the electric baking oven for a fish

| Experiments | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Time (minutes) | 35 | 30 | 24 | 18 | 13 |
| Temperature (°C) | 120 | 150 | 170 | 200 | 230 |

**Table 3:** Time-taken and temperature attained by the electric baking oven for a piece of meat

| Experiments | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Time (minutes) | 50 | 37 | 25 | 20 | 13 |
| Temperature (°C) | 120 | 150 | 170 | 200 | 230 |

Though different food items have their varying moisture content and hence time to bake, it is however a general deduction from the tables that as time and temperature increases the food takes lesser time to dehydrate and bake. After the oven has been tested, it was realized that it is efficient and fast, it does not blacken the baking pan and it is pollution free.

Food items consisting of noodles, eggrolls etc were put in a container ware and were inserted into the solar compartment and cooked. The oven is placed and directed towards the sun ray of highest intensity at various times for maximum heat collection. The temperature of the food was taken at different times between the hours of exposure to the sun and the temperatures were plotted against time for the time duration of the experiment. Peak and lowest temperatures were also noted and recorded. The time for the various food items to get cooked is also noted. The table 4 shows results of the observation from the experiment.

The experimental results obtained from the thermal performance tests carried out show that the box type solar cooker employing a non-tracking solar concentrator could provide improved heat collection and, hence efficient cooking. The cooker offers advantages of faster cooking and hence reducing the cooking time considerably.

## 4. CONCLUSION

The research outlined in this work was completed to help achieve the goal of developing an affordable, thermal storage solar cooking system that can be used in Nigeria and other developing countries.

## 5. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

## REFERENCES

Adegbola, A.A., Adogbeji, O.V, Abiodun, O. and Olaoluwa S. (2012), Design construction and performance evaluation of low cost electric baking oven, *Innovative Systems Design and Engineering*, 11(3), pp. 2222-2217

Carvalho, M. G. and Martins, N. (1992). Mathematical modelling of heat and mass transfer in a forced convection baking oven. In: *AIChE Symposium Series* (Vol. 88, pp. 205-205). American Institute of Chemical Engineers.

Genitha, I., Lakshmana, G.B.T. and John, D.R. (2014), Design Fabrication and Performance Evaluation of Domestic Gas Oven. *IOSR Journal of Engineering (IOSRJEN),* 4(5), pp. 35-38

Mercer, M. D. (2014). Design, fabrication and analysis of thermal storage solar cooker prototype for use in Rajasthan, India*. Masters Thesis, University of Iowa Iowa Research.*

Okafor, B.E. (2014). Simple Design of a Dual-Powered Domestic Oven. *International Journal of Engineering and Technology*, 4(5), pp. 313-317.

Ozilgen, M. and Heil, J.R. (1994). Mathematical modelling of transient heat and mass transport in a baking process. *Journal of Food Processing and Preservation,* 18(2), pp. 133–148.

Shahzad, A., Kanwal, T. and Mao-Gang, H. (2013). Design and development of efficient domestic electric cum solar oven. *Journal of Basic and Applied Sciences*, 9(3), pp. 296-300.

Shaw, S. (2002). Development of a comparative framework for evaluating the performance of solar cooking devices. *Combining Ergonomic, Thermal and Qualitative Data into an Understandable, Reproducible and Rigorous Testing Method, NY, USA*, 1-53.

Solihin, Z.H. and Wisnoe, W. (2014). An experimental metal material as heat absorbent material in the solar oven. *International Journal of Latest Research in Science and Technology,* 3(4), pp. 224-227.