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Simple Design of a Dual-Powered Domestic Oven

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ABSTRACT

Due to irregular power supply common in developing countries, as well as growing high cost of hydrocarbon, the need arises for the development of a dual energy source that uses both electricity and gas for heating oven chambers. The dual-powered oven is a combination of components that make possible the use of alternative heat sources. The upper chamber is powered by electricity whilst the lower chamber works for the supply of gas located outside the chamber as a heat source. In the upper chamber is a heating element that generates and dissipates heat within the enclosure. The element is connected to a thermostat that regulates the rate of heat generation in the system. Cooking gas is supplied to the burner located in the lower chamber of the oven via a pipe connection to the gas cylinder. Perforations allow for heat dissipation within the lower chamber. The performance test gave oven efficiency of 95.2 per cent. The oven can be adapted for both domestic and industrial purposes and have been found very useful in bakery industries.

Keywords*: Oven, Electric, Gas, Thermostat, Heating element, Burner***.**

1. INTRODUCTION

An oven is a thermally insulated enclosure used for heating, baking or drying of a substance. Firewood and smoked dry charcoal had been used on open bricks by early man but could no longer meet the need of the growing world population. Furthermore the issue of environmental safety has become most important to the modern man. Earlier improvements on wood burning stoves were primarily to contain the bothersome smoke being emitted. Fire chambers were invented that contained the fire woods, and holes were provided on top were cooking lots with flat bottoms could be placed. The first cast iron oven was of German design. The Rumford oven was specifically designed for very large kitchens (Rumford, 1728). It had one fire source that could heat several cooking pots, with the cooking level of each pot being regulated individually. The Rumford design was however considered too large for an average kitchen.

Cast iron oven continued to evolve with iron gratings added to the cooling holes and with added chimneys and connecting flue pipes. The British inventor, James sharp was the first to patent a gas oven in 1826 and by 1920, gas ovens were found in most house-holds with top burners and interior ovens. By 1910, gas stoves appeared with enamel coatings that made it easier to clean. One important gas design of note was the AGA cooker invented by the Swedish Noble Price Winner, Gustaf Dalen. In 1896 William Hadawy got the first patent for an electric oven and by 1910 had designed the first electric toaster oven – a horizontal combination toaster cooker. A major improvement in electric ovens was the invention of resistor heating elements.

Modern ovens are fuelled by gas or electricity and are commonly used for baking and roasting. Conventional ovens have a simple thermostat which puts the oven on and off and thereby regulates its operating temperature. A timer may allow the oven to be turned on and off automatically of pre-set times. Solar ovens are used in situations varying in necessity. Energy from the sun is harnessed and used in heating and cooking. In this case, solar energy is reflected into the cavity of the oven with a glass door or lid, keeping heat to enable a rapid rise in temperature. Solar oven is however best adapted for domestic use and may not be suited for commercial purposes. Today electric oven readily provides dry-heat for sterilization. But constant supply of electricity is necessary in order to supply heat energy to the oven on regular basis through electric heating elements usually connected inside the oven chamber.

Understanding The Baking Process

The design of an oven is principally a matter of heat transfer and its control. Heat and temperature are not the same and should not be confused. It is relatively easy to measure temperature in an oven, but much more difficult to measure heat or heat flux (rate at which heat is being transferred). Heat is transferred much more effectively if the air is moving near the dough piece at a given temperature.

Today nearly all kinds of biscuits are baked in band or travelling ovens with several independently controlled zones. This means that oven conditions such as temperature and humidity may be altered during baking period. Baking times for biscuits are usually quite short , 2.5 ~ 15 minutes (www.thebiscuitdoctor.com). It is not normally possible or easy to change the temperature of a static or reel such that the results of baking in these ovens compared with those in travelling ovens are quite different. The conditions needed for different types of biscuit are usually not the same because the desired texture and the amount of moisture to be removed depend on the richness or level of fat and sugar in the recipe.

The dough piece undergoes four major changes which can be observed during baking.

(1) A large reduction in product density as the dough gets thicker, associated with the development of an open porous or flaky structure.

(2) A change of shape associated with shrinkage or spread and increase of thickness.

(3) A reduction in moisture level to between 1 ~ 4%.

(4) A change in surface colouration (reflectance).

An oven can be regarded as a hot box designed to provide the necessary conditions of heat and temperature to the dough pieces and to allow adequate removal of moisture. The heat is usually provided through burning of fuel such as wood (wood-fired oven), gas (gas-fired oven), oil or electricity and the heat generated is transferred by the three modes of radiation, conduction and convection. Oven design is thus determined by the constraints associated in providing efficient heat transfer, allow rapid and precise temperature control under varying load conditions and to transfer heat in predominately one of the three modes required. All ovens fall short in one respect or another.

In general, oven temperature varies according to ingredients used to make the bread. Leaner breads (made with flour, water and yeast) are usually baked at 400 ~ 425ºC. Richer breads (made with more fat and eggs) are baked at lower temperatures (www.tasteofhome.com). Breads made with less quantity of sugar (less than ½ cup of sugar) are generally baked at 375ºC and breads with more sugar content are baked at 350ºC. A loaf of bread can bake from 25 ~ 45 minutes. The baking time however, depends on the size and shape of the loaf as well as the temperature of the oven.

2. PRELIMINARY DESIGN

Figure 2.1 shows the assembly view of the dual powered oven and Fig. 2.2 shows the orthographic view. Table 2.1 gives the component parts of the oven.

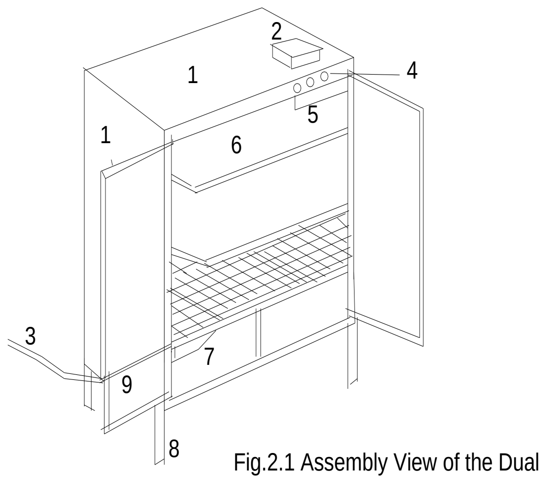

Fig.2.1 Assembly View of the Dual Powered Oven

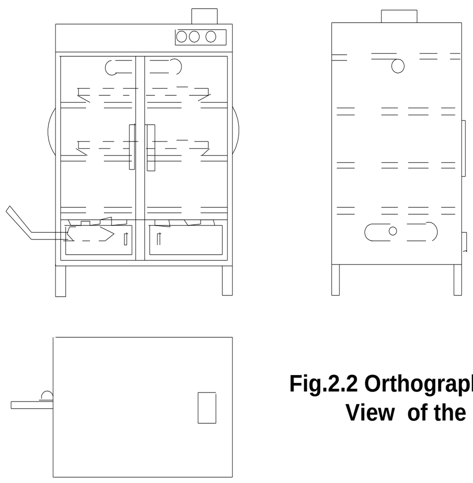

Fig.2.2 Orthographic View of the Oven

Table 2.1 Component Parts of the Oven

S/N	Component	Number of Items
1	Body Casing	5
2	Thermostat	1
3	Gas Hose	1
4	Power Switch	1
5	Heating Element	1
6	Tray	2
7	Gas Burner	1
8	Support Stand	4
9	Doors	4

2.1 Description

The oven is a combination of units and components that make possible the use of two alternative heat sources, namely electric and gas. The body is made of well coated mild steel while the internal surface is made of galvanized sheet owing to its resistance to rust or corrosion and does not contaminate the food substance in process. Fibre glass (rock wool) is stuffed in-between the mild steel and galvanized sheet and which acts to prevent loss of heat (insulation). Fibre glass is known to have light weight, high strength and high thermal shock resistance characteristics. The oven supports have rollers for easy movement and to absorb shock as well as sustain weight of the oven. At the upper chamber is a voltage indicator consisting of green and red bulbs. The former indicates the presence of electricity and the latter indicates when the oven is in operation.

The oven has two door chambers. The upper chamber uses electricity while the lower chamber uses cooking gas as heat source, respectively. Inside the upper chamber is a heating element incorporated with a thermostat to regulate the rate of heat generation in the system. Wire mesh is welded to provide the required base or support for the baking trays. In the lower chamber of the oven is a gas burner connected by means of suitable hose to the gas cylinder located outside the oven. Perforations created just below the burner allow for heat dissipation.

2.2 Principle of Operation

The electric oven works on the principle of electric resistance. The resistance to current flow causes the heating element to be heated up. The voltage indicator shows a green light confirming the presence of current. As soon as the switch is turned on, the indicator shows red indicating that the oven is in operation. Heat generated by the heating element is dissipated within the oven chamber and by convection, is transferred to the metal pans placed on the wire mesh. Since the food substance is in direct contact with the pans, greater heat is transferred to the dough mainly by conduction. The thermostat regulates current flow to the heating element in order to prevent excess heat and avoid burning or over- roasting.

In case of power failure, the oven is disconnected from power source and the gas is used as an alternative heat source. The gas oven works on a similar principle, but uses a burner in place of an electric coil to heat the chamber. The gas burner is activated by turning on the temperature knob. Gas flows to the gas burner and is ignited by a lighter. Heat energy is caused to escape through holes created just below the burner and circulates round the oven chamber. The same modes of heat transfer are replicated. A thermostat is also incorporated to control the heat generation by regulating gas flow.

3. DESIGN ANALYSIS

3.1 Capacity of the Oven

The capacity is in terms of the number of loaves of bread the oven can process per batch.

Average mass of a loaf of bread = 0.5kg

Size of tray = 750 mm (length) x 500 mm (width)

= 375,000 mm^2

Size of loaf of bread considered = 200 mm (length) x 100 mm (width) = 20,000 mm^2

Capacity of Oven = Size of tray / Size of bread = 375,000 / 20,000 = 19 Loaves of bread per batch

3.2 Electric Energy Requirement

Average baking (oven) temperature = 350° C = 673K

Let, M_b = Mass of loaf of bread, 500g

C_b = Specific heat capacity of bread,

2900J/kgK (Vogel, 2005)

T_{RM} = Oven room temperature, 28°C = 301K

Heat required, $Q_H = M_b \times C_b \times T_{RM}$

Q_H = 0.5 kg x 19 x 2900J/kgK x (623 – 301)

K = **8871100 Joules**

This is the quantity of heat required to bake 19 loaves of bread per batch.

3.3 Capacity of Electric Heating Element

Power of Electric Heating Element, P = Rate of expenditure of energy = Energy / Time

Let average processing time per dough batch = 40 minutes (www.tasteofhome.com)

Quantity of heat supplied to the oven chamber = 8871100 Joules

Considering 80% heat transfer to the dough;

Heat = 1.2 x 8871100 = 10645320 Joules

This means that the heating element should supply a minimum of 10645320 Joules of heat energy to the oven chamber in 40 minutes.

Thus, Power of Heating Element = 10645320 J / 40 x 60 sec = 4435.55 J/sec. = 4435.55 W = **4.44 kW**

Thus, power of electric heating element ≥ 4.44 kW

But Power (W), P = Current (A), I x Volt (V), V (1)

(Anyakoha, 2000)

Also $P = I^2 R = V^2/R$ (2)

Where R is the electric resistance, Ohms

Work done or energy expended, W = IVt where t = time in seconds

Voltage supply (in Nigeria) = 220 ~ 240 volts

Thus from Eqn. (2), Resistance of the Heating Element, $R = V^2 / P = 240^2 / 4435.55$ = **13 Ω**

From Eqn. (1), Current, I = P / V = 4435.55 / 240 = **18 A**

3.4 Energy Requirement (Cooking Gas, Methane)

The combustion reaction of methane is given by;

CH_4 (g) + $2O_2$ (g) → CO_2 (g) + $2H_2O$ (g) + Heat (kJ)

But heat of formation of water vapour;

2H (g) + O (g) → H_2O (g) --------- 241.8 kJ (Vogel, 2005)

Heat of formation of Carbon IV Oxide;

C (s) + O_2 (g) → CO_2 (g) -------- 393.5 kJ

Also heat of combustion of methane = 74.8 kJ

Thus, Total Heat involved in the combustion reaction of methane is:

(Heat of formation of CO_2 + 2 x Heat of formation of H_2O) – (Heat of combustion of CH_4 +

2 x Heat of combustion of O_2) =

-393.5kJ + 2 x (-241.8kJ) – (-74.8kJ + 2 x 0kJ) = **- 802.3 kJ**

Thus, total heat involved in the combustion reaction of methane is **-802.3 kJ** (note that the negative sign indicates that the reaction emits heat to the environment, i.e. exothermic reaction).

4. PERFORMANCE TEST

The efficiency of an oven may be defined in terms of the time taken to bake a batch of dough to the desired taste, colour, texture and moisture content. The performance test shows that it took approximately 42 minutes to bake a batch of dough to the desired quality.

- Design baking time - 40 minutes
- Actual baking time – 42 minutes

Baking efficiency, η = (40/42) x 100 = 95.2%

Different sizes of dough were baked to examine the effect of dough size on baking time. Figure 4.1 shows the result obtained.

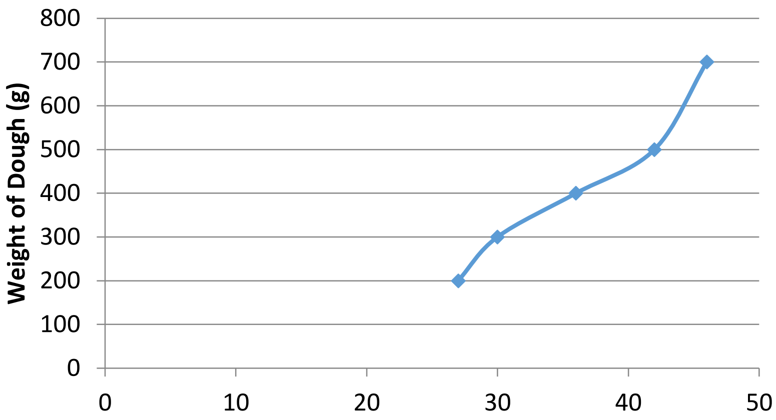

Fig.4.1 Size of Dough Vs Baking Time

5. DISCUSSION

There is observed sharp increase in baking time as the weight of dough increases. This is quite understandable since as the dough size increases more time is needed for sensible heat to penetrate the dough. It is further observed that there is less marginal increase in baking time as the size of dough is increased beyond a certain point. Too much heat will burn the dough whilst leaving the inside undone. In industrial (large) ovens, baking time can be improved a great deal by introducing forced air to increase heat flux within the system.
The high efficiency record of 95.2% can be attributed to the 20 per cent allowance for sensible heat transfer considered in the design.

REFERENCES

[1] Anyakoha,W. (2000). New School Physics for Secondary Schools. Africana First Publisher Limited, Ibadan.

[2] Hadawy, W. (1910). Design of the First Toaster Cooker. Wiki.answers.com>Answers.com.

[3] Rumford, C. (1728). First Oven of German Design (a.k.a Jamb Stoves). www.inventors.about.com/oven.htm.

[4] Sharp, J. (1826). First Semi-Successful Gas Oven. www.rangemaster.co.uk/

[5] Vogel, A.I. (2005). Textbook of Practical Organic Chemistry. 3rd Edition. www.bookboon.com/en/chemistry-ebooks.

[6] www.tasteofhome.com/cooking-Tips/Bread www.thebiscuitdoctor.com/manufacture