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Design and Development of a Domestic Biscuit Cabinet Tray Dryer

Abiola Olufemi Ajayeoba [1] Samson Olusegun Fatukasi [2] Olawale Waliyi Awotunde [3]

[1]Mechanical Engineering Department, Ladoke Akintola University of Technology,

P.M.B. 4000, Ogbomoso, Nigeria.

[2,3]Mechanical Engineering Department Osun State Polytechnic, P. M. B. 301, Iree, Nigeria

Abstract
A locally made biscuit cabinet dryer to be operated in homes was designed and developed to prepare biscuits in Nigeria homes. A thorough study of the imported dryer for home use was done. Design drawings and calculations were established and the machine was fabricated with well selected materials and components all sourced locally. The 714mm x 574mm x 984mm box shaped cabinet was constructed using mild steel and fiber glass was used as insulator to control heat loss by conduction The performance of the fabricated cabinet tray dryer was finally evaluated against an imported cabinet tray dryer in using a t-test analysis at 95% confidence level, and the result showed that there is no significant difference between the locally fabricated and the imported dryers.
Keywords: Dryer, Machine, Temperature, Dry basis.

I. Introduction

Drying is a method of food preservation that works by removing water from the food, which prevents the growth of microorganisms and decay. Drying food using the sun and wind to prevent spoilage has been known since ancient times. Drying is the thermal removal of liquid moisture from a material. The heat for drying is provided by hot air/ inert gas that have been directly heated. Drying is usually above the boiling point of water 120oC (Hampton1997),of suitable drying equipment cannot be separated from the selection of the upstream equipment feeding the drying stage. (Masters 1985)

The dryer is made up of three sections, the energy source (electricity), blower and the drying cabinet sections. The energy source is located behind the dryer, which is used to connect the dryer to electricity source for proper functioning. The blower is located at the middle of the drying chamber and has a power rating of 1.02 Watts. The blower helps in circulating heat for effective and efficient heat flow rate within the drying cabinet. During this period the blower helps in maintaining the temperature within the drying chamber.

The cabinet is fabricated from mild steel of 2mm thickness and the fiber glass was used as insulator to control heat loss by conduction. The drying chamber has three slots for each drying tray. The trays are perforated to effectively allow the airflow within the chamber. In line with the need to evolve a dual purpose effective cabinet tray dryer for home use with 100% locally sourced materials and components which will be cheap and readily available for home usage to average citizen of Nigeria and will improve productivity, quality control, also spurs National economic growth, the design and fabrication of a cabinet tray dryer (Fig 1) is carried out.

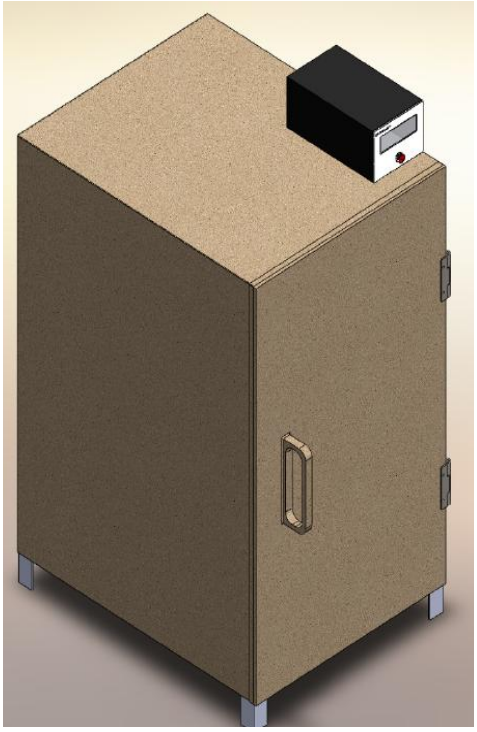

Fig. 1: Fabricated cabinet tray dryer

II. Methodology

Putting in mind the environmental factor, economic factor and availability of this dryer to Nigerian for quality control, the materials used were sourced locally and they were selected based on the following factors; ability to withstand heat, vibration, humid air fatigue and stress without failure during operation. Electric heater and thermostat were purchased and used in. However, the fabrication was then carried out based on the design calculation below;

2.1 Design Calculation.

Estimate of both the constant rate and the falling rate period are needed to estimate the total drying for given drying operation. If estimate for these periods are available, the total drying time estimated by summing as:

$\theta t = \theta c + \theta f$ …………………… (1)

Where θt = total drying time.

θc = drying time for constant rate period.

θf = drying for failing rate

2.2 Amount of moisture to be removed

Amount of moisture to be removed from a given quantity of dough to bring the moisture content to a safe edible level in a specified time is calculated below.

The amount of moisture to be removed from the product, m_w, in kg will be calculated using the following equation:

$$m_w = m_p(m_i - m_f)/(100 - m_f) \quad \text{………… (2)}$$

Where:

m_p= the initial mass of product to be dried, kg;

m_i= the initial moisture content, % wet basis and

m_f=Is the final moisture content, % wet basis.

2.3 Final relative humidity

Final relative humidity will be calculated as Hernandez et al (2000);

$$a_w = 1 - \exp[-\exp(0.914 + 0.5639 \ln M)] \text{… (3)}$$

Where:
a_w = the water activity, decimal
M = the moisture content dry basis, kg water/kg dry solids

2.4 Quantity of heat needed to evaporate the water (H2O)

The quantity of heat required to evaporate the H2O would be:

$$Q = m_w \times h_{fg} \text{…………….. (4)}$$

Where:

Q is the amount of energy required for the drying process, kJ

m_w = the mass of water, kg

hfg = the latent heat of evaporation, kJ/kg H2O

The amount needed is a function of temperature and moisture content of the dough. The latent heat of vaporization will be calculated using equation given by Youcef-Ali et al. (2001) as follows:

$$h_{fg} = 4.186 \times 10^3 \, [597 - 0.56(T_{pr})] \text{… (5)}$$

Where:

T_{pr} = the product temperature(°C)

2.5 Average drying rate

Average drying rate, mdr, will be determined from the mass of moisture to be removed by electric heat and drying time by the following equation:

$m_{dr} = \frac{m_w}{t_d}$ .... (6)

The mass of air needed for drying will be calculated using equation given by Sodhaet al. (1987) as follows:

$m = {m_{dr}}/{[w_f - w_i]}$ .... (7)

Where:

mdr = the average drying rate, kg/hr

wf –wi = the final and initial humidity ratio, respectively, kg H2O/kg dry air

2.6 Air vents dimensions

The air vent was calculated by dividing the volumetric airflow rate by wind speed

$A_v = {V_a}/{V_w}$ .... (8)

Where:

Av is the area of the air vent, m2,

Vw is the wind speed, m/s.

The length of air vent, Lv, m, will be equal to the length of the dryer. The width of the air vent can be given by:

Bv = Av/Lv .... (9)

Where: Bv is the width of air vent, m

2.7 Drying rate

The calculation involving the design and analysis of dryers requires the knowledge of the length of time needed to dry a product from initial moisture content Q1 to final moisture content Q2 and the rate at which drying is taking place. The rate and time of drying equations are expressed (Ceankoplis, 1993).

$R_c = \frac{M_d}{A_s}\left({m_i - m_f}/{T}\right)$............... (10)

Where:

Rc is the drying rate (Kg/mol);

mi = Initial moisture content; and

Md is the total weight of dried product;

mf = Final moisture content

As is the surface area of the dried solid;

T is the drying time;

2.8 Fabrication: All the parts of the dryer were designed as follows:

a) Drying tray
lenght of a tray = 440mm
Bread the of tray = 400mm
Height of tray = 10mm
Surface area of tray = L × B = 440 × 400
= 176000mm2
Volume of tray = L × B × H = 440 × 400 × 10
= 1760000mm3

b) Inner drying cabinet
Lenghtofdrying cabinet = 670mm
Breadthofdryingcabinet = 530mm
Heightofdryingcabinet = 940mm
volumeofdryingchamber = L × B × H
= 670.00 × 530.00 × 940.00
= 333794000mm3

c) Outer drying cabinet
Lenghtofdrying cabinet = 714mm
Breadthofdryingcabinet = 574mm
Heightofdryingcabinet = 984mm
volumeofdryingchamber = L × B × H
= 714mm × 574mm × 984mm
= 403278624mm3

Construction Procedure

The construction procedure was in sequential order so as to make convenient the process of final assemblage. This made possible the correction of faults being detected at each stage of construction and also guided against failure at the end of construction. The stages and parts include:

a. Frame construction

The frame is 714mm × 574mm × 984mm constructed from square pipe of 20mm joined together through welding in such a way to give rigidity to the oven under construction as shown in Figure 2 below. The frame was divided into four compartments to accommodate four trays. One inch angle bar was welded to the sides as shown in the diagram, to give base for the tray.

Fig. 2: Cabinet frame work

a. Construction of the drying chamber

Using 2mm mild steel, two pieces of 984mm×574mm were then cut and welded to the external and the internal parts of the back part of the cabinet. While four pieces of 984mm×714mm also were cut and two each were welded to the external and the internal parts of the cabinet giving room for layers of fiber glass as insulator.

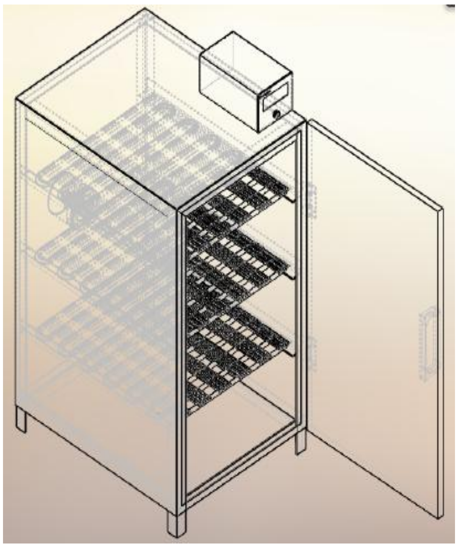

Fig. 3: Main cabinet tray dryer

b. Doors Construction

Using 20mm square pipe, the door frame was fabricated to form 984mm x574mm rectangular shape. 2mm mild steel plate was then cut and welded to the frame fabricated as shown in fig 4. A double layer of fiber glass was then filled into the interior part of the door to serve as insulator.

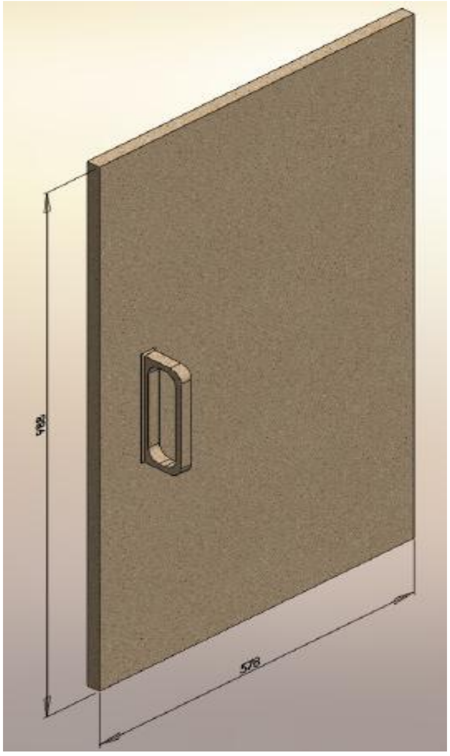

Fig. 4: The Cabinet door

c. Control panel box construction

A measured piece of 2mm mild steel plate was cut and folded to form cover for the thermostat controls as seen in Fig 3.

d. Exhaust, fan and element housing

A measured piece of 2mm mild steel was cut and folded to form a cylindrical shape. This protrudes out the middle section of the back of the chamber where air is allowed to flow into the chamber as seen in the arrangement in Figure 5.

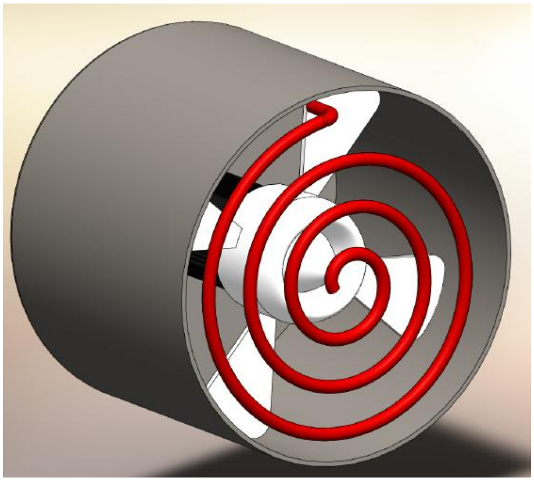

Fig 5: Fan/heating element arrangement

III. Results

In order to present the results obtained to form the basis for drying of both the imported and fabricated dryer, the temperature effect of the fabricated dryer when it was not loaded was tabulated as shown in Table 1. Also Tables 2 and 3 show the results obtained from both imported and locally fabricated dryer respectively when 100g of biscuit dough was dried in the dryer. Their efficiency was calculated and compared.

Table 1: Temperature Monitored with no Load

Time Temperature (0C)

(Minutes)	1st trial	2nd trial	3rd trial	Average
5	28	30	27	28.3
10	80	80	75	78.3
15	110	110	100	106.7
20	118	112	116	115.3
25	120	119	120	119.6
30	130	128	129	129
35	145	144	145	144.3
40	153	155	154	154
45	158	160	160	159.3
50	164	165	163	164

Table 2 Drying rate of 1000g of biscuit dough when drying in an imported dryer

Time (Minute)	SW (g)	ML (g)	MR (g)	WB %	DB %
0	1000	0	373.5	37.35	59.65
20	850	150	223.5	22.35	35.67
40	745	105	118.5	11.85	18.91
60	681	64	54.5	5.45	8.69
80	657	24	30.5	3.05	4.86
100	657	0	30.5	3.05	4.86

Note: SW = Sample Weight, ML = Moisture loss, MR = Moisture retained, WB = Wet basis, DB = Dry basis

Table 3: Drying rate of 1000g of biscuit dough when drying in a fabricated dryer

Time (Minute)	SW (g)	ML (g)	MR (g)	WB %	DB %
0	1000	0	373.6	37.36	59.66
20	850	150	223.7	22.37	35.71
40	745	105	118.9	11.89	18.97
60	681	64	54.3	5.43	8.65
80	657	24	30.8	3.08	4.90
100	657	0	30.5	3.45	5.49

From Table 2, using AOAC (2000) method,

Moisture Content of the dry basis

$$= \frac{\text{moisture retained}}{\text{Weight of sample} - \text{moisture retained}}$$

Initial moisture content =37.35% WB, 59.60%DB

Final weight of sample=657g

Final moisture content 3.05%WB, 4.86%DB

$$\text{Efficiency} = \frac{\text{wet basis}}{\text{dry basis}} \times 100$$

$$= \frac{3.05}{4.86} \times 100$$

62.8%

From Table 3, also using AOAC (2000) method,

Moisture Content of the dry basis

$$= \frac{\text{moisture retained}}{\text{Weight of sample} - \text{moisture retained}}$$

Initial moisture content =37.36% WB, 59.66%DB

Final weight of sample=657g

Final moisture content 3.45%WB, 5.49%DB

$$\text{Efficiency} = \frac{\text{wet basis}}{\text{dry basis}} \times 100$$

$$= \frac{3.45}{5.49} \times 100$$

62.8%

3.1 Discussion of Result

The efficiency calculated for fabricated dryer which is 62.8% compared favorably with that for the imported dryer which was 62.8%. Similarly the result obtained from both fabricated and imported dryer was subjected to t-test analysis at 95% confidence level as shown in Table 4.It is however seen from the table that, there is no significant difference in imported and locally fabricated cabinet tray dryer since T –tabulated (2.570582) is greater than T- calculated(1.239355) and that there is no significance difference in imported and locally fabricated tray dryer since T-tabulated (2.570582) is greater that the T – calculated (1.205269).

The cost estimate which is the bill of Engineering Measurement and Evaluation (BEME) of locally fabricated cabinet tray dryer is given in Table 5 below.

Table 4: T-test comparison of % wet basis and % Dry basis between fabricated and imported cabinet tray dryer

	Wet Basis% (Wb)		Dry Basis%(Db)	
	Wbfabricated %	wbimported %	Dbfabricated%	Dbimported%
Mean	13.93	13.85	22.23	22.10667
Variance	184.8326	186.468	471.6632	475.7173
Observations	6	6	6	6
Pearson Correlation	0.999942		0.999943	
Hypothesized Mean Difference	0		0	
df	5		5	
t Stat	1.239355		1.205269	
P(T<=t) one-tail	0.135106		0.141012	
t Critical one-tail	2.015048		2.015048	
P(T<=t) two-tail	0.270213		0.282024	
t Critical two-tail	2.570582		2.570582	

Table5 : Bill of Engineering Measurement & Evaluation for the Apparatus

S/N	Items	Quantity	Unit Cost (N)	Cost (N)
1.	Square Pipe 25mm x 170mm	7	1000	7000
2	Mild Steel Plate 1.4mmx2.8mmx2mm	2	7200	14400
3	Fiber Glass	-	2000	2000
4	Hinges	2	60	120
5	10mm diameter of Aluminum hollow pipe	2	600	1200
6	Blower 1.02Watt	1	550	550
7	Electric Heater	1	1500	1500
8	Thermostat	1	500	500
9	Bolts and Nuts	8	30	240
10	Miscellaneous	-		2000
11	Over Head	-		2500
12	Contingence	-		2000
	Total			34010

IV. Conclusions

The values of efficiency calculated and t-test analysis carried out on the result for rate of 100g of biscuit dough when drying in a dryer confirmed the reliability of locally fabricated cabinet tray dryer. It has also been established in this paper that the result carried out using imported cabinet tray dryer and locally fabricated cabinet tray dryer for home use has no significant difference at 95% confidence level.

The production cost of the locally fabricated cabinet tray dryer is N34010 as stated in table 5.The cost is likely to reduce when standard approach is adopted in manufacturing component on a large scale. Invariably, the locally fabricated cabinet tray dryer can be used to dry our domestic food like home-made biscuit dough, fish, meat and meat pie for the purpose of preservation and edibility and will give adequate product which would compare well with those from the standard (imported) cabinet tray dryer

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Appendices

(a)

(b) Exterior view of the Cabinet

(c)

(c)

(b) and (c) Interior view of the Cabinet