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Development and Performance Evaluation of A Convective Paddle Grain Dryer

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Abstract: Grains are routinely seen dumped in villages and major cities during the peak of harvest. Therefore it is necessary that these grains are properly dried and stored to ensure availability and wholesomeness throughout the year. A convective paddle grain dryer was designed, constructed and evaluated. The dryer consists of; a drying chamber, receiving tray, thermostat, heating element, bearing, discharge tray, paddle shaft, frame and fan. The frame was fabricated from (25 x 25) mm square pipe iron with dimension (530 x 450 x 660) mm. The drying chamber was fabricated from 2.0 mm thickness mild steel with dimensions of radius 165 mm and other dimensions of height and width were 330 x 420mm. The fan housing consists of three (03) fan blades and electric heating element (1500) W. The moisture contents of corn seeds were measured with a grain moisture meter (PM400, Japan). Four kg of corn seeds of samples A, B, C, D and E containing 32% initial moisture content were dried at 50 ^{0}C, 55 ^{0}C, 60 ^{0}C, 65 ^{0}C and 70 ^{0}C respectively for 80 minutes. The trend of behaviour observed generally revealed that during the warm- up stage, the drying rate increases with decrease in moisture contents. In sample (A), the maximum constant drying rate 0.47 was observed between the moisture content of 25 % and 20 %. The drying rate gradually falls to zero at 6 % moisture contents. Also in sample (B) – (E), the highest drying rate of 0.4, 0.42, 0.44 and 0.35 with a moisture contents of 28 %, 26.9 %, 26 % and 29 % was observed. The drying rate gradually falls to zero at a moisture contents of 8 %, 6 %, 4 % and 8% respectively.

Keywords: ***:***convective, grain dryer, moisture contents, drying rate, local construction.

INTRODUCTION

Traditional drying of grains, which is frequently done on the ground in the open air, is the most widespread method used in developing countries because it is the simplest and cheapest method of conserving foodstuffs. Some disadvantages of open air drying are: exposure of the foodstuff to rain and dust; uncontrolled drying; exposure to direct sunlight which is undesirable for some foodstuffs; infestation by insects; attack by animals; etc (Madhlopa *et al;* 2002). Drying of various feed-stocks is needed for one or several of the following reasons: need for easy-to-handle free-flowing solids, preservation and storage, reduction in cost of transportation, achieving desired quality of product, etc. (Mujumdar, 2006).

Country’s food security heavily relies on its ability to safely store its food, feed-grain and seed stocks and to ensure the more food availability for growing population and to increase the socio-economic condition of the farmers.

Grain is harvested at the peak of the rainy season making preservation difficult and causing most of the grains to perish. This results in scarcity in the supply of the grains which leads to subsequent hunger and malnutrition. Drying has become popular postharvest operation to obtain highly commercial agricultural products and preserve the products for longer self-life (Yang, 2005). Grains are usually harvested at moisture content too high for safe storage. Thus drying is a necessity. It is clear that the length of time in which grains can be safely stored with varies with the moisture contents. If grain is intended to be used as a seed, then it must be dried in a manner that preserves its viability. The application of dryers in developing countries can reduce post- harvest losses and significantly contribute to the availability of food in these countries. A significant percentage of these losses are related to improper and/or untimely drying of foodstuffs such as cereal grains, pulses, tubers, meat, fish, etc. (Bassey, 1989; Togrul and Pehlivan, 2004).

MATERIALS AND DESIGN METHODS

The convective drying system which includes: drying chamber, paddle shaft, frame, receiving tray, thermostat with sensor, discharge handle, heater, insulation material and the fan.

Drying chamber with lid: The drying chamber was an important component in the machine. It was fabricated from 2.0 mm thickness mild steel with dimensions of radius 165 mm and other dimensions of height and width were 330 x 420mm. It was mounted on shaft (SS). The thickness of chamber was decided on consideration of temperature attained on it. It has to resist the drying temperature in order to avoid from crumble and melting down. The applications of mild steel are able to resist the heat at the process temperature range of 400 – 500 °C.

Receiving tray: The receiving tray is a rectangular box of (520 x 470 x 90) mm as length, breadth and height respectively which is positioned below the drying chamber.

Paddle shaft: Three numbers of V shaped detachable fins were fabricated to stir the corn in the chamber during drying. It was also made out from the mild steel and attached to shaft (SS) by bolting. It served to agitate the corn thoroughly in the drying chamber. The shaft is made out from a mild steel rod of 30 mm diameter with length 700 mm was cut with hack saw blade and turn on a lathe machine. One end of the shaft was turned to 20 mm diameter and 67 mm length while the other end of the shaft was turned to 20mm diameter and 123 mm length. Toward the end of the 123 mm a hole of diameter 6 mm was drilled to allow the locking position of the handle. The clearance gap between tip of fins and interior chamber surface was limited to 1 to 5 mm in order to avoid from the struck or damage the corn.

Frame: The cabinet is a rectangular frame box made of (25 x 25) mm mild steel square pipe iron with dimensions (530 x 450 x 660) mm.

Fan: The fan aids in heat distribution by sucking ambient air from the surrounding to the heater housing and discharging heated air to the drying chamber. An axial flow fan with three blades is used to ensure proper distribution of air to the drying chamber and for effective heat distribution.

Thermostat: The thermostat is simply the unit that controls the system and maintains constant temperature in the drying chamber.

Electric Heater: The source of heat was from the electric heater coil of 1500 watts, amperes, 220 volts (single-phase supply). The shape and size of heater was spiral coil type. The electric heater system assembled on top of the chamber and 1-5 mm below exterior surface of the corn drying chamber. The force convection heat from top of the chamber was drawn with the aid of centrifugal fan and transported to drying chamber to dry the corn.

Insulation of the drying chamber: Different materials are available for insulation but considering the drying temperature, availability and cost of insulating material, Fibre wool of 0.004W/mK has been chosen for installation.

Components design

In order to develop an efficient batch type convective grain dryer, the major components were design based on the following equations.

(i) Design of drying chamber.

Volume of drum (V_D) $=\pi R_D{}^2 L_D$ (1)

where,

V_D= Volume of drum.

L_D= Length of drum.

R_D= Radius of drum.

(ii) Quantity of heat required to remove moisture contents.

$Q = ML + Mh_{fg}$ (Brooker et al, 1974) (2)

Where,

M = Mass of water, (kg)

L = Specific latent heat of vapourization of water, (kJ/kg)

Q = Quantity of heat, (J/s or Watt)

h_{fg} = Heat co-efficient of water, (kJ/K)

(iii) Design of receiving trough tray.

Volume of receiving trough tray = $L\ x\ B\ x\ H$ (3)

Where,

L = Length of tray, (mm)
B = Breadth of tray, (mm)
H = Height of tray, (mm)

(iv) Drying rate.

According to www.practical.action.Org (2010), the drying rate (D.R) is defined as:

$$D.R = \frac{M_i - M_d}{t_i} \quad (4)$$

Where,
D.R = drying rate (%/min)
M_i = initial moisture content of sample, (%)
M_d = dried sample (final moisture content) (%)
t_1 = drying time interval.

(v) Percentage moisture contents and moisture losses.

The percentage (%) moisture content and moisture loss according to Handerson *et al*, (1997) is expressed as:

Moisture Loss (M.L) = $M_w - M_d$ (5)

Moisture Content (M.C) = $\frac{M_w - M_d}{M_w}$ x 100 (6)

where
M_w = initial moisture content of sample, (%)
M_d = final moisture content of sample, (%)

(vi) Determination of shaft diameter.

$$D_s^3 = \frac{16}{\pi S_s}\sqrt{(K_b M_b)^2 + (K_t M_t)^2}$$ (Hallet al, 1980) (7)

where,
S_s= Allowable combine shear stress for bending and torsional = 40MN/m^2
K_b=1.5, K_t=1.0,M_t=27.1 Nm, M_b=104.4 Nm (for gradually applied load on rotating shaft).
K_b= combined shock and fatigue factor applied to bending moment.
K_t= combined and fatigue factor applied to torsional moment.
M_t = Combine shock and fatigue factor applied for torsional moment 1.0 to 1.5 for heavy shock
M_b= Combine shock and fatigue factor applied for torsional moment
S_s= allowable shear stress for type of shaft.

Description of the dryer

The corn dryer operates on the principle of batch drying. The drying chamber was fabricated in the shape of concave to accommodate 4 kg of corn. After the corn was loaded, the lid closed and heated air of about 50 ^{0}C is blown across the corn from the heater housing through electrical heating element and fan. Both heater and fan terminals are connected to electricity. The heat being supplied by the heater is controlled by a thermostat which turns off the machine if inlet temperature exceeds the actual temperature required for drying. There is a shaft joined with paddles that passes through the centre of the drying chamber. A mild steel handle is fixed to the paddle fin shaft that was positioned outside the drying chamber for manually stirring of the corn. After drying, the drying chamber is turned anti-clockwise at angle 180 ^{0}C to discharge grains to the receiving tray placed under the drying chamber.

The component parts of the dryer are:

1. Fan
2. Electric heater housing
3. Thermostat to regulate the temperature
4. Sensor
5. Grain discharge handle
6. Ball bearing and housing
7. Electric cable
8. Receiving tray
9. Frame
10. Paddle shaft with handle
11. Drying chamber with lid

Plate 1 Full pictorial view of the Corn Dryer

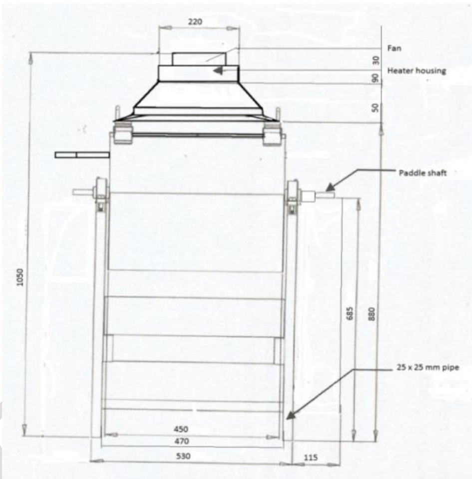

Fig. 1 Front view of the Corn Dryer

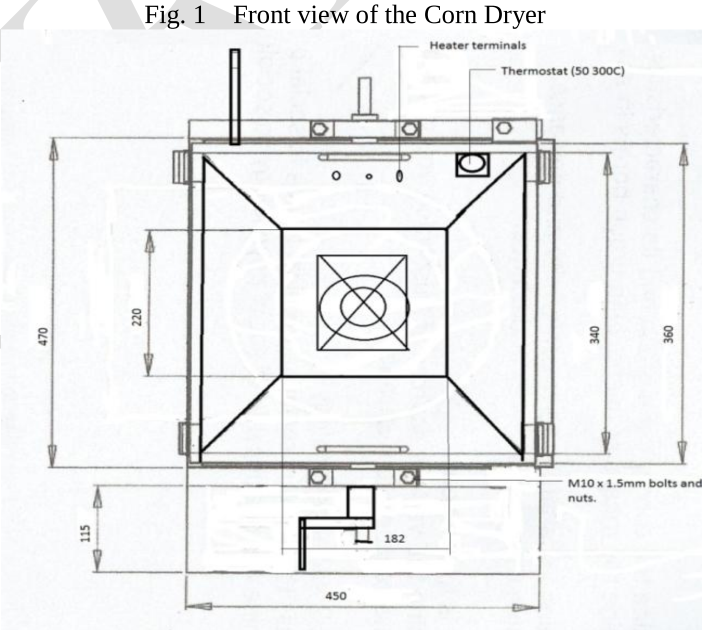

Fig. 2 Top view of the Corn Dryer

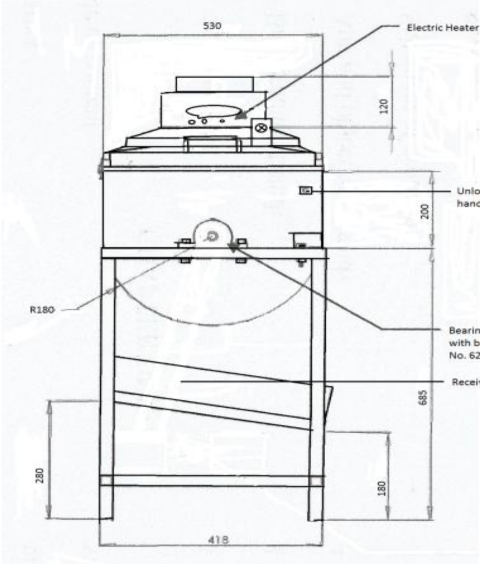

Fig.3 Side view of the developed corn dryer

EXPERIMENTAL PROCEDURE

Performance parameters

The following performance parameters for the dryer was estimated using the procedure detailed by www. practical action. Org (2010), and Handerson *et al,* (1997)

- Percentage (%) moisture contents and moisture loss of the sample.
- Drying rate of the sample.

Procedures for experimentation

i. The corn with known initial weight, initial moisture content was thoroughly sieved and poured into the drying chamber and covered with the lid chamber that comprises of a fan, heater and thermostat.
ii. A digital thermostat with a temperature sensor fixed to the wall of the lid chamber to facilitate temperature regulation was set at required drying temperature of 50 ^{0}C.
iii. The stop watch set to (0) minute.
iv. Power button of the dryer is switched ON at constant electricity supply.
v. After 10 minutes in operation with thorough stirring, the machine is OFF, the top cover of the drying chamber is removed and a moisture meter is inserted.

Plate2. Moisture meter inserted in the drying chamber for readings.

Plate3. Discharge of dried corn from the drying chamber.

vi. Moisture content is recorded with a digital moisture meter at four different points around the corn inside the drying chamber at 10minutes interval for a period of 80 minutes as indicated in plate 2.
vii. After drying, the drying chamber lid is removed and the drying chamber is turned anti-clockwise at angle 180 ^{0}C to discharge grains to the receiving tray placed under the drying chamber as shown in plate 3.

RESULT AND DISCUSSION

Moisture content and moisture loss of different samples at various drying temperature and time.

Table 1 shows the percentage moisture contents and moisture losses of different samples of the corn at various temperatures as measured with a digital moisture meter.

Table 1 Percentage (%) moisture content and moisture loss of different samples at various drying temperature and time.

Time (min)	Sample A 50 ^{0}C	Sample B 55 ^{0}C	Sample C 60 ^{0}C	Sample D 65 ^{0}C	Sample E 70 ^{0}C
0	32	32	32	32	32
10	31	30.7	30.4	30	29
20	29	28	26.9	26	25
30	25	23.4	22	21	20
40	20	18.4	17	15.5	14
50	15	13.1	11.4	9.5	8
60	10.3	8	6	4	0
70	6	0	0	0	0
80	0	0	0	0	0

where,
Sample A = Corn dried at 50 ^{0}C
Sample B = Corn dried at 55 ^{0}C
Sample C = Corn dried at 60 ^{0}C
Sample D = Corn dried at 65 ^{0}C
Sample E = Corn dried at 70 ^{0}C
t = Drying time (minutes)

Also, from the results of moisture content presented in Table 1, the moisture contents of all corn samples (A to E) at 0 minutes (control samples) were 32 %. At 70 minutes the moisture content of dried sample A at 50 °C was 6 %, but 8%, 6% and 4 % moisture content dried in sample B, C and D were recorded in 60 minutes at temperature 55 °C, 60 °C, and 65 °C respectively. Furthermore, at 50 minutes the moisture content of dried sample E at 70 °C was 8 %. However, the percentage average moisture loss are 4.0 %, 4.57 %, 4.42 %, 4.57 % and 5.33 % obtained from dried corn at 50 ^{0}C, 55 ^{0}C, 60 ^{0}C,65 ^{0}C and 70^{0}C respectively.

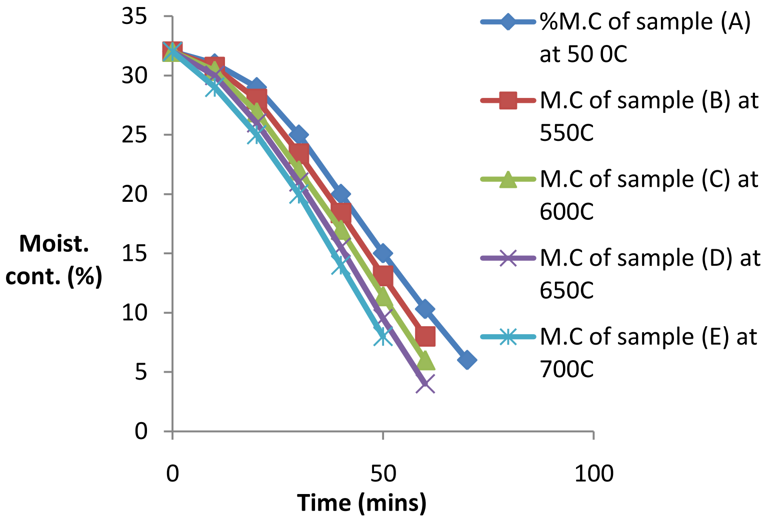

Fig. 4 Moisture content versus drying time of corn at various drying temperature and time.

Effect of moisture contents on drying rate at 50^{0}C, 55^{0}C, 60^{0}C, 65^{0}C and 70^{0}C

According to www.practical action.Org (2010), the drying rate (D.R) is defined as:

$$D.R = \frac{M_i - M_d}{t_i} \quad (4)$$

For sample (A) at a drying temperature 50 ^{0}C, M_d is calculated as shown;

D.R for Sample A at 0 min = $\frac{32-6}{70}$ = 0.37

D.R for Sample A at 10 min = $\frac{31-6}{60}$= 0.41

D.R for Sample A at 20 min = $\frac{29-6}{50}$ = 0.46

D.R for Sample A at 30 min = $\frac{25-6}{40}$ = 0.47

D.R for Sample A at 40 min = $\frac{20-6}{30}$ = 0.47

D.R for Sample A at 50 min = $\frac{15-6}{20}$ = 0.45

D.R for Sample A at 60 min = $\frac{10.3-6}{10}$ = 0.37

The same is repeated for 55 ^{0}C, 60 ^{0}C, 65 ^{0}C and 70 ^{0}C drying temperatures and time.

Table 2 Drying rate of different corn sample at various drying temperatures and time.

	Drying Temperatures (^{0}C)				
Drying time (min)	Sample A 50^{0}C	Sample B 55^{0}C	Sample C 60^{0}C	Sample D 65^{0}C	Sample E 70^{0}C
0	0.37	0.34	0.37	0.4	0.34
10	0.41	0.38	0.41	0.43	0.35
20	0.46	0.40	0.42	0.44	0.34
30	0.47	0.39	0.40	0.43	030
40	0.47	0.35	0.37	0.38	0.20
50	0.45	0.26	0.27	0.28	0.0
60	0.37	0.0	0.0	0.0	0.0
70	0.0	0.0	0.0	0.0	0.0

In Figure 5 (a) – (e), the trend of behaviour observed generally revealed that during the warm- up stage, the drying rate increases with decrease in moisture contents.

In Figure 5(a), the maximum constant drying rate 0.47 was observed between the moisture content of 25 % and 20 %. The drying rate gradually falls to zero at 6% moisture contents.

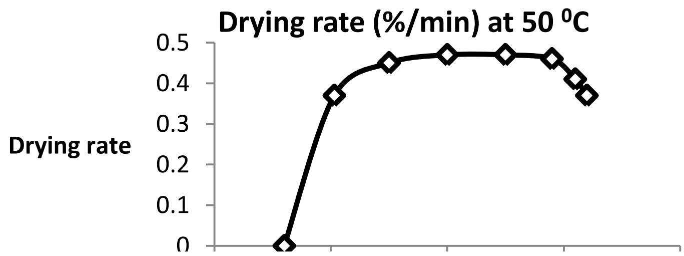

Fig 5 (a

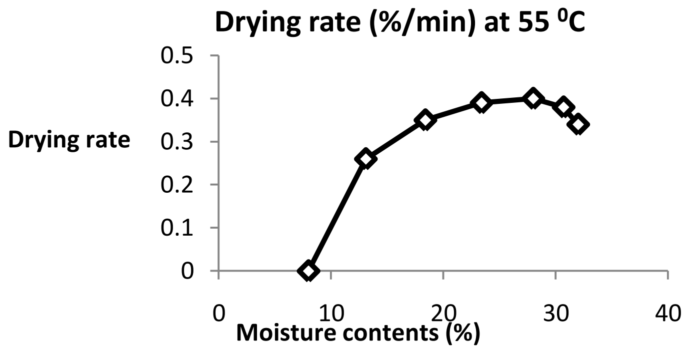

Fig 5 (b) Drying rate versus moisture content at 5 5^{0}C for sample B

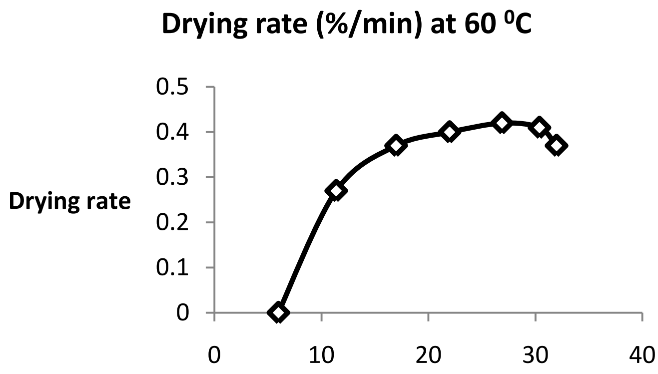

Fig 5(c)

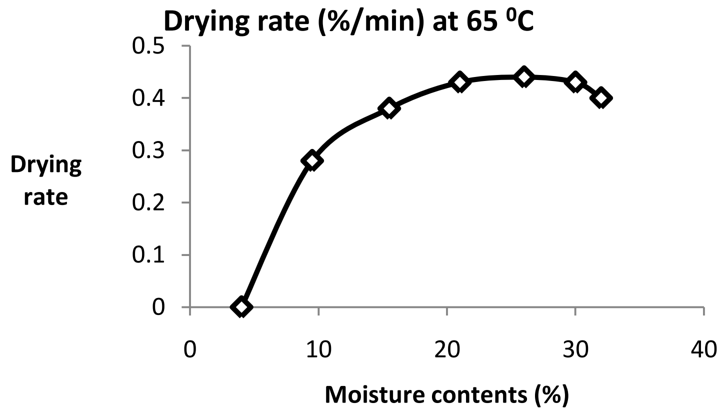

Fig 5(d) Drying rate versus moisture content at 65 ^{0}C for sample D

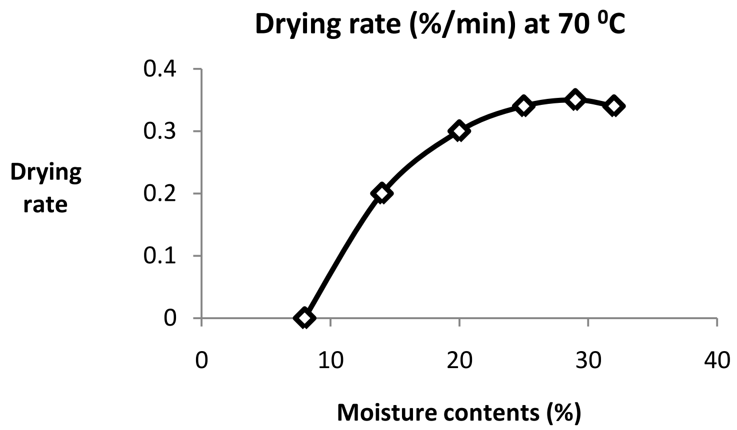

Fig 5(e) Drying rate versus moisture content at 70 ^{0}C for sample E

CONCLUSIONS

As a means of arresting the occurrence of post- harvest losses of corns in the farm due to local methods of preserving it, a convective corn dryer has been successfully developed using locally available material.

From the experimental procedure and results, it revealed that drying rate increases as the temperature of the dryer increases.

The moisture loss obtained from dried sample (A, B, C, D and E) at drying chamber temperatures of 50 ^{0}C, 55 ^{0}C, 60 ^{0}C, 65 ^{0}C, and 70 ^{0}C were 4.0 %, 4.57 %, 4.42 %, 4.57 %, and 5.37 % respectively during 80minutes of continuous drying process.

REFERRENCES

[1]. Bassey, M.W. (1989): "Development and use of Solar Drying Technologies", *Nigerian Journal of Solar Energy*:Pg. 133-64.

[2]. Brooker, D.B; Baker-Arkema, F.W and Hall C.W (1974): "Drying Cereal Grains",*The AV1 Publishing coy; Inc. West port Connecticut USA,*Pg. 256.

[3]. Handerson, S. M, Perry, R. L and Young, J.H (1997): "Principles of Process Engineering", *4th Edition, ASAE Michigan, U.S.A,* Pg.280-283

[4]. Hall A.S, Holowenko, A.R and Laughlin, H.G (1980): "Theory and Problems of Machine Design",*Schaum's Outline Series, McGraw- International Book Company, Singapore.* Pg.113- 130

[5]. Madhlopa A, Jones S AKalengaSaka J D (2002): "A Solar Air Heater with composite Absorber Systems for Food Dehydration. Renewable Energy", 27; 27 – 37

[6]. Togrul, I.T.; and Pehlivan, D. (2004): "Modelling of Thin Layer Drying Kinetics of some Fruits under Open-Air Sun Drying Process",*J. Food Engineering.* 65: 413-25.

[7]. www.practicalaction.org (2010): "Drying of Foods",*Accessed* 14th May, 2010.

[8]. www.Engineeringtool.com (2010):"Thermal Conductivity of some Materials",*Accessed* 15th March, 2010.

[9]. Yang, W.,P. Winter, S. Sokhansanj, H. Wood and B. Crerer. (2005): "Discrimination of Hard–to–pop Popcorn Kernels" *by Machine Vision and Neural Networks. Bio-Systems Engineering",* 91(1): Pg. 1-8.