Scholars Journal of Engineering and Technology (SJET) **ISSN 2321-435X**
Sch. J. Eng. Tech., 2013; 1(3):91-97

(An International Publisher for Academic and Scientific Resources)
www.saspublisher.com

Research Article

Design and Construction of Forced Convection Indirect Solar Dryer for Drying Moringa Leaves

S.K. Amedorme[1], J. Apodi[2], and K. Agbezudor[3]
[1]Ghana Prisons Service, Senior Correctional Centre (SCC), P. O. Box 129, Accra
[2]Department of Agricultural Engineering,Bolgatanga Polytechnic, P.O. Box 767 Bolgatanga.
[3]Department of Mechanical Engineering, KNUST, Kumasi, Ghana

***Corresponding author**
S.K. Amedorme
Email: smedorme@yahoo.com

Abstract: Drying of moringa leaves is a preservation activity done by farmers and herbal practitioners. The most common way to do this is to place the leaves on a mat, floors etc. and leave it in the open to dry. This process takes a long time and makes the leaves subjected to attack by the weather, animals and insects. It also affects the quality, nutritional values and the potency level of the leave when exposed to the direct sunlight. This paper outlines systematic design and construction of indirect forced convention solar crop dyer for drying moringa leaves and presents the results of calculations of the design parameters. A batch of moringa leaves 2 kg by mass, having an initial moisture content of 80% wet basis from which 1.556 kg of water is required to be removed to have it dried to a desired moisture content of 10% wet basis, is used as the drying load in designing the dryer. A drying time of 24-30 h is assumed for the anticipated test location (Kumasi; 6.7^{o}N, 1.6^{o}W) with an expected average solar irradiance of 320 W/m^2 and ambient conditions of 25^{o}C and 77% relative humidity. A minimum of 0.62 m^2 of solar collection area, according to the design, is required for an expected drying efficiency of 25%. The dryer was constructed using locally available materials. It is recommended that a test under full loading conditions should be carried out in order to know if all the design parameters have been met and laboratory experiment should also be done to know the effects on the nutritional values of the moringa leaves when sun dried and solar dried.
Keywords: Drying moringa, moisture content, drying efficiency, solar collection area

NOMENCLATURE

$I_o = solar\ intensity\ on\ a\ horizontal\ surface\ (W/m^2)$
$I_t = solar\ intensity\ on\ a\ tilted\ surface\ (W/m^2)$
$M = mass\ of\ moisture\ evaporated\ per\ second\ (kg/s)$
$L_w = latent\ heat\ of\ evaporation\ of\ water\ (kJ/kg)$
$\eta_d = drying\ system\ efficicny\ (\%)$
$A_c = area\ of\ collector\ (m^2)$
$M_w = mass\ of\ water\ removed (kg)$
$M_i = initial\ moisture\ content\ (\%)$
$M_f = final\ moisture\ content\ (\%)$
$M_p = mass\ of\ product\ (kg)$
$R_g = gas\ constant\ for\ water\ vapour\ (J/kg\ K)$
$L_m = latent\ heat\ of\ evaporation\ of\ moringa\ (J/kg)$
$T_b = boiling\ point\ of\ water\ (°C)$
$T_c = critical\ temperature\ of\ water\ (°C)$
$P_c = critical\ pressure\ of\ water\ (N/m^2)$
$T_{pt} = temperature\ of\ the\ product (moringa) (°C)$
$T_o = ambient\ temperature\ (°C)$
$T_o = temperature\ at\ collector\ outlet\ (°C)$
$W_o = initial\ moisture\ content\ on\ wet\ basis\ (\%)$
$W_f = final\ moisture\ content\ on\ wet\ basis\ (\%)$
$W_c = critical\ moiture\ content\ (\%)$
$R_c = constant\ rate\ of\ drying$
$V_A = volume\ of\ air\ (m^3)$
$R_a = specific\ gas\ constant\ of\ air\ (J/kg\ K)$
$C_{pa} = specific\ heat\ capacity\ of\ air\ (J/kg\ K)$
$P_a = atmospheric\ pressure (\ N/m^2)$
$T_f = temperature\ of\ air\ leaving\ the\ drying$
$\rho_{gr} = bulk\ density\ of\ moringa\ on\ wet\ basis (g/m^3)$
$h_L = depth\ of\ the\ drying\ rack\ (m)$
$\epsilon = crop\ porosity$
$\varepsilon_v = loadinng\ bed\ void\ fraction$
$A_{rac} = drying\ rack\ area\ (m^2)$
$\Delta P_B = pressure\ drop\ across\ the\ moringa\ leaves (N/m^2)$
$L_c = length\ of\ collector\ (m)$
$d_c = depth\ of\ collector\ (m)$

INTRODUCTION

Drying of foodstuffs or leaves is a very important post-harvest activity in a farmer's life or in herbal practitioner's life. The purpose of drying is basically to prevent the spoilage of the foodstuffs and to preserve them for a long time[1]. Other reasons that could be associated with drying are to prevent the germination of seeds and make leaves retain maximum or essential ingredients. Some examples of foodstuffs that require drying are tubers, vegetables, fruits, leaves and spices. Microorganism causes spoilage of these foodstuffs and water is very essential to the growth of these organisms. Hence, the need to remove the water. Different degrees of drying can affect the quality such as colour, chemical composition, potency and value among others of these foodstuffs especially themoringa leaves [2]. Solar drying is just one of the various methods by which the drying of leaves can be carried out. Solar drying of moringa leaves will reduce the moisture content of the leaves to a desired level and thereby prevent the growth of these microorganisms and subsequent spoilage of the leaves. It can preserve the quality, nutritional values and increase the potency level of the moringa leave. Since according to farmers and herbalist direct sun drying of moringa leaves affect its performance [2]. Basically, solar drying utilizes the energy in the sun to accomplish this task.The solardrying is achieved by the absorption of heat energy by an absorber from the solar radiation (insolation) incident on it. This heat energy elevates the air temperature in the drying chamber, which then causes drying of its content[4].Wayo[3] shows that solar drying can bring about the following improvements over the sun drying systems. It is hygienic, efficient, safer, healthy, faster, cheaper and higher quality. Solar dryers are classified into three main types according to the exposure of drying products to solar radiation, the mode of air flow through the dryer and the temperature of air entering the drying chamber [5]. Based on exposure of the drying products to solar radiation. The solar drying systems are categorized as sun drying, hybrid solar crop dryer, direct solar crop dryer, indirect solar crop dryer and mixed mode solar crop dryer [6]. Sun dryer is the process by which the products are spread on cement floor, ground, mats etc. to receive the solar radiation. No specialized tools are involved and this is common with the rural folks.Hybrid solar drying mode has a combination of two or more energy sources. It makes use of solar energy during the day and an alternate energy source at night. The alternate source of energy could be electricity, diesel, biomass or kerosene to supplement the variation of solar radiation [6]**.** In thedirect solar dryer**,** the crops are placed under a transparent enclosure. The radiation incident on the crop is absorbed within it. The gradual heat gain by the crop internally leads to the removal of moisture. Heat transfer properties of the crop such as absorptivity and thermal conductivity of crop also determines how fast the crop dries. The cabinet and tent dryer are typically of this mode [5]. Cabinet dryersconsist mostly of an insulated rectangular container with a transparent roof. There are small outlets at the base and upper part to serve as exit point for the residue air. Perforated drying trays are positioned within the cabinet with access to them provided by doors. The inside is painted black to serve as the absorber. There is heat transfer through the transparent roof, the absorber gains heat and transfers this heat to the air in the cabinet. The air rises as a result of heat gain passes through the drying trays and out of the cabinet outlets provided at the top while fresh air enters at the bottom and is heated by energy transmitted by the absorber. The air rises and the process repeats itself.Tent dryer has the ridge tent**-** like structure covered by transparent plastic sheets on the ends. The rock bed is covered with a blackened material. The transparent plastic sheets are well arranged in such a way that there is access to the centrally placed trays [7]. In indirect solar dryers the products are shielded from direct incidence of solar radiation. Heated air from the solar absorber and the air is directed to the drying chamber. Air flow is by natural or forced convection. Crops in this type of chamber are monitored by periodic inspection because of the temperature variance. Crop stirring is also required. Mixed mode solar dryer has the advantage of utilizing both direct and indirect solar dryers. The air is heated by an external collector and is channeled to a transparent drying chamber. This has a higher and effective rate of drying than the direct and indirect solar dryers [3]. When the dryer is classified by mode of air flow then the air flow into the chamber is mostly by forced or natural convection. The natural method relies on the thermally induced density gradient for the flow of air through the chamber by convectional means as a result of buoyancy forces and wind pressure. The forced convection depends on a pressure differential by use of a fan or blower. Forced convection gives greater air circulation making it good for drying large quantities of produce [8]. The fan requires external source of power, PV panel etc.Based on the air temperature entering the drying chamber the inlet air temperature can be either ambient or elevated. Elevated temperature is achieved by passing the ambient air through a solar collector prior to its entering the drying chamber. Dryers that use elevated temperature have greater efficiency than those that use ambient air temperature [9].

METHOD AND MATERIALS

Design equations and parameters

For natural convection solar dryer, natural circulation of air is the only means by which the products can be dried but the forced convection drying is achieved using forced circulation of air through the collector to the drying chamber. The period of drying by natural convection is longer than as compared to the forced convection. The use of the extractor fan and the blower in the forced convection dryer will reduce the drying time significantly as more moist air will be removed and higher percentage of the hot air in the collector will be transferred into the drying chamber.

Solar energy incident on the collector surface

Solar intensity on a horizontal surface in Kumasi in the month of April from available data is given as I_o = 12.31MJ/m^2 per day (Solar lab, KNUST).

Since the angle of inclination of the collector is very small $I_o = \mathrm{I_t} = \frac{12.31\times10^6}{12\times3600} = 318.76\ \mathrm{W/m^2}$

System drying efficiency η_d

System efficiency can be expressed mathematically as

$$\eta_d = \frac{ML}{I_t A_c} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(1)$$

where M = mass of moisture evaporated per second (kg/s)

L= latent heat of evaporation of water (kJ/kg)

I_t = insolution on tilted collector surface (W/m^2)

Ac = collector area (m^2)

Values of 20-30% are obtained from forced convection dryers.

$$M_w = \frac{M_p(M_i - M_f)}{1 - M_f} \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

where M_w = mass of water removed

M_i = initial moisture content

M_f = final moisture content

M_p = mass of product

Mass of water removed per second =1.8 x 10^{-5} kg/s

Total drying time is expressed by $t = \frac{W_o - W_o}{R_c} + \frac{W_c}{R_c}\ln\left(\frac{W_c}{W}\right)$ (4)

where$R_c = constant\ rate\ of\ drying = \frac{dw}{dt} = \frac{W_o - W_c}{t_c}$

W_o = initial moisture content = 80% = 0.80/0.20 = 4kg H_2O/kg solid

W_f= final moisture content =10% =0.10/90 = 0.11kg H_2O/kg solid

Wc = critical moisture content = 25% = 0.25/0.75 kg = 0.33kgH^2O/kg solid (from table),

R_c = 0.012kg H^2O/kg solid, t_c =300s, total drying time, t = 1.17 day = 1 day

Volume of air required for removing the moisture

$$V_A = \frac{M_w L_t R_a T_a}{C_{pa} P_a (T_o - T_f)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(\mathbf{5})$$

$V_A = volume\ of\ air, M_w = mass\ of\ water\ removed,$

$R_a = specific\ gas\ constant, C_{pa} = specific\ heat\ capacity\ of\ air,$

$P_a = atmospheric\ pressure,$

$T_o = temperature\ of\ drying\ air\ leaving\ the\ collector,$

Effective drying rack area is obtained from the relation

$$A_{rac} = \frac{M_p}{\rho_{gr} h_L \epsilon(1 - \varepsilon_v)}, \ldots\ldots\ldots\ldots\ldots\ldots (6)$$

$M_p = mass\ of\ moringa = 2kg,$

$\rho_{gr} = bulk\ density\ of\ moringa\ on\ wet\ basis = 450kg/m^3$

$h_L = depth\ of\ the\ drying\ rack = 0.2m, \epsilon = crop\ porosity = 0.44,$

$\varepsilon_v = loadinng\ bed\ void\ fraction = 0.7 \quad A_{rac} = 0.168m^2$

When the mass of moringaM_p= 2000g, initial moisture content of moringa = 80%, final moisture content desired = 10%, expected drying time of I day = 24hrs.

The actual value of the latent heat of evaporation for moringa is estimated using the expression

$$L_m = R_g T_c T_b \ln(P_c/10^5)\frac{(T_c - T_{pt})^{0.38}}{(T_c - T_c)^{1.38}} \ldots\ldots\ldots (3)$$

R_g = gas constant foe water vapour, T_b = boiling point of water, T_c = critical temperature of water,

P_c = critical pressure of water, T_{pt} = temperature of the (product) moringa = 0.25(3T_o + T_a) where T_a = ambient temperature T_o = temperature at collector outlet

Since water is to be evaporated from the product to be dried, the value of the L_m estimated is increased by a factor of 10-20%. Using 12%, L_m = 2.743 MJ/kg

Therefore the collector area can be calculated from eq(1). Assumed $\eta_d = 25\% = 0.25$

Area of collector, $A_c = 0.6m^2$ $(1000mm \times 600mm)$

Drying time

$T_f = temperature\ of\ air\ leaving\ the\ drying\ rack$

$T_f = (T_a + 0.25\{\Delta T\}) = 30°C, \ \Delta T = 2B(T_b - T_c)(I_t/I_0) = 18.5°C,$ B = constant

$\Delta T = T_o - T_a T_o = 43.5^o C$

$V_A = 9945m^3$

$t = maximum\ expected\ drying\ time\ of\ 24h\ (86400s)$

$volume\ flow\ rate, \dot{Q} = \frac{V_A}{t} = 0.115\,m^3/s$

$mass\ flow\ rate, \dot{m} = density\ of\ air \times discharge = 0.138\,kg/s$

Sizing of fan

$volume\ flow\ rate, \dot{Q} = Av, \ v = \dot{Q}/A, diameter\ of\ fan = 100mm$

$Useful\ power\ of\ the\ motor\ for\ the\ fan, P = \frac{1}{2}\dot{m}v^2 = 14.6W, speed\ N\ in\ RPM = \frac{\omega}{2\pi}$

$where\ \omega = {}^{v}/_{r}$

Area of Dying rack

Height of the drying chamber

The resistance to the flow of air through a parked bed of agricultural produce is expressed in the form Jindal V.K, Gunasekara S. (1982)

$$u = a\left(\frac{\Delta P_B}{h_L}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

$where\ u = superficial\ air\ velocity\ which\ lies\ between\ 0.2\ and\ 0.4m/s$

$a = constant = 0.465m^3/kg$

$for\ force\ circulation\ of\ air\ through\ agricultural\ produce\ h_L \leq 0.2m,$

ΔP_B
$= pressure\ drop\ across\ the\ moringa\ leaves\ in\ the\ rack = \frac{u \times h_L}{a} = 0.17Pa$

Total pressure across the system is twice the pressure drop across the drying rack

$\Delta P_T = 2(\Delta P_B) = 0.34Pa$

Applying Bernouli's equation between the relevant sections of the dryer and sampling the results leads to height of the drying chamber

$$H = \frac{\Delta P_T}{g(1/T_a - 1/T_o)P_a/R} = 0.756m$$

$where\ T_a = 298K, T_o = \Delta T + T_a = 310K, P_a = 101325\,N/m^2, R = 287\,J/kg\,K,$
$g = 9.81\,m/s^2$

CONSTRUCTION PROCESS

Conceptual design is one of the most important activities in product development. Inappropriate design concepts could result in high redesign cost and delay in product realization. It involves combining design

Depth of collector

A collector with tilt angle up to 60^0, length-to-depth ratio lies between 5 and 10 (Forson, 2007)

$\frac{L_c}{d_c} = 5, \quad d_c = \frac{L_c}{5}$

$Lengh\ of\ collect = 1000mm$

$depth\ of\ collector = 200mm$

Chimney height

According to Bolaji 2005, the height difference between the inlet air and exhaust a forced convention should not exceed 1200 mm with collector area less than $10m^2$

$Chimney\ height, h_c = 1.2 - (0.75 + 0.1) = 0.35m$

Conceptual Design

features to generate as many potential design concepts. The drawings below are the conceptual designs generated for the indirect solar crop dryer.

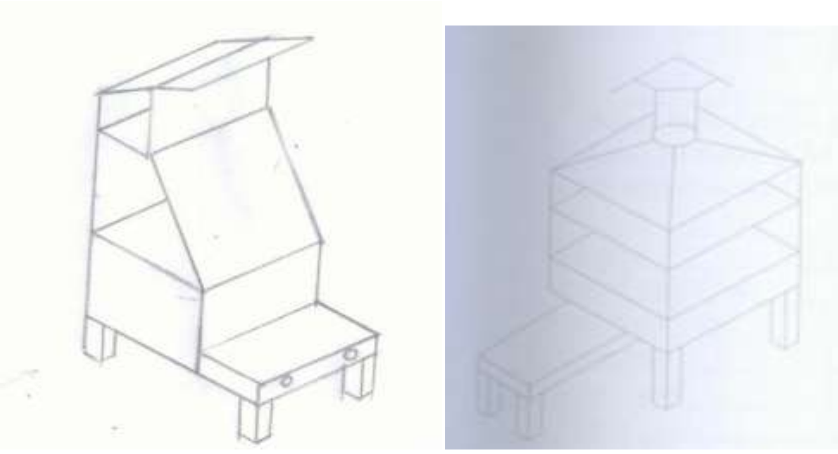

Fig.1 a.Conceptual design A b. Conceptual Design B

SELECTION OF APPROPRIATE CONCEPTUAL DESIGN USING DESIGN MATRIX

Evaluation of Design Alternative –Criteria are of Equal Weights		
a. Rank each design/process from poor(1) to excellent(5) a. Sum all ranking for each design/process ($C = \sum r_i$) c. A higher score from step b indicates a favourable design/process		
Criteria	**Design A ratings(r)**	**Design B ratings(r)**
Ease of operation	3	2
Assembly time	4	3
Aesthetics	2	1
Unit cost	4	4
Safety	3	1
Reliability	2	2
Shape	5	4

Total score ($C = \sum r_i$) 23 18

Conclusion: **Design A is better than Design B**

Construction of the Indirect-Mode Solar Dryer

The criteria for selection of materials are suitability, availability in the local market, cost, durability and safety when in contact with the moringa leaves. Care was taken in material selection because of the hygienic state of the leave. Care was also taken in selecting materials for the drying chamber because of the possibilities of rustcontaminating the leaves being dried. Odum and plywood were selected for the structure and enclosed chamber and the nylon net for the dying rack. The odum and plywood were sprayed with chemicals and painted to prevent insects attack.All the materials used for the construction of the forced convection indirect mode solar dryer were relatively cheap and easily obtained from local market .Tools used in the construction of the dryer arehammer, rolling machine, handsaw, paint brush, grinding machine, chisel, measuring tape, screw driver, square/straight edges.

MATERIAL COST AND ANALYSIS

Material	Quantity	Unit cost GH₵	Description	Total cost GH ₵
Wood	1	50	2/4 inch	50
Plywood	2	12	1/8 inch	24
Galvanized alum. sheet	1	9	One slit	12
glass	2	15	100 cm x60 cm	30
Wire mesh	1	3	One yard	3
Oil paint black	1	5	One(1) milo tin	5
Oil paint green	1	5	one	5
turpentine	1	7	One gallon	7
brush	1	2	4 inch	2
Blower/fan	1	50	Small size (1398 RPM)	50
Foam/cotton		5	500 grams	5
Nails		4	2 pounds	4
Total				200

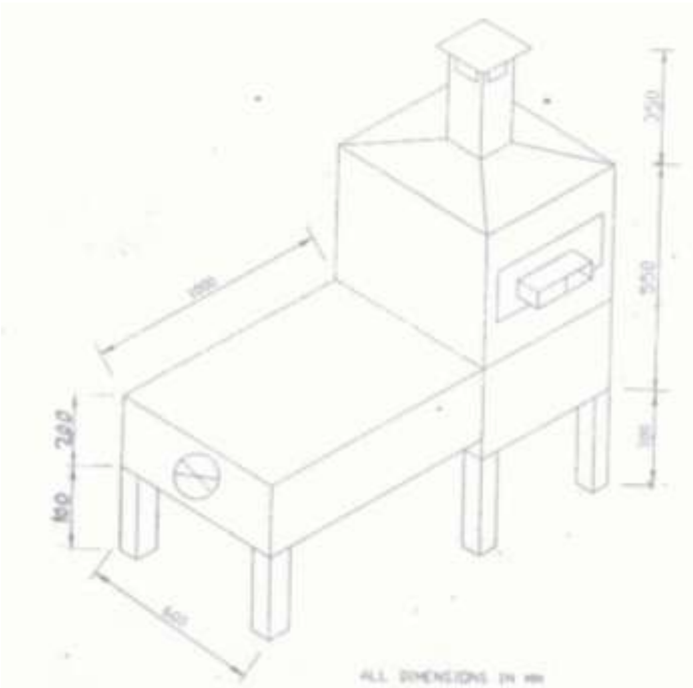

Fig.2 a. Isometric drawing of developed selected design

Fig. 2 b. Constructed indirect solar dryer

PARTS LIST

ITEM NO	DESCRIPTION	QUANTITY	MATERIAL
1	collector	1	glass
2	Collector side	3	plywood
3	Supporting stand	6	hardwood
4	Drying chamber	4	plywood
5	Chimney side	4	plywood
6	Absorber plate	1	Alumi sheet
7	fan	1	metal

Description of features of the forced convection indirect solar dryer

The Fig. 1b shows the constructed indirect solar dryer, consisting of the solar collector (air heater), the drying cabinet, drying rack, chimney and fan.

Collector (Air Heater):

The heat absorber (inner box) of the solar air heater was constructed using 2 mm thick aluminum plate, painted black, is mounted in an outer box built from well-seasoned Odum and plywood. The space between the inner box and outer box is filled with foam material of about 40 mm thickness and thermal conductivity of 0.043 $Wm^{-1}K^{-1}$.The solar collector assembly consists of air flow channel enclosed by transparent cover (glazing). The. Glazing is a single layer of 4 mm thick transparent glass sheet; it has a surface area of 1000 mm by 600 mm and of transmittance above 0.7 for wave lengths in the rage 0.2 – 2.0 µm. One end of the solar collector has an air inlet vent of area $0.0457m^2$, which is fitted with fan and blower to provide the forced convection, the other end opens to the drying chamber.

The Drying Cabinet:

The drying cabinet together with the structural frame of the dryer was built from well-seasoned Odum and plywood which could withstand termite and atmospheric attacks. An outlet channel was fitted with chimney. Access door to the drying chamber was also provided at the side of the cabinet.

Drying Rack:

The drying trays are contained inside the drying chamber and were constructed from a double layer of fine chicken wire mesh with a fairly open structure to allow drying air to pass through the moringa leaves.

The orientation of the Solar Collector:

The flat-plate solar collector is always tilted and oriented in such a way that it receives maximum solar radiation during the desired season of used. The best stationary geographical orientation in Kumasi is 6.7^oN, 1.6^oW. Therefore, solar collector in this work is oriented facing west and tilted at 16.5^o to the horizontal.

Conclusion

Simple and inexpensive indirect forced convection mode of solar crop dryer was designed and constructed using locally sourced materials. The dryer exhibited sufficiently ability to dry the leaves reasonably rapidly so that a safe moisture level can be attained in order to ensure superior quality of moringa leaves.

Recommendation

A test under full loading conditions should be carried out in order to know if all the design parameters have been met and laboratory experiment should also be done to know the effects on the nutritional values when sun dried and solar dried.

References

1. Hall DW. Principle of a continuous-flow dryer: FAO, Rome, 1982.
2. AL- Kahtani HA, Abou-Arab AA, Comparison of physical, chemical and functional properties of Moringa peregrine, 1993.
3. Wayo E.K. Design, construction and testing of a solar tent dryer. BSc thesis, Department of Mechanical Engineering KNUST, Kumasi, Ghana, 1990.
4. Duffie, Beckman, Solar engineering of thermal sciences, 2nd ed. 1991; New York.
5. Forson FK, Nazha M.A.A, Akuffo F.O, Natural convection solar crop dryers of commercial scale design in Ghana: Design, construction and performance. Ambient Energy, 1996; 17(3):123-130
6. Akuffo FO, Forson F.K, Nazha M.A.A, Rajakaruna H. Design of mixed-mode natural convection solar crop dryers. Renewable Energy, 2007; 32: 2306-2319
7. Kumah CD. Design, construction and testing of a direct solar tent dryer for drying crops andfoodstuffs. BSc thesis, Department of Mechanical Engineering KNUST, Kumasi, Ghana, 2004.
8. Ong K.S. Results of investigation into forced convection and natural solar heater and dryers. Reg J Energy Heat and Mass Transfer, 1982; 4(1): 29-45.
9. Cengel YA and Boles. Thermodynamics: An Engineering Approach. 3rd ed. New York: McGraw-Hill, 1998
10. Afriyie JK, Nazh M.A.A, RajakarunaH,Forson F.O . Experimental investigations of a chimney-dependent solar crop dryer.Renewable Energy, 2009; 34: 217-222
11. Bolaji BO, Olalusi A.P, Department of Mechanical Engineering, University of Agriculture,Abeokuta, Ogun State, Nigeria, 2005
12. Jindal V.K, &Gunasekara S. Estimating airflow and drying rate due to natural convection in solar rice dyers. Renewable Energy, , Bangkok, 1982.