DESIGN, CONSTRUCTION AND PERFORMANCE EVALUATION OF SOLAR MAIZE DRYER

Ass. Prof. Dr Saad M. Saleh
Mechanical Eng. Dept.
College of Engineering
University of Baghdad

Ahmad Abd Gatwa
Agricultural mechanization
College of agriculture
University of Baghdad

Abstract

This paper presents the design, construction and performance evaluation of solar drying for maize, the solar drying system consists of V-groove collector of 2.04 m² area, Drying Chamber and blower. It was designed in such a way that solar radiation is not incident directly on the maize. K-type thermocouples were used for temperature measurement, while solar radiation was measured by (solar meter mod.776). The thermal energy and heat losses from solar collector were calculated for each three angles tilt (30º, 45º, 60º). The results obtained during the test period denoted that the maximum gained energy occurred at 11 o'clock hour and then gradually declined since the maximum solar radiation occurred at this time. The performance of the solar drying system was highly dependent on the solar radiation, angle tilt and ambient temperature.

الخلاصة

يتضمن هذا البحث تصميم ، بناء وتقييم اداء منظومة تجفف شمسي لتجفيف الذرة الصفراء ، المنظومة تتألف من جامع شمسي متعرج على شكل حرف V مساحته 2.04 م^2 ، كابينة تجفيف ودافعة هواء.طريقة تصميم المنظومة تضمن عدم تعرض الحبوب الى اشعة الشمس بصوره مباشرة. اذ استخدمت مزدوجات حرارية من نوع k لغرض قياس درجات الحرارة، كذلك استخدم جهاز قياس شدة الاشعاع الشمسي لقياس شده الاشعاع الساقطة على سطح الجامع لوحدة المساحة ، التجربة تهدف الى حساب الطاقة الحرارية المكتسبة والخسائر الحرارية من الجامع الشمسي باستخدام ثلاث زوايا ميل (30º،45º،60º). اظهرت النتائج ان الطاقة الحرارية تزداد بزيادة شده الاشعاع الشمسي الساقط على وحدة المساحة، اقصى طاقة كانت عند الساعة 11 صباحاً وبعد ذلك تبدا الطاقة بالهبوط التدريجي، ان اداء منظومة التجفيف تعتمد بشكل رئيسي على شدة الاشعاع ، زاوية ميل الجامع ودرجة حرارة المحيط.

Keywords: Solar Energy, Solar Air Collector V-Corrugated Collector, Solar Drying System Performance Study.

Introduction

In many parts of the world there is a growing awareness that renewable energy have an important role to play in extending technology to the farmer in developing countries to increase their productivity (Waewsak, et al. 2006). Solar thermal technology is a technology that is rapidly gaining acceptance as an energy saving measure in agriculture application. It is preferred to other alternative sources of energy such as wind and shale, because it is abundant, inexhaustible, and non-polluting (Akinola 1999, Akinola and Fapetu 2006, Akinola, et al. 2006). Solar air heaters are simple devices to heat air by utilizing solar energy and employed in many applications requiring low to moderate temperature below 80 ^{o}C, such as crop drying and space heating (Kurtbas and Turgut 2006). Drying processes play an important role in the preservation of agricultural products.

They are defined as a process of moisture removal due to simultaneous heat and mass transfer (Ertekin and Yaldiz 2004). According to (Ikejiofor1985) two types of water are present in food items; the chemically bound water and the physically held water. In drying, it is only the physically held water that is removed. The most important reasons for the popularity of dried products are longer shelf-life, product diversity as well as substantial volume reduction. This could be expanded further with improvements in product quality and process applications. The application of dryers in developing countries can reduce post harvest losses and significantly contribute to the availability of food in these countries. Estimations of these losses are generally cited to be of the order of 40% but they can, under very adverse conditions, be nearly as high as 80%. 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) Traditional drying, 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). Solar drying may be classified into direct, indirect and mixed-modes. In direct solar dryers the air heater contains the grains and solar energy passes through a transparent cover and is absorbed by the grains. Essentially, the heat required for drying is provided by radiation to the upper layers and subsequent conduction into the grain bed. In indirect dryers, solar energy is collected in a separate solar collector (air heater) and the heated air then passes through the grain bed, while in the mixed-mode type of dryer, the heated air from a separate solar collector is passed through a grain bed, and at the same time, the drying cabinet absorbs solar energy directly through the transparent walls or roof. Therefore, the objective of this study is to develop a mixed-mode solar dryer in which the grains are dried simultaneously by both direct radiation through the transparent walls and roof of the cabinet and by the heated air from the solar collector. The performance of the dryer was also evaluated.

Theory, Materials and Methods

Basic Theory

The energy balance on the absorber is obtained by equating the total heat gained to the total heat loosed by the heat absorber of the solar collector. Therefore

$$IA_c = Q_u + Q_{cond} + Q_{conv} + Q_R + Q_\rho, \quad (1)$$

The three heat loss terms Q_{cond}, Q_{conv} and Q_R are usually combined into one-term (Q_L), i.e.

$$Q_L = Q_{cond} + Q_{conv} + Q_R. \quad (2)$$

$$IA_c = \tau\, I_T A_c \tag{3}$$

The reflected energy from the absorber is given by the expression:

$$Q_\rho = \rho\tau\, I_T A_c \tag{4}$$

Substitution of Eqs. (2), (3) and (4) in Eq. (1) yields

$\tau\, I_T A_c = Q_u + Q_L + \rho\tau\, I_T A_c$, or $\quad Q_u = \tau\, I_T A_c (1 - \rho) - Q_L$

For an absorber $(1 - \rho) = \alpha$ and hence

$$Q_u = (\alpha\tau) I_T A_c - Q_L \tag{5}$$

The total heat loss coefficient is given the following Eg.(6)(Karim and Hawlader,2006)

$$UL=Ut +UB \tag{6}$$

$$U_t = \left[\frac{N}{\frac{C}{T_p}\left[\frac{T_p - T_a}{N + f}\right]^e} + \frac{1}{h_w} \right]^{-1} + \frac{\delta(T_p^2 - T_a^2)(T_p + T_a)}{\frac{1}{d} + \frac{2N + f - 1}{\varepsilon_g} - N}$$

$$f = (1 + 0.089 h_w - 0.1166 h_w \varepsilon_p)(1 + 0.07866 N)$$

$$C = 520(1 - 0.000051\beta^2) \text{ for } 0° < \beta < 70°$$

$$e = 0.252$$

$$h_w = 5.7 + 3.8v$$

$$U_B = K_{INS}/L_{INS}$$

Q_L composed of different convection and radiation parts. It is presented in the following form (Bansal *et al.* 1990):

$$Q_L = U_L A_c (T_c - T_a) \tag{7}$$

From Eqs. (5) and (7) the useful energy gained by the collector is expressed as:

$$Q_u = (\alpha\tau) I_T A_c - U_L A_c (T_c - T_a) \tag{8}$$

Therefore, the energy per unit area (q_u) of the collector is

$q_u = (\alpha\tau)I_T - U_L(T_c - T_a)$. (9)

If the heated air leaving the collector is at collector temperature, the heat gained by the air Q_g is:

Q_g = m□cp $(T_c - T_a)$ (10)

The collector heat removal factor, F_R, is the quantity that relates the actual useful energy gained of a collector, Eq. (8), to the useful energy gained by the air, Eq. (10). Therefore

$$F_R = \frac{\dot{m}_a C_{pa}(T_c - T_a)}{A_c[\alpha\tau I_T - U_L(T_c - T_a)]} \quad (11)$$

$Q_g = A_c F_R[(\alpha\tau)I_T - U_L A_c(T_c - T_a)]$ (12)

The thermal efficiency of the collector is defined as (Itodo *et al.* 2002):

$$\eta_c = \frac{Q_g}{A_c I_T} \quad (13)$$

Energy Balance Equation for the Drying Process.

The total energy required for drying a given quantity of food items can be estimated using the basic energy balance equation for the evaporation of water. (Youcef-Ali, et al. 2001)
Mwhfg= ma Cp□ (Tica-Toca□) (14)

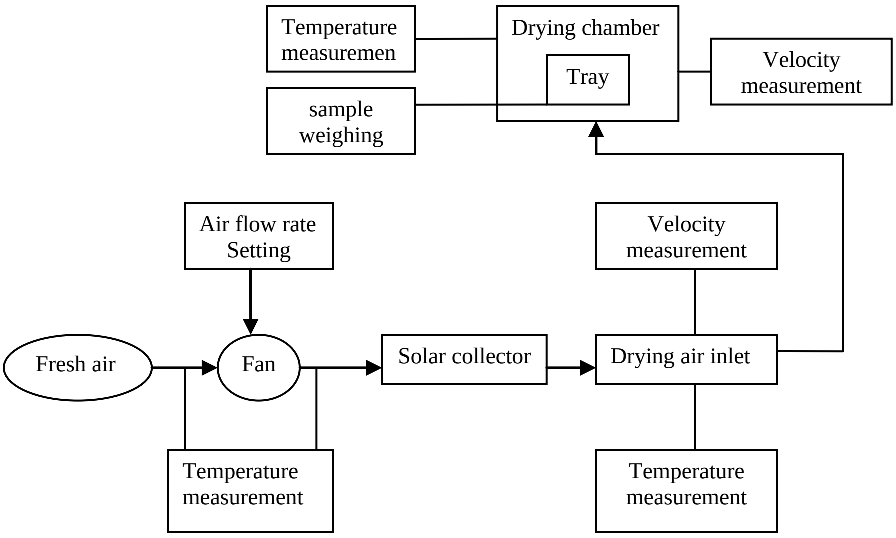
The amount needed is a function of temperature and moisture content of the crop. The latent heat
of vaporization was calculated using equation given by Youcef-Ali et al. (2001) as follows:

hfg = 4.186*10^3 (597-0.56(Tpr))

The mass of water evaporated is calculated from Eq. 15:

$$m_w = \frac{m_i(M_i - M_e)}{100 - M_e} \quad (15)$$

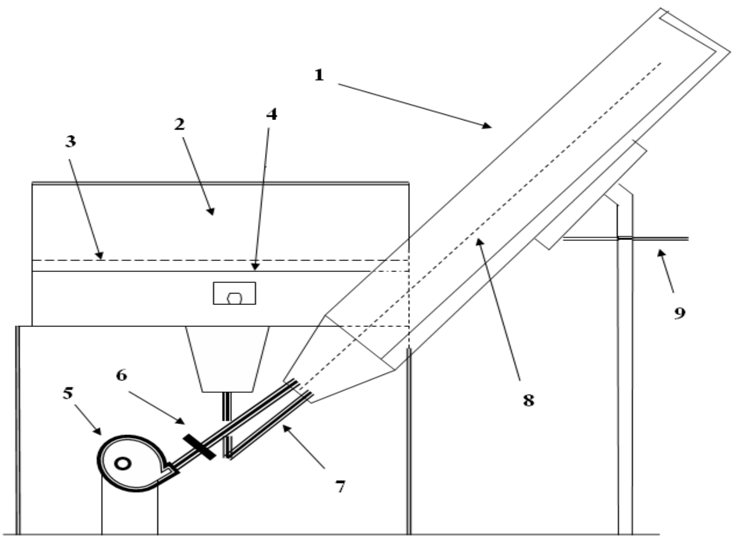
During drying, water at the surface of the substance evaporates and water in the inner part migrates to the surface to get evaporated. The ease of this migration depends on the porosity of the substance and the surface area available. Other factors that may enhance quick drying of food items are: high temperature, high wind speed and low relative humidity. In drying grains for future planting, care must be taken not to kill the embryo. In drying items like fish, meat, yam chips, plantain chips etc., excessive heating must also be avoided, as it spoils the texture and quality of the item.



Flow Diagram of drying process.

The solar drying system

Fig. 1 shows the solar drying system, which includes collector, drying chamber, and the blower, the use of V-grooved absorbers improves the heat transfer coefficient between the absorber plate and the air as well as it increases the absorptivity to solar radiation (Goel et al, 1987, Chaudhory et al1988, Hafiz et al, 1999), as shown in figure. 2. it is made of galvanized steel with black paint containing (5%) black chromium powder to increase its absorbing capability.



1. Solar collector. 2. Drying chamber. 3. Tray drying. 4. Thermostat temperature. 5. Air blower. 6. Air valve. 7. Connecting pipes. 8. Absorption plates of two air passes. 9. Slide rule

Fig.1. Section of the solar drying system.

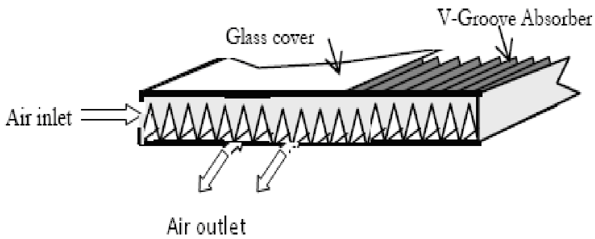


Fig.2. Schematic of the using V-groove absorber collector.

The collector was insulated with rock wool of 10 mm thickness from the bottom and 5 mm thickness from sides. The collector was contained within galvanized steel frame. The drying chamber used in this work was (1.06x0.66x0.56 m) (width, depth, and height) respectively , all the system components connected with each other's, as well as to transport the air between the collector and the drying chamber, plastic pipes of 63 mm diameter were used.

Experimental set-up

The performance of the solar drying system was evaluated experimentally using three collectors´ angles tilt (30º, 45º, 60º)
By measuring the following parameters: (a) radiation incident on the collector, (b) air temperatures at various locations in the collector and dryer, and (c) relative humidity of air.

To measure the temperature of air at various locations of the collector and dryer, K-type thermo-couples were installed at various points along the length and breadth of the solar dryer system. All temperature data were registered at an interval of 15 minutes. Drying test was started at 9:00 hours and stopped at 14:00 hours.

Results and discussions
Performance of the solar drying system

Solar drying performance was compared between ambient temperatures for the period of experimentation. The performance of the solar drying was highly dependent on the solar radiation and ambient temperature. Fig.3. shows each change of air ambient temperature and the air inside and outside of the collector solar during daylight hours on the inclination angle of 30º. It was the highest temperature out of the collector (40.5 Cº) of the Whole at the 11 o'clock hour at the highest intensity of radiation 350w/m².

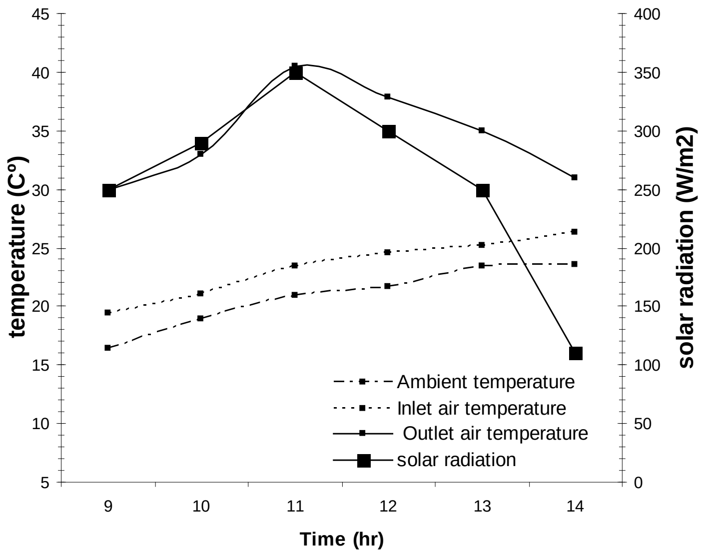


Fig.3. air ambient temperature, air inside, outside of the collector solar and solar radiation for angle 30º. (history 21/11/2008)

Fig.4. shows the change of the temperature of the ambient air and the temperature of the air inside and outside of the collector solar during daylight hours on the inclination angle of 45º. It was the highest temperature out the collector 49 Cº of the whole at the 11 o'clock hour at the highest intensity of radiation 540 w/m². The highest temperature out of the collector at inclination angle of 60º (42 Cº) at the highest intensity of radiation 365 w/m², of the whole at the 11 o'clock hour Fig.5.

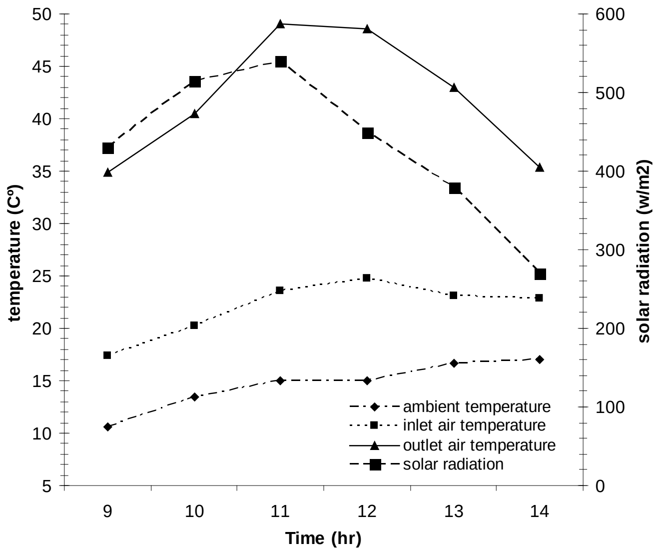


Fig.4. air ambient temperature, air inside, outside of the collector solar and solar radiation for angle 45°. (history 22/11/2008)

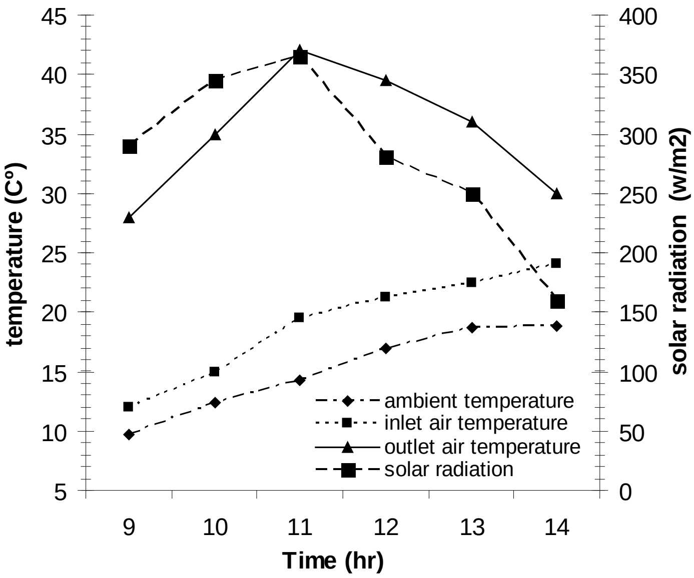


Fig.5. air ambient temperature, air inside, outside of the collector solar and solar radiation for angle 60°. (history 23/11/2008)

Fig.6. shows the relation between the theoretical thermal energy and the experimentally actual heat gain on the inclination angle 30 °, the highest values 669.6 and 589.4 w for the theoretical thermal energy and the experimentally actual heat gain respectively at 11 am and then gradually declined. Theoretical energy and actual heat gain (which were calculated through FORTRAN 99 program computer) depend on the intensity of radiation. We also note that the total loss factor of the collector is increasing with the increase in solar radiation, the highest value (4.59 w/m².C°) of thies losses occurred at 11 am. From fig.7. the highest values of theoretical thermal energy, experimentally actual heat gain and total loss factor of the collector at the inclination collector tilt -45° at the 11 am are (996.4, 900.7 w, and 4.48 w/m².C°) respectively.

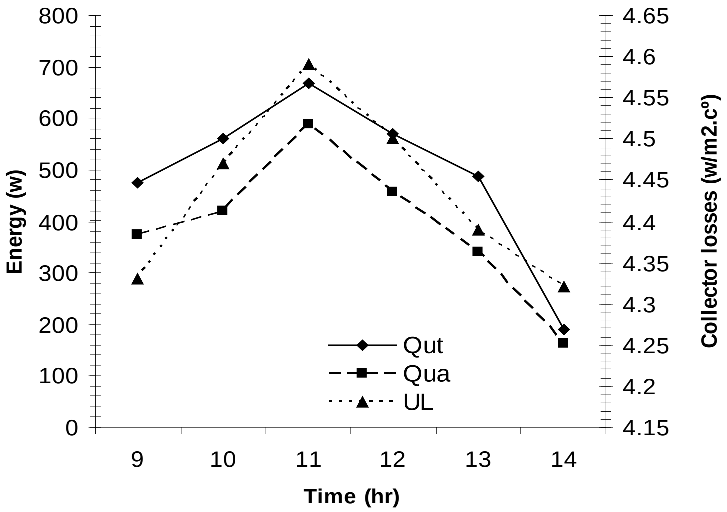


Fig.6. the theoretical thermal energy, the experimentally actual heats gain and the total loss factor of the collector versus the daylight hours of the inclination angle of 30º. (history 21/11/2008)

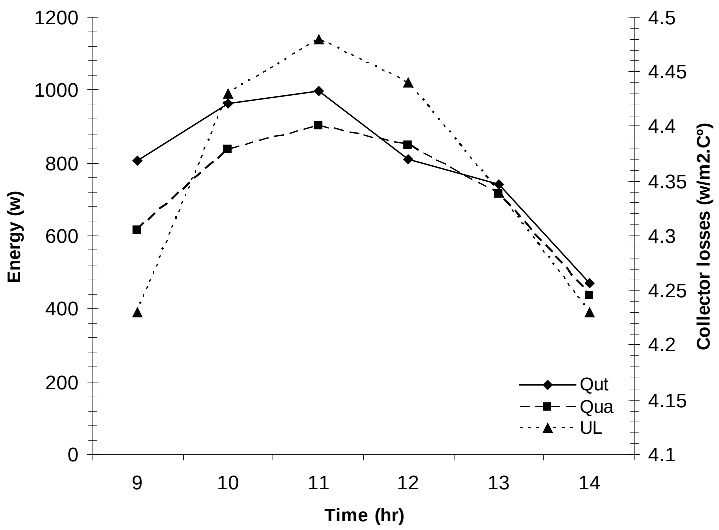


Fig.7. the theoretical thermal energy, the experimentally actual heats gain and the total loss factor of the collector versus the daylight hours of the inclination angle of 45º. (history 22/11/2008)

From fig.8. the highest values of theoretical thermal energy, experimentally actual heat gain and total loss factor of the collector at the inclination collector tilt 60º at 11 am are (619.3, 606 w and 4.5 w/m².Cº) respectively,

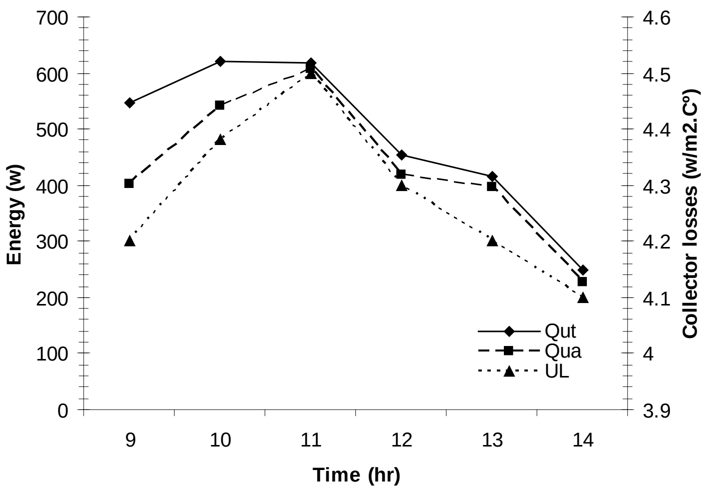


Fig.8. the theoretical thermal energy, the experimentally actual heats gain and the total loss factor of the collector versus the daylight hours of the inclination angle of 60º. (history 23/11/2008)

Economic Evaluation

To evaluate the economic performance of the solar drying system, the method proposed by (Audsley and Wheeler, 1978) is used taking into account the economic condition in Iraq. The various construction and operating costs of the dryer are given as table.1
(1 USD =123 ID)

Table.1. Cost and economic parameters

Material cost for the construction of the solar drying system	649583 ID
maintenance cost	601.4 ID/day
Interest rate	19487.49 ID
Life span of the dryer	12.5 years
Electricity cost	15.6 ID/ day
labour cost	5000 ID/day

Conclusions

1. The theoretical thermal energy, the experimentally actual heats gain increase by increasing radiation intensity, the maximum values occurred at the 11 am and then gradually declined.
2. The energy gained obtained at the angle tilt 45º is higher than the corresponding values obtained at 60º, 30º tilt.
3. The total loss factor of the collector increases with the increase in the intensity of solar radiation intensity, as well as this factor depends on the convection coefficient for the air between the top glass cover and environment.
4. The performance of the solar drying system was highly dependent on the solar radiation and ambient temperature.

References

Audsley, E. and Wheeler, J. 1978. The annual cost of machinery calculated using actual cash flows. Journal of Agricultural Engineering Research 23, pp. 189-201

Akinola, A.O. 1999. Development and Performance Evaluation of a Mixed-Mode Solar Food Dryer. M. Eng. Thesis, Federal University of Technology, Akure, Nigeria.

Akinola, A.O. and Fapetu, O.P. 2006. Exergetic Analysis of a Mixed-Mode Solar Dryer. J. Engin. Appl. Sci. 1: 205-10.

Akinola, O.A., Akinyemi, A.A., and Bolaji, B.O. 2006. Evaluation of traditional and solar fish drying systems towards enhancing fish storage and preservation in Nigeria. J. Fish. Int., Pakistan 1(3-4): 44-9.

Bassey, M.W. 1989, Development and use of solar drying technologies, Nigerian Journal of Solar Energy 89: 133-64.

Choudhury, C., Anderson S.L. and Rekstad J., 1988. A Solar Air Heater for Low Temperature Applications, *Solar Energy* 40, 335 – 344.

Ertekin, C. and Yaldiz, O. 2004. Drying of eggplant and selection of a suitable thin layer drying model, J. Food Engin. 63: 349-59.

Fisk, M.J. and Anderson, H.C. 1982.Introduction to solar technology, Addison-Wesley publishing Company Inc.

Goel, V.K., Ram Chandra and Raychaudhuri ,B.C., 1987. Experimental Investigations on Single-Absorber Solar Air Heaters. Energy Convers. Mgmt. Vol. 27 No. 4, pp. 343-349.

Hafiz, M.R., Othman, M. Y., Salleh, M.M. and Sopian, K., 1999. Design and Indoor Testing of the V-Groove Back Pass Solar Collector. Renewable Energy 16, 2118 – 2122.

Itodo, I.N, Obetta, S.E., and Satimehin, A.A. 2002. Evaluation of a solar crop dryer for rural applications in Nigeria. Botswana J. Technol. 11(2): 58-62.

Ikejiofor, I.D. 1985. Passive solar cabinet dryer for drying agricultural products. In: O. Awe (Editor), African Union of Physics. Proc. Workshop Phys. Tech. Solar Energy Convers. Univ. of Ibadan, Nigeria, pp. 157-65.

Kurtbas, I. and Turgut, E. 2006. Experimental investigation of solar air heater with free and fixed fins: efficiency and energy loss. Int. J. Sci. Technol. 1(1): 75-82.

Karim, M.A and Hawlader, M.N.2006. Performance evaluation of a v-groove solar air collector for drying applications. Applied Thermal Engineering 26: 121–130.

Madhlopa, A.; Jones, S.A.; and Kalenga-Saka, J.D. 2002. A solar air heater with composite absorber systems for food dehydration. Renewable Energy 27: 27–37.

Togrul, I.T. and Pehlivan, D. 2004. Modelling of thin layer drying kinetics of some fruits under open-air sun drying process. J. Food Engin. 65: 413-25.

Waewsak, J., Chindaruksa, S. and Punlek, C. 2006. A mathematical modeling study of hot air drying for some agricultural products. Thammasat Int. J. Sci. Technol. 11(1): 14-20.

Youcef-Ali, S., Messaoudi, H., Desmons, J.Y., Abene, A, and Le Ray, M. 2001. Determination of the average coefficient of internal moisture transfer during the drying of a thin bed of potato slices. J. Food Engin. 48(2): 95-101.

Nomenclature

I	Radiation on tilted surface (W/m²)

A_c	Collector area (m^2).
Q_u	Rate of useful energy collected by the air (W).
Q_{cond}	Rate of conduction losses from the absorber.
Q_{conv}	Rate of convective losses from the absorber (W)
Q_R	Rate of long wave re-radiation from the absorber (W).
Q_ρ	Rate of reflection losses from the absorber (W).
U_L	Overall heat transfer coefficient of the absorber ($Wm^{-2}K^{-1}$).
UT	Top loss coefficient, ($Wm^{-2}K^{-1}$).
UB	Bottom loss coefficient, ($Wm^{-2}K^{-1}$)
T_c	Temperature of the collector's absorber (K).
T_a	Ambient air temperature (K).
m□	Mass of air leaving the dryer per unit time (kgs^{-1}).
Cp	Specific heat capacity of air ($kJkg^{-1}K^{-1}$).
m_w	Mass of water evaporated from the food item (kg).
hfg	Latent heat of evaporation, kJ/kg H2O
m_a	Mass of drying air (kg).
hW	Wind induced heat transfer coefficient, $W/m^2.K$
k	Thermal conductivity of plate material, W/m .K
kINS	Thermal conductivity of rock wool insulation (=0.04), W/m. K
LINS	Thickness of insulation (=0.05), m
Tpr	Product temperature ºC
T	Temperature ºC
Ta	Ambient temperature, K
Tp	Plate temperature, K
v	Wind speed, m/s
N	Number of glazing (=1)
T_1 and T_2	Initial and final temperatures of the drying air respectively (K).
m_i	Initial mass of the food item (kg);
M_e	Equilibrium moisture content (% dry basis);
M_i	Initial moisture content (% dry basis).

Greek

α	Absorption
τ	Transmittance of cover
ρ	Reflection coefficient of the absorber
η	Thermal efficiency, %
σ	Stefan-Boltzmann constant, $W/m^2 K^4$