Journal of Agricultural Biotechnology and Sustainable Development Vol. 2(3), pp. 039-046, March 2010
Available online http://www.academicjournals.org/JABSD

Full Length Research Paper

Design, construction and performance evaluation of solar maize dryer

Ahmed Abed Gatea

Department of Agricultural mechanization, College of Agriculture, University of Baghdad, Iraq.
E-mail: ahmedabd192000@yahoo.com.

Accepted 29 October, 2009

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 m od.776. The thermal energy and heat losses from solar collector were calculated for each three tilt angles (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, tilt angle and ambient temperature. The total loss factor of the collector increases with the increase in the intensity of solar radiation intensity. The theoretical thermal energy, the experimental actual heats gain increase by increasing radiation intensity.

Key words: 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, wind (Akinola, 1999; Akinola and Fapetu, 2006; Akinola et al., 2006).

Solar air heaters are simple devices to heat air by utilizing solar energy and it is employed in many applications requiring low to moderate temperature below 80°C, such as crop drying and space heating (Kurtbas and Turgut, 2006). They are defined as a process of moisture removal due to simultaneous heat and mass transfer (Ertekin and Yaldiz, 2004). According to Ikejiofor (1985) 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; effect 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 lost by the heat absorber of the solar collector. Therefore,

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

Where

I = Rate of total radiation incident on the absorber's surface (Wm^{-2}).
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 (W).
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).

The three heat loss terms Qcond, Qconv and QR are usually combined into one-term (QL), that is,

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

$$IA_c = \tau I_T A_c \quad (3)$$

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

$$Q_\rho = \rho\tau I_T A_c \quad (4)$$

where

ρ = Reflection coefficient of the absorber.
τ = Transmittance of cover.

Substitution of Equations (2), (3) and (4) in Equation (1) yields

or

$$\tau I_T A_c = Q_u + Q_L + \rho\tau I_T A_c$$

or

$$Q_u = \tau I_T A_c (1 - \rho) - Q_L$$

For an absorber (1 – ρ) = α and hence

$$Q_u = (\alpha\tau) I_T A_c - Q_L \quad (5)$$

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

$$U_L = U_C + U_t \quad (6)$$

$$Ut = \left(\frac{N}{\frac{C}{Tp}\left(\frac{TP - Ta}{N + f}\right)^e} + \frac{1}{hw} \right)^{-1} + \frac{\sigma(Tp^2 + Ta^2)(Tp + Ta)}{\frac{1}{d} + \frac{2N + f - 1}{\varepsilon g} - N}$$

$$C = 520(1 - 0.000051\beta^2$$
$$d = \varepsilon p + 0.0425N(1 - \varepsilon p)$$
$$f = (1 + 0.089hw - 0.1166hw\,\varepsilon_p)(1 + 0.07866N)$$
$$hw = 5.7 + 3.8u$$
$$e = 0.252$$
$$Ub = \frac{k_{ins}}{L_{ins}}$$

QL composed of convection conduction and radiation parts. It is presented in the following form ;

$$Q_L = U_L A_c (T_c - T_a) \quad (7)$$

Where

U_L =Overall heat transfer coefficient of the absorber ($Wm^{-2}K^{-1}$).
Tc = Temperature of the collector's absorber (K).
Ta = Ambient air temperature (K).
From Eqs. (5) and (7) the useful energy gained by the collector is expressed as:

$$Q_u = (\alpha\tau) I_T A_c - U_L A_c (T_c - T_a) \quad (8)$$

Where

Absorption = α
Therefore, the energy per unit area (qu) of the collector is:

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

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

$$Q_g = \dot{m}\, cp\, (T_c - T_a) \quad (10)$$

$\dot{m}$ = Mass of air leaving the dryer per unit time (kg s– 1).
Cp = Specific heat capacity of air ($kJkg^{-1}K^{-1}$).

The collector heat removal factor, FR, is the quantity that relates the actual useful energy gained of a collector, Eq. (8), to the useful

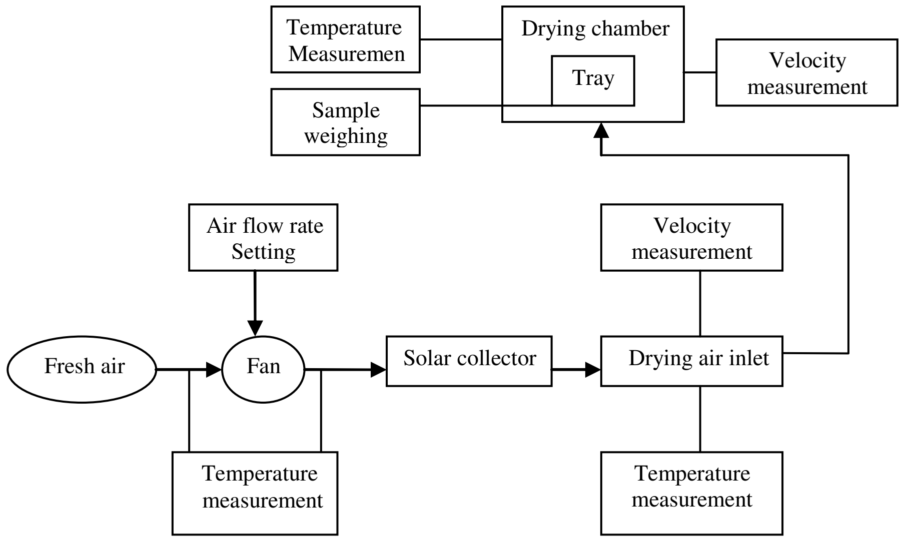

Figure 1. Flow diagram of drying process.

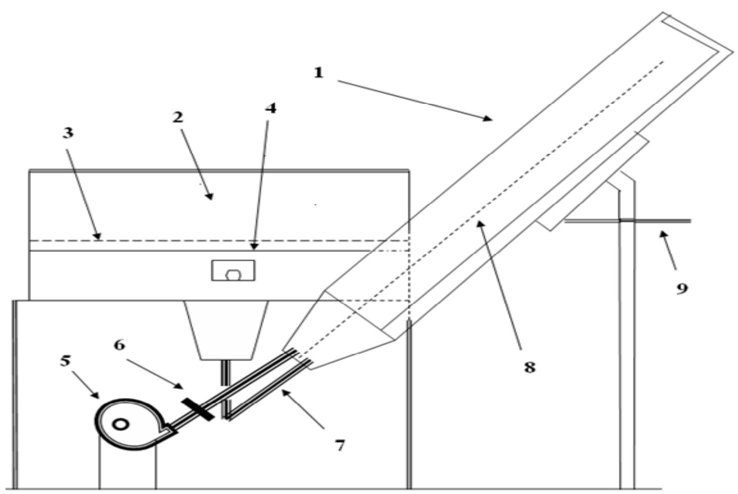

Figure 2. Section of the solar drying system: 1. Solar collector. 2. Drying chamber. 3. Drying tray. 4. Thermostat temperature. 5. Air blower. 6. Air valve. 7. Connecting pipes. 8. Absorption plates of two air passes. 9. Slide rule.

energy gained by the air, Eq. (10). Therefore

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

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

Q_g = The useful energy gained.

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

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

The solar drying system

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 airs as well as it increase the absorptivity to solar radiation (Goel et al., 1987; Chaudhory et al., 1988; Hafiz et al., 1999). It is made of galvanized steel with black paint containing (5%) black chromium powder to increase its absorbing capability (Figures 1 and 2).

The collector was insulated with rock wool of 10 mm thickness

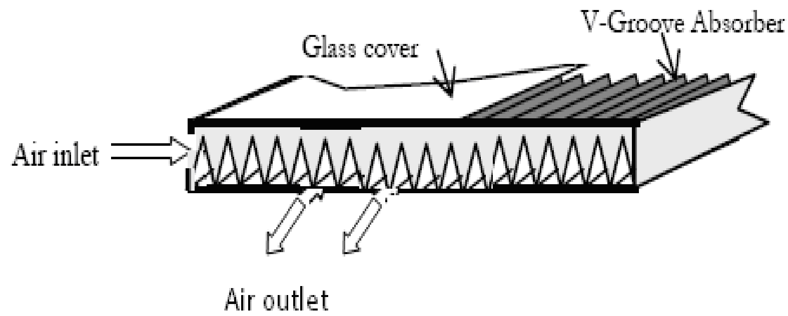

Figure 3. Schematic of the V-groove absorber collector.

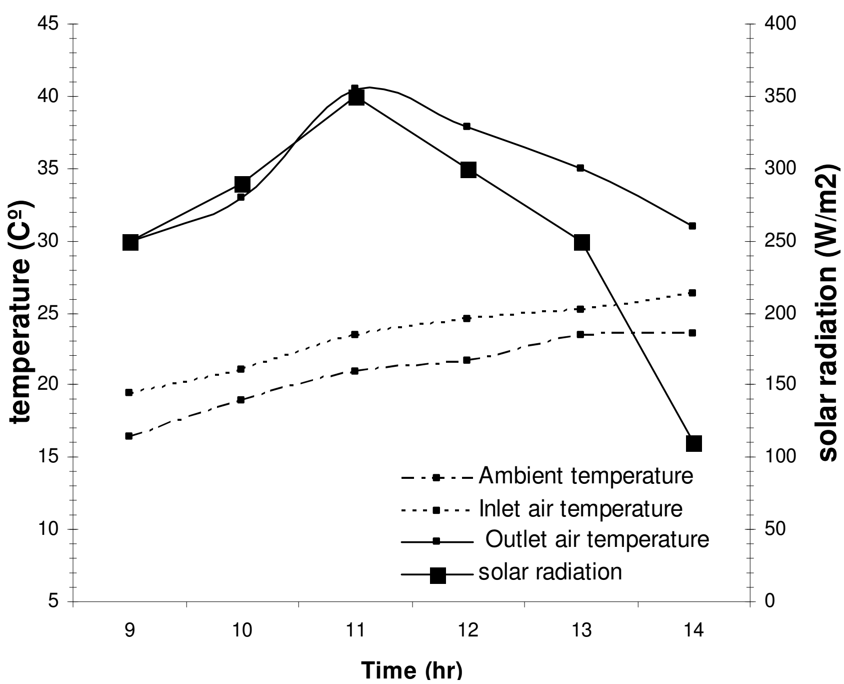

Figure 4. Time variation of air ambient temperature, air inside, outside of the collector and solar radiation for angle 30º (Date 21/11/2008).

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 [1.06 x 0.66 x 0.56 m] [width, depth and height] respectively. All the system components are connected with each other by plastic pipe 63 mm diameter, as well as to transport the air between the collector and the drying chamber (Figure 3).

EXPERIMENTAL SET-UP

The performance of the solar drying system was evaluated experimentally using three collector tilt angles for horizontal (30º, 45º, 60º). The following parameters are measured (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 with of the solar dryer system. All temperature data were registered at an interval of 15 min. Drying test was started at 9:00 h and stopped at 14:00 h. Preliminary calculations that to be dried at (38 kg) of maize , After field drying the moisture content of the maize 21% (wet basis) and should be reduced to 13% during drying.

RESULTS AND DISCUSION

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. Figure 4 shows each change of air ambient

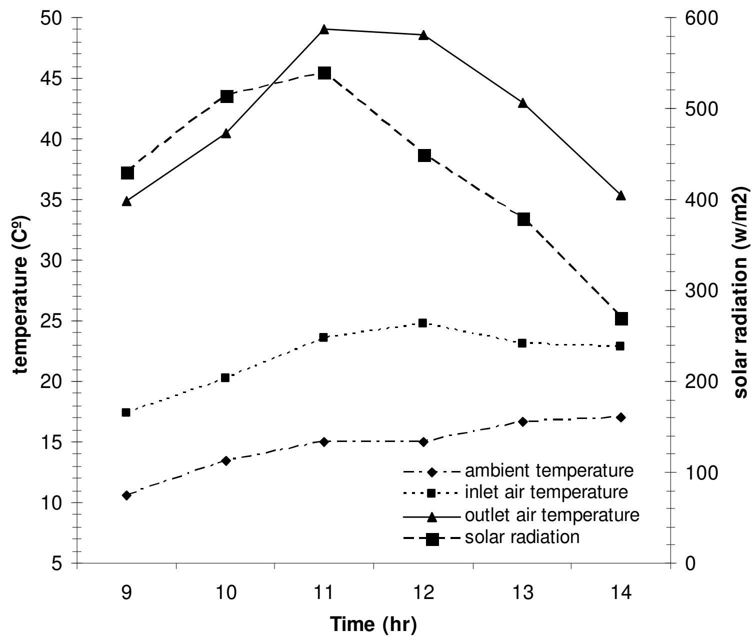

Figure 5. Time variation of air ambient temperature, air inside, outside of the collector solar and solar radiation for angle 45º (Date 22/11/2008).

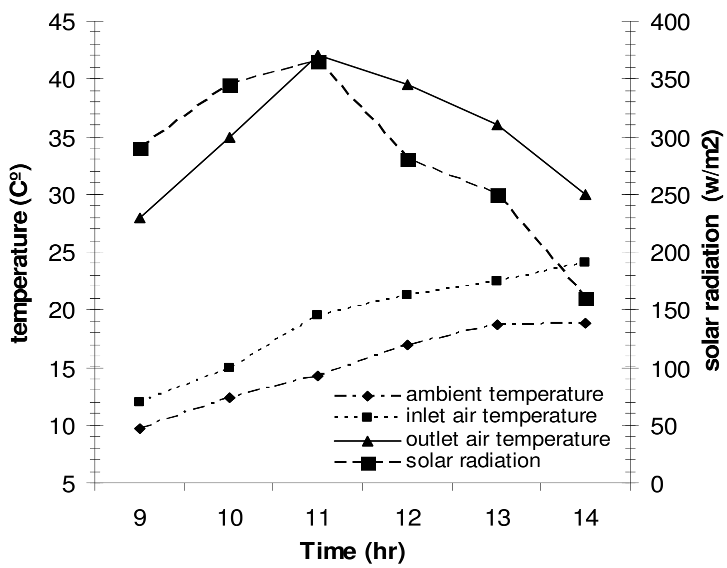

Figure 6. Air ambient temperature, air inside, outside of the collector solar and solar radiation for angle 60º (Date 23/11/2008).

temperature and the air inside and outside of the collector solar during daylight hours for the inclination angle of 30º. It was the highest temperature out of the collector (40.5°C) of the whole at the 11 o'clock hour at the highest intensity of radiation 350 w/m².

Figure 5 shows the change of the temperature of the ambient air and the temperature of the air inlet and outlet of the collector solar during daylight hours for the inclination angle of 45°. It was the highest temperature out the collector 49°C 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 (42ºC) at the highest intensity of radiation 365 w/m², of the whole at the 11 o'clock hour (Figure 6).

Figure 7 shows the relation between the theoretical thermal energy and the experimentally actual heat gain

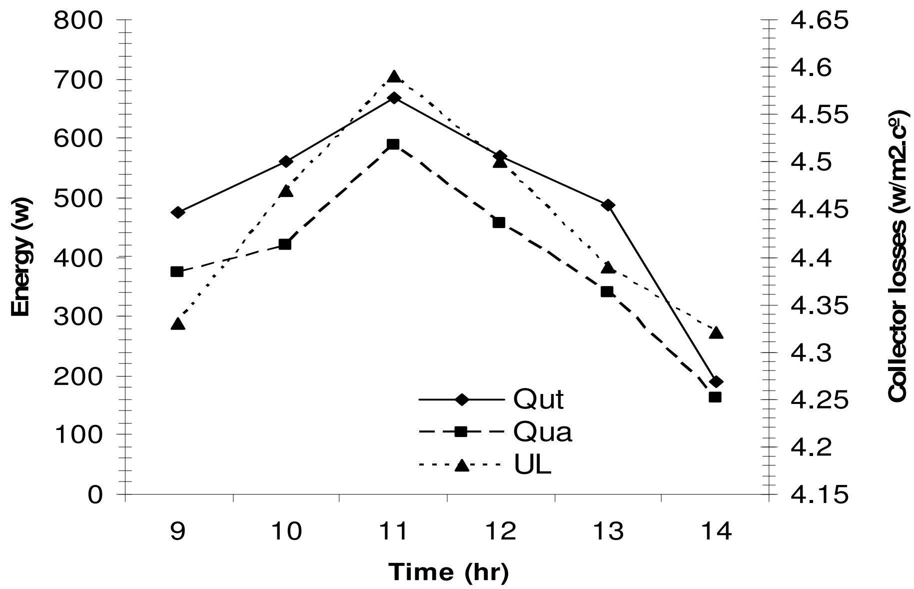

Figure 7. The theoretical thermal energy, the experimentally actual heat gain and the total loss factor of the collector versus the daylight hours for the inclination angle of 30º (Date 21/11/2008).

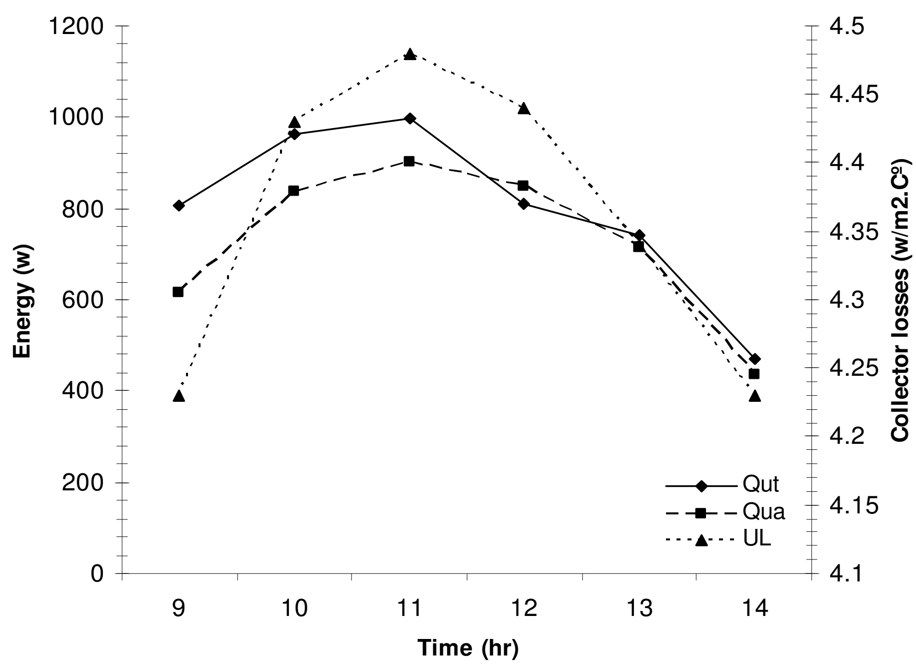

Figure 8. The theoretical thermal energy, the experimentally actual heats gain and the total loss factor of the collector versus the daylight hours of the inclination angle of 45º (Date 22/11/2008).

for the inclination angle 30º, 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.Cº) of these losses occurred at 11 am. From Figure 8, the highest values of theoretical thermal

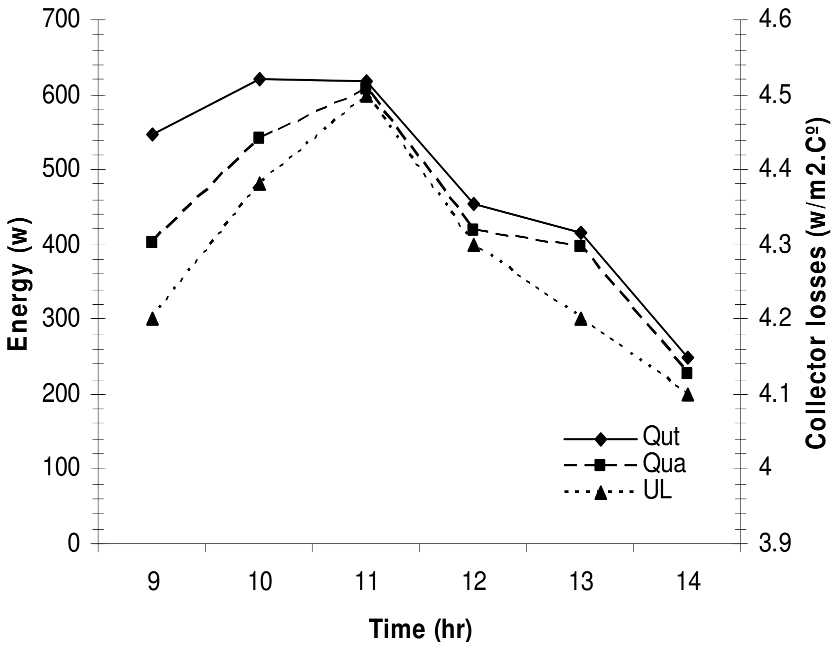

Figure 9. The theoretical thermal energy, the experimentally actual heats gain and the total loss factor of the collector versus the daylight hours of the inclination angle of 60º (Date 23/11/2008).

energy, experimentally actual heat gain and total loss factor of the collector at the inclination collector tilt -45º at the 11 am are (996.4, 900.7 w and 4.48 w/m².Cº) respectively (Figure 9).

Conclusion

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.

Abbreviation: IT, 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 ($Wm^{-2}K^{-1}$); U_T, top loss coefficient, ($Wm^{-2}K^{-1}$); U_B, bottom loss coefficient, ($Wm^{-2}K^{-1}$); T_c, temperature of the collector's absorber (K); T_a, ambient air temperature (K); $\dot{m}$, mass of air leaving the dryer per unit time (kgs^{-1}); C_p, specific heat capacity of air ($kJkg^{-1}K^{-1}$); **mw,** mass of water evaporated from the food item (kg); **hfg,** latent heat of evaporation, kJ/kg H2O; **ma,** 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; T_{pr}, product temperature ºC; **T,** temperature ºC; **Ta,** ambient temperature, K; T_p, 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); **α,** Absorption; **τ,** transmittance of cover; **ρ,** reflection coefficient of the absorber; **η,** thermal efficiency, %; **σ,** Stefan-Boltzmann constant, W/m²

FORTRAN 99 program computer

```
! Computer program for calculation overall heat loss coefficient
! From solar air collector ,useful energy and efficiency

Open (1,file = 'as.txt')
open (2,file = 're.txt')
Do 10 I = 1, 6
```

```
Read (1,*)ti,ta,tp,ai,v,to
 tp = tp+273
 ti = ti+273
 ta = ta+273
 to = to+273
 hw = 5.7+(3.8*v)
 f = ((9./hw)-(30./((hw)**2)))*(ta/316.9)*1.091
 w = .00000005667
 u1 = 1./(434.61/tp)*((tp-ta)/(1.+f))**0.252
 u2 = 1./(u1+(1./hw))
 u3 = w*(tp**2+ta**2)*(tp+ta)
 u4 = 1.24+(1.13*f)
 u = u +(u3/u4)
 ui = u+0.4
 write (*,'(1x,5f10.4)')u,ui
 write (2,'(1x,5f10.4)')u,ui
 ru = 348.3/tp
 b = 1.02
 dh = 0.1125
 y = 0.0000179
 pr = 0.71
 Cp = 1006
 ag = 0.01485
 uii = ui/3600
 ac = 2.04
 re = (ru*b*dh)/y
 nu  =  (0.0192*(re**(0.75))*pr)/(1.+(1.22*(re**(-.125))*(pr-
2.)))
 hc = (nu*cp*y)/(pr*dh)
 fd = hc/(hc+ui*0.5)
 fr = ((ag*cp)/uii)*(1.- exp((-fd*uii)/(cp*ag)))
 qi = ai*0.817-(ui*(ti-ta))
 q = 2.04*fr*qi*1.75
 eff = (q/(ai*2*ac))
 ruu = 348.3/((to+ti)/2.)
 w1 = 0.025*ruu
 qu = w1*cp*(to-ti)
 effu = qu/(ai*2*ac)
 tm = to-ti
 write (*,'(1x,5f10.4)')ru,re,hc,fd,fr,qi,q,eff,qu,effu,tm
 write (2,'(1x,5f10.4)')ru,re,hc,fd,fr,qi,q,eff,qu,effu,tm
10 read*
!9 format (1x,2f9.4,1i5,6f9.4)
stop
end.
```

REFERENCES

Audsley E, Wheeler J (1978). The annual cost of machinery calculated using actual cash flows. J. Agric. Eng. Res. 23: 189-201

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

Akinola AO,Fapetu OP (2006). Exergetic Analysis of a Mixed-Mode Solar Dryer. J. Eng. Appl. Sci. 1: 205-210.

Akinola, OA, Akinyemi AA, Bolaji BO (2006). Evaluation of traditional and solar fish drying systems towards enhancing fish storage and preservation in Nigeria. J. Fish. Int. Pakistan 1(3-4): 44-49.

Bassey MW (1989). Development and use of solar drying technologies, Niger. J. Solar Energy 89: 133-164.

Choudhury C, Anderson SL, Rekstad J (1988). A Solar Air Heater for Low Temperature Applications, Solar Energy 40: 335–344.

Ertekin C, Yaldiz O (2004). Drying of eggplant and selection of a suitable thin layer drying model, J. Food Engr. 63: 349-359.

Fisk MJ, Anderson, HC (1982). Introduction to solar technology, Addison-Wesley,Company Inc. 23: 2269

Goel VK, Ram Chandra, Raychaudhuri BC (1987). Experimental Investigations on Single-Absorber Solar Air Heaters. Energy Convers. Manage. 27: 343-349.

Hafiz MR, Othman MY, Salleh MM, Sopian K (1999). Design and Indoor Testing of the V-Groove Back Pass Solar Collector. Renewable Energy 16: 2118-2122.

Itodo IN, Obetta SE, Satimehin AA (2002). Evaluation of a solar crop dryer for rural applications in Nigeria. Botswana J. Technol. 11(2): 58-62.

Ikejiofor ID (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. 157-165.

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

Karim MA , Hawlader MN (2006). Performance evaluation of a v-groove solar air collector for drying applications. Appl. Thermal Eng. 26: 121-130.

Madhlopa A, Jones SA, Kalenga-Saka JD (2002). A solar air heater with composite absorber systems for food dehydration. Renewable Energy 27: 27–37.

Togrul IT, Pehlivan D (2004). Modelling of thin layer drying kinetics of some fruits under open-air sun drying process. J. Food Engr. 65: 413-425.

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

Youcef-Ali S, Messaoudi H, Desmons JY, Abene A, 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 Engr. 48: 95-101.