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Development and Evaluation of a Solar Thermal Collector Designed for Drying Grain

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Abstract: The present research study is on development and performance evaluation of a solar thermal collector that warms up air as transferring medium of heat for drying of grains. A 6 meter long, 4 meter wide and 0.3 meter thick solar thermal collector was constructed in which a V-corrugated steel sheet was used as absorber and a 6 mm thick glass used as glazing. The collector body was fabricated from plywood. The solar thermal collector is linked with a 4 meter high grain storage bin having a diameter of 2 meter. Performance of this collector was evaluated from November 2011 to January 2012 at seven different convective flow rates of air (7.5, 14.16, 28.30, 56.6, 112.2, 168.5 and 224.4 kg.h^{-1}). The statistical analysis showed that increase in mass flow rate significantly ($P > 0.003$) increases the performance of the solar collector. Also there was decrease in performance by the change of months of year. The efficiency was 10% higher in November 2011 as compared to January 2012. It was concluded that for drying of grains the solar thermal collector must be operated at high mass flow rates of air from 9:00 am to 4:00 pm to get maximum performance from the solar thermal collector used for grain drying.

Key words:

INTRODUCTION

Solar energy conservation technologies in the form of solar collectors are proven the best choice for economical drying of grains. Solar collector is a device which helps in heating of air which is then used for grain drying, heating livestock buildings and drying of different fruits and vegetables. Solar collectors are most constructed from local farmers from locally available ordinary materials; hence they are of low performance. The key factor in building a solar collector is its performance in terms of efficiency to be determined [1]. The present research study is on development of a 6m x 3m ft flat plate solar collector and its performance evaluation. The flat plate solar collector assembly composed of two parts is shown in Figure 1. The two main parts of the flat plate solar collector assembly are:

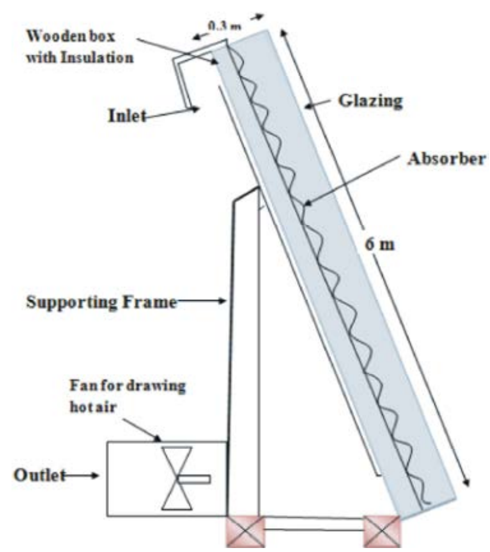

Fig. 1: Cross Sectional View of the Solar Thermal Collector

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- Solar Thermal Collector
- Storage bin for drying of grains

Solar Thermal Collector: To develop a high performance solar thermal collector, the characteristics of materials and dimensions of each part of flat plate solar collector are described as under:

The Insulation Box: The insulation box (6m x 4m x 0.3m) was made of plywood externally finished to protect it from rain water and heat of summer. It was internally insolated with the help of polystyrene foam locally called as packing material. It is done to minimize heat loss from the solar collector. Wood was used for manufacturing of the insulating enclosure because wood is a good insulator, it is inexpensive, easily available, having high melting point and light weight. The box was black painted and made fully air tight to minimize heat loss from its walls.

Absorber: The absorber, which is (5.99m x 3.99 m x 4mm) v- ribbed, black painted steel sheet, fixed in the middle of the wooden box. The absorber was implicit to be a perfect black body and absorbs greatest heat. The ribbed steel was used for fabrication of the absorber because it has a high value of adsorption (88%) and high value of emissivity (30%). It is low cost, have high melting point, inflammable and easily available in the local market.

Covering: The cover material or glazing was (6m x 4m x 8mm) thick glass sheet placed at the top of the wooden box. Glass was used glazing so that it shelter the absorber from wind and allowed solar radiation to reach the absorber. The glass was used as glazing because it was easily available, low cost, has high value of transmittance for long and short wave radiations (80%), not flammable and have high melting point.

Inlet and Outlet Ducts: The inlet is 0.3m in diameter made up of steel fixed at the bottom of the collector due to the fact that air enters from lower side at lower temperature. The outlet has the same diameter and provided at the top of the collector. It is due to the fact that hot air goes up and colder air comes from lower side to replace the hotter air. There was a 0.28 meter exhaust fan fixed in the outlet of the collector for pushing the hot air in to the drying chamber. This fan delivers 7.5, 14.16, 28.30, 56.6, 112.2, 168.5 and 224.4 $kg.h^{-1}$. A regulator (dimmer) has been installed on the fan so that the fan can be operated at different speeds.

Supporting Frame: The collector was supported and tilted with the help of a frame made up of angle iron. The frame was built with four legs in such a way that the front two legs have a height of 0.3 meter and the rear two are 2 meter high making the collector tilted at 30° with the horizontal towards south.

Storage Bin for Drying of Grains: A Storage bin is a (4m x 2m) steel cylinder which was linked to the outlet duct with the help of steel pipe. Total volume available for grain drying in the storage bin was 26 m^3.

MATERIALS AND METHODS

Collector Orientation and Tilt Angle: The collector was oriented facing North- South axis, having a tilt angle of 30° with horizontal. It was done to normal the angle of incidence of solar radiation coming from the sun on the collector surface. To receive maximum solar radiation at Peshawar the collector was tilted to 30° so that the incident solar radiation was normal to the collector surface. As Peshawar is located at 34° latitude, from September to December, solar radiation at Peshawar will be normal to plane facing south and making 30 to 35° with horizontal [2, 3, 4].

Recording Solar Radiation Intensity (Is): The solar radiation data was recorded with the help of Mechanical Pyranometer. The Mechanical Pyranometer gives the incoming solar radiation data in the form of a graph or chart. This chart reading was multiplied with the Mechanical Pyranometer constant to get the radiation data. The constant for the mechanical Pyranometer used in this study was 0.88. The data recorded by Mechanical Pyranometer was in $cal.cm^{-2}.min^{-1}$. To convert this radiation into standard unit we multiplied a constant 418 to the data to convert it to $kJ.m^{-2}.min^{-1}$. [5, 6]

Recording the Air Velocities Outlet: Velocities of air at Outlet duct was recorded with the help of a digital anemometer [7].

Recording Relative Humidity and Temperature Data of Air Pumping Through Inlet and Outlet: Relative humidity and temperature data was recorded with the help of digital thermo-hygrometer at both inlet and outlet of the solar thermal collector [7].

Performance of the Solar Thermal Collector: The solar collector performance in terms of efficiency is determined at seven different levels of air mass flow rates (7.5, 14.16, 28.30, 56.6, 112.2, 168.5 and 224.4 kg.h^{-1}) in three different months of year (November 2011 - January 2012). Efficiency is determined using equation.

Efficiency equation $\eta = \Phi o / \Phi A \times 100$ [8]

where ΦA is the heat available to the collector and is the product of collector area and solar intensity at unit area which is determined by a mechanical Pyranometer. The heat available to the collector is calculated using equation.

Heat input equation $\Phi A = A_c \times I_s$ [2]

Φo is the heat output of the collector which is determined by the product of air mass flow rate, specific heat value of air and change in collector's temperature at inlet and outlet. The heat output is calculated using equation.

Heat output equation $\Phi o = \ell \times C_a \times \Delta T$ [5]

The air flow rate through the collector is determined by the product of air speed at out let, density of air and outlet ducts cross sectional area. The flow rate is calculated by using equation.

Air flow rate equation $\ell = V_o \times \rho_a \times A_o$ [9]

RESULTS AND DISCUSSIONS

Solar Radiation Intensity: Solar radiation intensity was recorded with the help of a Mechanical Pyranometer. The average solar radiation intensity was recorded in each month of November 2011 to January 2012 respectively and is given in Figure 1. The maximum solar radiation intensity was recorded in November which was 1 cal. hr^{-1}.cm^{-2} 12:00 noon. There is a 0.1 cal.hr^{-1}.cm^{-2} difference between the solar intensity of November and December. Similarly the change is there between December 2011 and January 2012. There is 10% decrease in the solar radiation intensity From November 2011 to January 2012 which is due to the change in azimuth and zenith angles of the sun rays incident on solar thermal collector at these months of the year. It is observed that solar radiation intensity is high at 12:00 noon. The collector is used for collecting solar energy in the form of heat for drying purposes from 9:00 am to 4:00 pm.

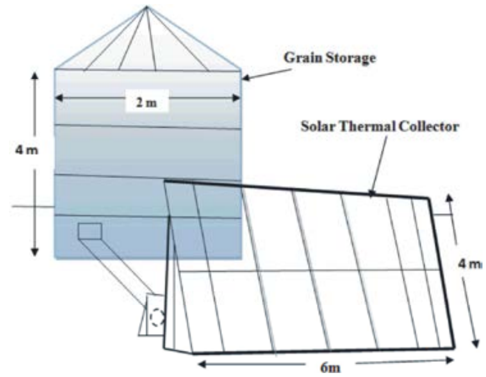

Fig. 2: Perspective View of the Solar Thermal Collector and Storage Bin for Grain Drying

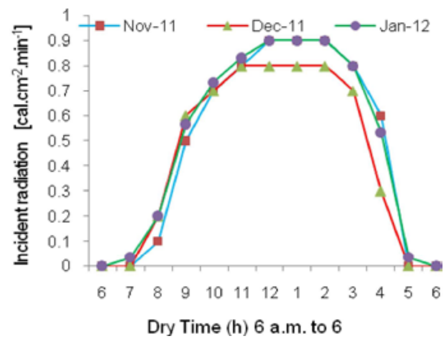

Fig. 3: Solar Radiation Intensity

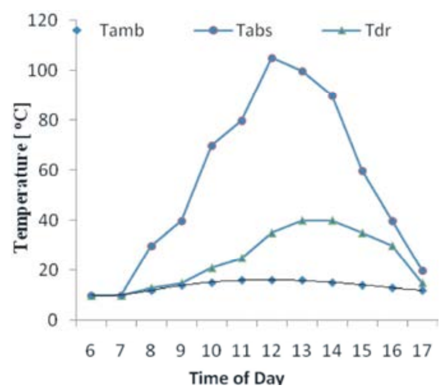

Fig. 4: Temperature Data of the Solar Collector Assembly

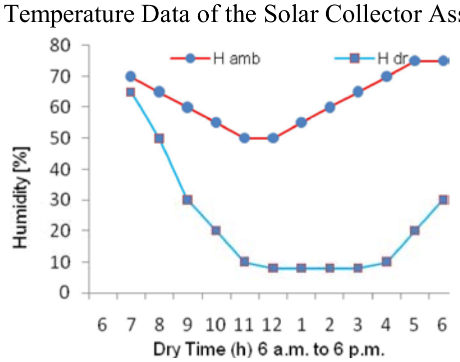

Fig. 5: Humidity data of the out going air from solar thermal collector and ambient air

Table 1: Effect of Mass Flow Rates and Ambient Temperature on the Efficiency (%) of a Flat Plate Solar Collector

	Efficiency				
	November 2011				
Flow Rates	Replicate 1	Replicate 2	Replicate 3	Replicate 4	Mean
7.5 $Kg.h^{-1}$	24.1	22.8	19.0	22.0	22.0 a
14.16 $Kg.h^{-1}$	32	33.6	35.2	33.5	33.6 b
28.30 $kg.h^{-1}$	40.3	40.3	42.6	41.0	41.1 c
56.6 $kg.h^{-1}$	51.8	46.0	46.0	47.8	47.9 c
112.2 $kg.h^{-1}$	53.7	46.0	46.0	48.4	48.6 c
168.5 $kg.h^{-1}$	57.6	48.0	48.0	51.1	51.2 c
224.4 $kg.h^{-1}$	59.5	51.8	53.7	55.0	55.0 cd
December 2011					
7.5 $kg.h^{-1}$	20.6	18.5	18.2	19.2	19.1 a
14.16 $kg.h^{-1}$	36.4	36.0	32.0	34.7	34.8 b
28.30 $kg.h^{-1}$	42.6	41.1	38.4	40.6	40.7 c
56.6 $kg.h^{-1}$	52.8	46.0	46.0	48.4	48.3 d
112.2 $kg.h^{-1}$	53.7	48.8	44.7	49.0	49.1 d
168.5 $kg.h^{-1}$	57.6	50.1	48.0	51.7	51.9 d
224.4 $kg.h^{-1}$	57.6	51.8	51.8	52.9	53.7 d
January 2012					
7.5 $kg.h^{-1}$	20.0	19.8	19.7	19.6	19.8 a
14.16 $kg.h^{-1}$	30.0	31.2	31.7	30.5	31.0 b
28.30 $kg.h^{-1}$	34.5	35.8	35.8	35.5	35.4 b
56.6 $kg.h^{-1}$	46.0	40.3	43.2	43.4	43.2 c
112.2 $kg.h^{-1}$	48.6	44.7	46.0	46.6	46.4 c
168.5 $kg.h^{-1}$	52.8	48.0	46.4	48.9	49.1c
224.4 $kg.h^{-1}$	57.6	51.8	49.9	52.9	53.1c
Mean	44.3 a	40.6 b	40.1 b	40.9 b	

Mean values followed by different letters are significantly ($P < 0.05$) different from each other

LSD value for means = 5.466

LSD value for Interaction = 1.786

[a] = Mean of three replicates

Table 2: ANOVA Table

SV	DF	SS	MS	F	P
Month of year (A)	2	269.799	134.900	146.3522	0.0000
Air Mass Flow Rate (B)	6	9911.212	1651.869	1792.1074	0.0000
A x B	12	114.478	9.540	10.3498	0.0000
Error	51	38.713	0.922		
Total	71	10334.203			

Drying Condition During Operation of the Solar Thermal Collector: Temperature of the inlet and outlet is recorded with thermometer. The temperature of absorber started increasing at 8:00 am and reached to a maximum of 110°C at 12:00 noon. Due to this the heat from the absorber was transferred to the drying chamber by the air blowing inside the collector and temperature of the outlet air to the storage bin increased with increase in absorber's temperature. The suitable temperature range for drying grains is from 40 to 50°C. In the storage bin at 9:00 am temperature was 40°C and at 12:00 noon it reached to 50°C. The temperature remained in the range of 40 to 50°C for 7 hours (9:00 am to 4:00) pm. For drying of grains the humidity range required must be less than 10%. The humidity of storage bin started decreasing from 50% at 9:00 am in the morning and decreased to 10% at 12:00 noon. The humidity remained in the range of 10 to 20% for 5 hours (10:00 am to 3:00 pm). Humidity and temperature data are illustrated in Figures 2 and 3. A total of 7 hours per day were available for drying of grains by the solar thermal collector.

Performance of the Solar Thermal Collector: Performance in terms of efficiency of the solar thermal collector was evaluated for the months of November 2011 to January 2012 at seven different convective air mass flow rates of 7.5, 14.16, 28.30, 56.6, 112.2, 168.5 and 224.4 $Kg.h^{-1}$ and is given in Table 1. The various air flow rates were changed by changing the fan speed. The statistical analysis showed that month of year, mass flow rate and their interaction all have P-value of 0.000 thus these factors have highly significant affect on the performance of the solar thermal collector. For the month of December, flow rate with P values of 0.000 and 0.000 respectively (Table 2) were showing significant decrease in efficiency of the solar thermal collector as compared to November. Also the interaction between month and flow rate was significant with P-value = 0.000. A 5% variation in the overall data during the month of December 2011 was noted. It is revealing considerable decrease as compared to the month of November 2011.

CONCLUSIONS AND RECOMMENDATIONS

- It was concluded that efficiency of the solar thermal collector increased significantly with the increase in the air flow rate. So it is recommended to operate a solar thermal collector with air as medium of heat transfer at a high mass flow rate.
- Solar thermal collector showed maximum performance as a drier for grains and work efficiently for 7 hours in a day from 9:00 am to 4:00 pm in the months of November 2011 to January 2012. So it is recommended to dry grains using a solar thermal collector from 9:00 am to 4:00 pm.

Nomenclatures:

Ac	Cross Sectional Area of the collector (m^2)
Ao	Cross Sectional Area of outlet (m^2)
Ca	Specific heat capacity of air ($kJ.kg^{-1}.°C^{-1}$)
ρa	Density of air ($kg.m^{-3}$)
Hamb	Relative Humidity at outlet (%)
Hi	Relative Humidity at inlet (%)
Hdr	Relative Humidity of the drying chamber (%)
Is	Incident radiation ($kJ.m^{-2}.min^{-1}$)
T_{amb}	Ambient temperature (°C)
T_{dr}	Drier temperature (°C)
Tabs	Absorber temperature (°C)
ΔT	Difference of inlet and outlet temperatures (°C)
Φi	Heat input to the collector ($kJ.min^{-1}$)
Φo	Heat output by the collector ($kJ.min^{-1}$)
η	Eta, Efficiency of the solar collector (%)
ℓ	Air mass flow rate ($kg.h^{-1}$)
Vo	Velocity of air at outlet ($m.sec^{-1}$)

REFERENCES

1. Bennamoun, L. and A. Belhamri, 2002. Design and simulation of a solar dryer for agriculture products. Department of the Genic Climatic, Faculty of Engineering Sciences, University Mentouri Constantine, Constantine 25000, Algeria.
2. Akpinar, K.E., 2010. Drying of mint leaves in a solar dryer and under open sun, A Modeling, performance and its analysis. Mechanical Engineering Department, Firat University, 23279, Elazig, Turkey.
3. Fadhel, A., S. Kooli, A. Farhat and A. Bellghith, 2005. Study of the solar drying of grapes by three different processes. National institute of Scientific and Technical Research, BP 95 Hammam-lifs. Tunisia.
4. Santos, B.M., R. Quiroz and T.P.F. Borges, 2005. A Solar Collector Design Procedure for Crop Drying. Brazilian Journal of Chemical Engineering, 22(2): 0104-6632.
5. Sharma, A., C.R. Chen and N.Y.V. Lan, 2008. Solar energy drying systems. Department of Mechanical Engineering, Kun Shan University, 949, Da-Wan Road, Yung-Kang city, Tainan Hsien 71003, Taiwan.
6. Philibert, C., 2005. The present and future use of solar thermal energy as a primary source of energy. International Energy Agency, Pairs, France.
7. Fuller, R.J., T. Lhendup and L. Aye, 2005. International Drying Technologies Centre (IDTC). Department of Civil and Environmental Engineering the University of Melbourne Australia.
8. Ahmed, A.G., 2011. Design and construction of a solar drying system and analysis of the performance of the thermal drying system. African Journal of Agricultural Research, 6(2): 343-351.
9. Behessiotis, V. and E. Delyannis, 2010. Solar drying. Laboratory of solar and other energy systems, NSRC "DEMOKRITOS", P.O. Box: 60228, 153-10, Aghia-Paraskevi, Greece.