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Experimental & Numerical Analysis of a Solar Dryer

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Abstract

An experimental investigation on natural convection solar dryer was designed. The solar dryer consists of a flat plate collector with dimensions of 0.15m height, 1m width and 1 m length; dryer is used to dry grapes. The grapes are placed on the trays of drying chamber of length 1m long made of aluminum. The two trays are separated equally from each other at a distance of 0.3 m. Each tray has a cross section of 1m*0.5m.

The solar collector is analyzed separately to establish the effect by changing its width and length. The drying chamber is used to dry 2 kilograms of grapes; each 1 kilogram is distributed on the each tray. The total solar irradiation on the solar collector surface and chamber walls at hour intervals for 4 days is studied. Drying of grapes in natural convection solar dryer reduces the moisture content from around 75% (wet basis) to the final moisture content about 11.2% in 24 hours. It was observed that the solar collector efficiency of the designed solar dryer given 46% average efficiency with a maximum temperature of 45^{0}c.

Introduction

The biggest parts of economy of the majority of countries are agriculture. 80-90% of the effective population is engaged in agriculture. Even though these large numbers, national food making still does not meet the needs of the population. The lack of appropriate conservation and storage systems caused significant victims, thus diminishing the food supply extensively. The world's food supply is lost as a result of microbial spoilage. Due to this, preservation of food and agriculture products is necessary for storing and maintaining their quality for a longer period of time. This can be done in several methods such as refrigeration, heat treatments, radiation, filtration, drying and many other methods. Dehydration is the simplest method of all. Drying generally means removal of relatively small amount of water from material. The water is usually removed as a vapor by air. Microorganisms that cause food spoilage and decay cannot grow and multiply in the absence of water. Also many enzymes that cause chemical changes in food and other biological materials cannot function without water. When the water content is reduced below about 10% by weight, the microorganism are not active. Solar dryer is the simplest strategy used to accumulate the solar radiations and transmit that radiation in the form of heat energy and this heat energy then transfer to product for drying. Solar dryers are devices that use solar energy to dry substances, particularly food.

Solar dryers can be classified based on the following criteria:

- Mode of air movement
- Exposure to insulation
- Direction of air flow
- Arrangement of the dryer
- Status of solar contribution

According to E V Fodor, on clear day solar radiation existing to any site is dependent on the point of view of the sun relative to sphere. Solar energy is liberated, renewable, plentiful, and an atmosphere friendly power sources. This reduces drying time due to valuable consumption of solar power. It maintains the eminence of the manufactured goods and act as an ultimate alternate for remnant fuel based dryers. The two basic restrictions faced by the solar dryers are sunshine hours and climate change. There are two types of solar dryers;

1. The passive type (natural convection) dryer and
2. The active type (forced convection) or Hybrid solar dryer.

These solar driers may be again sub-grouped under three categories:

- Integral type (direct mode),
- Distributed type (indirect mode), and
- Mixed mode.

In an integral (direct) type, solar drying substance is positioned in drying chamber having translucent or transparent cover through which solar radiation enters and heats the food resources to be dried.

In an indirect mode, solar energy is capture by a solar antenna, which is in turn heats the air. This excited air is passed to the drying cabinet/chamber.

In mixed mode, solar energy collected in separate solar collector and heated air is then passed over the drying substance. The drying substance absorbs the solar energy straightforwardly through the transparent cover and stockade.

Objective:

The primary objectives of the present study are:

1. To experimentally investigate the performance of this natural convection solar dryer.
2. By varying the solar flat plate collector dimensions changing its width or length on the air outlet temperature and mass flow rate.
3. To find out the variations of temperature gradient of absorber plate and drying chamber walls of a natural convection solar dryer in four conjugative days.
4. To find out the average solar collector efficiency for drying the fruit in drying chamber.
5. To find out the percentage of moisture removed from the fruit (grape)
6. To design natural convection solar dyer in Auto Cad for aluminum as absorber plate and smoothed mica glass sheet as thermal storage medium

EXPERIMENTAL INVESTIGATIONS

Solar Collectors

Solar collectors are the key component of active solar-heating systems. They gather the sun's energy, transform its radiation into heat, then transfer that heat to a fluid (usually water or air). The solar thermal energy can be used in solar water-heating systems, solar pool heaters, and solar space-heating systems.

There are a large number of solar collector designs that have shown to be functional. These designs are classified in two general types of solar collectors:

1. Flat-plate collectors – the absorbing surface is approximately as large as the overall collector area that intercepts the sun's rays.

2. Concentrating collectors – large areas of mirrors or lenses focus the sunlight onto a smaller absorber.

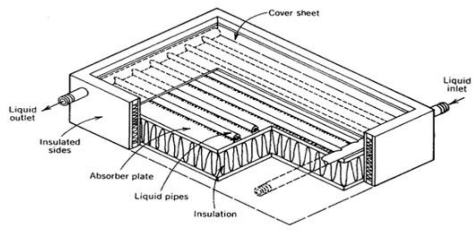

Fig. 1 A typical liquid Flat Plate Collector

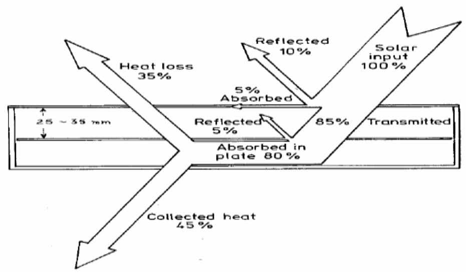

Fig. 2 Heat flow through a Flat Plate solar collector

$Q_i = I*A$

Thus, $Q_i = I\,(\alpha\tau)*A$

$$F_R = \frac{(m_a\, c_{pa})*((T_C - T_a)}{A_C(\alpha\tau\, I_T - U_L(T_C - T_a))}$$

$$Q_u = F_R\, A\,[I(\alpha\,\tau) - U_L\,(T_i - T_a)$$

$$\eta = Q_u / (IA)$$

$$\eta = F_R\, A\,[I(\alpha\,\tau) - U_L\,(T_i - T_a) / (IA)$$

Where,

A = Collector area in m^2
F_R = Collector heat removal factor
I = Solar intensity in w/m^2
T_i = Inlet fluid temperature in ^0C
T_a = Ambient temperature in ^0C
U_L = Collector over all heat transfer coefficient in w/m^2
T_c = Collector inlet fluid temperature in ^0C
Q_0 = Heat loss in W
Q_i = Collector heat input in W
Q_u = Useful energy gain in W
Ƞ = Collector efficiency in %
α = Absorption coefficient of plate
τ = Transmission coefficient of glass

Experimental Procedure

Only good quality grapes were used in the experiments. About 2000g of fresh grapes were dried as whole fruits, without any chemical pre-treatment, until the required final moisture content was attained. The fresh grapes were loaded over the trays of drier chamber having about 90% perforation. During sunshine hours the air flow over the absorber plate gets heated and simultaneously the grapes in the drying chamber get dried and its moisture gets reduced. Temperature at inlet and outlet of the solar collector and the drying chamber were measured at every one hour interval. The experiment was conducted for 8 hours during potential sunshine hours. During idle conditions, the grapes were covered with polyethylene sheet to avoid de-absorption of moisture. The experiments were repeated thrice and an average was considered. The drying characteristics of grapes such as moisture content, drying rate, and drier thermal efficiency were determined by using Equations.

Description of Apparatus

A mathematical modeling was held for a simple indirect natural convection solar dryer as shown in figure the dryer consists of a flat plate solar collector attached to a drying chamber made of aluminum. The collector is 1 m long, 0.15 m height and 1.0 m width. The black sheet is made of oil painting (black) of 0.01 m thickness and the insulation from aluminum of 0.5 m thickness. The transparent cover is taken as glass with negligible thickness. Here two cover plates are used one is, Mica glass with transmissivity 0.82 and second one is smoothed glass with transmissivity 0.85. The drying chamber consists of two trays separated equally from each others at a distance of 0.3 m; each tray is 1 m length and 0.5 m width.

DAY-1

Sl.No.	Time (IST)	Ambient temperature (°C)	Absorber length (m)	absorber area	Inlet collector dimensions	speed air flow (m/s)	Air flow rate (kg/s)	Black absorber temperature (°C)	Outlet temperature (°C)	Temperature gradient
1	8 'O' Clock	29	1.5	1.5	0.15*1	3.8	0.661	34.29	31.64	2.64
2	9 'O' Clock	30	1.5	1.5	0.15*1	4	0.696	37.33	33.66	3.66
3	10 'O' Clock	30	1.5	1.5	0.15*1	4.2	0.730	39.44	34.72	4.72
4	11 'O' Clock	31	1.5	1.5	0.15*1	4.3	0.748	41.83	36.41	5.41
5	12 'O' Clock	33	1.5	1.5	0.15*1	4	0.696	46.36	39.68	6.68
6	13 'O' Clock	33	1.5	1.5	0.15*1	4.2	0.730	49.83	41.42	8.42
7	14 'O' Clock	32	1.5	1.5	0.15*1	4	0.696	49.46	40.73	8.73
8	15 'O' Clock	32	1.5	1.5	0.15*1	4.8	0.835	44.93	38.47	6.47
9	16 'O' Clock	31	1.5	1.5	0.15*1	4	0.696	45.76	38.38	7.38
10	17 'O' Clock	30	1.5	1.5	0.15*1	4.2	0.730	38.78	34.39	4.39

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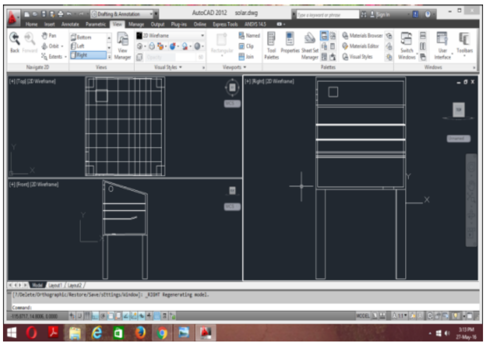
DAY-2										
Sl.No.	Time (IST)	Ambient temperature (°C)	Absorber length (m)	absorber area	Inlet collector dimensions	speed air flow (m/s)	Air flow rate (kg/s)	Black absorber temperature (°C)	Outlet temperature (°C)	Temperature gradient
1	8 'O' Clock	29	2	2	0.15*1	4.1	0.713	35.53	32.27	3.27
2	9 'O' Clock	30	2	2	0.15*1	4	0.696	39.77	34.89	4.89
3	10 'O' Clock	30	2	2	0.15*1	4.2	0.730	42.59	36.29	6.29
4	11 'O' Clock	31	2	2	0.15*1	4.3	0.748	45.43	38.22	7.22
5	12 'O' Clock	33	2	2	0.15*1	4	0.696	50.82	41.91	8.91
6	13 'O' Clock	33	2	2	0.15*1	4.2	0.730	55.44	44.22	11.22
7	14 'O' Clock	32	2	2	0.15*1	4	0.696	55.28	43.64	11.64
8	15 'O' Clock	32	2	2	0.15*1	4.8	0.835	49.24	40.62	8.62
9	16 'O' Clock	31	2	2	0.15*1	4	0.696	50.68	40.84	9.84
10	17 'O' Clock	30	2	2	0.15*1	4.2	0.730	41.71	35.86	5.86

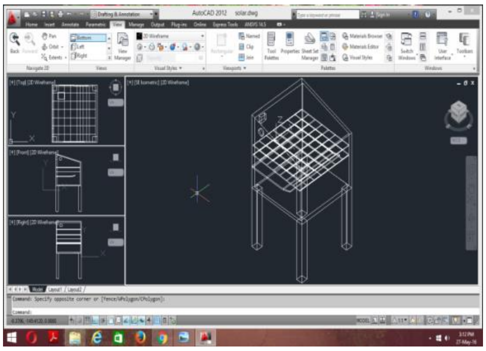
DAY-3										
Sl.No.	Time (IST)	Ambient temperature (°C)	Absorber length (m)	absorber area	Inlet collector dimensions	speed air flow (m/s)	Air flow rate (kg/s)	Black absorber temperature (°C)	Outlet temperature (°C)	Temperature gradient
1	8 'O' Clock	28	2.5	2.5	0.15*1	4.1	0.713	36.17	32.08	4.08
2	9 'O' Clock	29	2.5	2.5	0.15*1	4	0.696	41.21	35.11	6.11
3	10 'O' Clock	30	2.5	2.5	0.15*1	4.2	0.730	45.74	37.87	7.87
4	11 'O' Clock	31	2.5	2.5	0.15*1	4.3	0.748	49.04	40.02	9.02
5	12 'O' Clock	33	2.5	2.5	0.15*1	4	0.696	55.27	44.14	11.14
6	13 'O' Clock	35	2.5	2.5	0.15*1	4.2	0.730	63.05	49.03	14.03
7	14 'O' Clock	32	2.5	2.5	0.15*1	4	0.696	61.09	46.55	14.55
8	15 'O' Clock	33	2.5	2.5	0.15*1	4.8	0.835	54.55	43.78	10.78
9	16 'O' Clock	31	2.5	2.5	0.15*1	4	0.696	55.60	43.30	12.30
10	17 'O' Clock	31	2.5	2.5	0.15*1	4.2	0.730	45.64	38.32	7.32

DAY-4										
Sl.No.	Time (IST)	Ambient temperature (°C)	Absorber length (m)	absorber area	Inlet collector dimensions	speed air flow (m/s)	Air flow rate (kg/s)	Black absorber temperature (°C)	Outlet temperature (°C)	Temperature gradient
1	8 'O' Clock	30	3	3	0.15*1	4.1	0.713	39.80	34.90	4.90
2	9 'O' Clock	30	3	3	0.15*1	4	0.696	44.66	37.33	7.33
3	10 'O' Clock	30	3	3	0.15*1	4.2	0.730	48.88	39.44	9.44
4	11 'O' Clock	31	3	3	0.15*1	4.3	0.748	52.65	41.83	10.83
5	12 'O' Clock	33	3	3	0.15*1	4	0.696	59.72	46.36	13.36
6	13 'O' Clock	33	3	3	0.15*1	4.2	0.730	66.66	49.83	16.83
7	14 'O' Clock	32	3	3	0.15*1	4	0.696	66.91	49.46	17.46
8	15 'O' Clock	32	3	3	0.15*1	4.8	0.835	57.86	44.93	12.93
9	16 'O' Clock	31	3	3	0.15*1	4	0.696	60.53	45.76	14.76
10	17 'O' Clock	30	3	3	0.15*1	4.2	0.730	47.57	38.78	8.78

Solar dryer design in Auto Cad



Different views of solar dryer



RESULTS AND DISCUSSION

According to the solar collector considered in this study, the average solar collector efficiency was estimated to be about 47% observed in day1 is more, as compared to other days. The effect of changing the width of the collector on the outlet temperature and mass flow rate of the air is studied at different solar radiations as shown in table obviously that the temperature of the air slightly decreases while the mass flow rate of the air increase as the width of the collector increases. The solar radiation in b/w 5000-6500 w/m^2, the solar collector efficiency was increases. Then after it will be decreases.

Solar collector efficiency

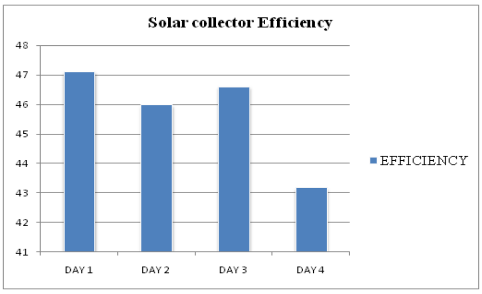


Fig 5.1 Solar collector efficiency in different days

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The above bar graph represents average solar collector efficiencies in four days intervals. It is clearly shows that the day1 average solar collector efficiency is more, when compared to remaining days.

Solar radiation

It appears that the maximum solar radiation on the collector equals 8200 W/m² .Table shows the results for solar radiation and ambient temperature calculated previously. It is clear that as the solar radiation increases the outlet temperature from the collector increases. Hence, the temperature difference between the outlets air from the collector and the ambient temperature increases.

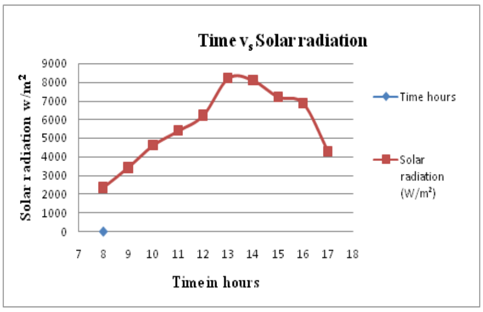

Fig 5.2 Solar radiation in time intervals

Figure shows the total solar radiation on the solar collector and the walls of the drying chamber versus time. The peaks can be clearly seen at 1p.m. Therefore the solar radiation 8200 w/m^2 will be high at noon hrs.

Temperature gradient & Solar collector efficiency

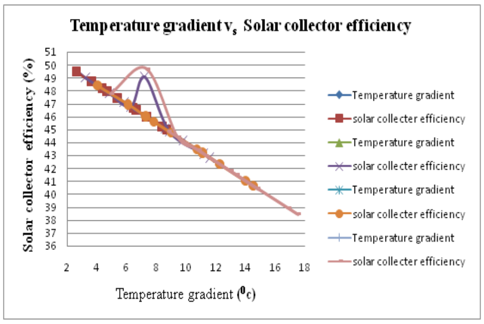

Fig 5.3 Temperature gradient with collector efficiency

The above graph represents temperature gradient in between 8-10^{0}c, the solar collector efficiency is to be high.

Time & Air flow rate

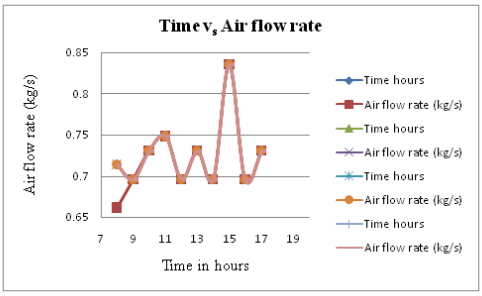

Fig 5.4 Air flow rate as a function of time

Figure shows that, the air flow rate of the air increase as the width of the collector increases. It is of various importances to achieve high air temperatures in drying systems in order to enhance the evaporation of water from the product. Moreover, increasing the mass flow rate of the air will enhance the mass transfer process of water from the product to the drying air.

Time & Temperature gradient

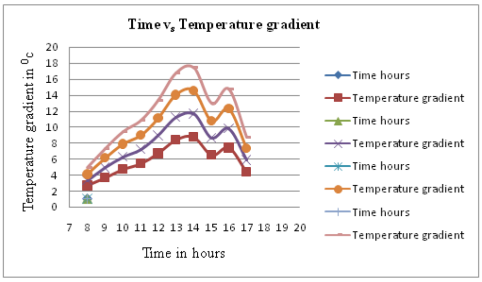

Fig 5.5 Time as a function of temperature difference

Solar radiation & Collector efficiency

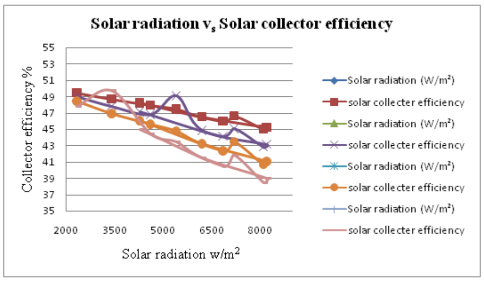

Fig 5.6 Collector efficiency with solar radiation

The above fig represents the solar collector efficiencies with different solar radiations. The solar radiation in b/w 5000-6500 w/m^2, the solar collector efficiency is increases. Then after it will be decreases, because the effect of sun will start to diminish.

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Absorber temperature & collector efficiency

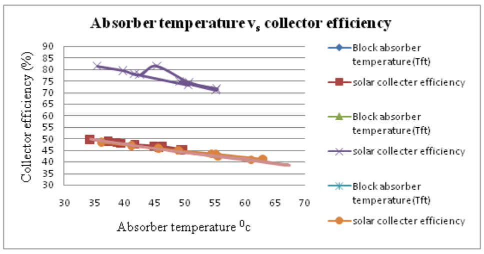

Fig 5.7 Efficiencies at each absorber temperatures

According to the figure, absorber temperature in between 40-55 ^{0}c the solar collector efficiency to be high.

Conclusion

A natural convection solar dryer was constructed, analyzed and validated using theoretical and experimental calculations. The solar dryer is used to dry any type of product (food product or agricultural product), that is acceptable to be dried in indirect contact methods also. The steady state drying process is very dependent on the film of moisture on the surface of the food. Thus knowing the initial mass of the food, its initial moisture content and desired moisture content will be enough to give an acceptable approximation of the drying time needed for the food.

The solar drying system can be optimized to calculate the dimensions of the solar collector to give a higher value of air temperature and flow rate. It is clear that the temperature and air flow rate slightly increases as the length of the absorber increases. Moreover, the width of the collector is inversely proportional to the outlet temperature and directly proportional to air flow rate. It is also observed that with change in time intervals the temperature gradient is also varied. Therefore maximum temperature gradient occurred at the time of 13-14 hours.

The average solar collector efficiency is 47% at four days observations were taken. Graph shows that day 1 efficiency is more as compared to other days of observations. The collector dimensions to be 0.15 m x 1.0 m x 1.5 m (height, width and length) would give a good optimization regarding the mass flow rate and temperature of the air in addition to the price of the system, but it is not the perfect optimization. To evaluate the perfect optimization one should make use of the optimization techniques such as: Lagrange method, golden section method…etc, to optimize the system for any objective desired.

Future scope

- In place of flat plat solar collectors we use Hybrid type solar collectors.
- It is also suitable for small farmers in rural areas, where electrical power is not available.
- Not only dried fruits, it is used to dry the vegetable products, agricultural products and marine products like fish etc.

REFERENCES

1. Ghassan M. Tashtosh, a Mathematical Model of Indirect Solar Drying of Dairy Products Jameed, in Jordan Energy and Environmental Engineering 2(1): 1-13, 2014.

2. Thermal engineering data hand book by B. Srineeevasa reddy & K. Hemachandra reddy.

3. Christie John Geankoplis, Transport Processes and Separation Process Principles, 4th ed. New Jersey: Prentice Hall, 2008.

4. Othieno H., "Circulation of Air in Natural-Convection Solar Dryers: research and development solar drying in Africa", In Proceedings of a Workshop held in Dakar; 1986. p. 47–59.

5. Amouzou K., Gnininvani M. and Kerim B., "Solar Drying Problem in Togo: research and development solar drying in Africa", In Proceedings of a Workshop held in Dakar; 1986. p. 252–71.

6. Bolaji BO., "Development and Performance Evaluation of Box-Type Absorber Solar Air Collector for Crop Drying", Journal of Food Technology 2005; 3(4): 515–600.

7. Bolaji BO, Olalusi AP., "Performance Evaluation of a Mixed-Mode Solar Dryer", AU Journal of Technology 2008; 11(4):225–31.

8. Simate IN., "Optimization of mixed-mode and indirect-mode natural convection solar dryers", Renewable Energy 2003; 28:435–53.

9. Madhlopa A, Jones SA and Saka JDK, "A Solar Air Heater

10. With Composite-Absorber Systems for Food Dehydration", Renewable Energy 2002; 27:27–37.

11. Ekechukwe OV, Norton B., "Review of Solar Energy Drying Systems II: an overview of solar drying technology", Energy Conversion and Management 1999; 40:616-55.

12. Frank P. Incropera, David P. DeWitt, Theodore L. Bergman and Adrienne S. Lavine, Fundamentals of Heat and Mass transfer, 6th ed. New York: Wiley and Sons Book Company, 2007.