The First and Second Law Analyses of Thermodynamics of Potato Slices Drying Process

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ABSTRACT

The objective of the work being presented is to investigate the thermal performance of indirect, multi-tray solar drying system. Expressions for exergy in, exergy out and exergy loss for flat plate solar collector, drying chamber and trays kept in drying chamber were written under steady state conditions. Experiments were performed for 6 to 8 hours on two days namely 14/03/2014 and 24/03/2014 and the observations taken on 24/03/14 has been analyzed using Energetic and Exegetic approach. The value of first law efficiency for flat plate solar collector and solar dryer varied between 10% to 30.49% and 4.009% to 9.45% respectively. Second law efficiency of solar collector and solar dryer have been found varying from 0.7126% to 1.829%.and 49.85% to 67.75% respectively. The Exergetic efficiency for tray 1, tray 2 and tray 3 has been computed and these values varied from 90.43% to 93.412%, 72.684% to 92.352% and 78.179% to 94.61% for each trays respectively. Considering heavy energy and exergy losses from flat plate solar collector and drying chamber, the results of first Law and second Law efficiencies are in fair agreement with each other.

Key words: solar collector, solar dryer, energetic efficiency, exergetic efficiency, exergy loss

INTRODUCTION

Nowadays, drying is a well known, energy intensive, unit operation of all industrial processes. It constitutes an important process for a large part of the food processing industry. Initially it is a necessary step for the preservation of final food product and further to make the food stuffs ready to be stored for future consumption. The application of solar energy for drying applications has become an healthy and cheaper alternative. This is because of the reasons that solar energy is renewable, environmentally friendly, easily available and free of cost.

In present time world's non-renewable energy resources are rapidly getting depleted. The reason for this depletion is that humans are utilizing energy at a much faster rate than is being produced. Energy thinkers and managers are of the opinion that the primary sources of certain forms of energy will just get exhausted. Therefore, it has become imperative that effective solutions for the forthcoming energy crisis can be devised. Solar energy is one such alternative form whose effective utilization has been the keen interest of scientists and engineers.

Nomenclature:

I_t	Incident solar radiation (W/m^2)
T_a	ambient air temperature (°C)
T_{ci}	temperature of air at the inlet of collector (°C)
T_{co}	temperature of air at the outlet of collector (°C)
Tdco	temperature of air at the outlet of drying chamber (°C)
Tc1	temperature of crop in tray1(°C)
Tc2	temperature of crop in tray2 (°C)
Tc3	temperature of crop in tray3 (°C)
m_a	mass flow rate of drying air (Kg/ sec)
C_{pa}	specific heat of air (KJ / Kg °C)
η_c	First law efficiency of solar collector (%)
η_{dc}	First law efficiency of drying chamber (%)
η_d	First law efficiency of solar dryer (%)
η_T	First law efficiency of tray (%)
1,2,3	tray1, tray2 and tray3 respectively
η_{exc}	Second law efficiency of solar collector (%)
η_{exdc}	Second law efficiency of drying chamber (%)
η_{exds}	Second law efficiency of solar dryer (%)
η_{exT}	Second law efficiency of tray (%)

Solar drying system consists of solar collector unit and drying chamber. Solar collectors are special devices that can absorb and transfer energy of sun to a usable or storable form. Solar thermal collectors, which are a group of solar collectors, can be made in different shapes based on their application. The flat plate collector is the heart of any solar energy collection system which is designed for their operation in from 60° to 100°C. Solar collector collects both beam and diffused radiation incident upon its surface, absorbs it, converts it into heat and finally transfers the heat to a stream of fluid (liquid and air) which flows over the absorber surface. Flat plate type solar collector has been recognized as the most appropriate collector for drying fruits and vegetables. Concentrating type solar collector is a device which concentrates the solar energy incident over a large smaller surface by using a suitable focusing device, a receiver system and a tracking arrangement. Very high temperature of the order of 3000°C can be achieved. Hence such collectors have potential applications in both thermal and photovoltaic utilization of solar energy at high delivery temperature.

As a result of an extensive literature survey, we find that energy thinkers and managers are concerned with the rational utilization of available energy resource. Thus, Ebru Kavak Akpinar et. al [1] experimentally investigated the thermal performance of four different types of flat plate solar air heater, out of which three having obstacles (triangular type, leaf type, rectangular type) on absorber plate and one having no obstacle. The value of first law efficiency varied between 20% to 82%. The value of second law efficiency changed from 8.32% to 44%.

Filiz Ozgen et al. [2] constructed a double flow flat plate solar air heater having absorber plate made of aluminum cane and experimentally studied its thermal performance. This method substantially improves the collector efficiency by increasing the fluid velocity and enhancing the heat transfer coefficient between the absorber plate and air. Effective utilization of available energy was always into the thoughts of researchers.

S.K. Tyagi et al.[3] has performed comparative experimental study based on energy and exergy analysis of a typical solar air heater collector with and without temporary heat energy storage material, viz. paraffin wax and hytherm oil. Calculations of 1st Law and Second Law efficiencies for three different arrangements i.e. one arrangement without heat storage material and two arrangements with THES, viz. hytherm oil and paraffin wax respectively were done. This has been reported that both the efficiencies in case of heat storage material/fluid are significantly higher than that of without THES, besides both the efficiencies in case of paraffin wax are slightly higher than that of hytherm oil case.

Lyes Bennamoun [4] presented an overview on application of energy and exergy for determination of solar drying efficiency. As a result of simulation, mathematical modeling and analysis this has been reported that the calculated efficiencies of various components of solar drying system are deeply influenced by several parameters such as variation of the received radiation, the external temperature and the wind velocity during daytime by internal parameters and design such as surface of solar collector and the characteristics of dried product.

Gupta, M.K., and Kaushik, S.C. [5] evaluated the thermal performance of solar air heater using Exergetic approach along with parametric studies of S.A.H system. In the study, optimal performance parameters for maximum exergy delivery during the collection of solar energy in a flat-plate SAH were established. The procedure to determine optimum aspect ratio (l/b ratio of absorber) and optimum duct length (the distance between the absorber and bottom plate) for maximum energy delivery has been developed. Analytically it was proved that the optimum exergy output depend on the inlet temperature of air if blower work and corresponding mass flow rate are neglected. The energy and exergy output rates of solar air heater were evaluated for various values of collector aspect ratio (AR) of the collector, mass flow rate per unit area of collector plate (G) and solar air heater duct depth (H). This has been reported that exergy output rate increases with G, AR & decreases with H and inlet temperature of air. The second finding which is worth to be mentioned is that exergy based performance evaluation criterion is not a monotonically increasing function of G and AR& decreasing function of H and inlet temperature of air.

Hanane Dagdougui et al. 2011,[6] has investigated the heat transfer process as well as the thermal behavior of a flat plate collector by evaluating different cover configurations. Secondly, a two objective constrained optimization model has been formulated and implemented to evaluate the optimality of different design approaches.

Arif Hepbasli, 2008, [7] has presented a key review on exergetic analysis and assessment of renewable energy resources for a sustainable future. According to his thought, there is a link between exergy and sustainable development. A sustainable energy system may be regarded as a cost efficient, reliable and environmentally friendly energy system that effectively utilizes local resources and network. This comprehensive study is very beneficial to everyone involved in the exergetic design, simulation, analysis and performance assessment of RERs.

E. Kavak, Akpinar, A. Midilli and Y. Bicer, 2006.[8] has presented the first and second law analysis of thermodynamics of pumpkin drying process in cyclone type dryer. Energy analysis of the drying system was performed using first law of thermodynamics by estimating ratios of energy utilization by trays. The second law analyses was done to determine the location, type and magnitude of exergy losses during the drying process. This has been reported that the exergy losses went up with the increase of energy utilization in both the trays and drying chamber.

Bennamoun, L. Belhami A., 2003 [9] and Boughali, S. et al. 2009[10] have presented and evaluated alternate energy backup system using electrical heaters because of intermittent nature of incident solar energy. Literatures reveal that different types of other energy backup systems has been used and investigated by different researchers. Packed Rockbeds were used by Jain D., 2007 [11] and Chauhan, P. Chaudhary, C., Garg, H.P., 1996[12], desiccants by Shanmugam, V., Natrajan, E. 2006[13] and PCM materials by Devahastin, S., Pitaksuriyarat,S. 2006[14], Bal, L.M. et al. 2009[15], Al-Hamadani, A., A.F., Shukla, S.K. 20011[16] and Gupta, Akansha, Shukla, S.K., Srivastava, A.K.

Therefore the objective of this work is to carry out the energy and exergy analysis of single layer drying of high moisture potato slices in indirect forced convection multi tray solar dryer. It is believed that such study will contribute to the potato chips producers to improve their process considering both the energy and exergy approaches.

MATERIALS AND METHODS

Sample Drying

Potatoes purchased from a local market were cut manually into slices of diameter 2.5cm and thickness 2.5mm. The samples were spread evenly in a single layer on three similar stainless steel wire mesh trays and kept inside the drying chamber of solar dryer. Solar drying experiments were conducted on the roof of the Renewable Energy Lab, Department of Mechanical Engineering, Indian Institute of Technology, Banaras Hindu University, Varanasi, India during the month of March 2014. The latitude, longitude and altitude of Varanasi are, 25.2°N, 83.00°E, and 80.71 m above sea level.

Measurements

During the experimental period, the following quantities were measured: ambient air temperature T_a, inlet and outlet temperature of air in solar collector, air temperature at the outlet of drying chamber, total solar radiation energy I_t on a inclined surface, and wind speed. The temperature of the air was measured by using calibrated copper–constantan thermocouples which have low-cost, acceptable accuracy and rapid response. The location of the thermocouples in the collector passage allowed the determination of temperature of entering and leaving air from collector. Thermocouple beads were put in the cylindrical passage 10 cm bellow. The air temperature was sampled every hourly. Solar radiation at a inclined surface and ambient air temperature were also recorded during the tests.

Solar radiation was measured by the solarimeter. A solarimeter is a pyranometer, a type of measuring device used to measure combined direct and diffuse solar radiation.

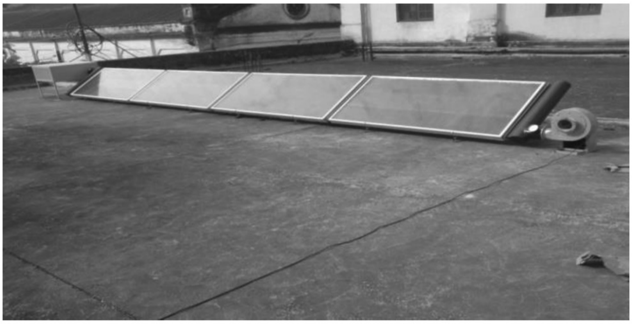

Figure 1. Flat Plate Solar Collector [25]

Figure 2. Drying Chamber [25]

Integrating solarimeter measures energy developed from solar radiation based on the absorption of heat by a black body. Its resolution is 1 W/m^2. This meter provides an accurate reading from 50 W/m^2 to 1200 W/m^2. The sensor is a silicon PV cell mounted on the front of the meter. Meters are calibrated on clear days in natural sunlight and adjusted to a reference cell measured against Pyranometers at Sandia National Laboratories. Meters are pointed directly at the sun for calibration; off-angle calibration is not done, but performance seems to be consistent up to ~40° off-direct normal.

Wind speed was measured using the anemometer with the range of 0.3–75 m/s. The accuracy of the anemometer is +2% + 0.2 m/s. The wind speed was always below 1 m/s and was recognized as small, thus the effect of wind and its direction was neglected. The ambient temperature is measured by digital thermometer, which has a resolution of 0.1°C/F. The accuracy of the digital thermometer is +/–1°C or +/–2°F (from 0 to 80°C) and +/–5–10°C or +/–10–20°F (other temperature range).

The sample weight loss was measured at regular time intervals, using a precision Goldtech Brand electronic scale capable of 20kg maximum and 0.40gm minimum. Moisture content (dry basis) was calculated from weight loss data and dry solid weight of the samples. Drying of food stuff was continued from an initial moisture content of 80% to final of 12%.

The tests were conducted between 10:00 and 17:00 solar time. The maximum temperature difference between air outlet and inlet is 27°C. The solar radiation energy I_t has been recorded in the range of 27–965 W/m^2. The recorded hourly data are listed in Table 1.

FIRST LAW ENERGY ANALYSIS

Collector Efficiency

The first law efficiency of the solar collectors is defined as the ratio of the useful energy gain over some specific period of time to the solar radiation incident on the collector plane over the same period of time:

$$\eta_c = \frac{Q_c}{Q_i} \tag{1}$$

where Q_c is the rate of heat transfer to a working fluid in the solar collector, and Q_i the solar energy absorbed by the solar collector surface and is given by

$$Q_i = I_t A_c \quad (2)$$

where I_t is the rate of incidence of radiation per unit area of the tilted collector surface, A_c the collector area. The absorption heat transfer rate by the solar collectors, Q_c, can be estimated by using the following equation:

$$Q_c = m_a C_{pa}(T_{co}–T_{ci}) \quad (3)$$

Drying Efficiency:

The drying efficiency of the air heating-and-drying system shows how effectively the input energy to the system (solar radiation) is used in drying the product. The drier efficiency is the product of the collector efficiency and drying chamber efficiency.

$$\eta_d = \eta_c * \eta_{dc} \quad (4)$$

where, η_d is solar drier efficiency. η_c is average collector efficiency and η_{dc} is drying chamber efficiency.

Let us obtain expression for η_{dc}—

η_{dc} = (heat lost by air in drying chamber)/(input heat)

$$= m_a C_{pa} (T_{co}-T_{dco})/ma C_{pa} (T_{co} –T_{ci}) \quad (5)$$

First Law Efficiency of Trays:

First law efficiency of a tray may be computed as—

η_T = thermal energy utilized by tray/thermal energy entering into tray

$$= m_a C_p (T_c – T_{dco})/m_a C_p (T_{co} – T_{ci}) \quad (6)$$

Exergetic Approach for the Performance Evaluation of Solar Drying System:

The total energy is the sum of useful or available energy (exergy) and the unavailable energy (Anergy). The available energy or exergy is a measure of the maximum useful work that can be performed by a system interacting with one environment. This is a composite property depending upon the state of the system and the surroundings.

The concept of Exergy is very much useful in the analysis of thermal systems. In this analysis, available energy at different points in a system are evaluated. Actually exergy is a measure of quality of grade of energy and it can be destroyed in the thermal system. The second law of thermodynamics states that part of exergy entering a thermal system with fuel and flowing stream of air or matter is destroyed within the system due to irreversibility. The analysis and design of thermal system can be done by using the concept of exergy balance.

A solar drying system comprises of a solar air heater and a drying chamber which supports horizontal trays in which food stuff are dried up to the required moisture level. Performance evaluation of solar drying system based on exergetic concept involves the exergetic analysis of each units separately such as solar collector and drying chamber.

The exergy loss is the difference between the exergy in and exergy out both of which are functions of inlet and outlet temperature of system component. Mathematically this may be written as—

$$\text{Exergy loss} = (\text{Exergy})_{in} - (\text{Exergy})_{out} \tag{7}$$

$$\Sigma\, Ex_l = \Sigma\, Ex_i - \Sigma\, Ex_o \tag{8}$$

Assumptions and Exergetic Analysis Approach of Multi tray Solar Drying System

The following assumptions have been made prior to carrying out the analysis work:

1. Steady state condition prevails throughout the drying process.
2. The thermodynamic effect of changes in potential energy and kinetic energy is negligibly small.
3. No chemical and nuclear reactions take place in the process.
4. Air has been assumed as an ideal gas whose specific heat is taken constant. The psychometric property of the air ie humidity content of air is neglected in order to reduce the complexity of the process.
5. The heat transfer to the system and work transfer from the system has been taken as positive.

Thermodynamic analysis of solar drying system has been done by estimating exergy inflow, exergy outflow and exergy losses of the various components such as trays and drying chamber. For calculating exergy values at various steady state points of the components, 1st law energy balance equations have been written and characteristics of working medium has been used.

Let us write the most general form of Exergy equation—

$$\text{Exergy} = (u - u_x) - T_0(s - s_0) + P_0/J\,(v - v_0) + V^2/2gJ + (z - z_0).(g/g_c.J) + \Sigma_c(\mu c - \mu 0).N_c + E_iA_iF_i\,(3T^4 - T_0^4 - 4\,T_0\,T^3) + \_\_\_\_\_\_\_\_ \quad (9)$$

Neglecting most of the energy terms and as a result of successive simplifications, the most simplified form of exergy equation may be given as—

$$\text{Exergy} = m_{da}\,C_p\,[(T - T_a) - T_a\,l_n(T/T_a)] \quad (10)$$

Using Equation No. (10) inflow and outflow of exergy can be determined as per the given inlet and outlet temperatures of trays, drying chamber and other components of drying system.

$$\text{Exergy Loss} = \text{Exergy inflow} - \text{Exergy outflow} \quad (11)$$

The exergetic efficiency can be defined as the ratio of the product exergy to exergy inflow for each tray. According to Midilli and Kucuk, 2003b, the exergetic efficiency may be defined as—

$$\text{Exergetic Efficiency} = (\text{Exergy inflow} - \text{Exergy loss})/\text{Exergy inflow} \quad (12)$$

Exergy Inflow Equations For Trays and Drying Chamber

Exergy inflow of First Tray i.e.,

$$E_{xt1i} = m_aC_{pa}\,[(T_{co} - T_a) - T_a\,l_n(T_{co}/T_a)] \quad (13)$$

Exergy inflow of Second Tray i.e.,

$$E_{xt2i} = m_aC_{pa}\,[(T_{c1} - T_a) - T_a\,l_n(T_{c1}/T_a)] \quad (14)$$

Exergy inflow of Third Tray i.e.,

$$E_{xt3i} = m_aC_{pa}\,[(T_{c2} - T_a) - T_a\,l_n(T_{c2}/T_a)] \quad (15)$$

Exergy inflow of Drying Chamber i.e.,

$$E_{xdci} = m_aC_{pa}\,[(T_{co} - T_a) - T_a\,l_n(T_{co}/T_a)] \quad (16)$$

Exergy Outflow Equations For Trays and Drying Chamber

Exergy outflow of First Tray i.e.,

$$E_{xt1o} = m_a C_{pa} [(T_{c1} - T_a) - T_a l_n(T_{c1}/T_a)] \quad (17)$$

Exergy outflow of Second Tray i.e.,

$$E_{xt20} = m_a C_{pa} [(T_{c2} - T_a) - T_a l_n(T_{c2}/T_a)] \quad (18)$$

Exergy outflow of Third Tray i.e.,

$$E_{xt30} = m_a C_{pa} [(T_{c3} - T_a) - T_a l_n(T_{c3}/T_a)] \quad (19)$$

Exergy inflow of Drying Chamber i.e.,

$$E_{xdc0} = m_a C_{pa} [(_{Tco} - T_a) - T_a l_n(_{Tdco}/T_a)] \quad (20)$$

Exergy Loss For Trays and Drying Chamber

Exergy Loss of First Tray i.e., $E_{xLt1} = E_{xt1i} - E_{xt1o}$ (21)

Exergy Loss of Second Tray i.e., $E_{xLt2} = E_{xt2i} - E_{xt2o}$ (22)

Exergy Loss of Third Tray i.e., $E_{xLt3} = E_{xt3i} - E_{xt3o}$ (23)

Exergy Loss of Drying chamber i.e., $E_{xLdc} = E_{xdci} - E_{xdco}$ (24)

Exergetic Efficiency Expressions for Trays And Drying Chamber

Exergetic Efficiency of First Tray i.e., $\eta_{Ext1} = 1 - (E_{xLt1}/E_{xt1i})$ (25)

Exergetic Efficiency of Second Tray i.e., $\eta_{Ext2} = 1 - (E_{xLt2}/E_{xt2i})$ (26)

Exergetic Efficiency of Third Tray i.e., $\eta_{Ext3} = 1 - (E_{xLt3}/E_{xt3i})$ (27)

Exergetic Efficiency of Drying Chamber i.e.,

$$\eta_{Exdc} = 1 - (E_{xLdc}/E_{xdci}) \quad (28)$$

Exergetic Analysis Of Flat Plate Solar Collector

According to Ozturk, H.H. [17] the instantaneous exergy efficiency of solar collector may be defined as the ratio of the increased air exergy to the exergy of the solar radiation. And according to Singh, H. et al. [18], it is a ratio of the useful exergy delivered to the exergy absorbed by the solar collector.

Thus the Exergy collected by collector may be given as

$$E_{xc} = A.\, I_t [1 + (T_a/T_s)^4/3 - (4/3).(T_a/T_s)] \quad (29)$$

The exergy received by air may be given as—

$$E_{Xf} = m(E_o - E_i) = m [(h_{oa} - h_{ia}) - T_a (S_{oa} - S_{ia})]$$
$$= m_a C_{pa} [(T_{co} - T_{ci}) - T_a (L_n)] \quad (30)$$

Exergy efficiency of solar collector may be given as—

$$\eta_{exc} = E_{xf}/E_{xc} \quad (31)$$

Exergy Efficiency of drying system may be computed as—

$$\eta_{exds} = \eta_{exc} + \eta_{exdc} \tag{32}$$

EXPERIMENTAL OBSERVATIONS

Experimental Observations taken on 24/03/2014 are presented in Table 1.

Table 1. Observations taken on 24/03/15

Time	Tco	Tdco	Ta	Tc1	Tc2	Tc3	Tci	It
9:00 AM			306				300.2	510
10:00 AM	327	321	307	326	324	322	303	888
11:00 AM	329	324	307	328	325	324.5	305	905
12:00 PM	332	323.5	304.5	331	327	325.5	307	965
1:00 PM	333	328	304	332	330	329	308	880
2:00 PM	328	325	303	327	326	325	309	803
3:00 PM	326	321	300	325	324	322	310	521
4:00 PM	320	316	298	319	318	317	309	299
5:00 PM	317	314	296	316	315	315	309	27

RESULTS AND DISCUSSION

First Energy Law Analysis

Using the data in Table 1, the first law efficiency of flat plate collector, solar dryer and trays has been computed using Equations 1 to 3, and Equation 4, 5 and 6 respectively. The results obtained are depicted in Figure 3 and Figure 4. First law efficiency of flat plate collector and solar dryer has been found to vary from 25.39% to 30.49% and 4.01 % to 9.45%, respectively. First law efficiencies of the three trays are presented in Figure 5. Thermal performance of flat plate collector and solar dryer has been evaluated and a fair agreement between experimental and theoretical values of efficiencies has been already achieved. [25]

Second Law Exergy Analysis

Exergy collected by flat plate collector and exergy received by air has been computed using Equation 29 and Equation.30, respectively. Exergetic efficiency for solar collector and solar dryer has been computed using Equations 31 and 32. The results are presented on Figure 6 and Table 2. Percentage exergy losses for collector, drying chamber and all

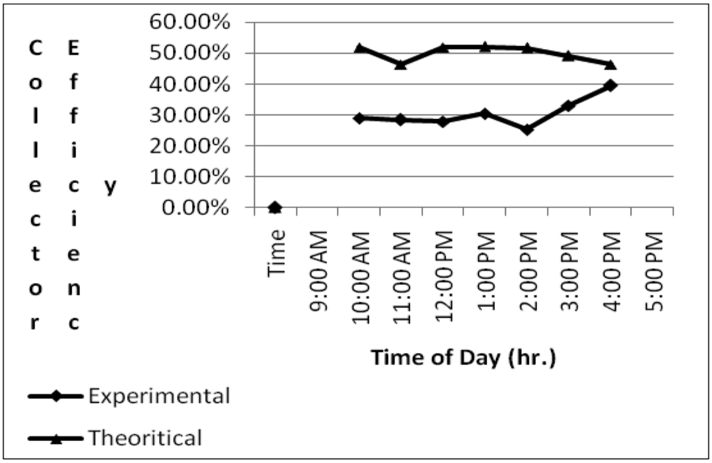

Figure 3. First Law Efficiency Of Solar Dryer [25]

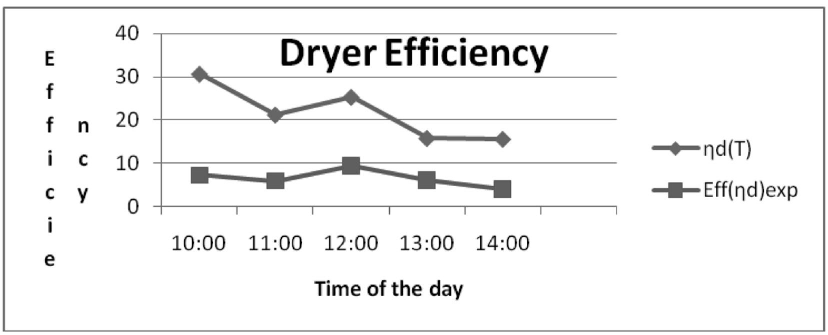

Figure 4. First Law Efficiency Of Solar Dryer [25]

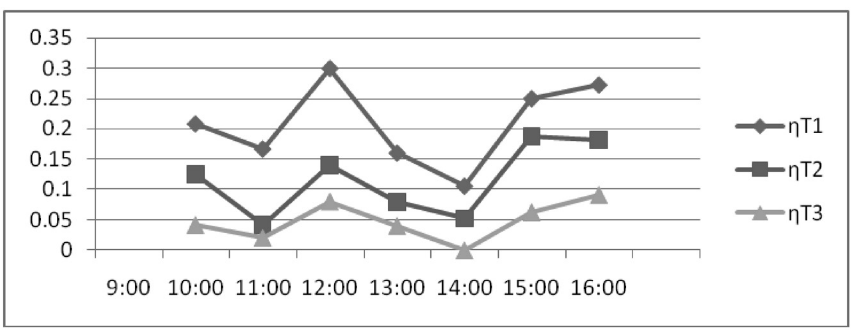

Figure 5. First Law Efficiency of Tray 1, Tray 2 and Tray 3

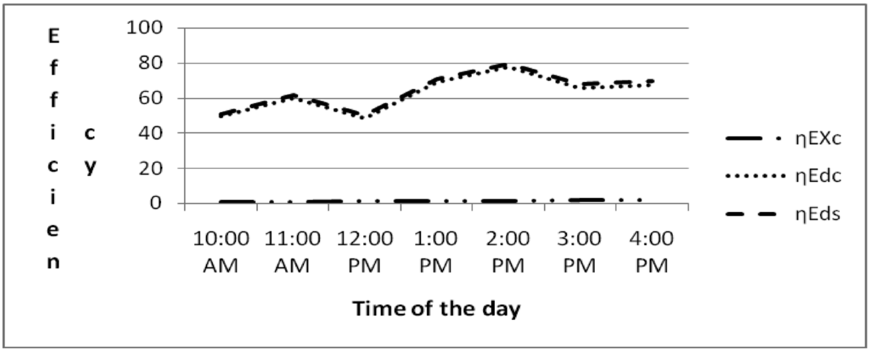

Figure 6. Exergetic Efficiency for Flat Plate Solar Collector, Drying Chamber and Dryer

three trays are shown in Figures 7, 8 and 9, respectively.

From the results on Table 2, the % exergy loss from collector surface varied from 97.967 % to 99.287 % with average loss as 96.52 %. Due to heavy exergy loss from the collector surface, the exergetic efficiency of solar collector has been found to vary from 0.713 % to 2.034 %. Percentage exergy loss from the drying chamber varied from 22.078 % to 51.422 % with average value as 37.276 % and exegetic efficiency of drying chamber has been found ranging from 48.57 % to 77.92 % with average value as 62.724 %. Similarly Exergetic efficiency of solar drying system or solar dryer has been computed and found in the range of 50.323 % to 79.132 % with average value as 64.076 %. This result shows that a portion of thermal energy discharged from solar collector and entering into drying chamber is fully utilized by drying chamber for meeting various losses from the drying chamber. This is the reason of very appreciable values of drying chamber as well as solar dryer efficiency.

Exergy inflows for tray1, tray2, tray3 and drying chamber have been computed using Equations 13 through 16. Exergy outflow for the same has been computed using Equations 17 to 20. Next, the exergy loss for three trays and drying chamber has been computed by using Equation 21 to 24. Exegetic efficiency for tray1, tray2, tray3 has been computed using equations 25 to 28 and the result is depicted in Fig 10 and in Table 2. Referring to Table 2, the average exergy losses for tray1, tray2 and tray3 has been computed as 0.556 %, 1.045 % and 0.626 % resulting in very encouraging value of average exergetic efficiency of all three trays as 92.07 %, 84.12 % and 88.48 % respectively.

Table 2. Summary of Results

S.No	Components	Parameters					
		First Law Efficiency (%)		Exergetic Efficiency in (%)		(%) Exergy Loss	
		Range values	Average value	Range Values	Average Value	Range Values	Averae Value
1.	Solar Collector	25.392% - 30.486 %	28.229%	0.713 % - 2.034 %	1.352 %	97.966% - 99.287 %	96.52%
2.	Drying Chamber	15.79%- 36.36%	21.2%	48.57 %- 77.92 %	62.724%	22.078 %- 51.422 %	37.28%
3.	Solar Dryer	4.009 % - 9.452 %	6.548 %	50.323 % - 79.132 %	64.076 %	-	-
4.	Tray 1	10.52%- 30%	20.89%	90.43 % - 93.049 %	92.07 %	0.454 % - 0.651%	0.557%
5.	Tray 2	4.1%- 18.75%	11.55%	72.684 % - 92.352 %	84.122 %	0.489 % - 2.263 %	1.045%
6.	Tray 3	0%-9.09%	4.8%	78.179 % - 94.61 %	88.475 %	0.208 % - 1.082 %	0.626%

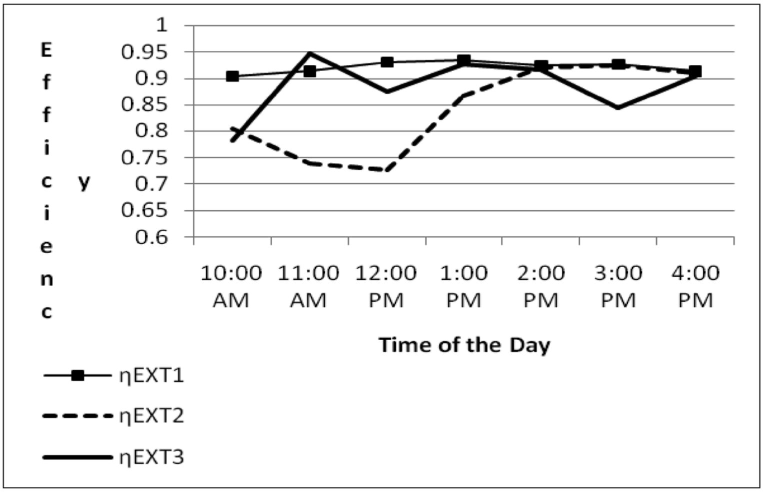

Figure 7. Exergetic Efficiency For Tray1, Tray2 and Tray3 respectively.

CONCLUSIONS

The comparative study based on the first and second law analyses of forced convection multi tray solar drying system lauric acid as thermal energy storage has been carried out using hourly incident radiation. From the experimental study and subsequent analysis summarized on Table 2, the following conclusions may be inferred.

1. It is found that there is fluctuation in both the efficiencies which is mainly due to the fact that solar radiation also fluctuates throughout the day. As the time progresses, both the efficiencies first increase after then decrease. Similar trend is found for incident solar radiation also.

2. From the observations, this has been also investigated that first law efficiency of drying system components such as solar collector and solar dryer is much higher than that of second law efficiency. This is because exergy represents the quality of energy which is obviously enhanced with the increase in temperature unlike the quantity of energy. Thus exergy, once lost is lost forever and cannot be recovered, unlike energy. This has been found that exegy loss is more in collector receiver- assembly and not in the low temperature utility unlike energy. This results in more losses in exergy than

that of energy and hence, we found the second law efficiency much less than that of the first law efficiency.

3. Second law efficiency curves for various components of drying system are found to be smoother than that of first law efficiency which may be due to the fact that exergy losses are less sensitive to the input energy viz. solar radiation, while the situation is quite reverse in case of energy losses.

4. The variations in exergy input, exergy loss and exergy outflow of the collector and dryer resulted from the variations in incident solar radiation. On an average of 60 % to 65 % of available energy was wasted in the collector and dryer respectively. Hence there is a significant improvement potentials in solar drying systems to increase actual efficiency and reduce exergy losses.

5. The concept of energy and exergy analysis can also be applied to other solar thermal systems to study the realistic performance of devices and energy conversion systems as well.

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References:

[1] Ebru Kavak Akpinar, Fatih Kocyigit (2010), "Energy and Exergy Analysis Of a New Flat Plate Solar Air heater having Different Obstacles On Absorber Plates," Applied Energy, Vol. 87, 3748-3450.

[2] Filiz Ozgen, Mehmet Esen, Hikmet Esen (2009), "Experimental Investigation Of Thermal Performance Of A Double – Flow Solar Air Heater Having Aluminium Cases," Renewable Energy, Vol.34, 2391-2398.

[3] V.V. Tyagi, A.K. Pandey, G. Giridhar, B. Bandyopadyay, S.R. Park and S.K. Tyagi (2012), "Comparative Study Based On Exergy Analysis Of Solar Air Heater Collector Using Thermal Energy Storage," International Journal Of Energy Research, 2012; 36: 724-736.

[4] Lyes Bennamoun (2012), "An Overview Of Application Of Exergy And Energy For The Determination Of Solar Drying Efficiency," International Journal Of Energy Engineering, 2(5): 184- 194.

[5] M.K. Gupta and S.C. Kaushik (2008), "Exergetic Performance Evaluation And Parametric Studies Of Solar Air Heater." Energy, 05, 010.

[6] Hanane Dagdougui, Ahmed Quammi, Michela Robba, Roberto Saate (2010), "Thermal Analysis And Performance Optimization Of a Solar water Heater Flat Plate Collector: Application To Tetonan (Moroco)," Renewable And Sustainable Energy Reviews, 15 (2011), 630-638.
[7] Arif Hepbasli (2008), "A Key Review On Exergetic And Assessment Of Renewable Energy Resources For A Sustainable Energy Reviews," 12(2008), 593-661.
[8] E. Kavak Akpinar, A. Midilli, Y. Bicer (2006), "The First And Second Law Analysis Of Thermodynamics Of Pumpkin Drying Process." Journal Of Food Engineering, 72 (2006) 320-331.
[9] Bennamoun, L., Belhamri, A., (2003), " Design And Simulation Of A Solar Dryer For Agriculture Products, Journal Of Food Engineering, 59(2-3), 259-266.
[10] Boughali, S., Benmoussa, H., Bouchekima, B. Mennouche, D., Bouguettaia, H., Bechki, D., (2009)," Crop Drying By Indirect Active Hybrid Solar – Electical Dryer In The Eastern Algerian Septentrional Sahara, Solar Energy, 83(12), 2223- 2232.
[11] Jain, D., (2007), "Modeling The Performance Of The Reversed Absorber With Packed Bed Thermal Storage Natural Convection Solar Crop Dryer," Journal Of Food Engineering, 78 (2), 637 – 647.
[12] Chauhan, P.M., Chaudhary, C., Garg, H.P., (1996), "Comparative Performance Of Coriander Dryer Coupled To Solar Air Heater And Solar Air – Heater- cum-Rock-bed Storage," Applied Thermal Engineering, 16(6), 475-486.
[13] Shanmugam, V., Natarajan, E.,(2006), "Experimental Investigation Of Forced Convection And Desiccant Integrated Solar Dryer," Renewable Energy, 31 (8), 305-314.
[14] Devahastin, S., Pitaksuriyarat, S., (2006), "Use Of Latent Heat Storage To Converse Energy during Drying And Its Effect On Drying Kinetics Of A Food Product," Applied Thermal Engineering, 26 (14-15), 1705-1713.
[15] Bal, L., Sudhakar, P., Satya, S., Naik, S.N., (2009), "Solar Dryer With Latent Heat Storage Systems For Drying Agricultural Food Products," Proceedings Of International Conference Of Food Security And environmental Sustainability.
[16] Ai-Hamadani, A., A.F., Shukla, S.K., (2011), "Water Distillation Using Energy System Using Lauric Acid As Storage Medium," International Journal Of Energy Engineering, 1(1), 1-8.
[17] Ozturk, H.H.(2004), "Experimental determination of Energy and Exergy efficiency of the solar parabolic cooker." Solar Energy, 2004; 77: 67-71.
[18] Singh. N., Kaushik S.C., Misra R.D.(2000)," Exergetic Analysis Of A Solar Thermal Power System." Renewable Energy; 2000: 19(1&2): 135-143.
[19] S.K. Shukla, D.C. Saraswat and T. Raj, (2008), Evaluation of Convective Heat and Mass Transfer in Open Sun and Green House Drying, International Journal of Energy Technology and Policy, Vol.6 (5/6), 543-553.
[20] A. Gupta and S.K. Shukla (2013) Analysis of Solar Drying Unit with PCM Storage Systems submitted to International Journal of Agile System and Management Vol. 6(2), 164-174
[21] S.K. Shukla, (2009) Comparison of Energy and Exergy Efficiencies of Community and Domestic Solar Cookers, International Journal of Green Energy, Vol. 6 (5), 437-449.
[22] S.K. Shukla and A.K. Sharma (2010) Design and Performance Evaluation of a Solar Assisted Drying of System Int. Journal Materials Engineering Innovation Vol. 1, Nos. 3/4, 338-349.
[23] S.K. Shukla and A.K. Sharma (2010) Design and Performance Evaluation of a Solar Assisted Drying of System Int. Journal Materials Engineering Innovation Vol. 1, Nos. 3/4, 338-349.
[24] S.K. Shukla et al. Evaluation of Heat and Mass Transfer Coefficients in Open Sun

and Greenhouse Drying. HT2008-56162, ASME 2008-Summer Heat transfer Conference held at Jacksonville, FL., USA between August 10-14, 2008.
[25] Srivastava A.K., Shukla S.K.," Thermal Modeling Of Indirect Drying System: An Experimental Validation." D.G.A.E., Taylor-Francis (Accepted For Publication)

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