International Research Journal of Advanced Engineering and Science
ISSN: 2455-9024

# Energy and Exergy Analysis of ETC Based Solar Air Dryer

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***Abstract*— *Most parts of India are blessed with an ample amount of sunshine, with around 300 sunny days per year and the peak value of solar radiations reaching as high as 800 W/m$^2$ to 1000 W/m$^2$. This indicates the potential use of solar radiations for direct thermal applications. Besides the availability of solar radiations resource, there are large energy consumptions in heating the fluid for their personnel use or for ample of application, due to large population and the crisis of energy in our world. The solar air dryer is the better substitute for heating the air and that dry air can be used for drying the wood as well the system can be used for heating water in the winter. On the basis of experimental study based on energy and exergy analyses of a typical solar air dryer it's showed the result of first and the second law efficiencies are calculated with respect to the available solar radiation. It is found that the second law efficiency is much less than the first law efficiency irrespective of the mass flow rate of the circulating fluid. It is also found that both efficiencies are an increasing function with respect to the mass flow rate of the working fluid. For a particular day, it is also found that first and second law efficiencies fluctuate according to radiation.*

***Keywords*— *Evacuated tube collector, solar air dryer, Solar Radiation.*

## I. INTRODUCTION

Solar energy is one of the most promising renewable energy resources available to most of the developing countries. Solar thermal is being developed and disseminated in many countries of the world. The ministry of New and Renewable Energy Sources (MNRES) of the Govt. of India has been pursuing a comprehensive program in the country on the development and dissemination of solar thermal technologies since its inception which includes providing support for research and development, demonstration and commercialization also.

One of the major developments in this direction is solar air dryer. Solar air dryer is a device, which heat the fluid to such a high temperature without using any conventional fuel (like cow dung, straw, wood, coal). It converts sunlight into heat energy and heats the fluid. As we know 70% population of India lives in rural areas and there are about 250 sunny days in India.

### A. Solar Drying

Drying or dehydration is a simple, low-cost way to preserve food that might otherwise spoil. Drying removes water and thus prevents fermentation or the growth of molds. It also slows the chemical changes that take place naturally in foods, as when fruit ripens. Surplus grain, vegetables, and fruit preserved by drying can be for future use.

People have been drying food for thousands of years by placing the food on mats in the sun. This simple method, however, allows the food to be contaminated by dust, airborne molds and fungi, insects, rodents, and other animals. Furthermore, an open air drying is often not possible in humid climates.

Solar food dryers represent a major improvement upon this ancient method of dehydrating foods. Although solar dryers involve an initial expense, they produce better looking, better tasting, and more nutritious foods, enhancing both their food value and their marketability. They also are faster, safer, and more efficient than traditional sun drying techniques. An enclosed cabinet-style solar dryer can produce high quality, dried foodstuffs in humid climates as well as arid climates. It can also reduce the problem of contamination. Drying is completed more quickly, so there is chance of spoilage. Because many solar dryers have no additional fuel cost, this method of preserving food also conserves non-renewable sources of energy.

In recent years, attempts have been made to develop solar dryers that can be used in agricultural activities in developing countries. Many of the dryers used for dehydrating foods are relatively low-cost compared to systems used in developed countries.

*a) Open sun drying*: Drying or dehydration means removal or reduction of water from any material may be vegetable, fruit, grain, milk or meat. Drying may be carried under open sunlight directly. Drying foods in open sun is being followed since ancient times. Foods containing high moisture content are simply dried under open sun during hot sunny days to the desired texture qualities. In these technique vegetables, fruits, greens, spices, legume-based products, wafers, papads etc. are dried & stored for longer periods. Intermittently the foods are exposed to sunlight to prolong shelf life.

*b) Solar air drying*: Solar air drying is done under controlled conditions of temperature, humidity & airflow. The costs of processing are usually high. Air is used as drying medium. Temperature, moisture & velocity of air are controllable depending on the foods to be dried. Cooking quality foods are superior. Sanitary conditions are controllable with in a dehydration plant. It is a continuous fast process & the product is obtained within a short period. Labour requirements are minimal. Dehydration of foods can be carried in all seasons for prolonged shelf life.

Due to abundant availability of solar radiation attention has been gradually diverting to utilize this renewable energy for a number of applications. Among these dehydration of food & non-food items is an important sector.

This solar drying enables Good Manufacturing Practices (GMP) & yields export worthy processed foods with long shelf life meeting the sanitary & phyto sanitary standards of the importing countries. This novel technology is a very viable & valuable one.

*B. Solar Radiation at the Earth's Surface*

The solar radiation that penetrates the earth's atmosphere and reaches the surface differs in both amount and character from the radiation at the top of the atmosphere. In the first place, Part of the radiation is reflected back in to the space, especially by clouds. Furthermore, the radiation entering the atmosphere is partly absorbed by molecules in the air. Oxygen and Ozone (03), formed from oxygen, absorb nearly all the Ultraviolet radiation, and water vapour and carbon dioxide absorb some of the energy in the infrared range. In addition, part of the solar radiation is scattered (i.e. its direction has been changed) by droplets in clouds by atmosphere molecules, and by dust particles.

Solar Radiation that has not been absorbed or scattered and reaches the ground directly from the sun is called "Direct Radiation" or Beam Radiation. Diffuse radiation is that Solar Radiation received from the sun after its direction has been changed by reflection and scattering by the atmosphere. Because of the Solar Radiation is cattered in all directions in the atmosphere, diffuses radiation comes to the earth from all parts of the sky.

The sum of the beam and diffuse radiation flux is referred to as total or global radiation.

*C. Instruments Used*

Solar Radiation flux is usually measured with the help of a pyranometer or a Pyrheliometer, sunshine recorder is used for measuring sunshine.

*a) Pyranometer*: A pyranometer is an instrument which measures either global or diffuse Radiation over a hemispherical field of view. Basically the pyranometer consists of a 'black' surface which heats up when exposed to solar radiation. Its temperature increases until its rate of heat gain by solar radiation equals its rate of heat loss by convection, conduction and radiation.

The hot Junctions of a thermopile are attached to the black surface. While the cold junctions are located in such a way that they do not receive the radiation. As a result, an e.m.f is generated. This e.m.f which is usually in the range of 0 to 10MV can be read, recorded or Integrated over a period of time and is a measure of the global radiation.

The pyranometer is used commonly in India it has its hot Junctions arranged in the form of a circular disc of diameter 25MM and is coated with a special black lacquer having a very high absorptivity in the solar wave length region. Two concentric hemispheres, 30 and 50MM in diameter respectively made of optical glass having excellent transmission characteristics are used to protect the disc surface from the weather. An accuracy of about ±2 percent can be obtained with the Instrument.

The duration of bright sun shine in a day is measured by means of a sunshine recorder. The sun's Rays are focussed by a glass sphere to a point on a card strip held in a groove in a spherical bowl mounted concentrically with the sphere. Whenever there is bright sunshine, the image .formed is intense enough to burn a spot on the cord strip. Though the day as the sun moves across the sky, the image moves alone the strip. Thus, a burnt trace whose length is proportional to the duration of sunshine is obtained on the strip.

## II. EXPERIMENTAL ANALYSIS

In this experimental study of a solar air dryer made of an evacuated tube collector (ETC), Nine ETC collector tubes were arranged in series and a copper tube of 12mm diameter was inserted inside the evacuated tubes for air circulation. Figure 1 shows the frontal view of nine tubes evacuated collector. Asbestos cloth was used for covering the copper tubes for insulation purposes. Calibrated J-type thermocouples made of copper with a temperature range of -200 to 1350.0 were used to measure the air temperature at different state points. Thermocouples were inserted in such a manner as to not touch the surface of the copper tube. One thermocouple was used for measuring the input air temperature and the other were used for measuring the outlet temperature of air at the exit of each tube.

The outlet air temperature of the first tube is the inlet of the second tube and the outlet of the second tube is the inlet to the third tube and so on. A rotameter of 200 LPM capacity was used for measuring the air flow rate. The air was forced through the system using a Half HP air compressor. As solar radiation pyranometer with multiplication factor 8.52 × 10-6 $V/W/m^2$ was used in the experiment for measuring the solar radiation. For collection of data, manually system was used in this experimental study. In every five minutes data were recorded for all the desired parameter.

Fig.1. Frontal view of nine tubes evacuated collector.

The solar collector consists of double-walled evacuated glass tubes. Forced air flow is used as the working fluid in the system. There are nine vacuum tubes in this solar dryer and a black absorbing coating covers the outer surface of the inner tubes. The coating is for the silver nitrate material. The vacuum between the collector is provided so that the radiation



Ankush Gupta, Sahil Sharma, and Sourabh Abrol,, "Energy and exergy analysis of ETC based solar air dryer," *International Research Journal of Advanced Engineering and Science*, Volume 1, Issue 1, pp. 17-24, 2016.

should be trapped in the tubes and the main aim is the reduction of vapour pressure so that the fluid should attain boiling point in minimum possible pressure and temperature.

In the present study have fabrication a typical solar air dryer in workshop and photographic view of the system is shown in figure 1.

The tubes are made of glass with the specifications given. The specifications of a typical solar air dryer total length 179.5cm, inner length 176cm, Coating length 172cm Inner diameter 44mm, Outer diameter 57.5mm, while the length exposed to sunlight is around 1670mm.

The tubes are inclined at angle of write this is tabular form $45^0$. The volume flow rate of the fluid is measured using a volume flow meter before the fluid enters the first tube. In this setup, vacuum is created between the annular spaces of the double-walled glass tubes. Whenever the fluid enters the first tube, its temperature rises, which can be identified by measuring the temperature with the help of the thermocouple provided at the inlet and outlet of first and last tube respectively.

The data from the system collector were measured for a few days in different months by varying the volume flow rate of the air in the months of June-July 2010 at the central workshop.

### *A. Analysis*

Energy and Exergy analysis were carried out to evaluate the first and second law efficiency of solar air' dryer system. Volume flow rate of the fluid in the system is specified. Energy and Exergy analysis have been performed based on the configuration.

*a) Energy analysis*: The energy analysis is based on the first law of thermodynamics First law efficiency or energy analysis is based on the fact that it is an upper limit of efficiency with which a radiation can transfer maximum useful work from a given frequency spectrum and intensity.

Energy received by collector Q = Al

Energy absorbed by fluid $Q = mC_p\ \Delta T$

First law efficiency of the system $\eta = Q_f / Q_c = mc_p \Delta T$

*b) Exergy analysis*: Exergy analysis is based on the second law of thermodynamics. It is nearer to the actual efficiency of the system.

Exergy received by collector $(E_c) = Q_c\,(1- (T_0 / T_s)$

Exergy received by fluid $(E_f) = m(E_0 - E_i) = m[(h_0-h_i) - (T_a(S_0 - S_i))]$

Second law efficiency of the system can be written as:

$\eta 11 = E_f/E_C = m[h_0-h_i)-T_0(S_0-S_i)]/Q_C(1-T_0/T_S)$

$h1 = C_{Pi}T_i$

$C_{Pi} = a + b \times T_i$ (1)

$C_{P0} = a + b \times T_i$ (2)

$ds = dq/T = C\times dT/T=(a+bT)\times(dT/T) = a\times dT/T+kdT$

$A$ = projected area = $d \times L = 0.09686\text{m}^2$

$Q_C = 4AQ\cos 45 = 0.19973$

$E_C = Q_C(1-T_0/T_S)$ $E_f = m(h_0-h_i)-T_a\Delta S)$

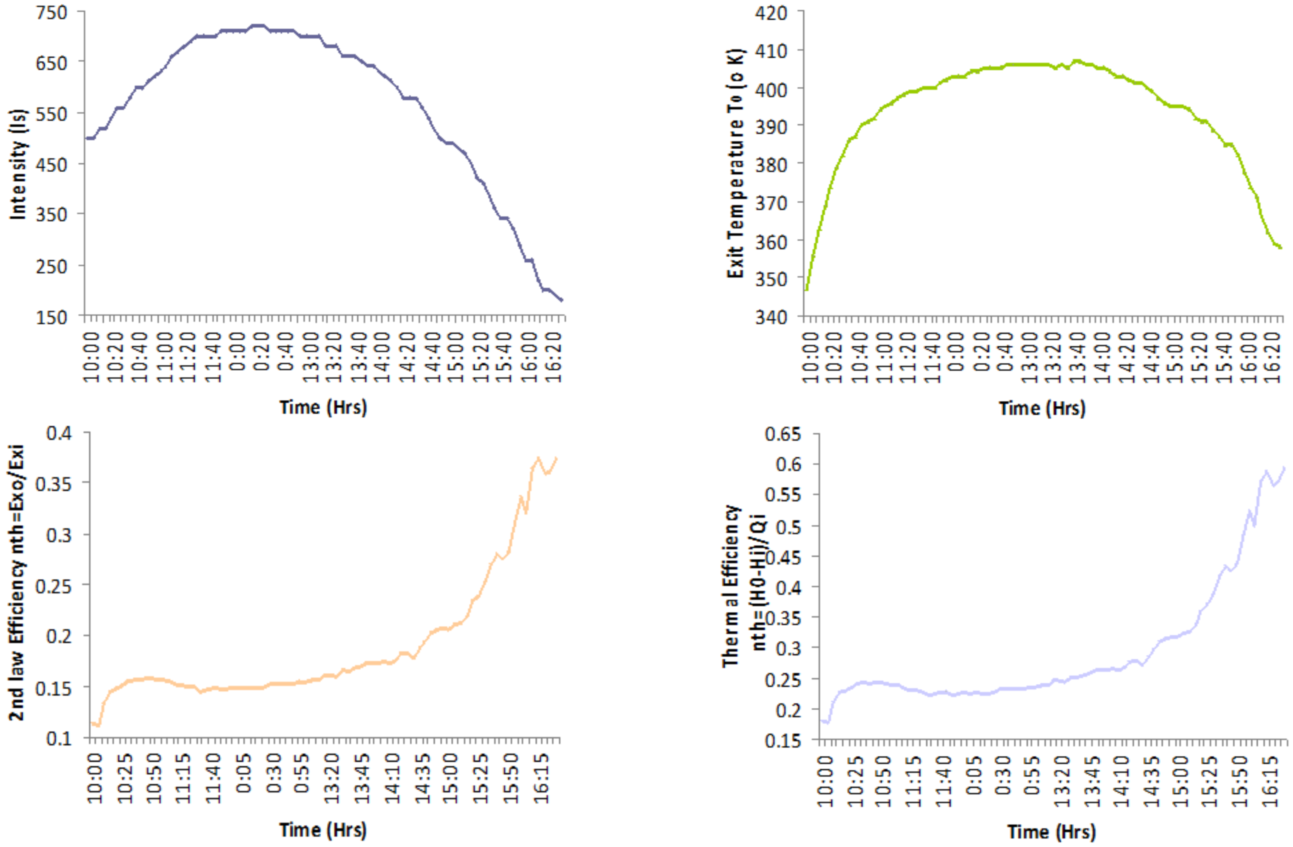
$\eta_1 = m(h_0-h_i)/Q_C$ $\eta_{11} = (E_f/E_C) \times 100$

## III. RESULTS AND DISCUSSION

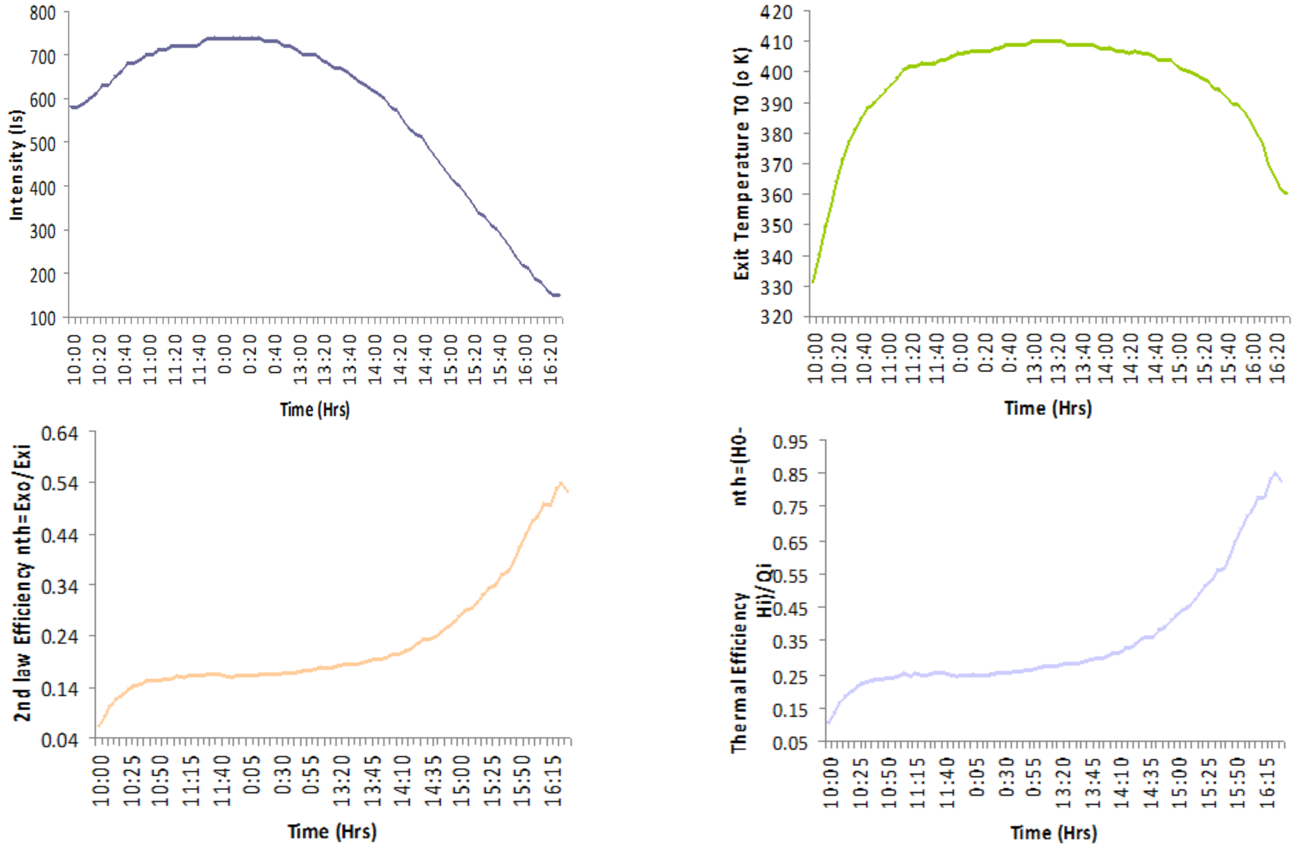
The exergy and energy analysis were carried out for different mass flow rate & volume flow rate of air & water respectively and based on the data recorded in the workshop, the first law efficiency has been calculated. From the efficiency vs Time curves for different mass flow rate of air & water, it is clear that irrespective of the mass flow rate, the nature of curves for first law efficiency and second law efficiency are almost similar. With increase in mass flow rate of air, the first law efficiency and second law efficiency increases. During the start of the experiment, due to less intensity of radiation the value of efficiencies is small but as soon as the time increases the value of efficiency also increases. It is also noted that due to inconsistent radiation during the day, the value of both the efficiencies decreases and then increases.

The first and the second law analyses of typical solar air dryer have been carried out for different flow' rates of air & water based on the hourly study of the parameter on different days besides the variation of solar radiation at a typical location in India. It is to be noted that there is fluctuation in both the efficiencies which may be due to the fact that the solar radiation also fluctuates with time. It can be found that both efficiencies enhance as time increases up to a certain extent then decrease as the time increases Moreover, both the efficiencies attain peaks at around mid-day, which is an obvious case. It exhibits that the present system has similarity with the general trend of solar heating systems. It is important to note that the major part of high quality energy s lost by the collector tubes and only a small part of energy transmitted by it is absorbed by the receiver tubes in which the working fluid (air) is flowing. The second law of efficiency is found to be much less than the first law of efficiency. Again, as the mass flow rate of the working fluid increases, both the efficiencies enhance further, which is clear by the fact that the heat loss within the receiver tube decreases, as a result of which we got better performance. Also, no matter what the mass flow rate is, the second law efficiency is always found to be less than the first law efficiency. It can be explained on the basis of irreversibility associated to such a process. As the mass flow rate of the working fluid increases, the peak of both the efficiencies shifts slightly towards the origin. For example, the peak is observed around 13:00 h in the case of the lowest volume/mass flow rate, viz. 10 1pm, while is found to be around 11:05-12:40 h in the case of medium volume/mass flow rates. On the other hand, it is found to be around 11:00 h for the highest volume/mass flow rate, viz. 50 1pm. Thus the volume/mass flow rate plays an important role in the performance of an air dryer system.

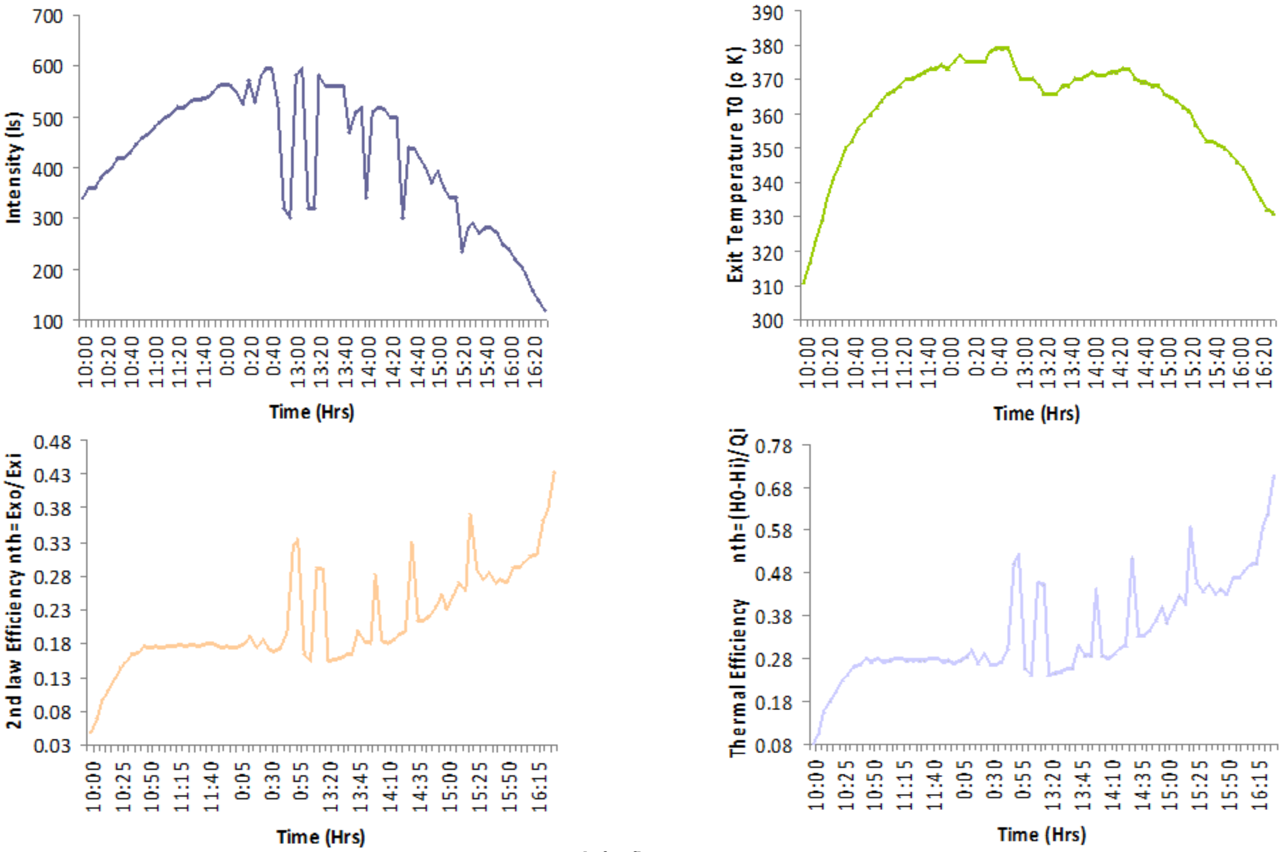
This particular result once again has shown that the mass flow rate is a critical parameter in the investigation of a concentrating collector/dryer The curve for the second law of efficiency, is smoother than that of the first law of efficiency, which may be due to the fact that exergy losses are less sensitive to the input energy, viz, solar radiation, while it is reverse in the case of energy losses.



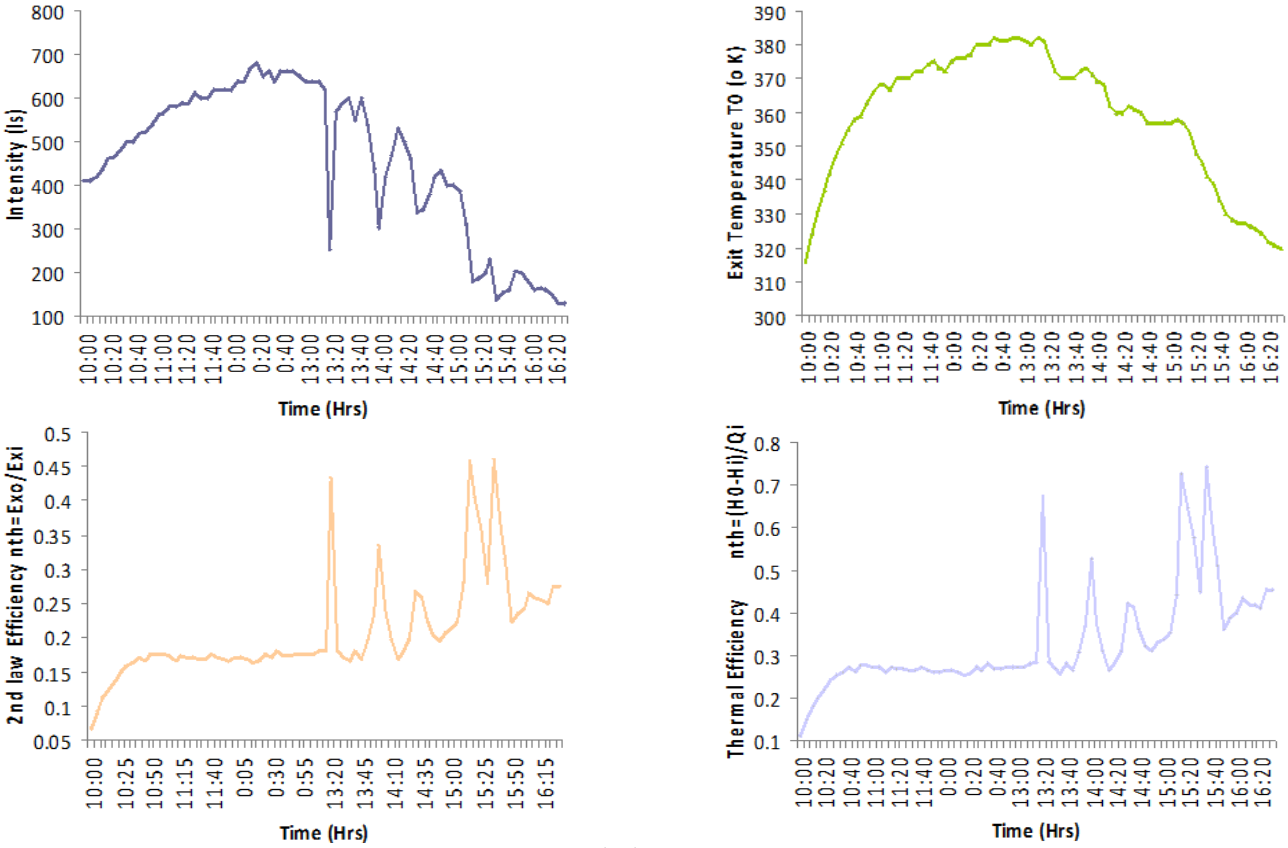

Graph for flow 90 LPM




Graph for flow 100 LPM

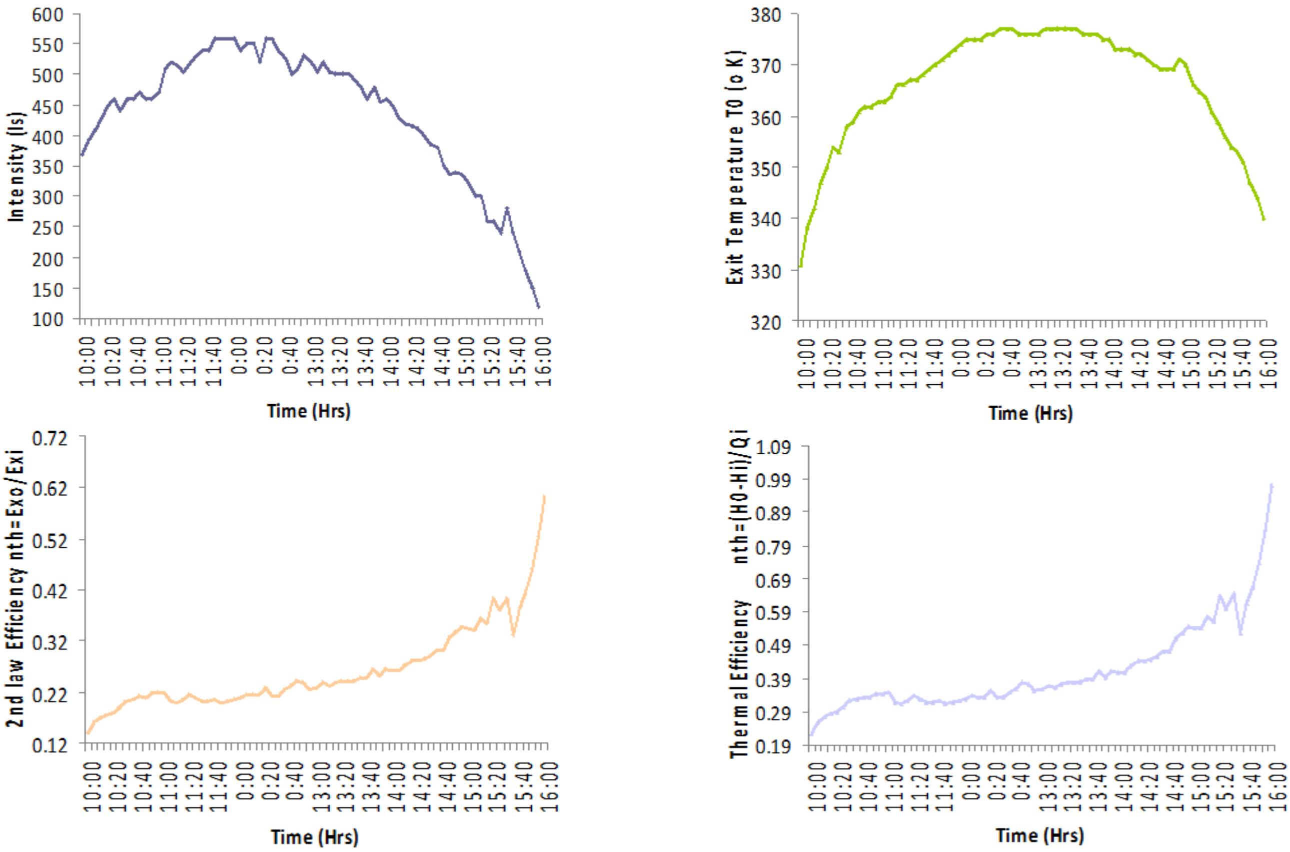



Graph for flow 110 LPM

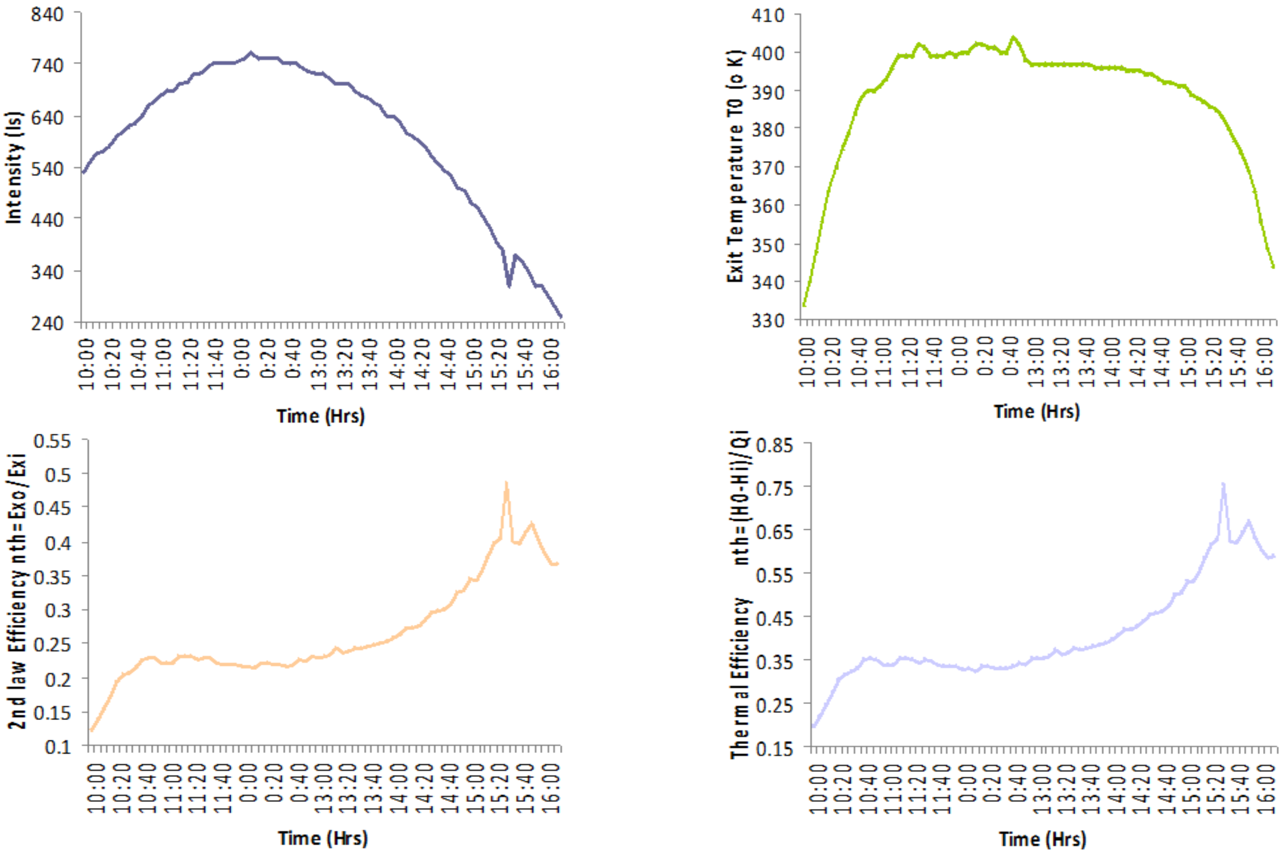



Graph for flow 120 LPM

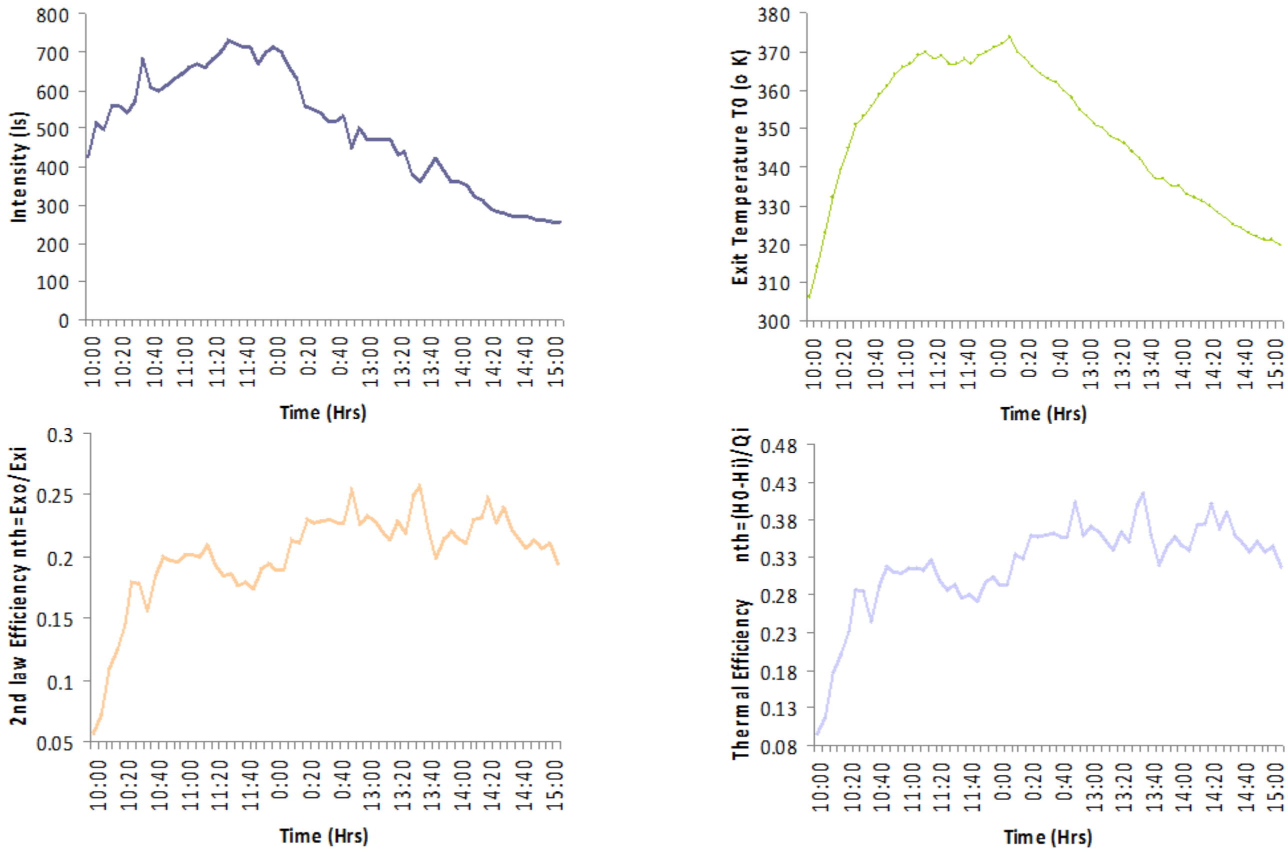
ISSN: 2455-9024




Graph for flow 130 LPM




Graph for flow 140 LPM




Graph for flow 150 LPM

It can be seen that efficiencies at the beginning are much higher, this is due to the fact that the experiment was run a little late and the air trapped within the collector tube got heated due to the NRV (non return valve) mechanism provided in the instrument, and we got higher efficiencies in the beginning than those in the other days and cases. It is also important to note that the results found in the present paper are in good agreement with those obtained by earlier workers, as available in the literature.

## IV. Conclusion

It is to be noted that there is fluctuation in both the efficiencies which may be due to the fact that the solar radiation also fluctuates with time. It can be found from the results that both the efficiencies enhance as the time increases up to a certain extent then decreases as the time increases, which is found to be in good agreement with the results obtained by others. However, some fluctuations were observed in 'both the efficiencies, which is due to the fact that there are also fluctuations in the solar radiation. The fluctuation in the first law of efficiency is found to be more, while it is the reverse in the case of second law of efficiency. Moreover, both the efficiencies attain peaks around the same time in the day, an obvious case in all practical applications related to solar energy, and hence our system is found to be consistent with the real-life applications of solar energy. The first law of efficiency is much higher than the second law of efficiency, which can be explained in terms of exergy losses. Besides, the major part of the quality of energy (exergy) is lost from the surface of the collector and hence a small part is being transmitted and absorbed by the working fluid (air) circulating within the collector tube. As a result, the second law of efficiency is found to be much less than the first law of efficiency, Again, as the mass flow rate of the working fluid increases, both the efficiencies enhance further, which is clear from the fact that the heat loss within the receiver tube decreases, as a result of which we got better performance.

Also, no matter whatever the mass flow rate is, the second law of efficiency is always found to. be less than the first law efficiency. As the mass flow rate of the working fluid increases, the peak of both the efficiencies slightly shifts towards the origin. Thus the volume/mass flow rate plays an important role in the performance of an air dryer.

## Acknowledgment

We would like to express our heartfelt thanks to Dr. S.K. Tyagi & Mr. Sanjeev Anand, SITRM for their time to time guidance, help and encouragement, during, the entire study, without which, this work would have not completed. Their learned advice, guidance constant supervision and have helped us to a great extent to complete work.

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