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Experimental Investigation Of The Integrated Solar Photovoltaic Thermal Collector And Dryer (ISPVTCD) For Drying Of Sea Foods

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Abstract: This research article deals with the design and development of photovoltaic thermal system with solar dryer. This system was carried out diverse analysis on sea foods which was performed three modes of operation such as solar sun drying with forced convection, solar sun drying with natural convection and traditional drying. Various parametric studies also handled in this article such as solar radiation intensity, moisture removal, outlet air temperature from the collector. In general, solar radiation is a prime factor which was provided a sources of generating energy to drive a solar dryer. The Integrated solar photovoltaic thermal collector and dryer (ISPVTCD) has been provided the electrical and thermal energy to run anISPVTCD. The ISPVTCD was tested by 20 kg of sea foods in the drying air temperature in the range of 35^0C – 72^0C. The initial moisture content of the sea foods was 84 % (weight basis) and was reduced to the final moisture content of 16 % (weight basis) in 5 days with clear sunny days in the month of June 2021. The ISPVTCD was operated between 9 hrs to 16 hrs. Finally, comparative study was also handled for better understanding with ISPVTCD, in which solar sun drying with forced convection mode attained better results than other two modes of operations

Keywords: Electrical efficiency, Thermal efficiency, Natural convection, Forced convection, Sea Foods.

1. INTRODUCTION

Weiet al.[1]haveinvestigatedtheperformanceofISPVTCDbyexperimentallyandalsodeveloped a model which compared to experimental study. The thermal performance was attained between 30.9 % to 33.8%. Simotagne et al. [2] created a model for drying of timber in aISPVTCD and also computed the measured outlet temperatures of the solar collector that compared with the earlier one. The new model would be used to design the other ISPVTCDs. Ilhem et al. [3] studied the solar greenhouse dryer for drying of grapes through experimentally and numerically. The performance of the collector found to be from 29.63 % and 19 88.52 %.

Hao et al. [4] presented a dual function solar collector in a hybrid solar drying system and also investigated the operation strategy, drying performance and economic aspects. Further, they had created a drying model and attained better efficiency from 32.5 % to 50.8 %. Ali Heydaria and MehrdadMesgarpour [5] design and fabricated a helical channel solar heater which validated by numerical model. The results were attained to be 65.14 W/m^2K and 55.4 %. Sumit Tiwari and Tiwari. [6] fabricated a greenhouse ISPVTCD integrated with PVT collector for New Delhi climatic conditions. They coined a thermal model in which they analysed various parameters and finally they found various performances.

Chandrasekar et al. [7] analysed the drying behaviour of sultana grapes in the ISPVTCD. They generated electrical energy to drive a dryer and also found the thermal energy for drying commodities. Prashant et al. [8] established a dryer with solar air collector for drying bitter gourd with various modes of operations. They also created a model which were validated by experimental study.Lakshmi et al. [9] executed aISPVTCD with thermal energy storage system for drying the sliced black turmeric. They also developed a model and found the heater efficiency and overall dryer efficiency.
Karthikeyan and Murugavelh [10] fabricated a tunnel dryer for agro products which were validated by mathematical model and analysed first and second law of thermodynamics for drying agro products. Hedayatizadeh et al. [11] analysed the exergy loss on double-pass/glazed v-corrugated plate solar air heater and formulated a thermal model which was validated with the previous literature. Bahrehmand and Ameri [12] described a mathematical model for single and two glass cover solar air collector and further investigated the energy and exergy efficiencies of the solar air collector.Bahrehmand et al. [13] analytically derived energy balance equations for solar air collector and developed a mathematical model for single and two glass cover solar air collector.

Yadav and Kaushal [14] assessed the exergetic efficiency of roughened solar air heater and compared it with smooth flat plate solar air heater. Amori and Abd-AlRaheem[15] analysedfour types of air based PVT hybrid collectors namely model I (double duct, double pass), model II (single duct double pass), model III (double duct, single pass) and model IV (single duct single pass) for Iraq climatic conditions and developed a MATLAB computer program for developed the mathematical model. The obtained results showed that the thermal performance of model IV was found to be18.04%.

Chen et al. [16] presented PVT system with triple junction solar cells and conducted the thermalconversion efficiency analysis through experimentally.Sobhnamayanet al. [17] carried out the exergy analysis on solar PVT water collector and derived theenergybalanceequationsforvariouscomponentsofthecollector.Theexperimentalresultswere validated by simulation program and they obtained a maximum exergy efficiency of about 11.36%. Dubey and Tay[18] tested two different photovoltaic-thermal modules (type A, the PV module is encapsulated with mono-crystalline Si solar cells and integrated with a tube-and-sheet type thermal collector and type B, the PV module is encapsulated with multi-crystalline Si solar cells and integrated with a parallel-plate type thermal collector) under tropical conditions and performed experimental analysis considering two types of flow rates (0.03 kg/s and 0.06 kg/s). The obtained thermal and PV efficiency for Type A and B were 40.7%, 11.8% and 39.4%, 11.5% respectively.

Rajoriaet al. [19] studied two types of enviro-economic analysis (case 1: Two integrated columns each having 18 PVT modules in series were connected in parallel and case 2: Two integrated columns of 18 modules each having 36 PVT tiles in the module was connected in series) of hybrid photovoltaic thermal (PVT) array and conducted the comparative performance on above types that based on annual energy and exergy gain for four climatic conditions (cold weather season, hot weather season, rainy season and monsoon season) of India.Salox et al. [20]described the exergy analysis of PV and PVT systems and also developed an electrical and thermal model.

Agarwal and Tiwari [21] studied the various types of photovoltaic thermal air collector for the climate of Srinagar in India and evaluated the energy and exergy gain of collectors. They concluded that glazed collector obtained better exergy efficiency than unglazed one. Exergycompetenceismoreaccuratethanenergyproficiencyandexergyscrutinycan bedeliberated in the assessment and analogy of the solar thermal systems [22]. Therefore, recently works on energy and exergy analysis of solar PV or PVT system using fin / baffle (or) by creating artificial roughness (or) by providing roughness is gaining muchimportance.

Sabzpooshaniet al. [23] studied the performance of baffled type solar air heater theoretically and analysedthe effect of different geometrical configurations and various mass flow rates. They found that, fins and baffles with low mass flow rate significantly enhances the exergy efficiency.Chabaneet al. [24] presented the performance of single pass solar air heater attached with five fins withtwomassflowratesofair. It wasfoundthatthesolarairheaterefficiencywithfinsfoundtobe 40.02 %, 51.50 % respectively and without fins found to be 34.92 %, 43.94 %, respectively. Mohammadi and Sabzpooshani[25] presented analysis on three types of baffled solar air heater. As cited in the above literature have shown various commodities with different modes of drying process whereas in this article deals with integrated solar photovoltaic thermal collector and dryer (ISPVTCD). This shows a novel method to remove the moisture content from the sea foods. This system can be generated electrical energy which can be used for forced convection form of drying, In other words which can be acted as a self-drive system. Finally, electrical efficiency, thermal efficiency, electrical thermal and overall thermal efficiency can be found better and significantly coincidence of previous literatures.

2. EXPERIMENTAL DETAILS

The photovoltaic thermal system with dryer is a diverse kind of heat exchangers. In general, sun shine falls on the solar panel that transforms solar energy or photo energy or light energy into heat energy. Top surface of solar panel absorbs the incoming solar radiation and convert it into heat energy and electrical energy simultaneously. Then heat energy transfers to a moving fluid that fluid travels from inlet duct to outlet duct of air passage. The experimental set- up is designed and tested at Chennai (13.0827° N, 80.2707° E). Chennai is situated in South India where has a grand potential of receiving solar energy due to its location in the tropical region. The external dimensions of hybrid collector is 1115 mm x 670 mm. The experimental setup of integrated solar photovoltaic thermal collector and dryer (ISPVTCD)is shown in Fig. 1.

This system consists of solar collector, fan, drying chamber and aluminium roof air vent hot fluid air comes from the solar collector which feeds to the drying chamber with the help of small fan. The moisture of Sea foods with in the drying chamber were evaporated with the help of thermalenergy. As a result, moisture were removed from the Sea foods which makes into dry Sea foods subsequently. In this research work, moisture content, temperature of the Sea foods , pressure of the drying chamber, air velocity and other related energy measurements were utilized for testing the complete setup. Relative humidity and temperature of Sea foods in the drying chamber were monitored with the help of various sensors which were mounted at the selected location of the drying chamber. Solar panel were wedded with air channel medium which was tilted 13^0.

Fig. 1. Photographic view of the experimental detail.

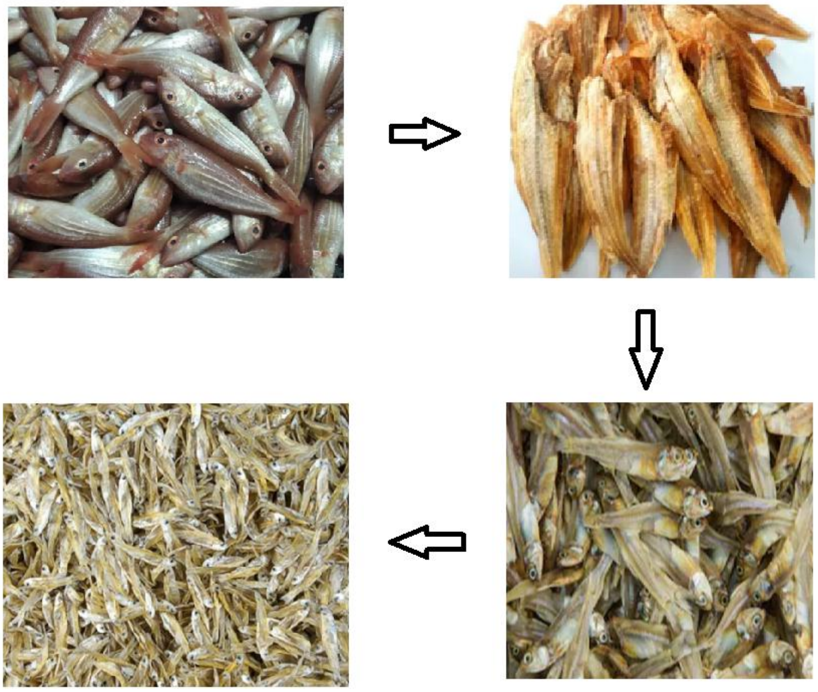

Fig. 2. Drying kinetics of sea foods at various stages**.**

The inclination of solar collector is designed in a way to extract more absorbed energy from the incident solar intensity. Experimental readings were taken between 9 am to 4 pm with a regular interval of 30 minutes for all the test days as a result sea foods were dried as shown on the figure 2.

Table. 1 Operating parameters & system parameters

Parameters	**Value**
Air velocity at the entry of the channel (v)	1.2 & 1.8 m/s
Ambient temperature (T_a)	307 - 316 K
Area of the panel, A	0.7471 m^2
Fan power	18 Watts
Height of the drying chamber	1.050 m
Length of the drying chamber	0.700 m
Length of the panel	1.115 m
Open circuit voltage of solar panel, *Voc*	18.98 V
Short circuit current of solar panel, *Isc*	5.26 A
Slope of the solar panel surface	13^{o}
solar radiation (G)	400-1100 W/m^2
Thickness of the panel	0.035 m
Width of the drying chamber	0.690 m
Width of the panel	0.670 m

3. METHODOLOGY

3.1 Electrical Efficiency Performance

Electrical efficiency performance of a PV panel could be determined as a ratio of electrical energy output of the PV panel to the solar energy (or) light energy falls on the solar panel which is carried out as given below [26 - 31] .

$$\eta_{el} = \frac{V_{mp} I_{mp}}{\dot{S}} = \frac{\dot{E}_{el}}{\dot{S}} \tag{1}$$

Where, $\dot{E}_{el}$is an outlet electrical power (W), $\dot{S}$ is a rate of solar energy falls on the solar panel (W).

$$\dot{S} = G\, A_{\mathrm{mod}} \tag{2}$$

Where, G = solar radiation, W/m^2, A_{mod} = PV module area, m^2.
A_{mod} = PV module area, m^2.

$$A_{\mathrm{mod}} = L_1 L_2 \tag{3}$$

Where, L_1 = length of PV module, m, L_2 = width of PV module, m,

3.2 Thermal Efficiency Performance

Thermal efficiency performance has been conducted with various parameters such as heat energy generation (KJ), area of the panel (m^2) and solar radiation intensity (W/m^2). The following equations were compiled the finding of thermal performance of solar hybrid collector as given below.The equation of mass flow rate of air (Kg/s) is expressed by

$$\dot{m} = \rho A_{mod} v \tag{4}$$

Where, $\dot{m}$ = mass flow rate of air, kg/s, ρ = density, kg/m^3,A_{mod} = PV module area, m^2,

V = velocity of air, m/s.

$$Q_u = \dot{m} Cp (T_{out} - T_{in}) \tag{5}$$

Where, Cp is a specific heat capacity of air (KJ/Kg K) and Tin and Tout shows input and output fluid air temperatures in the solar hybrid collector, respectively. Further, thermal energy were generated by forced convection through mini fan as follows.

$$\eta_{ther} = \frac{Q_u}{(A_{\text{mod}} G + P_{fan})} \tag{6}$$

Where, P_{fan}, (W) is the fan power using to generate thermal energy or heat energy in the solar hybrid collector which can be used to dry the commodities in the ISPVTCD.

$$\eta_{el,ther} = \frac{\eta_{el}}{C_f} \tag{7}$$

$$\eta_{en,overall} = \eta_{ther} + \frac{\eta_{el}}{C_f} \tag{8}$$

$$\eta_{en,overall} = \eta_{ther} + \eta_{el,ther} \tag{9}$$

Where, $\eta_{el,\ ther}$, electrical thermal efficiency, $\eta_{el,}$ electrical efficiency, $\eta_{en,\ overall}$, overall energy efficiency, η_{ther}, thermal efficiency and C_f is the conversion factor of the thermal power plant and its value may be taken as 0.36 for countries such as India.

3.3 Energy Balance and moisture content of the commodity

The mass and energy balances of any open system or control volume at a steady state conditions could be calculated as given below [32 & 33].

$$\dot{m}_{ai} = \dot{m}_{ao} \tag{10}$$

Where, $\dot{m}_{ai}$ and $\dot{m}_{ao}$ represent the inlet and outlet mass flow rates of the solar hybrid collector with dryer respectively.

The mass conservation for the moisture content of the commodity could be taken in terms of mass flow of the moisture from the sea level, and $\dot{m}_{mp,}$ and the inlet and outlet flow of specific humidities, ω_{ai} and $\omega_{ao,}$ respectively, as follows,

$$\dot{m}_{ai}\, \omega_{ai} + \dot{m}_{mp} = \dot{m}_{ao}\, \omega_{ao} \tag{11}$$

The initial and final stage of moisture level of the particular commodity with respect to time t which were designed with the assistance of following equations as follows.

$$M_o = \frac{m_i - m_d}{m_i} \tag{12}$$

$$M_f = \frac{m_s - m_d}{m_s} \tag{13}$$

$$M_t = \frac{m_t - m_d}{m_t} \tag{14}$$

Where, mi, Initial mass of the commodity (kg), md, Mass of dry matter in the dryer (Kg), ms, Mass of the dried sea foods (Kg), mt, Mass of the sample at time t (kg).

4. RESULTS & DISCUSSIONS

4.1. Solar radiation and ambienttemperature

ISPVTCD has been performed various analysis on sea foods. The performance tests were conducted on days with clear sky condition. In this study, various analysis were carried out such as electrical, thermal, electrical thermal, overall thermal efficiency of hybrid collector cum ISPVTCD. Further, removal of moisture from the Sea foods by ISPVTCD drying which were compared with traditional drying.

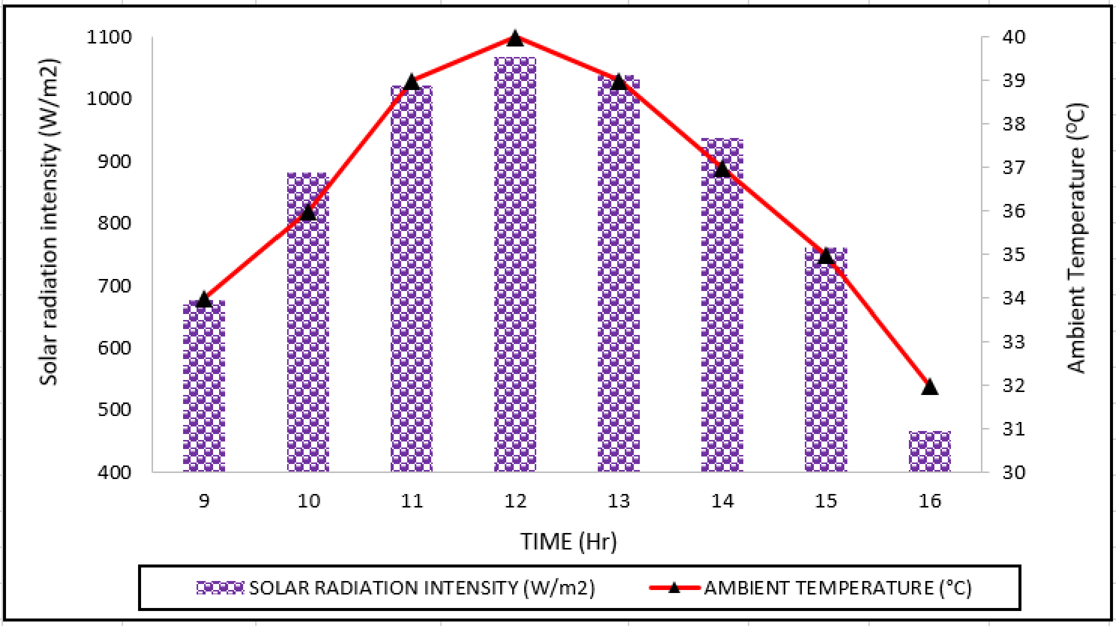

Fig. 3. Average solar radiation and ambient temperature with time (hrs).

Typical hourly values of average solar radiation and ambient temperature since 9 hrto 16 hr is revealed in Figure 3. The maximum solar radiation was found to be 1067 W/m^{2}at 12 hr and minimum solar radiation was found to be 468 W/m^2 at 16 hrs. Similarly, the maximum ambient temperature was found to be 40 °C at 12 hrs and minimum ambient temperature was found to be 32 °C at 16 hrs respectively. Solar radiation is always higher at midday and low in the morning and evening hours. On all test days, solar radiation range was from 468 W/m^{2}to 1067W/m^2.Evidently,thesolarradiationandambienttemperaturefrom9hrto16hrseemstobe existing a dome-shaped structure as shown in Fig 5.1.

4.2 Electrical efficiency with glazing surfacetemperature

Typical hourly values of electrical efficiency and glazing surface temperature of since 9 hr to 16 hr is shown in Figure 4. The parameters such as maximum power point voltage (V_{mp}), maximum power point current (I_{mp}), solar radiation (G) and area of the solar panel (A_{mod}) were assessed during electrical energy (η_{ELE}) analysis. Evidently, from 9 hr to 12 hr there was increase in glazing temperature and decreased electrical efficiency then vice versa till 16 hr. It was observed that when glazing surface temperature was maximum, electrical efficiency was minimum between 11 hr to 13 hr. Due to high glazing surface temperature, the electrical performance was very lower.

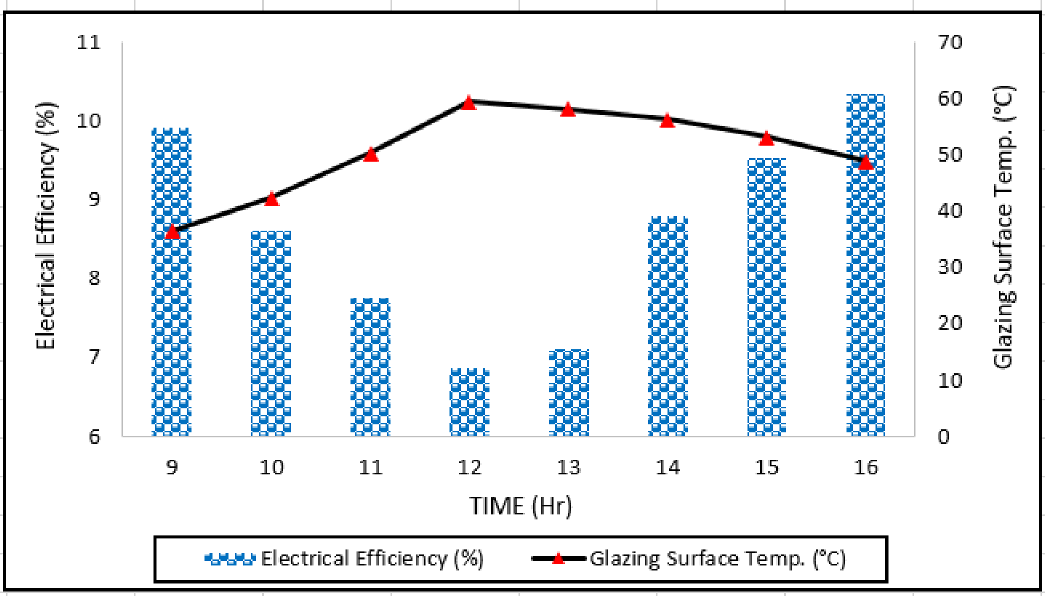

Fig. 4. Electrical efficiency and glazing surface temperature.

4.3 Thermal efficiency with outlet airtemperature

Typical hourly values of Thermal efficiency and Outlet air temperature of system is exposed in Figure 5. Thermal efficiency (η_{ther}) was determined based on the measured parameters such as difference in outlet and inlet air temperature (ΔT), mass flow rate of air ($\dot{m}$), specific heat of air (C_p), area of the solar panel (A_{mod}) and solar radiation (G). The thermal performance increased with increase in air mass flow rate and solar radiation. Extracted more heat energy from the tedlar side which generated better performance of the system. The hourly variations of thermal efficiency Vs outlet air temperature of was calculated by using Eqs. 4 to 6. Evidently, outlet air temperature was maximum between 12 hrs to 14 hrs, due to maximum solar radiation available during thosehours.

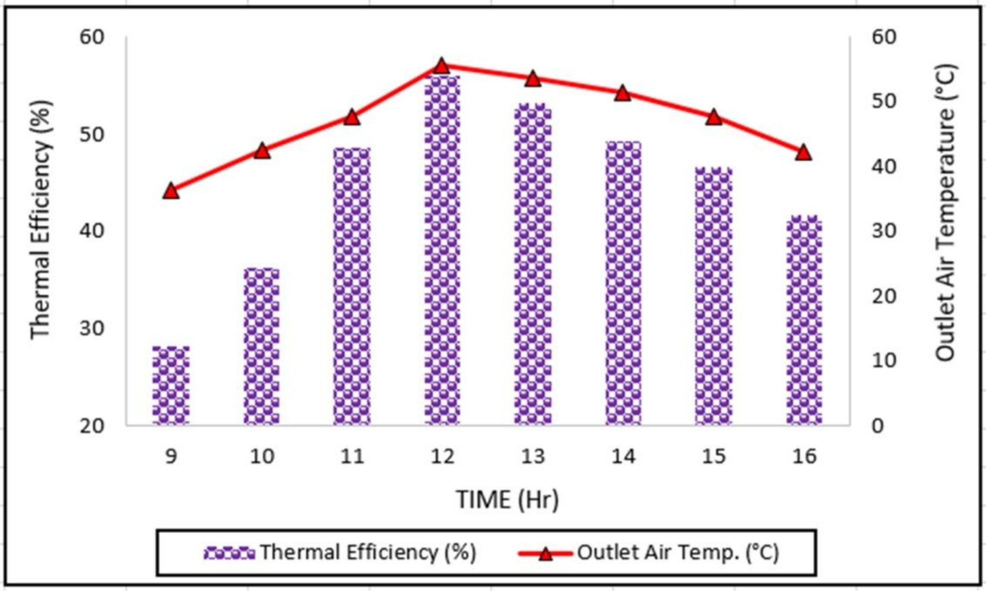

Fig. 5. Thermal efficiency and Outlet air temperature of the system.

4.4Electrical thermal efficiency with glazing surface temperature.

Typical hourly values of electrical thermal efficiency and glazing surface temperature of system is shown in Figure 6. The equation 7 can be assisted to find out the electrical and electrical thermal efficiency of system. This can be produced replication of electrical efficiency of system which has been compared with glazing surface temperature. Evidently, when glazing surface temperature has been increased from 9 am to 4 pm, electrical thermal efficiency has been decreased as shown in Figure 6.

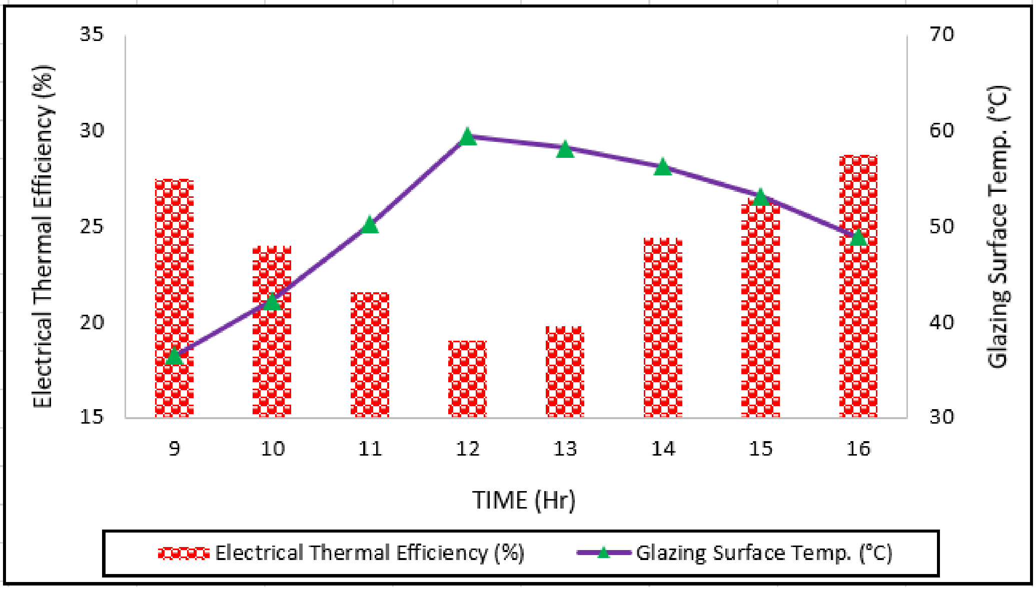

Fig.6. Electrical thermal efficiency and glazing surface temperature of system.

4.5 Overall thermal efficiency with ambienttemperature.

Typical hourly values of overall thermal efficiency of the system is revealed in Figure 8 and 9. Overall performance of ISPVTCDcan be performed by equation 13 & 14. In which all the performances such as electrical, electrical thermal, thermal efficiency were integrated.

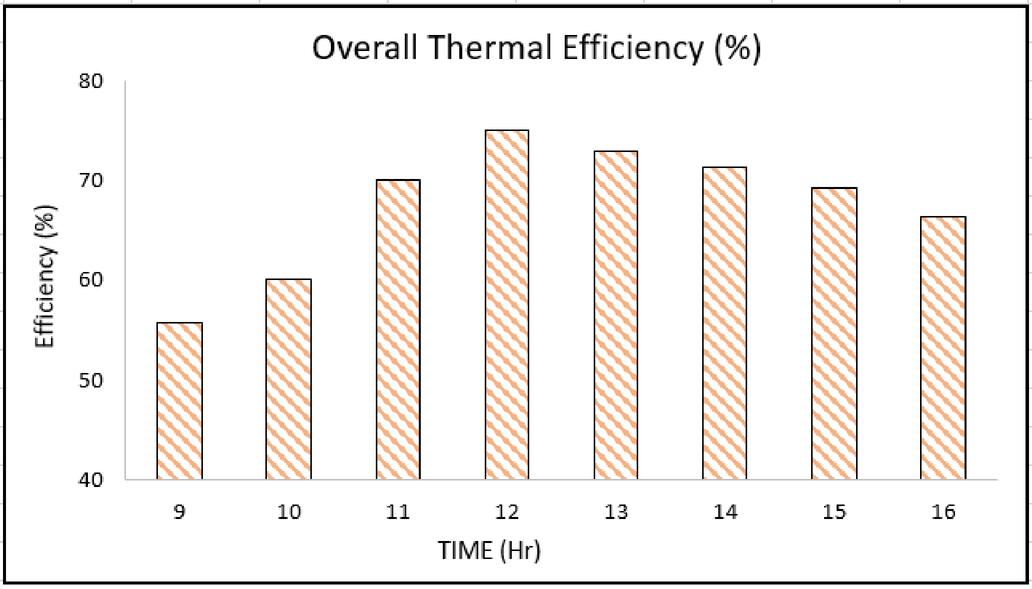

Fig. 7. Overall thermal efficiency of system.

Fig. 8. Shows the change in the moisture content of the solar and traditional dried Sea foods samples. The moisture content of the Sea foods was condensed from the initial value of 84 % (weight basis) to the final value of 16 % (weight basis) in 42 hours in the ISPVTCD drying and the traditional drying, respectively.

4.6 Moisture content removal of the sea foods with variousmodes

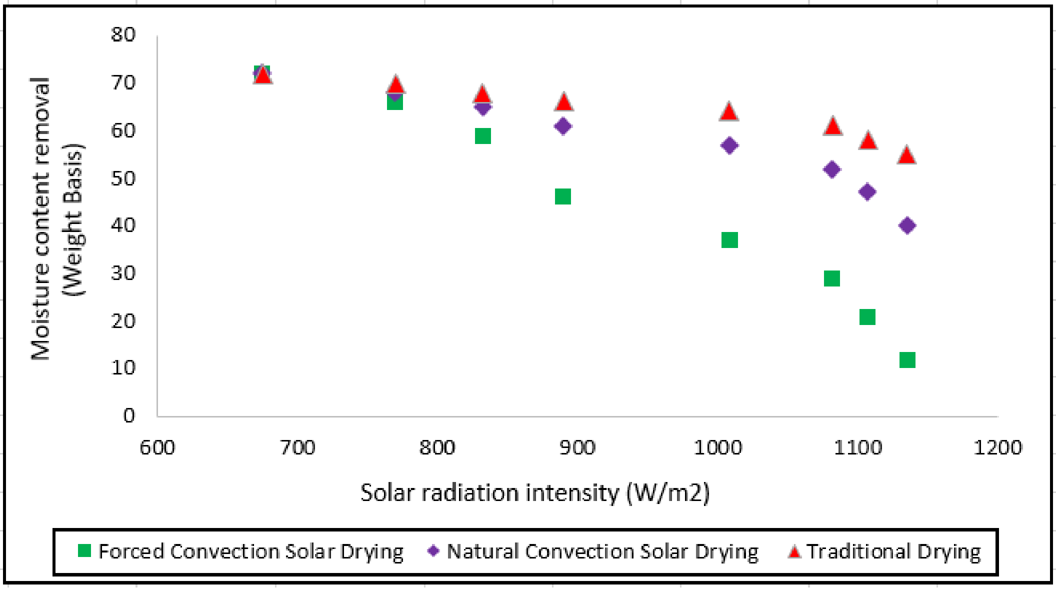

Fig.8. Average Change in the moisture content of the ISPVTCD drying and traditional drying.

The sun drying sample took 116.53% longer drying time in comparison with the sample dried in the newly developed. Further, the solar dried Sea foods was free from dirt and clean nature. Photovoltaic thermal system with dryer was performed various analysis on Sea foods. The performance tests were conducted on days with clear sky condition. In this study, various analysis were carried out such as electrical and thermal efficiency of. In addition to that, removal of moisture from the Sea foods by conventional form of drying which were compared with solar drying in natural and forced convection mode of operation.

5. CONCLUSION

- Three kinds of operation have been done this analysis such as traditional drying, natural convection mode of drying and forced convection mode ofdrying
- Traditional drying is old method which has long time to take drying process which can be damaged andalso polluted.
- Natural convection is better than traditional drying whereas slow process, further forced convection mode will be significantly better than other twoprocess.
- Electrical and thermal efficiency were achieved by system such as 12.63 %, 48.23 %, respectively.
- Moisture removal from the sea foods during the process of forced convection which can be significantly better in the range of 84 % to 16 %.

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