PERFORMANCE EVALUATION OF A SOLAR TUNNEL DRYER FOR CHILLI DRYING*

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Abstract

A multi-product solar tunnel dryer was fabricated based on the Hohenheim dryer design, but suitably modified to satisfy the drying requirements of small farmers and co-operatives. The collector-dryer system has been equipped with instrumentation to evaluate the performance. No-load tests on the dryer, with alternate current (AC) driven fans and solar photovoltaic (PV) based direct current (DC) driven fans have been conducted. The performance of the dryer during drying of chilli has also been analysed for the two configurations. The results, shown by plotting the variation of air temperature, moisture content etc. indicate that the dryer performs better with DC/PV driven fans, as they considerably reduce the fluctuations in the drying air temperature with fluctuating solar radiation.

Introduction

Natural convection type solar dryers considerably reduce drying time compared to open air sun drying, but their relatively small holding capacity is a major limitation, thereby making corresponding investment questionable (**Gnanaranjan, 1997**). Further, in many cases, the moisture removal rate is inadequate and the required rate of moisture removal could only be achieved with forced ventilation using a fan (**Lutz et al, 1987**).

A successful new solar tunnel drier was designed and developed at the University of Hohenheim, Germany, to meet the drying requirements of small farmers and smaller co-operatives (**Esper et al., 1994**). The new design realises the demand for higher drying capacity and better moisture removal. Instead of forcing the air through a depth of crop, it is just directed over the crop spread in a thin layer (**Universitat Hohenheim, 1996**). Products that can be dried efficiently include banana, apricot, grapes, chilli, coffee, ginger, pepper, and paddy, among others. The loading capacity of the dryer ranges between 1.5 kg/m^2 for medicinal plants and 25 kg/m^2 for grapes (**Esper et al., 1994**). This dryer is already in commercial production and is in operation in more than 25 countries world-wide. This new dryer design eliminated the dependence on grid electricity since the power consumption of the fan could be supplied by batteries or solar PV panels.

Another solar tunnel dryer, adapting the Hohenheim design and scaled down to fit the local conditions and requirements, has been constructed at the Asian Institute of Technology (AIT), Bangkok (**AIT Solar Tunnel Dryer, 1997**). This article presents the design of the

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AIT dryer and its performance during drying of chilli. Observations and analysis of experiments at no-load and at load conditions using AC and DC/PV driven fans are described in detail.

Design of the Tunnel Drier

The standard solar tunnel dryer of the University of Hohenheim, is 18 meter long and 2 meter wide, with a collector area of 16m^2 and a drying area of 20m^2. However, taking into consideration the land-holding capacities of marginalized rural farmers in the countries of the ASEAN region, a reduced size of the solar tunnel dryer was designed to make it more suitable for drying small quantities of agricultural products.

The AIT solar tunnel drier consists of a solar collector, drying tunnel, and five radial flow fans to drive the moist air out of the drier (figure 1). The product to be dried is placed as a single layer inside the drying tunnel. Air entering the solar collector is heated and is forced on the products placed in the drying tunnel using five fans at the air inlet of the solar collector. The fans, with a rating of 14W, have an air handling capacity of 130m^3/hour each. For experiments with DC power, three solar PV panels could be used. Glass wool insulation provided at the back side of the collector and drying chamber minimises heat losses.

For hygienic and ergonomic reasons, the drier stands on a 75 cm high brick plinth. Both the collector and tunnel are covered with a 0.2 mm thick, UV-stabilised polythene sheet. The collector is painted matt black to act as an absorber. Products to be dried are placed in perforated aluminium trays and loaded inside the drier. Easy loading and unloading of the materials is facilitated by rolling one side of the plastic cover up or down using a hand-operated pipe and crank arrangement.

The dimensions and other design parameters of the Hohenheim dryer and the AIT dryer are presented in table 1.

Table 1: Comparison of design parameters: Hohenheim dryer and AIT dryer

Parameter	Unit	Hohenheim Dryer*	AIT Dryer
Collector length	m	8.00	4.00
Dryer length	m	10.00	4.30
Total length	m	18.00	8.30
Width (Dryer/Collector)	m	2.00	1.80
Collector Area	m^2	16.00	7.20
Drying Area	m^2	20.00	7.74
Air Flow	m^3/min	400-1200	130-650
Air Temperature	°C	30-80	30-70
Power Requirement	W	20-40	14-70

*Universitat Hohenheim, 1996

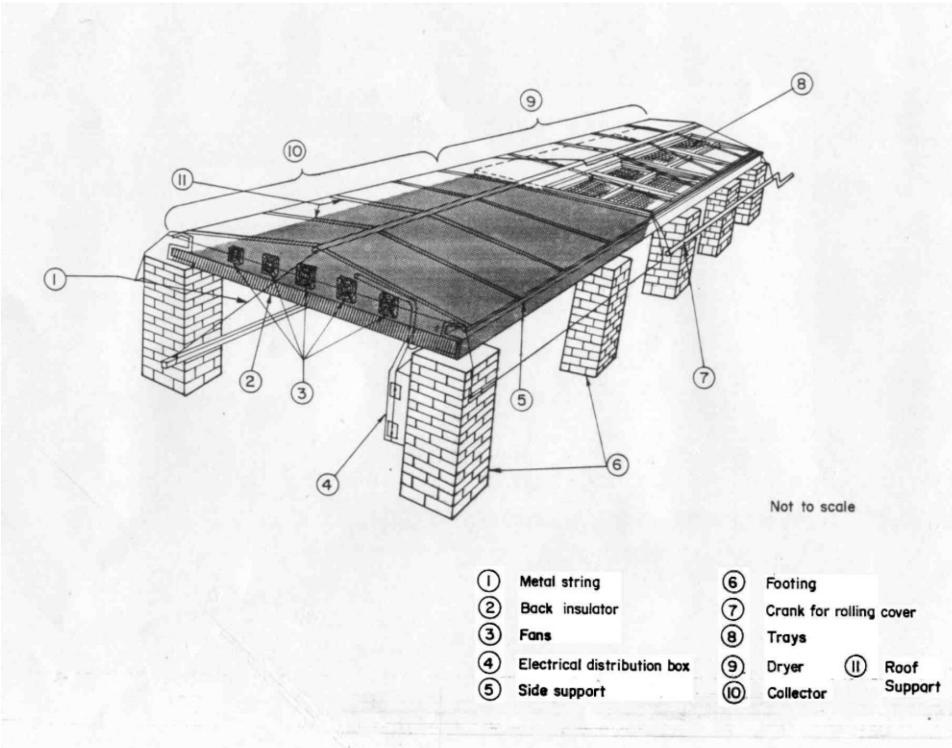
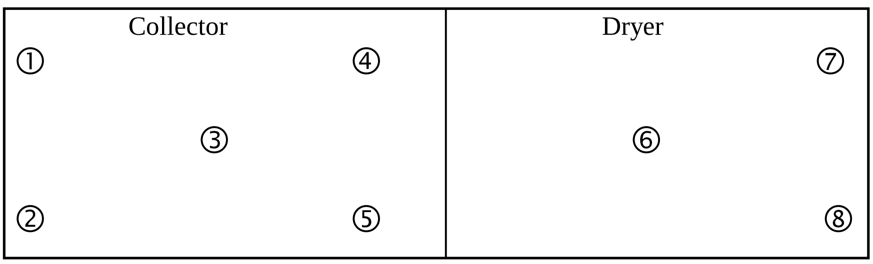


Figure 1: The AIT Solar Tunnel Dryer

Experimental set-up

The performance of the drier was evaluated by conducting tests at no-load and by loading with chilli, by measuring the following parameters: (a) radiation incident on the collector/dryer, (b) air temperatures at various locations in the collector and dryer, and (c) air velocity.

To measure the temperature of air at various locations of the collector and dryer, K-type thermocouples were installed at various points along the length and breadth of the solar tunnel dryer , as shown in figure 2. All temperature data were registered at an interval of five minutes by a data logger. Drying test was started at 8:00 hours and stopped at 17:00 hours.



T_1 - Dry bulb temperature at collector inlet, °C
T_2 - Wet bulb temperature at collector inlet, °C
T_3 - Dry bulb temperature at the middle of the collector, °C
T_4 - Dry bulb temperature at collector outlet/dryer inlet, °C
T_5 - Wet bulb temperature at collector outlet/dryer inlet, °C
T_6 - Dry bulb temperature at the middle of the dryer, °C
T_7 - Dry bulb temperature at dryer outlet, °C
T_8 - Wet bulb temperature at dryer outlet, °C

Figure 2: Position of thermocouples in the solar tunnel dryer

The daily drying rate was estimated by measuring the weight loss of the product after each day of drying. The sun dried control samples were weighed for comparison. The initial and final moisture contents of the product before and after each day of drying were ascertained by the oven method. The relative humidity of air inside the dryer was determined from the dry bulb and wet bulb temperatures recorded by a data logger. The solar radiation data and other meteorological data were obtained from AIT Energy Park Meteorological Station.

Performance analysis

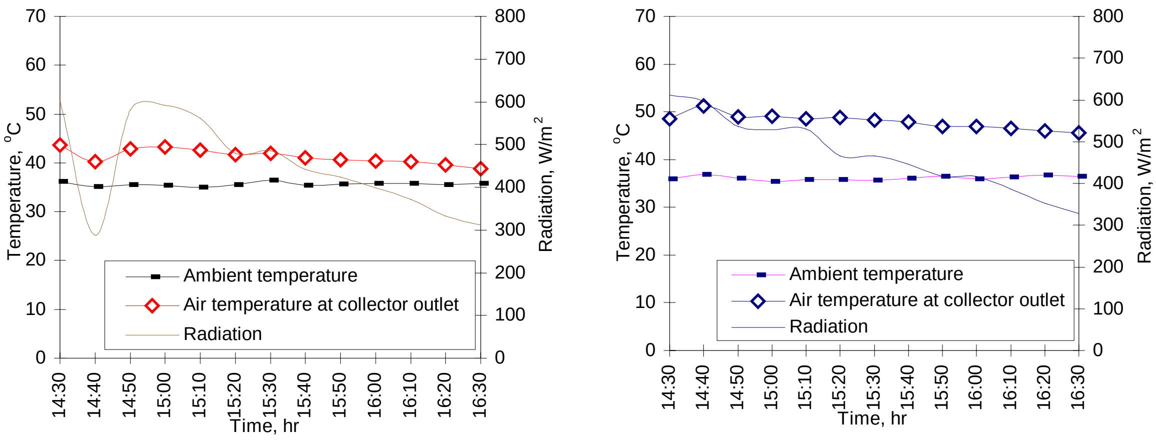
The performance of a dryer, or drying efficiency, depends on the duration of drying and the quality of the end product, besides factors such as collector performance and drying temperature. A detailed analysis of the performance of this dryer is being done (**Mastekbayeva, 1998**) and this article describes the results of tests conducted by drying chilli.

From experimental results of different combinations of panels and fans, one solar panel with three fans for solar PV operation, was found to give the highest air temperature rise through the collector/dryer under no-load condition. Hence, this particular combination has been used for experiments with DC/PV operation of the fans, for both the load as well as no-load condition. For the sake of consistency in comparison, only three fans were used for AC operation also.

(i) No-load test:

No-load tests were conducted with both AC and DC/Photovoltaic operation of the fans. During AC operation of fans, the air flow rate is steady irrespective of the drying temperature in the dryer. Hence, with fluctuations in solar radiation levels, the temperature also fluctuates. This may be seen in figure 3, where the drying temperature curve traces the radiation pattern fairly closely. Solar PV operated fans, however, minimise this fluctuation as the air flow rate is directly related to the radiation levels. At low levels of solar radiation, the flow rate is automatically reduced due to the reduced electrical power output of the solar panels, and vice versa. The lower the flow rate, the higher is the outlet temperature, and hence the air temperature inside the dryer is maintained almost steady. Figure 3 explains the phenomenon in more detail.

Air flow rate is an important factor influencing the performance of any dryer. For DC/PV operated fans in the tunnel dryer, the air flow rate has a direct relation with the solar radiation for the panel-fan configuration used in this system. Figure 4 shows that the air flow rate has an almost linear dependence on solar radiation.



(i) AC operated fans (ii) DC/PV operated fans

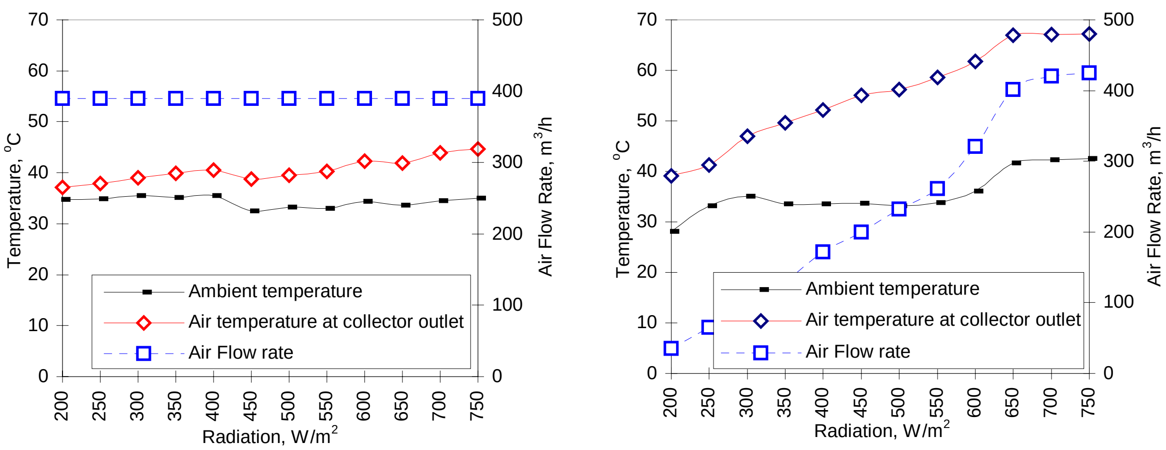
Figure 3: Effect of solar radiation on collector outlet air temperature

From a number of experiments conducted, and noting the primary dependence of air flow rate as a function of global solar radiation, the following equation describes the relation between the air flow rate F (m^3/hr) and global solar radiation R (W/m^2), for the AIT tunnel dryer:

$$F = -0.0213[(R-50)/50]^4 + 0.4507[(R-50)/50]^3 - 0.8223[(R-50)/50]^2 + 12.217[(R-50)/50] + 8.6066$$

$$\text{for } 100<R<800$$

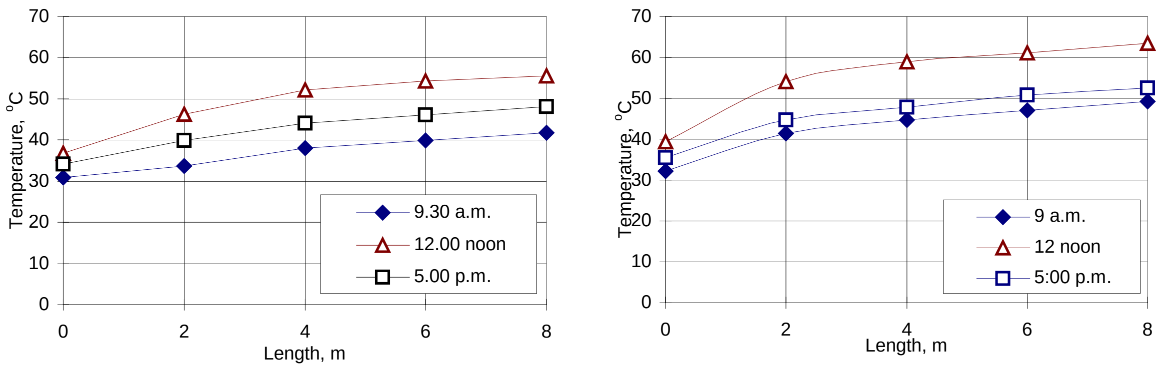
The steady air flow rate, irrespective of radiation levels, and a resultant fluctuation in drying temperature is shown in figure 4, for AC operated fans. The varying air flow rate according to the solar radiation levels and the consequent almost steady air temperature in the dryer during PV operated fans may be compared with AC operation in the same figure.



(i) AC operated fans (ii) DC/PV operated fans

Figure 4: Drying temperature and air flow rate, as a function of solar radiation

The temperature profile along the length of the collector/dryer has been shown in figure 5, for dryer operation with AC and DC/PV operated fans. At no-load condition, the drying air temperature increases steadily, from the inlet of the collector upto the outlet of the drying chamber, as the collector and dryer unit together, act as solar radiation absorber.



(i) AC operated fans

(ii) DC/PV operated fans

Figure 5: Temperature profile along the length of collector/dryer

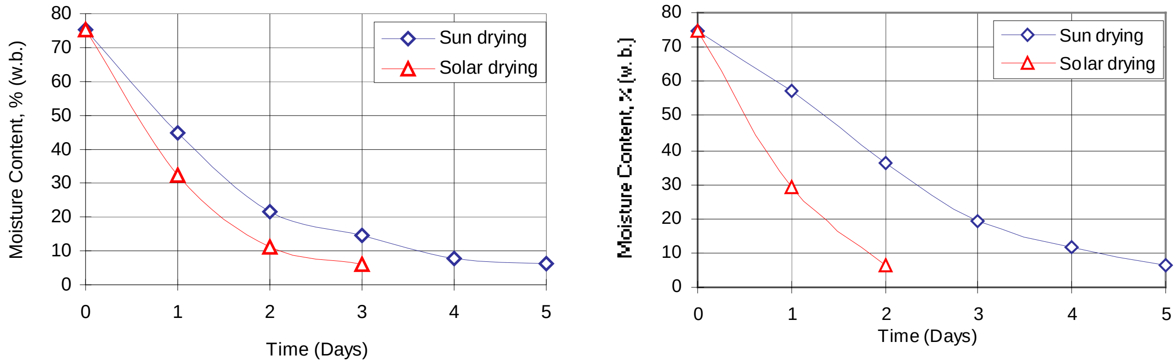
With AC driven fans, during periods of low solar radiation, the temperature inside the dryer is reduced considerably. However, with DC driven fans, the reduction in temperature was found to be not significant, since the air flow rate adjusts proportionally according to the incident solar radiation.

(ii) Load test: Chilli

Chilli is an important agricultural product in South East Asia, and is popular in fresh form as well as dried and powdered form. It plays a vital role in the traditional food habits of the region and imparts a sharp hot taste to food. Chillies are dried as whole vegetables and do not need any pre-treatment. This is done by spreading it in open sun during the day.

The experiment on drying chilli was conducted in the AIT solar tunnel dryer to evaluate the performance of the dryer under loaded conditions. The dryer was loaded at 8:30 a.m, with 19.5kg of chillies as ripe fruits, by spreading the chillies inside in a single layer. At the end of each day, chillies were collected and stored in a plastic bag. Drying was continued the next day, by spreading the chillies once again, in the dryer. The process was continued until the required moisture content was achieved. Control samples were dried simultaneously, in open sun, under the same weather conditions, for comparison. The moisture content of chilly before and after drying for each day was also determined, by taking a sample for analysis.

Experiments were conducted separately, with AC driven and DC driven fans, for drying the same quantity of chilli at almost similar weather conditions and the respective drying curves are shown in figure 6.



(i) AC operated fans (ii) DC/PV operated fans

Figure 6: Drying Curves for open air sun dried and solar dried chilli

Figure 7: Chilli-drying in AIT solar tunnel dryer

The drying time was reduced by one third with PV operated fans, for the same level of final moisture content, and without effecting any considerable change in the quality of the dried product.

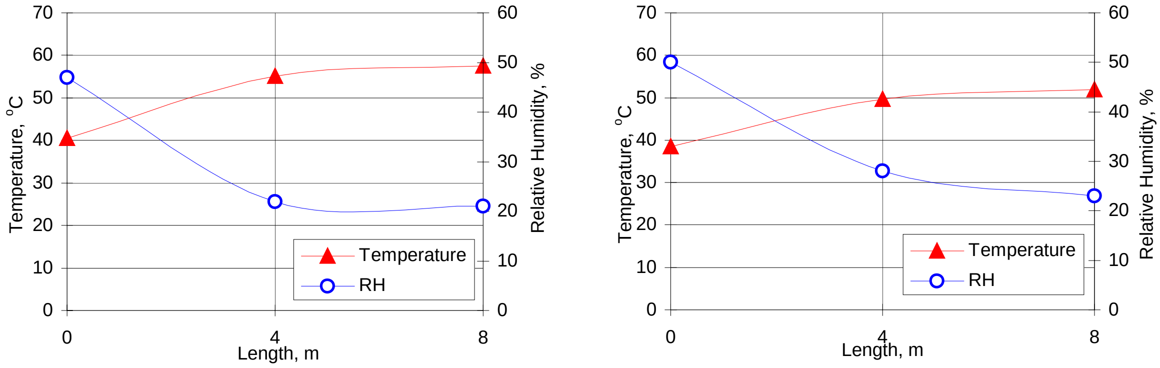
The efficiency of the dryer for DC/PV operation was estimated at 14.20% against 9.32% for AC operation. The low efficiency values are attributed to the low level of load (19.5kg of raw chilli) in the dryer. The full load capacity of the AIT dryer is about 85kg of raw chilly per batch.

Temperature/humidity profiles in the collector and dryer units:

The humidity of drying air is a critical factor controlling the drying rate of the product. The lower the relative humidity, the greater is the absorbing capacity of drying air. An ideal drying process would ensure 100% relative humidity in the air leaving the dryer, but considerably less relative humidity at the inlet of the drying chamber. A comparison of the temperature and humidity profiles along the length of the collector/dryer is presented in figure 8, for both the AC and DC/PV operation of fans.

It is interesting to note that the temperature profile over the length of the drying chamber is not significantly influenced by the moisture content of the product. The drying air temperature increases steadily across the drying chamber, showing that the additional thermal energy absorption directly by the product compensated for the evaporative heat loss from the drying air.

The relative humidity of air at the outlet of the dryer shows that the air still has a considerable drying potential, implying that the rated capacity of the dryer has not been fully utilised. Further studies on improving the performance are being considered.



(i) AC operated fans

(ii) DC/PV operated fans

Figure 8: Temperature and humidity profiles along the length of the dryer

Cost analysis

A cost analysis based on the local market conditions was made to estimate the value addition to the product, by the tunnel dryer (**Schirmer et al., 1995**). While the raw chilli fruit cost Baht 16/kg, the solar dried chilli cost Baht 85/kg. Considering that solar drying using AIT tunnel dryer requires a drying period of two days, about 12.75 tons of chilli could be dried in a year with AIT dryer with its full-load capacity of 85kg of fresh chilli/batch. This corresponds to a net value addition of Baht 129,460 per annum, with an assumption that drying could be carried out for 300 days in a year, typical for the tropical climate of the region. Considering this savings, the cost of AIT tunnel dryer is paid back in approximately 2 years, after sufficiently allowing for the operating and maintenance expenses.

The above calculation has been made for a single product - chilli. However, by using the dryer with multi-products, i.e., to dry various different products of better value addition, the pay-back period can be reduced considerably.

Conclusion

The no-load tests clearly indicate that the drying temperature fluctuations could be minimised to a considerable extent by using DC/PV operated fans instead of AC operated fans. The drying time could be reduced by one third for chilli, with PV operated fans, for the same level of final moisture content, and without effecting any considerable change in the quality of the dried product.

Furthermore, the air leaving the dryer was found to have still greater potential for drying more chillies. However, this should also be considered for other products, as this dryer is designed for multi-products use.

The economics of the dryer reveal a pay-back period of approximately two years for this solar tunnel dryer, after considering its value addition capacity for chilli. The pay-back period can be reduced considerably if the dryer is used for multi-products.

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