Thermal performance evaluation of a greenhouse solar dryer equipped with photovoltaic cells and phase change material

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ABSTRACT

The purpose of the present study is to investigate the performance evaluation of a greenhouse solar dryer equipped with photovoltaic cells and phase change material. The governing equations of problem is obtained by writing the energy balance for the various components of the system including photovoltaic module, greenhouse chamber air, crop, absorber plate and phase change material. In order to calculate the thermal and electrical parameters of the system including photovoltaic cells temperature, the temperature of greenhouse chamber air, crop temperature, phase change material temperature, absorber plate temperature and electrical power, the governing equations on the system performance are solved by numerical methods. Also, a relation for the overall energy efficiency of the system is introduced. The modeling results of the present study is in good agreement with the experimental data of the previous literature. The results obtained for the typical day of Zahedan show that the phase change material by storing the system loss heat during the day and releasing it at night enables the crop drying process to continue well into the night, so that the overall evaporation rate increases by about 38.76%. The maximum energy efficiency of the system is about 15%.

KEYWORDS

Greenhouse solar dryer, photovoltaic cell, phase change material, energy efficiency.

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1. Introduction

Solar drying is considered an old preservation method of agricultural products [1]. It benefits from free source of energy while the final product has high quality. Various designs of solar dryers are introduced among which, greenhouse solar dryers are favored due to their simple design and low cost of fabrication [2]. Berroug et al. [3] studied a greenhouse solar dryer in which north wall was loaded by phase change material (PCM). They reported that the given dryer had less thermal and relative humidity fluctuations during winter. Tiwari e al. [4, 5] also claimed that the greenhouse solar dryer is a promising candidate for drying different agricultural products with short payback period of investment

In the current study, a solar greenhouse dryer equipped with phase change material and a photovoltaic module (PV) is introduced. Hence, the PV meets the electrical need of ventilating fans and the PCM availability helps the drying to maintain through the night.

2. Geometry description and energy efficiency

The greenhouse solar dryer mainly comprises a PV module, DC fans, the greenhouse drying chamber and PCM (Fig. 1).

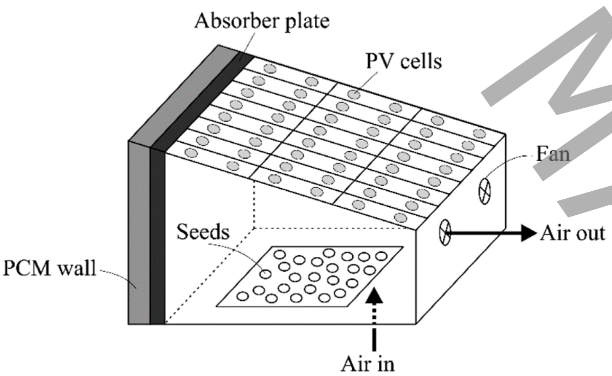

Fig. 1 Schematic diagram of the investigated greenhouse dryer in the present research

The PV module generates electricity to run DC fans during sun radiation (generating forced mode of air flow inside the enclosure). Moreover, its position upon the greenhouse dryer, hinders the direct exposure of product to sun radiation. To find the energy efficiency of the given dryer, it is required to thermally model the whole system for two different modes: charging and discharging of PCM i.e. daytime and nighttime, respectively. So, to perform the given analysis, it is essential to write the energy balance equation for each above-mentioned component for the two distinct conditions of PCM.

2.1 Charging mode energy efficiency

The energy efficiency of the system for the daytime was achieved as followings:

$$\eta_{en,day} = \frac{\left(\frac{I_t A_m \eta_{el} - p_{fan}}{0.38}\right) + h_{ew} A_{cr} \left(T_{cr} - T_r\right)}{A_m I\left(t\right) + \sum A_i I(i)} \tag{1}$$

while 0.38 in denominator is to turn the electrical energy into its thermal equivalent [6].

2.1 Discharging mode energy efficiency

The discharging mode-related efficiency is also given by:

$$\eta_{en,night} = \frac{h_{ew} A_{cr} \left(T_{cr} - T_r\right)}{M_{pcm} C_{pcm} \frac{dT_{pcm}}{dt}} \tag{2}$$

3. Validation

To examine the accuracy and the precision of the performed analysis, the theoretical results were validated against experimental ones reported by Tiwari et al. [4]. The greenhouse solar dryer of Tiwari et al. [4] did not have any PCM, so the daytime theoretical results were only compared with those of it.

Fig. 2 graphically compares the theoretical results (denoted by sim) with those of experiment (denoted by exp) for temperatures of PV cells, product, air inside the greenhouse and ambient.

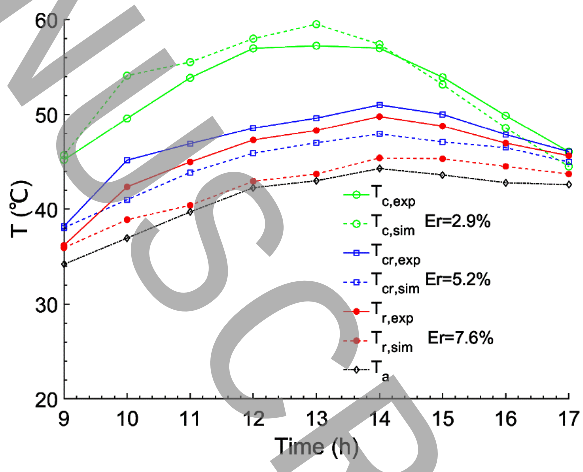

Fig. 2 Experimental and simulated temperature values of different components of the greenhouse dryer

Moreover, the mass of evaporation in case of theory and experiment are also shown in Fig. 3. As seen, the maximum average relative error is below 8 percent which shows the good agreement of theoretical results with those of experiment.

4. Results and discussion

The effects of operating and design parameters on energy efficiency and amount of evaporation/removal of moisture from product are investigated. Hence, the solar radiation and ambient temperature of a typical day (6 July) experienced in Zahedan is chosen as climatic reference.

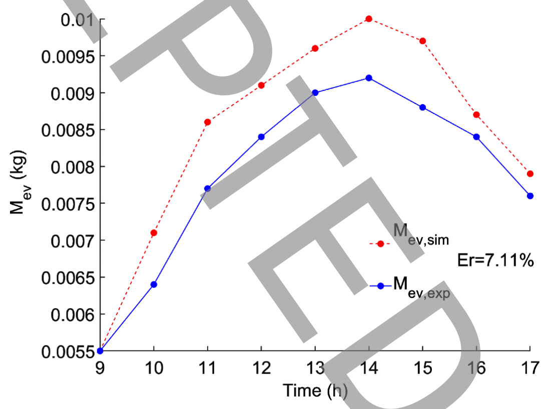

Fig. 3 Experimental and simulated values of evaporation mass against time of testing

Based on Fig. 4, the PCM stays in charging mode for 7 hours (above 54°C) which is highly favorable and shows the drying potential of dryer during the off-sunshine.

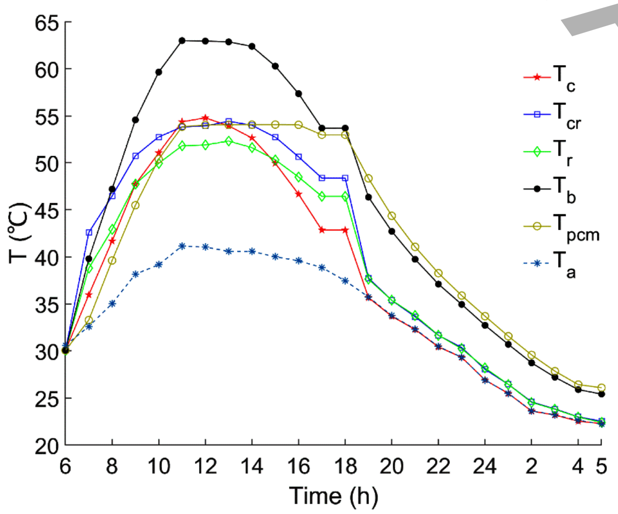

Fig. 4 Diagram of simulated temperatures of different components of the greenhouse solar dryer

Moreover, it is observed that only during 4 hours of the day, the temperature of PV module is above that of air inside the dryer. So, for cooling PV and heating the air inside the dryer, stream of air entering the enclosure can be guided beneath the PV module.

Finally, in Fig. 5, the effect of application of PCM and lack of it on mass of moisture evaporated is depicted. It is seen that application of PCM is only significant during nighttime and it improves the rate of evaporation by 38.76 percent round-the-clock.

5. Conclusion

The investigated greenhouse dryer having PCM showed promising results in terms of capability for extending the time period of drying products during nighttime while the round-the-clock improvement in amount of evaporated mass was achieved 38.76%.

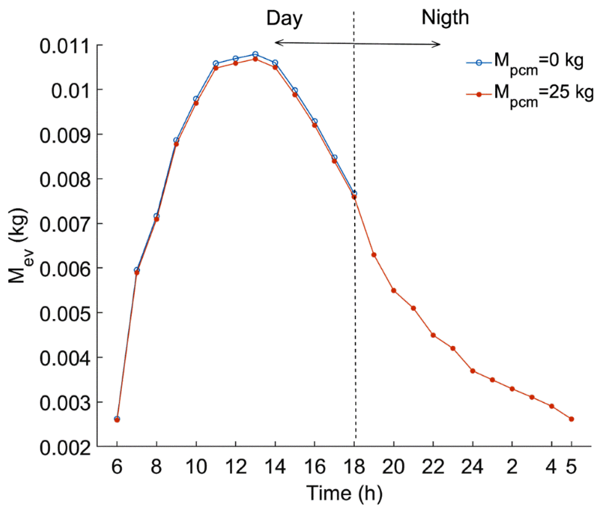

Fig. 5 Evaporation mass of the moisture in greenhouse dryer affected by presence and lack of PCM

6. References

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