Energy and exergy analysis of carbon nanotubes-based solar dryer

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Abstract

Solar dryers play a pivotal role in minimizing drying energy consumption in small farms. Therefore, its development is an urgent need. In this study, a developed solar dryer comprised of a smooth solar air heater, shell and tube storage unit, and drying chamber, has been constructed and tested to dry a Chinese medicinal fungus (Poria Cocos). The dryer has been operated under two airflow rates and then, energy and exergy analysis applied to the system. The results show that: solar air heater averaged thermal and exergy efficiency were 66.2% and 4.6%, 70.2 and 4.4% for 1st and 2nd experiments, respectively. Carbon nanotubes- paraffin wax shell and tube storage unit averaged overall thermal efficiency was 12.2% and 19.6% leading to 8.1% and 11.9% as averaged overall exergy efficiency for 1st and 2nd experiments, respectively. The specific energy consumption (SEC) was 6.545 and 7.917 kWh / kg moisture, also, the dryer's overall thermal efficiency was 36.4 and 30%, for 1st and 2nd experiments, respectively. The final moisture content of Poria Cocos was in the range of 6.6-8% w.b. The system payback period is 1.55 years.

Abdelkader, T. K., Salem, A. E., Zhang, Y., **Gaballah, E. S.,** Makram, S. O., & Fan, Q. (2021). Energy and exergy analysis of carbon nanotubes-based solar dryer. Journal of Energy Storage, 39, 102623. https://doi.org/10.1016/j.est.2021.102623

Journal of Energy Storage 39 (2021) 102623

Contents lists available at ScienceDirect

Journal of Energy Storage

journal homepage: www.elsevier.com/locate/est

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ARTICLE INFO

Keywords:
Indirect solar dryer
Shell and tube storage unit
CNTs-paraffin wax
Poria Cocos drying

ABSTRACT

Solar dryers play a pivotal role in minimizing drying energy consumption in small farms. Therefore, its development is an urgent need. In this study, a developed solar dryer comprised of a smooth solar air heater, shell and tube storage unit, and drying chamber, has been constructed and tested to dry a Chinese medicinal fungus (Poria Cocos). The dryer has been operated under two airflow rates and then, energy and exergy analysis applied to the system. The results show that: solar air heater averaged thermal and exergy efficiency were 66.2% and 4.6%, 70.2 and 4.4% for 1st and 2nd experiments, respectively. Carbon nanotubes- paraffin wax shell and tube storage unit averaged overall thermal efficiency was 12.2% and 19.6% leading to 8.1% and 11.9% as averaged overall exergy efficiency for 1st and 2nd experiments, respectively. The specific energy consumption (SEC) was 6.545 and 7.917 kWh / kg moisture, also, the dryer's overall thermal efficiency was 36.4 and 30%, for 1st and 2nd experiments, respectively. The final moisture content of Poria Cocos was in the range of 6.6-8% w.b. The system payback period is 1.55 years.

1. Introduction

With the advanced conservation methods, the post-harvest deficits of food and agricultural commodities have been shortened in recent years. Drying is among the earliest processes for the preservation of industrial and agricultural products used by humans. Among several other preservation approaches, this is the easiest and most expense-effective method [1,2]. Solar dryers are generally categorized into four (i) Sun or natural dryers, (ii) Direct solar dryers, (iii) Indirect solar dryers, and (iv) Mixed-type solar dryers [3]. To boost indirect solar dryer performance, optimal collector models, heat storage units, desiccative materials, air recirculating, PV cells, and supplementary heating methods were used [4]. Using a latent heat backup system utilizing phase-change materials (PCMs) is an impactful way to store thermal energy which has the advantages of high energy storage capacity as well as the storage undergoes isothermal mechanism [5–7]. Among many designs, the shell and tube system thermal-loss is the lowest. As well, commercial paraffin is most used in lower and medium temperature applications [8,9]. On the other side, PCMs have a principle problem which is low thermal conductivity as a result of that many approaches should be studied to overcome that property by embedding nanofiller as well as different fins designs [10,11]. Thus, nano graphite(NG) is used by Li [12] the result indicated that NG particles in paraffin enhanced thermal conductivity by 0.9362 W/m K for 10 w.t% nano graphite particles. Furthermore, Huang et al. [13] embedded expanded graphite(EG) in eutectic PCM ($LiNO_3$/KCl), then, thermal conductivity was 1.85–7.56 times greater than of $LiNO_3$/KCl based on the mass portion of EG. Wu et al. [14] used 5% CNTs with paraffin wax mechanically mixed, the composite is stable for 40 h under room temp. also shows a better thermal conductivity as well as carbon nano particles with paraffin comparing to pure paraffin, also in another study, CNTs enhanced the enthalpy of paraffin by 6.3% [15], similar trends achieved with graphite and paraffin [16]. Das et al. [17] numerically investigated the thermal behavior of n-alkane in a vertically oriented shell and tube storage unit by using nanofiller. And they reported that the incorporation of 1-D and 2-D nanostructures reduces the melting time by 15% and 25% respectively at 1 vol% load as a response to increased thermal conductivity. Furthermore, Qian et al. [18] boosted thermal conductivity of form-stable phase change composite (Fs-PCC) with SWCNTs, and the results indicated that the thermal conductivity of the formulated fs-PCC improved from 0.24 W/m.K to 0.87 W/m.k with a slight SWCN load of 2 wt%.

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https://doi.org/10.1016/j.est.2021.102623
Received 28 December 2020; Received in revised form 30 March 2021; Accepted 19 April 2021
Available online 18 May 2021