ELSEVIER

Solar Energy
Volume 262, 15 September 2023, 111836

Development of sensible heat storage based solar hybrid dryer with evacuated tube collector and biomass gasifier for shrimp drying

S. Murali, D.S. Aniesrani Delfiya, P.V. Alfiya, Manoj P. Samuel, George Ninan

Show more

https://doi.org/10.1016/j.solener.2023.111836

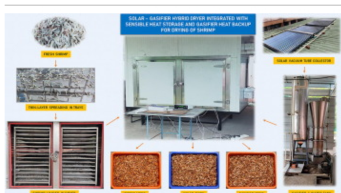
Highlights

- Introduced biomass gasifier as a backup heat source to the solar dryer with indirect heat transfer mechanism.
- Water (SHS) harnessed 193104kJ and 160185kJ of heat under solar & hybrid mode of operation.
- Obtained drying efficiency of 34.97%, 35.62%, and 41.66% under gasifier, solar & hybrid mode.
- Hybrid mode of operation is economical with the payback period of 0.62years.

Abstract

The work was aimed at developing an energy-efficient solar hybrid dryer with a biomass-based gasifier heat backup suitable for drying shrimps even during off-sunshine hours. In this dryer, water was utilized as a sensible heat storage (SHS) material as well as heat transfer fluid and biomass gasifier as an indirect backup heat source. The performance of the solar-gasifier hybrid dryer was assessed by drying shrimp (*Metapenaeus dobsoni*) samples and compared it with solar, and gasifier modes. Shrimp obtained the desired moisture content of 15.09 %, 13.46%, and 14.77% (w.b.) in 9h, 6h, and 6h of drying in solar mode, gasifier mode, and solar-gasifier hybrid drying mode, respectively. The average drying rate of the solar, gasifier and hybrid modes of drying were 0.33g/g dm.h, 0.46g/g dm.h, and 0.47g/g dm.h, respectively. Results revealed that the evacuated tube solar water collector harnessed 193104kJ and 160185kJ of heat energy during sunshine hours under the solar and hybrid mode of operation. The maximum drying efficiency of 34.97%, 35.62%, and 41.66% was obtained for gasifier mode, solar mode, and hybrid mode of shrimp drying. The economic evaluation revealed that the hybrid mode of operation is highly economical with the annual savings of $10983.06 and the lowest payback period of 0.62years.

Graphical abstract



Introduction

Shrimp is one of the major aquatic products in the world. It is highly perishable and requires immediate preservation after harvest and before processing. Drying is one of the oldest methods for shrimp preservation [1]. Dried shrimp is popular in Asian and Chinese recipes, imparting a delicious umami taste to foods. Open-air sun drying is the cheapest method of preserving shrimp, practiced in developing countries. However, the major drawbacks are prolonged drying periods, weather dependence, and the inferior quality of the final product. Solar drying is an improved form of sun drying and a glass structure is employed to augment the effect of solar radiation, thus ensuring hygienic, faster, and uniform drying of products [16], [25]. Various types of solar dryers used for drying of shrimps/prawns were walk-in type semi-cylindrical solar tunnel dryer [1], [22], [26], solar– liquefied petroleum gas (LPG) hybrid dryer [24], [3], and solar-electrical hybrid dryer [29].

To improve the effectiveness of the solar dryer, a sensible heat storage material (SHS) such as water, rock bed, thermal oils, concrete, pebbles, brick, gravel, and sand were incorporated into the solar dryer to harness the heat energy during sunshine hours and later use it for insufficient or off-sunshine periods [14], [4]. With the best balance of cost, density, heat storage capacity, and environmental effect, water continues to be the most popular material used in sensible heat storage systems and it can also be employed as both thermal energy storage (TES) and heat transfer fluid [39]. In most solar applications like solar water heating, air heating and drying, evacuated tube collectors provide higher efficiency than flat plate type due to its cylindrical shape [19]. Murali et al. [23] designed a solar-LPG hybrid dryer by employing water as SHS material and reported a peak collector outlet water temperature of 73.5°C. Nabnean et al. [28] reported that the heat energy absorbed by the water was utilized to regulate the dryer air temperature during very low solar radiation. Deeto et al. [9] stated that heat energy harnessed by water as SHS material was used during the absence of sunshine in the solar greenhouse dryer. However, it has been reported that the intensity of the incident radiation could be weak at times and the required rise in the temperature of SHS medium may be marginal compared to the ambient condition and thus restricting dryer usage during cloudy/rainy days and during the night [18].

To overcome the limitations of the rise in temperature of SHS material during low and off-sunshine hours, an auxiliary heat source such as a biomass gasifier, electric heater, biogas/ LPG heaters can be provided to supplement heating requirement [14]. Biomass gasification is a thermochemical conversion process of solid biomass materials into producer gas which consists of carbon monoxide (CO), hydrogen (H_2), nitrogen (N_2) and methane (CH_4) [38]. Biomass gasifiers are used to generate producer gas which can be used as a fuel in industrial boilers and large-scale water heating systems [36], [34]. Coconut shells can be considered a source of feedstock for the biomass gasifier unit due to its abundance, accessibility and cost-effectiveness in tropical countries [32], [2]. The availability, affordability, and clean combustion of biomass fuels make biomass-based gasifiers an excellent backup heat source for solar dryers [7]. Bhattacharya et al. [6] fabricated a solar dryer integrated with a gasifier stove for continuous drying operations. They reported that the gasifier mode of operation required about 20h for drying at a fuel consumption rate of 2kg/h for both banana and chilli. Ondokmai et al. [30] assessed the performance of a greenhouse solar dryer coupled with a gasifier system for drying paddy with charcoal as feedstock. The temperature of the greenhouse solar dryers was increased by 25°C in the hybrid mode of operation. Panwar et al. [31] studied the biomass gasification process for low heat in industries. The experiments revealed that about 6.5kg of LPG can be substituted by 38kg of wood per hour and the fuel economy was significant. Murugan and Raveendran [27] evaluated the producer gas obtained from the gasifier which is blended with fresh air in the fuel–air mixing chamber for tapioca drying. The tapioca dried in the gasifier-based dryer retained flavour, colour, and quality with a moisture content of 5–12%.

Limited literature is available on integration of biomass-based gasifiers as a backup heat source for solar hybrid dryers. The novel aspect of the present study is the introduction of a comparatively clean system i.e. biomass gasifier with producer gas fuel as an indirect heat source (heat exchanger-fan arrangement) for solar dryers over the directly fired conventional biomass heaters. To the best of our knowledge, no study reported on the usage of biomass gasifier/ producer gas as a comparatively clean and indirect heat backup with energy storage in sensible heat storage materials.

Therefore, the objectives of the study were formulated as,

1. Design and development of the sensible heat storage based solar hybrid dryer integrated with evacuated tube collector and biomass gasifier heater backup for drying of shrimps
2. Performance evaluation and economic analysis of the developed solar hybrid dryer at solar, gasifier and hybrid mode of operation using shrimps

---

Section snippets

Design of solar-gasifier hybrid drying system

A solar hybrid dryer with biomass gasifier heat backup was designed for drying shrimp at Kochi, Kerala, India. The drying conditions and assumptions considered for the development of the hybrid dryer are reported in Table 1. The dryer design procedure adopted by the authors in the previous publication was considered in this study for solar-gasifier hybrid dryer design for shrimp drying [23]....

Ambient conditions during the experiments

As part of the experiment, the variations in air temperature, relative humidity, and solar radiation were monitored and recorded at half-hour intervals throughout the experiment (Fig. 4). Air temperature varied from 28.3 to 36.5°C with a mean temperature of 33.27°C. Similarly, solar radiation ranged from 352 to 1046W/m^2 and relative humidity varied from 52.68 to 77.97 % with the mean value of 740.33W/m^2 and 64.23%, respectively. As the day progressed, the increase in solar radiation...

Conclusions

In this study, a novel solar-gasifier hybrid dryer was developed with a thermocline storage tank and evacuated tube collector. The performance of the developed dryer was tested in solar, gasifier, and hybrid modes using shrimp samples. The average air temperature in the drying chamber under solar, gasifier, and hybrid operation was 51°C, 53°C, & 55°C, respectively. Similarly, the average RH observed in the drying chamber was 42.5%, 36.5%, & 38.2% for Solar, gasifier, and hybrid modes of...

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper....

Acknowledgments

This research work was financially supported by the Department of Science and Technology, Science for Equity, Empowerment and Development Division, Government of India, with a grant number of SP/YO/150/2018. The authors profusely thank the Director, ICAR-CIFT, Cochin for permitting us to undertake the work at the Institute. Thanks, are also due to the staff of the Engineering workshop for extending the facilities for conducting the study....

FEEDBACK

References (40)

R. Kabir Ahmad *et al.*
Exploring the potential of coconut shell biomass for charcoal production
Ain Shams Eng. J. (2022)

P.V. Alfiya *et al.*
Kinetics, modelling and evaluation of Bombay duck (*Harpodon nehereus*) dried in solar-LPG hybrid dryer
Sol. Energy (2022)

G. Alva *et al.*
Thermal energy storage materials and systems for solar energy applications
Renew. Sustain. Energy Rev. (2017)

S.C. Bhattacharya *et al.*
Design and performance of a hybrid solar/biomass energy powered dryer for fruits and vegetables

H. Darvishi *et al.*
Drying characteristics of sardine fish dried with microwave heating
J. Saudi Soc. Agric. Sci. (2013)

S. Deeto *et al.*
The experimental new hybrid solar dryer and hot water storage system of thin layer coffee bean dehumidification
Renew. Energy (2018)

P.P. Dutta *et al.*
Gasification of tea (*Camellia sinensis (L.) O. Kuntze*) shrubs for black tea manufacturing process heat generation in Assam, India
Biomass Bioenergy (2014)

P. Dutta *et al.*
Thermal performance studies for drying of Garcinia pedunculata in a free convection corrugated type of solar dryer
Renew. Energy (2021)

M. Goud *et al.*
A novel indirect solar dryer with inlet fans powered by solar PV panels: drying kinetics of Capsicum annum and Abelmoschus esculentus with dryer performance
Sol. Energy (2019)

D. Jain *et al.*
Study the drying kinetics of open sun drying of fish
J. Food Eng. (2007)

FEEDBACK

View more references