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Review of solar drying systems with air based solar collectors in Malaysia

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ABSTRACT

Solar drying systems (SDSs) are environment friendly and enhance energy conservation. Such systems are a promising application of solar energy systems. SDS is an effective means of food preservation, particularly for small groups of farmers and fishers in Malaysia. Thus, these systems have been developed for agricultural and marine products in this country. This review describes the design and performance levels of different types of commercial-scale SDSs with air-based solar collectors established in Malaysia. To this end, the performances of various such SDSs are summarized in detail. Performance indices are presented as well, such as those for drying time, evaporative capacity, and drying efficiencies. Moreover, the SDSs are subject to energy–exergy–environment–economic analysis in this review.

Contents

1. Introduction

Solar energy is an abundant permanent and environmentally compatible energy source in the world. Conversion to clean energy sources such as solar energy facilitates improvement in quality of life throughout the planet not only for humans but also for flora and fauna. Most agricultural and marine products for storage must first be dried to preserve the quality of the final products. The majority of agricultural and marine products in Malaysia is subject to open sun drying (OSD). This method requiring a large open space; products are highly dependent on the availability of sunshine and are susceptible to contamination with foreign materials [1].

As an alternative to OSD, solar drying systems (SDSs) are an attractive and promising application of solar energy systems. This type of system is a renewable and environmentally friendly

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Nomenclature

A_c	collector area (m^2)
AC	dryer cost
B_t	annual benefit
C	specific heat of air (J/kg/°C)
C_t	annual cost
d	rate of interest
E	evaporative capacity (kg/h)
E	energy absorbed from the sun
f	rate of inflation
h_o	absolute humidity of air leaving the drying chamber (%)
h_i	absolute humidity of air entering the drying chamber (%)
h_{as}	absolute humidity of air entering the dryer at the point of adiabatic saturation (%)
i	discount rate
L	solar dryer life
L	latent heat of water vaporization at the exit air temperature (kJ/kg)
M_i	initial moisture content fraction on wet basis (wb)
M_f	final moisture content fraction on wet basis (wb)
M_t	moisture content at time t
M_{t+dt}	moisture content at time ($t+dt$)
$\dot{m}$	mass flow rate (kg/s)
m_o	initial total crop mass (kg)
$\dot{m}_{da}$	mass flow rate of dry air (kg/s)
$m_b \times H_b$	energy input by the additional energy source
m_i	maintenance cost in the ith year
P_f	fan power (W)
P_t	total energy input to the dryer (kW h)
S	solar radiation (W/m^2)
S_t	saved drying time (h)
t	drying time (s)
t_{OS}	time consumed by drying in open sun (h)
t_{SD}	time consumed by solar drying (h)
SEC	specific energy consumption (kW h/kg)
SMER	specific moisture extraction rate (kg/kW h)
T_a	ambient temperature (°C)
T_{at}	air temperature in the dryer (°C)
T_i	inlet air temperature (°C)
T_o	outlet air temperature (°C)
T_s	sky temperature (°C)
t	time (h)
v	volumetric airflow (m^3/s)
W	mass of water evaporated from the product (kg)
X_a	ambient absolute humidity
X_{2m}	dryer outlet absolute humidity
η_d	drying efficiency (%)
η_p	pick-up efficiency (%)
ρ	air density (kg/m^3)

technology. This method is also economically viable in most developing countries. Drying is among the oldest and most important preservation methods for reducing the moisture content of food or other heat-sensitive, biologically active products. Upon removing the water content in the product, the quality of the dried output must be considered. Product quality depends on many factors, including drying temperature and duration. Products such as medicinal herbs require low temperature to prevent active, volatile, essential ingredients from being stripped during conventional high-temperature drying [2,3]. Numerous types of SDSs have been designed, tested, and developed worldwide, and these systems exhibit varying degrees of technical performance. Various SDS designs for agricultural products have been reviewed [4–6], such as chamber-type (rack-type/tray-, bin-, and tunnel-type) and chimney-type SDS. These designs have been recommended for commercial use.

Several parties in Malaysia have investigated SDS use, including local universities, the Malaysian Agricultural Research and Development Institute (MARDI), Standards and Industrial Research Institute of Malaysia (SIRIM), New England Biolabs (NEB), Forest Research Institute of Malaysia (FRIM), and other agencies. The following studies have been conducted: one by the Rubber Research Institute of Malaysia (RRIM) on the drying of rubber sheets, one on the drying of paddies by Joming Solar Systems Pvt. Bhd in Butterworth, one on the drying of bananas, and one on the drying of cocoa by Harrisons Malaysian Plantations Berhad. Moreover, several recommendations have been made by works involving the use of SDSs in Malaysia, such as drying processes for anchovies, rubber, herbal tea, chili, medicinal herbs such as Centella, and palm fronds. MARDI and the Solar Energy Research Institute (SERI) at Universiti Kebangsaan Malaysia (UKM) have performed solar drying activities on many commodities and products, including paddies, tobacco, coffee beans, tapioca, noodles, groundnuts, banana, vermicelli, mussels, fish crackers, anchovies, and fish. RRIM has conducted technical and economic analyses on solar-assisted rubber smokehouses. FRIM and University of Malaya have tested a solar box dryer for bamboo. Most commercial applications of solar thermal systems report a favorable payback period (PP) of less than 3 y to replace conventional diesel-fired dryers [7–9]. Table 1 shows the present status of postharvest drying technology for selected tropical agricultural and marine products [10], as well as the energy sources and the required drying time. Most agricultural products are either sun-dried or dried using fossil fuels, such as kerosene, diesel, and liquefied petroleum gas (LPG). However, SDS has not been used.

2. Prospect and status of SDS in Malaysia

Malaysia is a tropical country wherein various fruits are cultivated as shown in Table 2. Some of these fruits are native to this country, whereas other types are imported from elsewhere because of their high commercial potential. The area cultivated for local fruit planting currently measures 298,429 ha and produces 1767,800 mt of fruit per year. The estimated amount of fruit consumed per capita in Malaysia was 48.82 kg in 2010 [11].

SDS is a promising option for preserving agricultural products in tropical and subtropical countries [12]. Malaysia is blessed with a tropical and humid climate which is suitable for agricultural industry [13], and agricultural products account for the majority of national income. SDS has been installed by Joming Solar System Sdn Bhd for the rice industry in Butterworth. This system saves RM 23,000 per year in energy costs in comparison with traditional drying. Tobacco curing systems can save fuel by approximately 30%. Muniandy [14] reported the results of a study conducted by RRIM. This research postulated that forced convection SDS, which is a mutual aid system of energy sources for drying rubber wood pieces, is economical. Furthermore, the surrounding operating system uses solar power; at night, the system is supported by wood energy. With this SDS, drying 2500 kg of rubber sheets takes only takes 4–6 d. Unlike conventional systems, the estimated energy saved by this system is RM 247.