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Techno-economic of solar drying systems with water based solar collectors in Malaysia: A review

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ABSTRACT

The paper describes the techno-economic of solar drying system (SDS) with water based solar collector in Malaysia. In Malaysia, SDS has been great potential to be used in drying purpose, which is relevant to the local climate. The design, performance and economic analysis of four types SDSs with water based solar collectors in Malaysia were described, (1) SDS with hybrid PVT-mechanical heat pump, (2) SDS with chemical heat pump, (3) SDS with dehumidification system, and (4) Greenhouse SDS with heat exchanger. Economic indicators such as payback period (PP), net present value (NPV), and life cycle saving (LCS) were presented. In addition, the various performances analysis of SDSs with air based solar collectors was presented. The energy and exergy analysis of SDS with water based collector was presented. Moreover, the energy and exergy analysis of PVT water collector was presented.

Contents

1. Introduction

Developing a solar energy technology would have strategic significance to shrink coal consumption and to cost-effectively accelerate the decarbonisation in the power sector and commercial and industrial process heat generation [1–3]. Drying is an essential process in the preservation of agricultural and marine products such as beans, chili, cocoa, coffee, fruit, nuts, tea, fish and seaweed. Traditionally, crop drying has been dried under the open sun drying and accomplished by burning fossil fuels and wood in chambers. These methods suffer from many problems. In open sun drying, the crops are lost because of inadequate drying. It is exposed to various contaminations with foreign materials. Other problems such as requiring large open space area, and very much dependent on the availability of sunshine are common [4,5]. As an alternative to traditional methods, solar drying system (SDS) provides an alternative to the use of fossil fuel. SDS

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seems promising options for agricultural products preservation in various countries [6].

A review of various types of SDS can be classified into three type namely Indirect SDS, Direct SDS and Mixed mode SDS was presented by Prakash and Kumar [7]. A review of various designs and performance evaluation of conventional solar air collectors for crop drying applications were presented by Ekechukwu and Norton [8]. A comprehensive review of the fundamental principles and theories about the drying process was presented by Ekechukwu [9]. A review of various type of SDS, detail of construction and operational principles were presented by Ekechukwu and Norton [10]. The classification of SDS were evolved, identifying two main groups, namely natural convection (passive) SDS and forced convection (active) SDS. Performance of SDSs for agricultural and marine products has been simulated, tested and suggested by many researchers [11–16]. The Solar Energy Research Institute (SERI) at Universiti Kebangsaan Malaysia has carried out solar drying activities on many commodities such as herbal tea, chili, Centella (medical herb), seaweed, fish, palm oil fronds and fruits [17–21].

Hence, the SDSs is increasing nowadays, and they have special economic attractions. SDS using flat plate solar collectors, which have at least a 10-year lifespan, are more efficient and economical than that using traditional method by burning fossil fuels or wood, as well as those that use electricity [22]. A simple framework for a comparison financial evaluation of solar drying versus open sun drying was developed by Purohit et al. [23]. An economic analysis of solar air collector used for drying of fruit and vegetable was studied by Sharma et al. [24]. Economic indicators such as payback period (PP) and internal rate of return were presented. In addition, the various economic parameters such as, lifecycle costing, fuel price, initial investment and interest on fuel price was presented. Four different economic indicators of SDS was suggested by Panwar et al. [25], namely net present worth (NPW), benefit–cost ratio (BCR), internal rate of return (IRR), and PP. The IRR can be found out by systematic procedure of trial-and-error to find that discount rate, which will make the NPW of the incremental net benefit stream equal to zero.

From the economic evaluation open sun drying method was excluded because of irrelevancy. The drier cost was calculated as a sum of cost of used construction materials including labor expenses. The drying cost was estimated as the ratio of annual cost to the quantity of dried product per annum. Economic analysis of SDSs usually aims at determining the PP [26]. Boroze et al. [27] reported thermo-economic analysis with identical evaporative capacity. The traditional method also known as open sun drying (OSD) was the least expensive with a cost of € 2.4 d/kg of evaporated water; the profit was rather low at about € 0.2/kg of evaporated water. Base on OSD as the reference, the Geho hybrid and gas Atesta dryers, their costs were 12 to 13 times higher (€ 24.7 d/kg and € 33.0 d/kg of evaporated water) than that of the OSD. The profit was three to five times higher than that of the leaves (€ 0.7/kg and € 1/kg of evaporated water). For the chamber solar dryer, an unusual case of significant investment 20 times that of the OSD (€ 50.4 d/kg of evaporated water) also gave a profit more than 20 times higher than that of the OSD (€ 4.2 d/kg of evaporated water). It turned out that higher investment in the purchase of the dryer when adapted to a need, made it possible to achieve greater benefits.

2. Performance of solar drying systems with air based solar collectors in various countries

Numerous types of SDSs with air based solar collectors had been designed, tested and developed in various countries, yielding varying degrees of technical performance. Various design of natural convection SDS has been tested and developed for agricultural and marine products. These designs have been recommended for commercial purpose and these include chamber-type (rack-type/tray-type, bin type, and tunnel type) SDS, and chimney-type SDS. Various design of forced convection SDS has been tested and developed. Direct mode forced convection SDSs essentially consist of a blower/fan to force the air through the product, a chamber, and covered with a transparent sheet. Indirect-mode forced SDSs essentially consist of an air heater, drying chamber, and a blower/fan to duct the heated air to the drying chamber [28]. Various design of SDS with thermal storage has been reviewed by Bal et al. [29]. Several workers have explored different techniques for accelerating the SDS for drying various agricultural products by considering the possible use of thermal storage materials, and developed deep bed drying model to predict the performance.

Table 1 summarizes the performances of SDSs with air based solar collectors as reported by different authors. Most authors report the capacity, drying time, energy consumption and efficiencies were reported [30–58]. Table 2 shows parameters and performance indices formula [59–82].

3. Techno-economic of solar drying systems with water based solar collectors in Malaysia: Case studies

Malaysia lies entirely in the equatorial region. Malaysia is located at Latitude 1.30°N–6.60°N and longitude 99.50°E–103.30°E with an equatorial climate received an amount of 4–5 kW h/m^2 daily solar radiation intensity [83]. The yearly average daily solar radiation of Malaysia was reported. On average, Malaysia receives about 4.96 kW h/m^2 of solar radiation in a year [84]. Malaysia is blessed with tropical and humid climate which is suitable for agricultural industry [85]. In Malaysia, some research institutions and universities have tried out SDS of various agricultural and marine products. Solar drying experiments have been carried out by various agencies sucs as the Malaysian Agriculture Research and Development Institute (MARDI), the Rubber Research Institute of Malaysia (RRIM), the Forest Research Institute of Malaysia (FRIM) and other agencies [86–89].

Financial viability is key to any SDS to successfully compete with other dryers. Economic analysis generally includes fixed cost of SDS, drying cost and PP. PP is estimated as the period (number of months/ years) when initial cost and annual expenses (including compound interest for operation and maintenance) equal total savings. Economic analysis on a SDS should incorporate the cost benefit due to improve quality, higher yields, less floor area and quicker drying [90,91].

3.1. Solar drying system with hybrid PVT-mechanical heat pump

Fig. 1 shows the schematics of a SDS with hybrid PVT-mechanical heat pump. The main components are, mechanical heat pump, thermal absorbers, drying chamber and the direct integration of PV panels. The mechanical heat pump consists of an air cooled condenser, a compressor, a water cooled condenser, an evaporator as air conditioner, an evaporator as dehumidifier, expansion valves which are interconnected in a closed-loop system, storage tank, an auxiliary heater, a water-refrigerant heat exchanger and water pump. This system was consists of three distinct flow paths: water, refrigerant and air. The performance of the system has been studied.

The system operation for cooling (air conditioner mode), heating (drying mode) and dehumidification air comprises of four separate modes: a cooling mode, a heating mode, a dehumidification mode and in a multipurpose mode. In the cooling mode, the valve means direct refrigerant to the evaporator of heat pump a