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Performances Analysis of Greenhouse Solar Dryer with Heat Exchanger

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Abstract

A greenhouse solar dryer with heat exchanger was tested for salted catfish in Perlis, Malaysia at average solar radiation of 626 W/m^2. The dryer consists of the heat pipe evacuated tube collector, electric heaters, blower, pumps, water tank, and greenhouse drying chamber. The average temperature of the drying chamber is 44°C. The drying time is 18 h (8h day time and 10h night time). The total energy required used is 294.98 kWh and the solar energy contribution is 60 % of the total energy. The electric heaters, and blower-pump power used is 29 % and 11 %, respectively. The moisture extraction rate (MER) and specific moisture extraction rate (SMER) obtained of 6.3 kg/h and of 0.385 kg/kWh, respectively. The values for exergy efficiency varied between 29 % and 82 % with an average of 46 %. Economic analysis showed that system is a payback period about 1 year.

Keywords: Solar energy, energy analysis, exergy analysis, economic analysis

1 Introduction

An alternative energy resource such as solar energy is becoming increasingly attractive. Solar energy is a part of the sun's energy that falls at the earth's surface, which has the world's most abundant permanent source of energy. Solar energy has the potential to meet a significant proportion of the world's energy needs. This energy is available for many applications. Solar energy is secure, clean, and available on the earth throughout the year. Such clean energy is very important to the word, especially at the time of high fossil fuel costs and critical situation of the atmosphere resulting from fossil fuel applications [1].

Solar drying system has been of great potential to be used in drying purpose, especially In Malaysia which is relevant to the local climate, with amount received of 4.21 to 5.56 kWh/m^2 daily solar radiation intensity. Solar drying system is among the most attractive and promising applications of solar energy systems. Most agricultural commodities and marine products require drying as part of the process of getting a quality product. Traditionally, all the agricultural crops were dried under the sun. Drying is one of the important post handling process of agricultural production. It can extend shelf life of the harvested products, improve quality, improve the bargaining position of the farmer to maintain relatively constant price of his products and reduces post harvest losses and lower transportation costs since most of the water is taken out from the product during the drying process. Open sun drying requires large open space area, and very much dependent on the availability of sunshine, susceptible to contamination with foreign materials such as dusts, litters and are exposed to birds, insect and rodents [2, 3].

Solar drying system was evaluated for agricultural and marine products in Malaysia [4-8]. Objective of this paper is to present the energy-exergy-economic analysis of a greenhouse solar dryer with heat exchanger for salted catfish.

2 Material and Methods

Fig. 1 shows the catfish Malaysian also known as "ikan keli" used in this study was obtained from Perlis, Malaysia. The scientific name for catfish is *Clarias gariepinus*. Catfish is a kind of freshwater fish. It has a physical shape elongated with a reinforced head, wide, flat and wide mouth. But not flaky skin covered with mucus that protects them when they are outside of the water. Catfish have a thick volume. Catfish is easy to breed and grow quickly. It can be cultured in the large pool. Fat content in catfish are among the highest among freshwater fish that is as much as 9-12% initial moisture content of catfish is 72.32% [8]. For Malaysian catfish, it was found to contain nutritious, with high moisture content (78g/100g), protein (17g/100g) and fat (4.5g/100g) as shown in Table 1 [9]. Catfish are very popular because of the good fatty acids can reduce the risk of cancer and heart disease. In addition, fish oil found in catfish can reduce instability heartbeat.

Fig. 1 Fresh catfish

Table 1 Concentration of elements for Malaysian catfish [9]

Nutrition	Unit/100g
Moisture content	78 g
Fat	4.5 g
Phosphor	200 mg
Protein	17 g
Carbohydrate	0 g
Iron	1.0 mg

Fig. 2 and Fig. 3 show schematic and photograph of greenhouse solar dryer with heat exchanger. It is classified as a forced convection. The dryer consists of the heat pipe evacuated tube collector, blower, electric heater, pumps, and drying chamber. Heat pipe evacuated tube collector collectors are connected in series with the total is 320. An electric heater is equipped with an on/off controller with the total power is 18 kW. It has been attached to the system in order to provide continuous heat as required by the drying commodity. The drying chamber temperature can be controlled by setting the temperature at the required drying temperature.

For daytime drying, the system is operated from 09:00 AM to 18:00 PM. Drying experiment has been done on 200 kg salted catfish. It is divided equally and then placed on 8 trays. During this process the drying temperature setting in drying chamber is fixed at 50^{o}C. The data are measured air temperature (ambient temperature, air temperature inlet and outlet of the collector), radiation intensity and air velocity, also measured the air temperature before it enters the dryer chamber, the temperature inside the dryer chamber, the temperature of the air out of the dryer chamber. The relative humidity sensors are installed in inlet, middle and outlets of drying chamber. Air temperature is measured by T-type thermocouple, and the intensity of solar radiation measured by pyranometer.

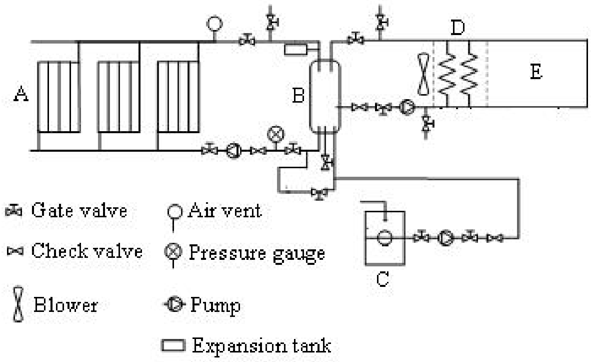

Fig. 2 Schematic of greenhouse solar dryer with heat exchanger (A: heat pipe evacuated tube collector, B & C: water tank, D: heat exchanger, E: greenhouse chamber)

Fig. 3 Photograph of greenhouse solar dryer with heat exchanger

Performance evaluation for solar dryer is moisture extraction rate (MER). It is described as the mass of moisture removal per unit time from a dryer [10]:

$$MER = \frac{W}{t} \tag{1}$$

where
t = drying time
W = mass of water evaporated from the product (kg).

Another common rate is the specific moisture extraction rate (*SMER*). This one describes SAD's effectiveness, which is the energy required to remove 1 kg of water, and was calculated as

$$SMER = \frac{W}{Q} \tag{2}$$

where,
Q = the total of energy consumtion which consists of the solar radiation, fuel and electrical which are consumed during the drying process.

The mass of water removed (W) to from wet product can be calculated as

$$W = \frac{m_o\left(M_i - M_f\right)}{100 - M_f} \tag{3}$$

where
m_o = initial total crop mass
M_i = initial moisture content fraction on wet basis
M_f = the final moisture content fraction on wet basis

The exergy analysis of greenhouse solar dryer with heat exchanger for salted catfish is given in Table 2 [11-13]. The exergy efficiency of the drying chamber is given by equation (4). The exergies equation for drying chamber and exergy loss during the solar drying process are given by Eq. (5) to (7).

Table 2 Exergy analysis of solar dryer [11-13]

Parameters	Symbol	Unit	Formula
The exergy efficiency	$\eta_{Ex,da}$		$\eta_{Ex,da} = \frac{Ex_{dco}}{Ex_{dci}} = 1 - \frac{Ex_{loss}}{Ex_{dci}}$ (4)
The exergy outflow of the drying chamber	Ex_{dco}		$Ex_{dco} = \dot{m}C\left[\left(T_{dco} - T_a\right) - T_a \ln \frac{T_{dco}}{T_a}\right]$ (5)
The exergy inflow of the drying chamber	Ex_{dci}		$Ex_{dci} = \dot{m}C\left[\left(T_{dci} - T_a\right) - T_a \ln \frac{T_{dci}}{T_a}\right]$ (6)
The exergy loss	Ex_{loss}		$Ex_{loss} = Ex_{dci} - Ex_{dco}$ (7)
The specific heat of air	C	J/kg^{o}C	
The drying chamber input temperature	T_{dci}	^{o}C	
The ambient temperature	T_a	^{o}C	

For economic analysis base on Fudholi et al. [14], capital cost (FC) of the solar dryer is defined as the sum of all the components, including the collector, drying chamber, blower, auxiliary heater, distribution system, and installation costs. The cost of drying (products) can be divided into fixed costs and direct costs. Direct costs comprise fresh materials, labor cost control, electrical, maintenance, and insurance costs. Product cost can be written as follows:

$$PC = MTC + LBC + ELC + EC \quad (8)$$

$$EXC = MC + IC \quad (9)$$

In these equations, *PC* is the production cost, *MTC* is the cost of fresh materials, *LBC* represents labor costs, *ELC* denotes the electricity costs, *MC* is the maintenance cost, and *IC* is the insurance cost. Investment performance can be studied by analyzing production. Profit is defined as the difference between total sales and all expenses. Profit can be written as

$$PR = PP - FC - PC \quad (10)$$

Payback period (*PP*) is the investment cost per average annual net income. Returns indicate the recovered invested capital. *PP* is calculated as

$$PP = \frac{FC}{PR} \quad (11)$$

3 Results and Discussion

Fig. 4 shows the variations in the moisture content and solar radiation with drying time. The experimental results of Greenhouse solar dryer with heat exchanger to 200 kg dry salted catfish so that the water content of 30% is required within 18 h to yield 65 kg. However, obtained weight of water evaporated from the salted silver jewfish of 113.5 kg by Eq. (3). By using Eq. (1) MER and SMER obtained of 6.3 kg/h and of 0.385 kg/kWh respectively. Table 3 shows the summary of the experimental results and observations of Greenhouse solar dryer with heat exchanger for salted catfish. And shown are the energy usage of the blower-pumps and the energy input by the additional energy source. The required drying time is also shown. Also shown are the initial and final moisture content (wet basis).

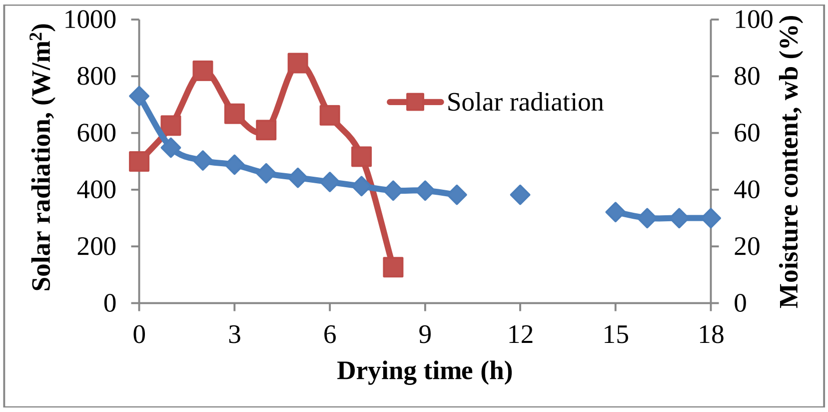

Fig. 4 Moisture content and solar radiation versus drying time

Table 3 Experimental results and observations

Parameters	Unit	Value
Initial weight	kg	200
Final weight	kg	65
Initial moisture content (wet basis)	%	73
Final moisture content (wet basis)	%	30
Drying temperature	°C	44
Blower and pumps energy	kWh	34.1
Electric heater energy	kWh	84.7
Solar energy	kWh	176.2
Drying time	h	18
Area collector	m^2	35.52
MER	kg/h	6.3
SMER	kg/kWh	0.385

Fig. 5 shows the variations of the solar radiation, ambient temperature, drying chamber air temperature, and relative humidity of drying chamber. From this figure, it is shown that at the increase solar radiation, the air temperature is increased. As well as, relative humidity decreases with the increase in the air temperature. During 8 h drying (daytime), the daily mean of drying chamber air temperature, relative humidity of drying chamber and solar radiation range vary from about 31 to 50°C, 23 to 70%, 88 to 946W/m^2, with an average of about 44°C, 34%, 626 W/m^2 respectively. The drying temperature and relative humidity in solar drying varied continuously a long drying time. It was observed that the drying temperature in solar drying was greater than the ambient temperature, whereas the relative humidity in it was lower than the ambient relative humidity. As well as, there is a significant difference between the values of the drying temperature and relative humidity.

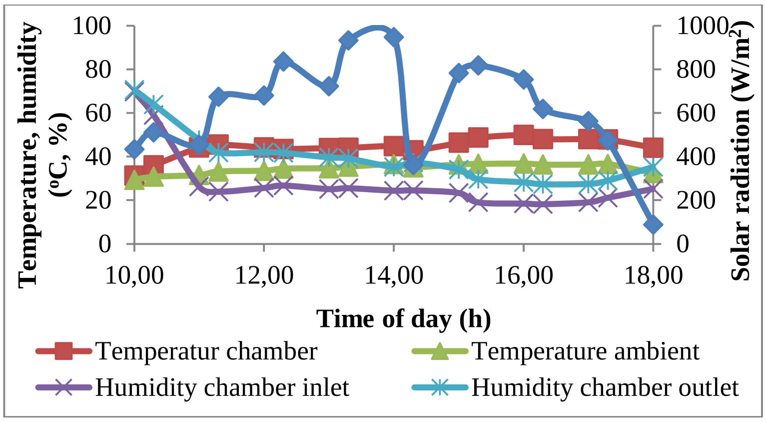

Fig. 5 Temperatures, relative humidity of chamber, and solar radiation at 5 March 2015

Fig. 6 shows variation exergies and solar radiation with respect to time. Minimum and maximum the exergy inlet, outlet, and loss of 821 W and 6321 W, 674 W and 2454 W, and 147 W and 4501 W, respectively, were observed.

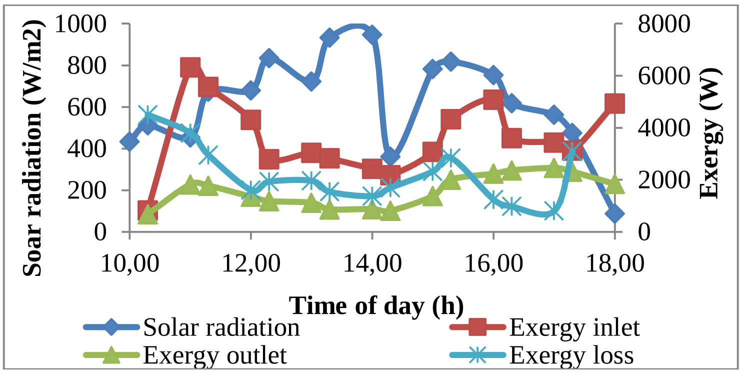

Fig. 6 Exergies (inlet, outlet and loss) and solar radiation at 5 March 2015

During the solar drying process, the exergy efficiency was calculated using Eq. (4). Fig. 7 shows the exergy efficiency values varied between 0.29 and 0.82 with an average of 0.46.

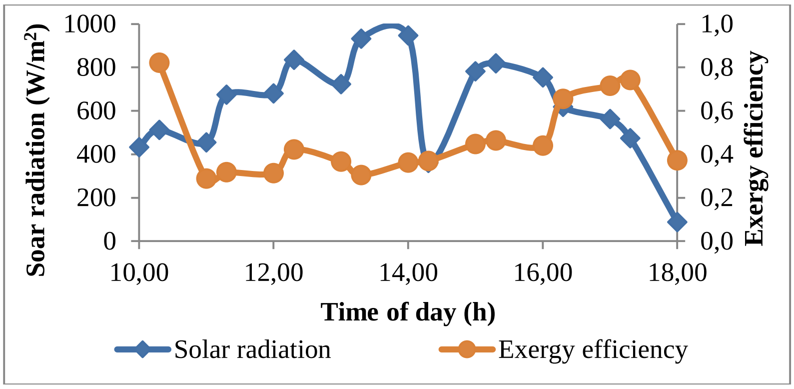

Fig. 7 Variation exergy efficiency with time at 5 March 2015

4 Conclusions

This paper presents the energy-exergy-economic analysis of a greenhouse solar dryer with heat exchanger for salted catfish. For 200 kg salted catfish to be dried using this dryer to reduce the moisture content from 73 to 30 % (w.b.) within 18 h to yield 65 kg of dried salted catfish. The total energy required used is about 295 kWh and the solar energy contribution is 60 % (176 kWh) of the total energy. The electric heater and blower-pumps power used is 29 % (85 kWh) and 11 % (34 kWh), respectively. Moreover, the moisture extraction rate (MER) and specific moisture extraction rate (SMER) obtained of 6.3 kg/h and of 0.385 kg/kWh, respectively. The values for exergy efficiency varied between 29 % and 82 % with an average of 46 %. On the other hand, economic analysis indicated that the greenhouse solar dryer with heat exchanger is best suited for use on salted catfish and that its payback period is as short as 1 year.

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