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Energy and Exergy Analysis of Hybrid Solar Drying System

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Abstract

In this study it was performed energy and exergy analysis of salted silver jewfish using a hybrid solar drying system (HSDS). An HSDS consisted of V-groove solar air collector, fans, rotating rack-drying chamber, diesel burner and PV array. At an average solar radiation of 540 W/m^2 and a mass flow rate of 0.0778 kg/s, the collector efficiency and drying system efficiency were about 41% and 23%, respectively. The total energy required used is 89.9 kWh and the solar energy contribution is 66% (59.6 kWh) of the total energy. The diesel burner and fans power used is 29 % (25.8 kWh) and 5 % (4.5 kWh), respectively. Specific energy consumption was 2.92 kWh/kg. Moreover, the exergy efficiency of solar drying ranged from 17% to 44%, with an average of 31%. The improvement potential was 106 W to 436 W, with an average of 236 W.

Keywords: Energy, exergy, improvement potential, solar drying, salted silver jewfish

1 Introduction

Solar energy is the world's most abundant, permanent, and environmentally compatible source of energy. Conversion to clean energy sources, such as solar energy, would improve the quality of life on Earth, not only for humans but also for flora and fauna. Most agricultural and marine products that are meant to be stored must be dried first to preserve the quality of the final product. Most of the dried salted fish in Malaysia are dried under open sun. This process requires large open space areas and is largely dependent on the availability of sunshine. This process is also susceptible to contamination by foreign materials, such as litter and dust, as well as exposure to rodents, insects and bird. As an alternative to open sun drying, the solar drying system is one of the most attractive and promising applications of solar energy systems. It is a renewable and environmentally friendly technology that is also economically viable is most developing countries. Recently, many studies have reported on various solar drying systems for marine and agricultural products [1-3].

The drying process aims to use a minimum amount of energy to remove the maximum moisture for the desired final conditions of the products. Thermodynamics significantly affects the energy efficiency of industrial processes. Exergy analysis is a useful method to establish strategies to design and operate many industrial processes, in which the optimal use of energy is an important issue. This information is relevant to determine plant and operation costs, energy conservation, fuel versatility, and pollutants [4, 5]. Exergy analysis has been widely used to evaluate the performance of solar drying systems. Several studies have analyzed the exergy of food drying. However, a detailed literature review in the present study found no information on energy and exergy analyses of solar drying systems for salted silver jewfish. Limited data are available on solar drying for salted silver jewfish and on the improvement potential of solar drying systems. Therefore, this study analyzes the energy and exergy in solar drying systems for salted silver jewfish.

2 Material and Methods

Samples of the Malaysian silver jewfish (*Johnius saldodo*), also known as "ikan gelama papan", were obtained from Johor Sea, Malaysia, as shown in Fig. 1. The Malaysian silver jewfish is very nutritious, with the following composition of nutrients in a 100 g edible portion: 18.7 g of protein, 9.0 g of fat, 12.0 g of carbohydrate, 14.0 g of ash, 34.0 mg of calcium, 211.0 mg of phosphorus, 0.4 mg of iron, 91.0 mg of sodium, and 405.0 mg of potassium. The Malaysian silver jewfish also contains several vitamins and energy of 50.3 kCal [6].

Fig. 2 shows the HSDS installed in Johor, Malaysia. The HSDS was of the forced-convection indirect type. The system consisted of a V-groove solar air collector, a diesel burner, fans, a rotating rack-drying chamber, and a PV array. Six collectors, which were connected in series, had a total area of 13.8 m^2. A diesel engine equipped with an on/off controller was attached to the system to provide continuous heat as required by the drying commodities. Setting the temperature at the required drying temperature can control the drying chamber temperature.

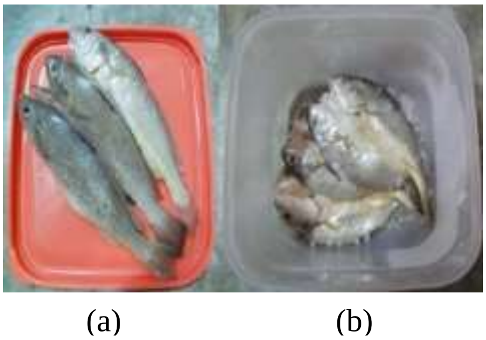

Fig. 1 (a) Fresh silver jewfish, (b) Salted silver jewfish

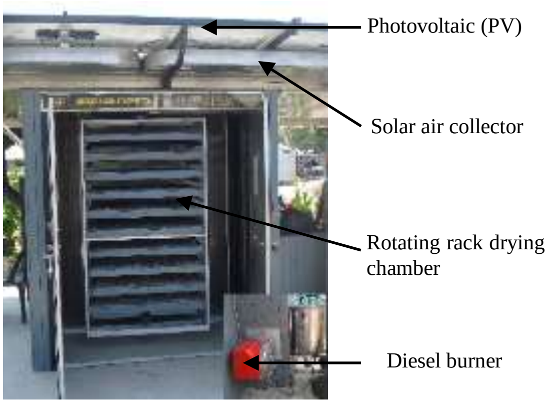

Fig. 2 Photograph of the salted silver jewfish in HSDS

Experiments were conducted between 8AM and 7PM. Drying experiments were performed on 51 kg of salted silver jewfish, and then the fish was divided equally and placed on 10 trays. During this process, the temperature setting in the drying chamber was fixed at 50 °C, and the flow rate was fixed at 0.0778 kg/s. Air temperature (ambient temperature and the air temperature at the inlet and outlet of the collector), solar radiation, and air velocity were measured. The temperature of air before it entered the dryer chamber, the temperature inside the drying chamber, and the air temperature outside the drying chamber were also measured. Relative humidity sensors were installed in the inlet, middle, and outlet of the drying chamber. Air temperature was measured by a T-type thermocouple, and the intensity of solar radiation was measured by a pyranometer.

3 Energy and exergy analyses

The specific energy consumption (SEC) of the solar drying system can be calculated as [7]

$$SEC = \frac{P_t}{W}, \tag{1}$$

where
SEC = the specific energy consumption (kWh/kg)
W = the mass of water evaporated from the product (kg)
P_t = the total energy input to the dryer (kWh)

The mass of water removed (W) from a wet product can be calculated according to [8]

$$W = \frac{m_o\left(M_i - M_f\right)}{100 - M_f}, \tag{2}$$

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

The thermal efficiency of the solar collector was estimated according to the following equation [9, 10]:

$$\eta_c = \frac{mC\left(T_o - T_i\right)}{A_c S} \times 100\%, \tag{3}$$

where
m = the mass flow rate (kg/s)
C = the specific heat of air (J kg^{-1} $°C^{-1}$)
A_c = the collector area (m^2)
T_i = the inlet air temperature (°C)
T_o = the outlet air temperature (°C)
S = the solar radiation (W/m^2)

System drying efficiency was defined as the ratio of the energy required to evaporate from the moisture to the heat supplied to the drier. The system efficiency for forced convection solar dryers need to take into account the energy consumed by fan/blower. For hybrid SDSs, which uses additional energy from a second source (e.g. biomass, LPG etc), the system efficiency is given by [11]:

$$\eta_d = \frac{W \times L}{\left(A_c S + P_f\right) + \left(m_b \times H_b\right)}. \tag{4}$$

where
W = weight of water evaporated from the product (kg)
L = latent heat of water vaporization at the exit air temperature (J/kg)
A_c = collector area (m^2)

S = solar radiation (W/m^2)
P_f = fan power (W)
$m_b \times H_b$ = energy input by the additional energy source

The general form of exergy efficiency is expressed as follows [12-14]:

$$\eta_{Ex} = \frac{Ex_{dco}}{Ex_{dci}} = 1 - \frac{Ex_{loss}}{Ex_{dci}}. \tag{5}$$

The exergy efficiency of a system or process is maximized when exergy loss Ex_{loss} is minimized. The concept of an exergetic “improvement potential” (IP) can be a very useful tool to analyze systems or processes efficiently. The IP of a system or process is given by [14, 15]:

$$IP = (1 - \eta_{Ex}) Ex_{loss}. \tag{6}$$

4 Results and discussion

An HSDS for drying salted silver jewfish was tested. The fish was dried to a final moisture content of 10% from 64% (wet basis) in 8 h. The thin-layer drying characteristics of the salted silver jewfish were investigated. The variations in solar radiation, ambient temperature, drying chamber air temperature, ambient relative humidity, and drying chamber relative humidity in 1 d of drying are shown in Fig. 3. Increasing solar radiation increased air temperature and thus decreased relative humidity. The daily mean of the drying chamber air temperature (T_c), drying chamber relative humidity (H_c), and solar radiation (S) varied from about 48 °C to 51 °C, 46% to 67%, 130 W/m^2 to 780 W/m^2, respectively (with an average of about 50 °C, 56%, and 540 W/m^2). The drying temperature and relative humidity in solar drying varied continuously with a long drying time. The solar drying temperature was greater than the ambient temperature, whereas the relative humidity in solar drying was lower than the ambient relative humidity. A significant difference was also found between drying temperature and relative humidity.

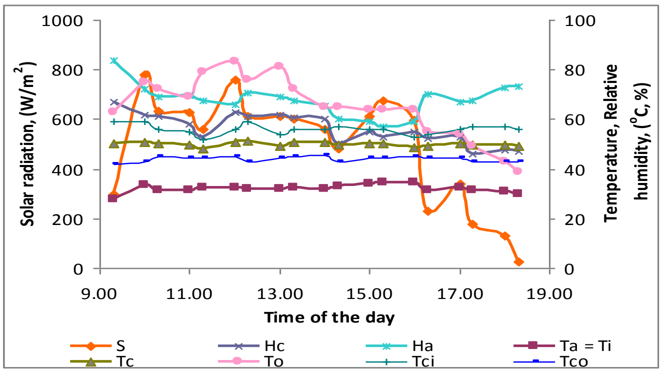

Fig. 3 Temperature, relative humidity, and solar radiation with time of day

The drying of about 51 kg of salted silver jewfish in the chamber took 8 h to reduce the initial moisture content of 64% to 10%, which is equivalent to 51.26 kg to 21.73 kg. During 1 d of drying (8 h), the daily average air temperature in the drying chamber was 50 °C, and the average solar radiation was 540 W/m^2 at a mass flow rate of 0.0778 kg/s, as shown in Fig. 4. The efficiency of the collector varied from 25% to 68%, and the average efficiency of the collector was about 41%, as shown in Fig. 4. At a low solar radiation, the thermal efficiency of the collector increased. A specific energy consumption of 2.92 kWh/kg was calculated according to Eq. (1). However, the weight of water that evaporated from the salted silver jewfish according to Eq. (2) was 30.76 kg. Adding L= 2383 kJ/kg (662 Wh/kg) at T = 50 °C [14], t = 8 h, and S = 540 W/m^2 to Eq. (4) yielded a drying efficiency of 22.6%.

During the solar drying process, the exergy efficiency calculated according to Eq. (5) was 17% to 44%, with an average of 31%, as shown in Fig. 5. Eq. (6) indicates that the improvement potential was between 106 and 436 W, with an average of 236 W, as shown in Fig. 5 and Table 1. Table 1 summarizes the experimental results and observations presented in the study.

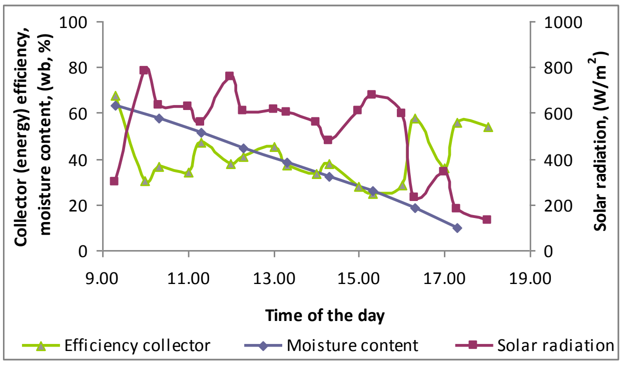

Fig. 4 Variation in moisture content, collector (energy) efficiency and solar radiation at a mass flow rate of 0.0778 kg/s

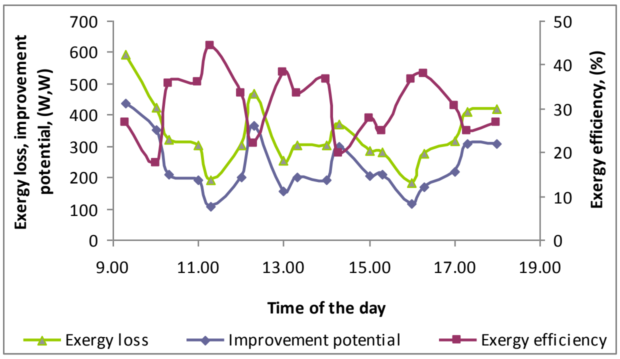

Fig. 5 Variation in exergy loss, improvement potential, and exergy efficiency as a function of time

Table 1 Performance of HSDS for salted silver jewfish

Parameters	Unit	Value
Initial weight (total)	kg	51.26
Final weight (total)	kg	21.73
Drying temperature	^{o}C	50
Mass flow rate	kg/s	0.0778
Fans and motor energy	kWh	4.5
Diesel burner energy	kWh	25.82
Solar energy	kWh	59.62
Volume diesel	L	2
Specific energy consumption	kWh/kg	2.92
Overall collector efficiency	%	41
Overall drying efficiency, up to 10% wet basis	%	23
Overall exergy efficiency, up to 10% wet basis	%	31
Overall improvement potential	W	236

5 Conclusions

A hybrid solar drying system (HSDS) was evaluated for 51 kg of salted silver jewfish. It was dried to the final moisture content of 10% from 64% (wet basis) in 8 h. The total energy required used is 89.9 kWh and the solar energy contribution is 66% (59.6 kWh) of the total energy. The diesel burner and fans power used is 29 % (25.8 kWh) and 5 % (4.5 kWh), respectively. The solar collector and drying system had an efficiency of about 41% and 23%, respectively, at an average solar radiation of about 540 W/m^2 and an air flow rate of 0.0778 kg/s. A minimum and maximum collector efficiency of about 25% and 68%, respectively, was observed. The specific energy consumption was 2.92 kWh/kg. Exergy efficiency varied between 17% and 44%. The improvement potential was between 106 and 436 W, with an average of 236 W.

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References

[1] A. Fudholi, K. Sopian, B. Bakhtyar, M. Gabbasa, M.Y. Othman and M.H. Ruslan, Review of solar drying systems with air based solar collectors in Malaysia, *Renewable and Sustainable Energy Review*, **51** (2015), 1191-1204. http://dx.doi.org/10.1016/j.rser.2015.07.026

[2] A. Fudholi, K. Sopian, M. Gabbasa, B. Bakhtyar, M. Yahya, M.H. Ruslan and S. Mat, Techno-economic of solar drying systems with water based solar

collectors in Malaysia: A review, *Renewable and Sustainable Energy Review*, **51** (2015), 809-820. http://dx.doi.org/10.1016/j.rser.2015.06.059

[3] A. Fudholi, K. Sopian, M.H. Ruslan, M.A. Alghoul and M.Y. Sulaiman, Review of solar dryers for agricultural and marine products, *Renewable and Sustainable Energy Reviews*, **14** (1) (2010), 1–30. http://dx.doi.org/10.1016/j.rser.2009.07.032

[4] A. Akbulut, A. Durmus, Energy and exergy analyses of thin layer drying of mulberry in a forced solar dryer, *Energy*, **35** (2010), 1754-1763. http://dx.doi.org/10.1016/j.energy.2009.12.028

[5] E.K. Akpinar, Drying of mint leaves in a solar dryer and under open sun: modelling, performance analyses, *Energy Conversion and Management*, **51** (2010), no. 12, 2407–2418. http://dx.doi.org/10.1016/j.enconman.2010.05.005

[6] T.E. Siong, S.M. Shahid, R. Kuladevan, Y.S. Ing and K.S. Choo, Nutrient composition of Malaysian marine fishes, *Asean Food Journal*, **3** (1987), no. 2, 67-71.

[7] A. Fudholi, K. Sopian, M.Y. Othman and M.H. Ruslan, Energy and exergy analyses of solar drying system for red seaweed, *Energy and Buildings*, **68** (2014), 121-129. http://dx.doi.org/10.1016/j.enbuild.2013.07.072

[8] A. Fudholi, M.Y. Othman, M.H. Ruslan and K. Sopian, Drying of Malaysian *Capsicum annuum* L. (red chili) dried by open and solar drying, *International Journal of Photoenergy*, **2013** (2013), 1-9. http://dx.doi.org/10.1155/2013/167895

[9] A. Fudholi, K. Sopian, M.H. Ruslan, and M.Y. Othman, Performance and cost benefits analysis of double-pass solar collector with and without fins, *Energy Conversion and Management*, **76** (2013), 8–19. http://dx.doi.org/10.1016/j.enconman.2013.07.015

[10] A. Fudholi, K. Sopian, M.Y. Othman, M.H. Ruslan, and B. Bakhtyar, Energy analysis and improvement potential of finned double-pass solar collector, *Energy Conversion and Management*, **75** (2013), 234-240. http://dx.doi.org/10.1016/j.enconman.2013.06.021

[11] L. Bennamoun, An overview on application of exergy and energy for determination of solar drying efficiency, *International Journal of Energy Engineering*, **2** (2012), no. 5, 184-194. http://dx.doi.org/10.5923/j.ijee.20120205.01

[12] A. Fudholi, S. Mat, D.F. Basri, M.H. Ruslan, K. Sopian, Performances analysis of greenhouse solar dryer with heat exchanger, *Contemporary Engineering Sciences*, **9** (2016), no. 3, 135-144. http://dx.doi.org/10.12988/ces.2016.512322

[13] A. Fudholi, K. Sopian, M.H. Yazdi, M.H. Ruslan, M. Gabbasa and H.A. Kazem, Performance analysis of solar drying system for red chili, *Solar Energy*, **99** (2014), 47-54. http://dx.doi.org/10.1016/j.solener.2013.10.019

[14] A. Fudholi, K. Sopian, M.A. Alghoul, M.H. Ruslan and M.Y. Othman, Performances and improvement potential of solar drying system for palm oil fronds, *Renewable Energy*, **78** (2015), 561-565. http://dx.doi.org/10.1016/j.renene.2015.01.050

[15] A. Ibrahim, A. Fudholi, K. Sopian, M.Y. Othman, M.H. Ruslan, Efficiencies and improvement potential of building integrated photovoltaic thermal (BIPVT) system, *Energy Conversion and Management*, **77** (2014), 527-534. http://dx.doi.org/10.1016/j.enconman.2013.10.033

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