Energy Consumption of Hybrid Solar Drying System (HSDS) with Rotating Rack for Salted Silver Jewfish

AHMAD FUDHOLI, MOHD HAFIDZ RUSLAN, MOHD YUSOF OTHMAN, KAMARUZZAMAN SOPIAN

Solar Energy Research Institute (SERI), Universiti Kebangsaan Malaysia
43600 UKM Bangi, Selangor,
MALAYSIA.

Correspondent author, Email: a.fudholi@gmail.com; hafidz@ukm.my; myho@ukm.my; ksopian@eng.ukm.my

Abstract: This paper presents the energy consumption of a hybrid solar drying system (HSDS) with rotating rack for salted silver jewfish. Performances including energy consumption of a HSDS are evaluated for Malaysian silver jewfish (*Johnius saldodo*) as known ikan gelama papan. There are dried from moisture content of about 64% (wet basis) to 10% (wet basis) in 8 h. Daytime and nighttime drying approaches are used, which a flow rate of 0.08 kg/s and the set temperature of the drying chamber is 50^{o}C. For daytime drying, the collector and drying system efficiencies is found about 40% and 23%, respectively. The solar, diesel and fans energy used is 59.6 kWh (66 %), 25.8 kWh (29 %) and 4.5 kWh (5 %), respectively. Than specific energy consumption (SEC) is found 2.92 kWh/kg. For nighttime drying, the volume consumption of diesel burner is 5 L. The total energy required used is 68.6 kWh, which the diesel contribution is 94 % of the total energy. The drying efficiency and SEC is found 29 % and 2.29 kWh/kg, respectively.

Keywords: Specific energy consumption, drying efficiency, hybrid solar drying system, salted silver jewfish

1. Introduction

Solar energy is the world's abundant permanent and environmentally compatible source of energy. Conversion to clean energy sources such as solar energy would enable the world to improve the quality of life throughout the planet Earth, not only for humans, but also for its flora and fauna as well. Most agricultural and marine products that are intended to be stored must be dried first in an effort to preserve the quality of the final product. Most of the dried salted fish in Malaysia are dried under the open sun. There is requires large open space area, and very much dependent on the availability of sunshine, susceptible to contamination with foreign materials such as litters, dusts and are exposed to rodents, insect and birds [1-4].

As an alternative to open sun drying, solar drying system is one of the most attractive and promising applications of solar energy systems [5]. It is renewable and environmentally friendly technology, also economically viable in most developing countries. Recently, many have reported on various solar drying systems of marine and agricultural products [6-11]. Objective of this paper is to present the energy consumption of HSDS for salted silver jewfish with daytime and nighttime drying.

2. Material and Methods

2.1 Fish

The silver jewfish (*Johnius saldodo*) Malaysian also known as "ikan gelama papan" used in this study was obtained from Johor Sea, Malaysia. The Silver jewfish is found to contain very nutritious. Composition of nutrients in 100 g edible portion of Silver Jewfish are protein of 18.7 g, fat of 19 g, carbohydrate of 12 g, ash of 14 g, calcium of 34 mg, phosphorus of 211 mg, iron of 0.4 mg, sodium of 91 mg, potassium of 405 mg etc. There are found to contain several vitamins and energy of 50.3 kCal [12]. The initial moisture content of salted fish was determined by using the drying in an air oven at a temperature of 120^{o}C in order to obtain a constant weight [13]. The salted silver jewfish has moisture content of 63.64% (wet basis).

Fig. 1 and Fig. 2 show fresh and salted silver jewfish, respectively. The silver jewfish are soaked in separate containers containing 25% (w/v) brine solution of NaCl for 4 h. A fish-to-brine ratio of 1:4 L is used [14,15]

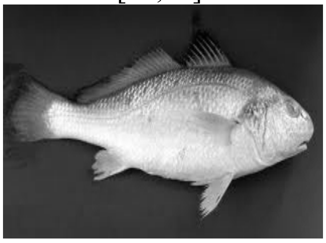

Fig. 1 Fresh silver jewfish

Fig. 2 Salted silver jewfish

2.2 Hybrid solar drying System (HSDS)

Fig.3 shows photograph of HSDS. It is classified as a forced convection indirect type. The HSDS consists of the V-groove solar air collector, diesel burner, fans, rotating rack drying chamber and PV array. The solar collector is of the back-pass V-groove as shown in Fig.4. The collector's efficiency with the V-groove absorber is 7.4% higher than the collector with the flat plate absorber [16]. Six collectors are connected in series with the total area is 13.8 m^2. A diesel engine is equipped with an on/off controller. 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.

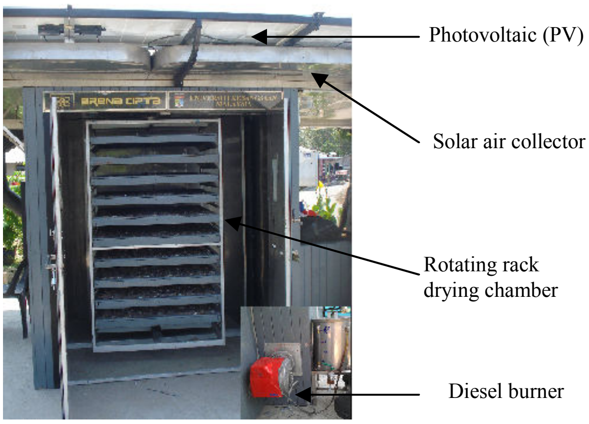

Fig.3 Photograph of salted silver jewfish in HSDS with rotating rack

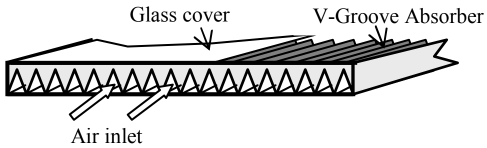

Fig. 4 The back-pass V-groove solar air collector

2.3 Experimental Methods

For daytime drying, the HSDS is operated from 8:00 AM to 7:00 PM. Drying experiment has been done on 51 kg salted silver jewfish. It is divided equally and then placed on 10 trays. During this process the drying temperature setting in drying chamber is fixed at 50^{o}C and the flow rate is fixed at 0.08 kg/s. 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.

The thermal efficiency of a solar collector is the ratio of useful heat gain to the solar radiation incident on the plane of the collector. It is defined as [17]

$$\eta_c = \frac{mC(T_o - T_i)}{A_c S} \times 100\% \qquad (1)$$

where,

m = mass flow rate (kg/s)

C = specific heat of air (J kg^{-1} ^{o}C^{-1})

A_c = collector area (m^2)

T_i = inlet air temperature (^{o}C)

T_o = outlet air temperature (^{o}C)

S = solar radiation intensity (W/m^2)

System drying efficiency is defined as the ratio of the energy required to evaporate the moisture to the heat supplied to the drier. For the solar collector the heat supplied to the drier is the solar radiation incident upon the solar collector. The system drying efficiency is a measure of the overall effectiveness of drying systems. For hybrid dryers, which uses additional energy from a second source (e.g. biomass, LPG etc), the system efficiency and specific energy consumption (SEC) are given by [18,19]

$$\eta_p = \frac{W \times L}{(A_c S + P_f) + (m_b \times H_b)} = \frac{W \times L}{Q} \qquad (2)$$

$$SEC = \frac{Q}{W} \qquad (3)$$

where,

$m_b \times H_b$ = the energy input by the additional energy source
Q = the total of energy consumtion which consists of the solar radiation, fuel and electrical which are consumed during the drying process
L = latent heat of vaporisation of water at exit air temperature (J/kg)
W = mass of water evaporated from the product (kg).
The mass of water removed (W) to from wet product can be calculated as [20]

$$W = \frac{m_o(M_i - M_f)}{100 - M_f} \quad (4)$$

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

3. Results and Discussion

Table 1 shows the summary of the experimental results and observations of open and solar hybrid drying for salted silver jewfish. And shown are the energy usage of the fans and the energy input by the additional energy source. The required drying time and performance are also shown. Also shown are the initial and final moisture content (wet basis). For nighttime drying, fan energy consumption less compared for daytime drying, because for daytime drying fan used to reduce over heat. The energy consumption of the experiments is displayed in Fig. 5.

Table 1 Experimental results and observations

Parameters and observations	Daytime drying	Nighttime drying
Initial weight (sample) (g)	220	200
Final weight (sample) (kg)	80	72
Initial weight (total)	51.3	50
Final weight (total)	21.7	20.6
Initial moisture content (wet basis)	64	64
Final moisture content (wet basis)	10	10
Drying temperature (°C)	50	50
Mass flow rate (kg/s)	0.08	0.08
Fans and motor energy (kWh)	4.5	4
Diesel burner energy (kWh)	25.8	64.6
Solar energy (kWh)	59.6	-
Drying time (h)	8	8
Volume diesel (L)	2	5
Drying efficiency (%)	22.6	29
SEC (kWh/kg)	2.92	2.29

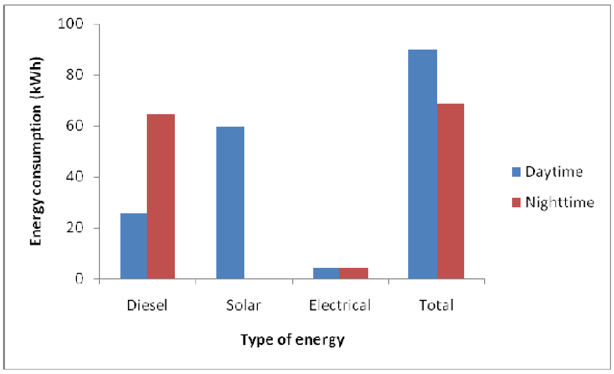

Fig. 5 Energy consumption during drying

During the daytime drying, the variations of the solar radiation, ambient temperature, drying chamber air temperature, relative humidity of ambient, and relative humidity of drying chamber is shown in Fig.6. 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 daytime drying, the daily mean of drying chamber air temperature, relative humidity of drying chamber and solar radiation range vary from about 48-51°C, 46-67%, 130-780W/m^2, with an average of about 50°C, 56%, 540W/m^2 respectively. The drying temperature and relative humidity in solar drying varied continuously a long drying time. It is 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. On the other hand, the efficiency of collector varies from 30 to 68%, and the average efficiency of collector was about 40% at drying air flow rate of 0.08kg/s. The collector efficiency is shown in Fig. 7. From this figure, it is observed that at low solar radiation, the thermal efficiency of collector is increased. Fig. 7 also shows the variations in the moisture content. The experimental results of HSDS to 51.3 kg dry salted silver jewfish so that the water content of about 10% is required within 8 h to yield 21.7 kg. However, obtained weight of water evaporated from the salted silver jewfish of 30.76 kg by Eq. (4). Putting L = 2383 kJ/kg or 661.2Wh/kg (for T = 50°C), t = 8 h and S = 540 W/m^2 into Eq. (2), obtained drying efficiency is 22.6%. By using Eq. (3) specific energy consumption is obtained is 2.92 kWh/kg.

ISBN: 978-1-61804-175-3

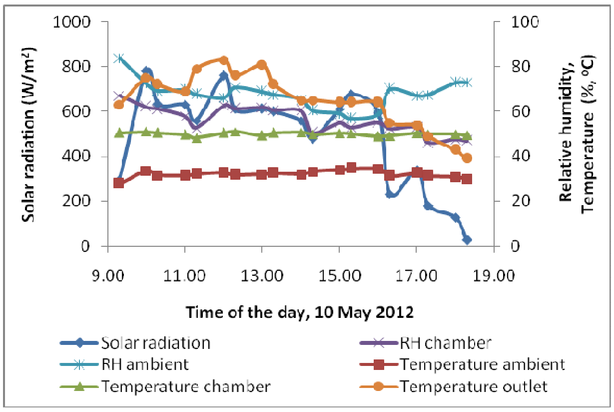

Fig.6 Temperatures (ambient and chamber), relative humidity of chamber, ambient humidity and solar radiation

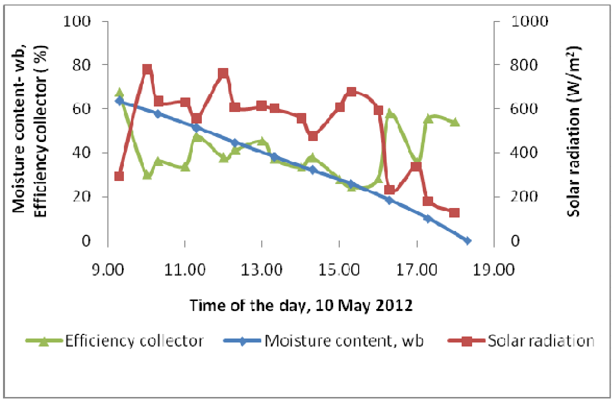

Fig.7 Moisture content, efficiency of collector and solar radiation with m = 0.08kg/s

For nighttime drying, 50 kg dry salted silver jewfish so that the water content of about 10% is required within 8 h to yield 20.6 kg. By using Eq. (4) obtained weight of water evaporated is 30 kg. By using Eq. (2) and Eq. (3) obtained drying efficiency and specific energy consumption is 29 % and 2.29 kWh/kg.

4. Conclusion

Performances of a HSDS are evaluated for Malaysian silver jewfish (*Johnius saldodo*) with daytime and nighttime dying. For daytime drying, the collector efficiency is about 30 – 68 % at solar radiation levels of 300 – 800 W/m^2 with a flow rate of 0.08 kg/s. For optimum storage and preservation of dried the salted silver jewfish, the final moisture content should be about 10 % (wet basis). The set temperature of the drying chamber is 50°C. The drying time is 8 h. The total energy required used is 89.94 kWh and the solar energy contribution is 66 % of the total energy. The diesel burner and fans power used is 29 % and 5 %, respectively. The drying system efficiency and specific energy consumption (SEC) obtained is 23 % and 2.92 kWh/kg. For nighttime drying, the volume consumption of diesel burner is 5 L. The diesel and fans energy used is 64.6 kWh (94 %) and 4 kWh (6 %), respectively. The drying efficiency and SEC is found 29 % and 2.29 kWh/kg, respectively.

Acknowledgements

The authors would like to thank the Universiti Kebangsaan Malaysia (UKM) and CIMB Bank for funding this research (UKM-HEJIM-KOMUNITI-13-2010). Also the Solar Energy Research Institute (SERI), UKM for providing the laboratory facilities and technical support.

References

[1] Sopian K, Mohd Y.O., Mohd H.R., Baharidin Y. Performance of a solar assisted drying system for chilies. International Jurnal of Renewable Energy Engineering 2001; 3 (1): 268-272

[2] Fudholi A, Mohd. H.R., Lim C.H., Sohif M., Mohd. Y.O., Azami Z, Kamaruzzaman S. Mathematical modeling of brown seaweed drying curves, in *WSEAS Int. Conf. on Applied Mathematics in Electrical and Computer Engineering*, USA, 2012: 207-211.

[3] Sopian K., Mohd Y.S., Mohd Y.O., Sohif M., Muhamad Y., Mohamad A.A., Baharudin A., Lim C.H., Mohd H.R., Azami Z. Advantaces in solar assisted drying systems for agricultural produce. In Proc. of the 4th IASME/WSEAS Int. Conf. on Energy & Environment (EE'09), 2009: 393-398.

[4] Sopian K., Mohd Y.O., Saleem H.Z. Advances in solar assisted drying system for marine and agricultural products. 2012. http://ases.conference-service.net/resources/252/2859/pdf/SOLAR2012

[5] Fudholi A, Kamaruzzaman S, Mohd. H.R, Mohamad A.A, Mohd. Y.S. Review of solar dryers for agricultural and marine products. Renewable and Sustainable Energy Review 2010;14:1-30.

[6] Othman M.Y., Kamaruzzaman S., Baharudin Y., Wan R.W.D. Solar drying technology for agricultural produce. Word Renewable Energy Congress VI (WREC2000), 2000: 922-927.

[7] Ruslan M.H, Ahmad F, Mohd. Y.O., Mohd. S.M.A, Muhammad Y, Azami Z and Kamaruzzaman S, The double-pass solar dryer for drying palm oil fronds, in *Proc. of the 10th WSEAS Int. Conf. on System Science and Simulation in Engineering (ICOSSSE'11)*, Malaysia, 2011, pp. 143-149.

[8] Kituu G.M., D. Shitanda, C.L. Kanali, J.T. Mailutha, C.K. Njoroge, J.K. Wainaina, V.K. Silayo. Thin layer drying model for

simulating the drying of Tilapia fish (Oreochromis niliticus) in a solar tunnel dryer. Journal of Food Engineering 2010; 98: 325-331.

[9] Fudholi A, Mohd Y.O, Mohd H.R, Muhamad Y, Azami Z and Kamaruzzaman S. Techno-economic analysis of solar drying system for seaweed in Malaysia, in *Proc. of the 7th IASME/WSEAS Int. Conf. on Energy, Environment, Ecosystems and Sustainable Development (EEESD,11),* France, 2011: 89-95.

[10] Fudholi A, Mohd. Y.O., Mohd. H.R., Muhammad Y., Azami Z., Kamaruzzaman S. Design and testing of solar dryer for drying kinetics of seaweed in Malaysia, in *Recent Research in Geography, Geology, Energy, Environment and Biomedicine,* Corfu, 2011: 119-124.

[11] Othman M.Y., Ahmad F, Kamaruzzaman S., Mohd H.R., and Muhamad Y. Analisis Kinetik Pengeringan Rumpai Laut *Gracilaria cangii* Menggunakan Sistem Pengering Suria (Drying Kinetics Analysis of Seaweed *Gracilaria cangii* using Solar Drying System). Sains Malaysiana 2012; 41 (2): 245-52.

[12] Siong T.E., Siti M.S., R. Kuladevan, Young S.I., Khor S.C. Nutrient composition of Malaysian marine fishes. Asean Food Journal 1987; 3 (2): 67-71.

[13] Fudholi A, Mohd. Y.O., Mohd. H.R., Muhammad Y., Azami Z., Kamaruzzaman S. The effects of drying air temperature and humidity on drying kinetics of seaweed, in *Recent Research in Geography, Geology, Energy, Environment and Biomedicine,* Corfu, 2011: 129-133.

[14] Chavan B.R., A. Yakupitiyage, S. Kumar. Drying performance, quality characteristics, and financial evaluation of Indian Mackerel (Rastrilliger kangurta) dried by a solar tunnel dryer. Thammasat Int. J. Sc. Tech. 2011; 16(2); 11-25

[15] Sankat C,K., Saheeda M. Sun and solar cabinet drying of salted shark fillets, in Proc. of the 14 th Int. Drying Symposium (IDS 2004), Brazil 2004; Vol.C: 1584-1591.

[16] Fudholi A, Kamaruzzaman S., Mohd Y. O., Mohd H.R., Mohamad A.G., Azami Z., Zulkifly. Heat transfer correlation for the v-groove solar collector, in *Proc. of the 8th WSEAS Int. Conf. on SIMULATION, MODELING and optimization (SMO'08)*, Spain, 2008: 177-182.

[17] Fudholi A, Kamaruzzaman S, Mohd H.R, Mohd Y.O., Muhammad Y. Analytical and experimental studies on the thermal efficiency of double-pass solar collector with finned absorber. American Journal of Applied Sciences 2011; 8 (7): 716-23.

[18] Leon M.A, Kumar S, Bhattacharya B.C. A comprehensive procedure for performance evaluation of solar food dryers. Renewable and Sustainable Energy Reviews 2002; 6: 367-393.

[19] Nelwan L.O., Kamaruddin A., A.H. Tambunan, A. Suwoto. Energy consumtion of solar-assisted dryer with rotating rack for cocoa beans, in Teknologi Berbasis Sumber Energi Terbarukan untuk Pertanian. IPB Press, 2007: 120-135.

[20] Al-Juamily K.E.J., Abdul J.N.K., Tadahmun A.Y. Testing of the performance of a fruit and vegetable solar drying system in Iraq. Desalination 2007; 209: 163-170.