Techno-Economic Analysis of Solar Drying System for Seaweed in Malaysia

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Abstract:- Solar drying system is one of the most attractive and promising applications of solar energy systems in tropical and subtropical countries. Up to now only a few solar dryers who meet the technical, economical and socio-economical requirements are commercially available. The design of suitable air collector is one of the most important factors controlling the economics of the solar drying system. A solar dryer system suitable for agricultural and marine products is designed, constructed and evaluated under the Malaysia climate conditions. The main components of the system are double-pass solar collector with finned absorber, the blower, the auxiliary heater and the drying chamber. The solar drying system is evaluated for drying seaweed. The initial and final moisture content of seaweed are 90% (wet basis) and 10% (product basis) respectively. The drying time is about of 15 hours at average solar radiation of about 507 W/m^2 and air flow rate 0.0536 kg/s. The collector, drying system and pick-up efficiencies are found to be 35, 27 and 95% respectively. From assuming potential market prices, the results of economic analyzed indicated that using the double-pass solar collector are best suited to be developed or marketed in marine products, as it is a payback period as low as 2.33 year to the drying of seaweed.

Key-Words:- Solar drying performance, double-pass solar collector, economic study, seaweed

1 Introduction

Malaysia is located in the equatorial region. Malaysia is located between 1.30^o to 6.60^o North longitude and 99.50^o to 103.30^o East latitude. Malaysia typically receives about 13 hours of solar radiation. The average solar radiation is 4-5 kWh/m^2, while the average number of hours of irradiation of between 4 to 8 hours, the average temperature is around 26 to 32^{o}C and the average relative humidity of 80 to 90% and never falls below 60% (Othman et al. 1993). In Malaysia, there is an increase in the mean daily global solar radiation. In the early 1990 about the value will rise to 4.5 kWh/m^2 (Sopian & Othman 1992), and added value rose again to a level 5.0 kWh/m^2 through research done by using satellite imaging (Azhari et al. 2008). Therefore, the use of solar drying system is a potential with the climate of Malaysia. An analysis of solar radiation at several main towns in Malaysia shows that solar radiation is possible to be used in solar drying (Sopian & Othman 1992).

Malaysia is a country that exports many agricultural and marine products to other countries. Demand for products of agriculture and marine products is a high quality dry. Most agricultural commodities and marine products such as dried seaweed require drying process in an effort to finally get a quality product. Seaweed (Eucheuma cottonii) is one source of income, particularly people in Semporna, Sabah. The seaweed industry is grown but it is also become a source of income if carried out by communities, associations as well as individuals. Seaweed is widely used in production of food and medical products and industry manufacture at present. Problems faced by the people of seaweed farmers are depending of the weather, requirement of large space and long drying time. Open sun drying take 10-14 days of 10% of original weight.

Solar drying system is one of the most attractive and promising applications of solar energy systems in tropical and subtropical countries. Up to now only a few solar dryers who meet the technical, economical and socio-economical requirements are commercially available. The technical development of solar drying systems can proceed in two directions. Firstly, simple, low power, short life, and comparatively low efficiency-drying system.

Secondly, high efficiency, high power, long life expensive drying system (Fudholi et al. 2010). The solar drying system consist collector, assisted heater, blower and drying chamber. The design of suitable air collectors is one of the most important factors controlling the economics of the solar drying. To date, flat plate solar collectors are widely used. This study is techno-economic of a solar assisted drying system using double-pass solar collector with finned absorbers.

2 Material and Methods

The experiment is carried out at the Green Energy Technology Innovation Park, Universiti Kebangsaan Malaysia.

2.1 Description of Solar Drying System

The solar assisted forced convection drying system is installed at the Green Energy Technology Innovation Park, Universiti Kebangsaan Malaysia. This drying system is capacity of drying 300 kg seaweed. Fig. 1 shows the schematic diagram of the solar drying system. The main components are solar collector array (Fig. 2), auxiliary heater, blower, and drying chamber. The size of the chamber is 4.8 m in length, 1 m width and 0.6 m in height. The collectors are the double-pass finned collector. The four collectors are set in series. The double-pass finned collector efficiency is about of 45-77% (Fudholi et al., 2011)

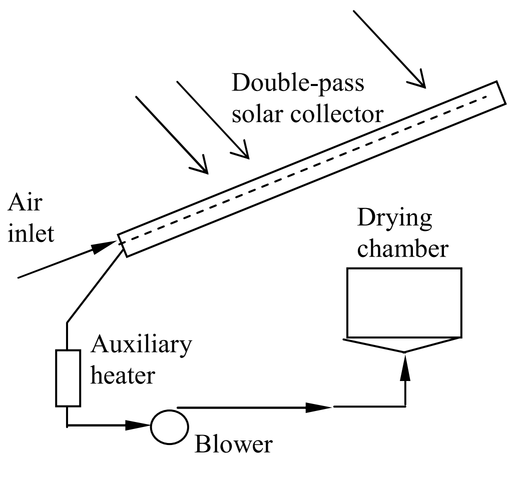

Fig. 1. Schematic diagram of solar drying system

The collector width and length were 1.2 m and 4.8 m respectively. The solar collector array consists of 4 solar collectors. The upper channel depth is 3.5 cm and the lower depth is 7 cm. The bottom and sides of the collector have been insulated with 2.5cm thick fiberglass to minimize heat losses.

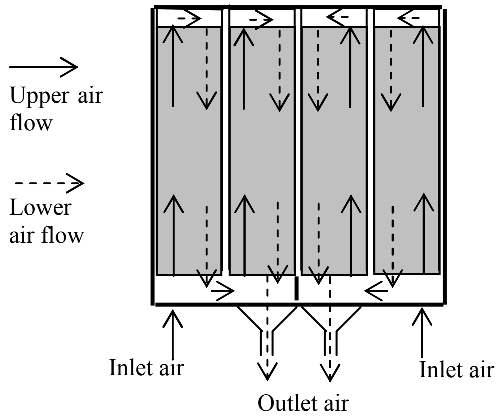

Fig. 2. The collector arrangement for the solar drying system

Fig. 3 shows the cross section of the collector with the aluminium plate fins. The collector consists of the glass cover, the insulated container and the black painted aluminium absorber. The size of the collector is 1.2 m wide and 4.8 cm long. In this type of collector, the air initially enters through the first channel formed by the glass covering the absorber plate and then through the second channel formed by the back plate and the finned absorber plate.

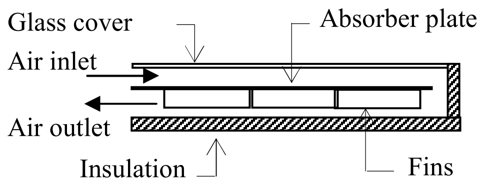

Fig. 3. The schematic of a double-pass solar collector with finned absorber

Table 1. Key parameters of the solar drying system

Parameters	Unit	Value
Collector area	m^2	11.52
Drying chamber area	m^2	4.8
Capacity of dryer	kg	250-300
Mass flow rate	kg/s	0.05-0.12
Average temperature of drying chamber	^oC	40-65

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2.2. Method

Experiment done begins at 08:00 am that day at 06:00 pm, which begins when the data was taken from 09:00 am to 05:00 pm. The next day continued and dryer stopped drying after heavy achieved continuous. The data measured are 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 and wet bulb temperature and dry bulb temperature of the air out of the dryer chamber. Air temperature was measured by T-type thermocouple is then recorded in a data acquisition system. The intensity of solar radiation measured by pyranometer and measurement data recorded in a computer.

3 Data Analysis

3.1 Estimating of Drying Time

Solar drying system is tested for drying of seaweed. The average solar radiation 500 W/m^2, the experiment data as follow:

1. Drying air conditions before entering the collection are:
   Dry bulb temperature of 30 ^{o}C and wet bulb temperature of 28 ^{o}C
2. Drying air flow rate = 0.053 kg/s
3. Average temperature of drying chamber = 60^{o}C

For 40 kg seaweed, water must be evaporated is 35.56 kg. From the psychometric chart in Fig. 4 obtained:

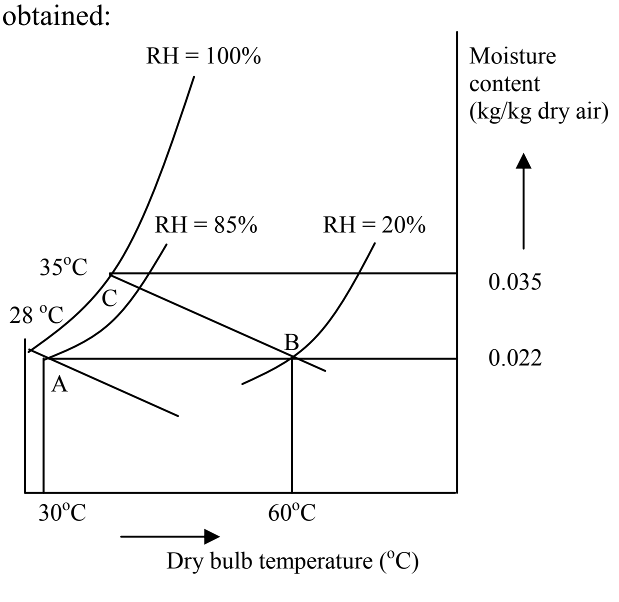

Fig. 4. Simple psychometric chart of drying process

where,
A : ambient air
B : inlet air to drying chamber
C : outlet air to drying chamber
AB: air heating from solar collector
BC: drying process

For 100 kg seaweed, water must be evaporated is about 89 kg, with temperature of drying chamber about 50^{o}C obtained:

(i) The time of drying = 23.35 hours (24 hours) or 3 drying day.
(ii) Evaporation capacity = 0.009 x 0.12 x 3600 = 3.89 kg/h
(iii) Water that can evaporated for 1 kg of dry air = (0035-0022) = 0.013 kg/kg
(iv) Dry air required for drying = 35.56/0.013 = 2735.38 kg
(v) The air dryer required = 2735.38 (1.02) = 2790.09 kg
(vi) The time of drying = 2790.09/ (0.0536) (3600) = 14.46 hours (15 hours) or 2 drying day.
(vii) Evaporation capacity = 0.013 x 0.0536 x 3600 = 2.48 kg/h

3.2 Estimating of Performance Solar Drying System

The 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 (Fudholi et al., 2011)

$$\eta_c = \frac{mC(T_o - T_i)}{A_c S} x100\% \quad (1)$$

where,
m = mass flow rate (kg/s)
C = specific heat of air (J kg^{-1} ^{o}C^{-1})
Ac = 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 (Supranto et al. 2009). For force convection dryer, typical, values are expected. The system efficiency for forced convection solar dryers need to take into account the energy consumed by fan/blower. The following relation is then used (Leon et al., 2002)

$$\eta_p = \frac{WL}{IA_c + P_f} \quad (2)$$

where,
W = weight of water evaporated from the product (kg)
L = latent heat of vaporisation of water at exit air temperature (J/kg)

Pick-up efficiency determines the efficiency of moisture removal by the drying air from the product (Leon et al., 2002).

$$\eta_p = \frac{h_0 - h_i}{h_{as} - h_i} = \frac{W}{v\rho t(h_{as} - h_i)} \quad (3)$$

where,
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 the air entering the dryer at the point of adiabatic saturation (%)
v = volumetric airflow (m^3/s)
ρ = density of air (kg/m^3)
t = drying time (s)

3.3 Economics Analysis

Capital costs (FC) solar drying system installed cost is the sum of all the components as collector, drying chamber, blower, the auxiliary heater, and distribution system and installation costs. The cost of drying (products) can be divided into fixed costs and direct costs. Direct costs comprise costs of fresh materials, labor cost control, electrical, maintenance and insurance. The cost of the product can be written as follows (Yahya 2007)

PC = MTC + LBC + ELC + EC (4)

where

EXC = MC + IC (5)

with
PC = production cost
MTC = cost of fresh materials
LBC = labor costs
ELC = electricity costs
MC = maintenance cost
IC = cost of insurance

Table 2. Estimated cost of components of solar drying system

No	Components/ Parameters	Cost (RM)
1	Double-pass solar collector with finned absorber	15000
2	Ducting system	250
3	Blower	1600
4	Auxiliary heater	1200
5	Distribution system and installation	10000
6	Flooring and drying chamber	4000
	Total capital cost	32050

The performance of an investment can be studied from the production. Profit is defined as the difference between total sales (PP) with all types of spending. Profits can be written as (Yahya 2007)

PR = PP – FC – PC (6)

Return of capital is also called the profit from the investment and is influenced by time, can be written as (Yahya 2007)

$$ROR = \frac{PR}{FC} \quad (7)$$

Simple Payback (SPB) is the investment cost per average annual net income. Returns are easy to recover the invested capital. SPB is calculated as (Fudholi 2006):

$$SPB = \frac{FC}{PR} \quad (8)$$

Parameters of the rate of return of capital and the payback period are not easy to take into account the impact on value for money. While the net present value method (NPV) is calculating the present value of excess cash flow during the project period. NPV is the total present value for each year of the net cash flow less capital costs. It is calculated as follows (Fudholi 2006)

$$\mathrm{NPV} = \sum_{n=1}^{N} \mathrm{P_n}(1+\mathrm{i})^{\mathrm{n}} - \mathrm{FC} \quad (9)$$

Where,

$$P_n = S(1+i)^{-n} \quad (10)$$

Where, P_n is the discounted present value (S) to be invested in the n years in the future. Investment is a positive NPV will be selected.

4 Results and Discussion

Fig. 5 and Fig.6 shows variation of solar radiation (S), collector inlet air temperature (Ti), collector outlet air temperature (To), ambient temperature and drying chamber air temperature (Tc). From these figures, it is evident that solar radiation influences the air temperature out. The higher the intensity of solar radiation means that more energy can be absorbed by the collector and the temperature of air leaving the collector high. The real intensity of solar radiation is not constant, changing from time to time.

During the two days, the daily average of air temperature at the drying chamber are 57 and 64^{o}C and for solar radiations 453 and 562 W/m^2 for mass flow rate 0.0536 kg/s. The efficiency of collector varies from 26 to 80%. The average efficiency of collector is 35%.

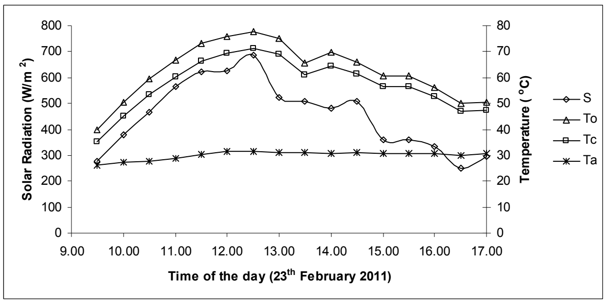

Fig. 5. Temperature (outlet, ambient and chamber) and solar radiation of the 1st drying day

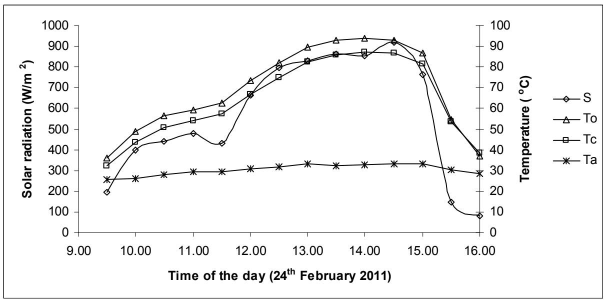

Fig. 6. Temperature (outlet, ambient and chamber) and solar radiation of the 2nd drying day

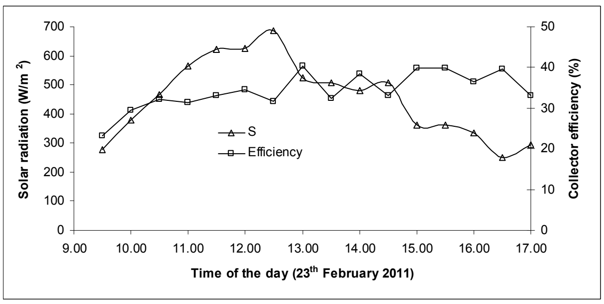

Fig. 7. Efficiency of collector and solar radiation for the 1st drying day

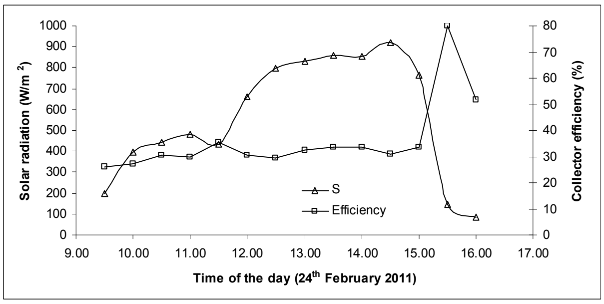

Fig. 8. Efficiency of collector and solar radiation for the 2nd drying day

Experimental results of solar drying system without auxiliary heating to 40 kg dry seaweed so that the water content of about 10% is required within 15 hours (2 days drying) to yield 4.01 kg of dried seaweed. The first day of drying up at 9.00 at 17.00, the second day of drying starts at 09:00 until 16:00. During the drying process of electrical energy supplied for blower = 0.42 kWh (cost about 13 cent). Experiments are in accordance with the previous estimate of 15 hours to 10% water content. By using equations (2) obtained system efficiency is 27.19%. By using equations (3) obtained pick-up efficiency 94.51%.

The cost benefit analysis is performed assuming prevailing market prices seaweed fresh (RM0.2/kg) and the dried products (RM5/kg). The operational cost includes cost of fresh products, salary for the worker (RM9000/year), the electricity costs (RM600/year), and maintenance and insurance costs (RM641/year). The annual operating cost is RM15421. Table 3 shows the cost benefit analysis. The NPV for seaweed is found to be negative, and hence there is no payback period. The negative value indicates that there is no net return from the investment in the solar dryer and thus the current design is not financially if include cost of salary worker. Table 4 shows NPV if the operational cost without of salary worker. Table 5 shows simple payback of solar drying system.

Table 3. Cost benefit analysis of solar drying system

No	Parameters	Cost (RM)
1	Capital cost	32050
2	Operating cost	15421
3	Benefit	12000

Table 4. NPV of solar drying system, NPV = RM34144.1

Year	FC (RM)	Net Cash-Flow(RM)	i (10%)	Present Value (RM) FC (RM)	Pn
0	32050	5959	1	32050	
1		5959	0.9091		5417.3
2		5959	0.8264		4924.8
3		5959	0.7513		4477.1
4		5959	0.6830		4070.1
5		5959	0.6209		3700.1
6		5959	0.5645		3363.7
7		5959	0.5132		3057.9
8		5959	0.4665		2779.9
9		5959	0.4241		2527.2
10		5959	0.3855		2297.5
	6410			2471.3	36615.5

Table 5. Simple payback (SPB) of solar drying system, SPB = 5.38 year

Year	FC (RM)	Annual Benefit (RM)	Benefit Cumulative (RM)
0	32050	0	0
1		5959	5959
2		5959	11918
3		5959	17877
4		5959	23836
5		5959	29795
6		5959	35754

If the costs benefit analysis is performed assuming potential market prices the dried seaweed products in Malaysia (RM20/kg), source: Kementerian Kemajuan Luar Bandar & Wilayah (KKLW) 2011, than the NPV is found to be positive. Table 6 and Table 7 shows NPV and SPB for the operational cost include of salary worker, respectively. Table 8 and Table 9 show NPV and SPB for assuming potential market prices if the operational cost without of salary worker, respectively.

Table 6. NPV of solar drying system for assuming potential market prices, NPV = RM82071.8

Year	FC (RM)	Net Cash-Flow(RM)	i (10%)	Present Value (RM) FC (RM)	Pn
0	32050	13759	1	32050	
1		13759	0.9091		12508.2
2		13759	0.8264		11371.1
3		13759	0.7513		10337.3
4		13759	0.6830		9397.6
5		13759	0.6209		8543.3
6		13759	0.5645		7766.6
7		13759	0.5132		7060.5
8		13759	0.4665		6418.7
9		13759	0.4241		5835.2
10		13759	0.3855		5304.7
	6410			2471.3	84543.1

Table 7. SPB of solar drying system for assuming potential market prices, SPB = 2.33 year

Year	FC (RM)	Annual Benefit (RM)	Benefit Cumulative
0	32050	0	0
1		13759	13759
2		13759	27518
3		13759	41277

Table 8. NPV of solar drying system for assuming potential market prices, NPV = RM137372.9

Year	FC (RM)	Net Cash-Flow(RM)	i (10%)	Present Value (RM) FC (RM)	Pn
0	32050	22759	1	32050	
1		22759	0.9091		20690.0
2		22759	0.8264		18809.1
3		22759	0.7513		17099.2
4		22759	0.6830		15544.7
5		22759	0.6209		14131.5
6		22759	0.5645		12846.9
7		22759	0.5132		11679.0
8		22759	0.4665		10617.2
9		22759	0.4241		9652.0
10		22759	0.3855		8774.6
	6410			2471.3	139844.2

Table 9. SPB of solar drying system for assuming potential market prices, SPB = 1.41 year

Year	FC (RM)	Annual Benefit (RM)	Benefit Cumulative
0	32050	0	0
1		22759	22759
2		22759	45518

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