Drying of Palm Oil Fronds in Solar Dryer with Finned Double-Pass Solar Collectors

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Abstract: - Solar drying system is very environment friendly and will enhance energy conservation. However, one of the main disadvantages of solar energy system is the problem associated with the intermittent nature of solar radiation and the low intensities of solar radiation in solar thermal systems. Many design of using solar systems for drying of agricultural products. A solar dryer system suitable for agricultural products have been 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 has been evaluated for drying the oil palm fronds. For 100 kg palm oil fronds, the drying time is about of 3 drying day in sunny day (without heater) from an initial moisture content of 60% to the final moisture content of 10% (wb). A temperature of 55 ^oC can be reached at a solar radiation level of 650 W/m^2, and mass flow rate of 0.13 kg/s, the overall system efficiency is about 20%.

Keywords: - Finned double-pass solar collector, palm oil fronds, performance

1 Introduction

In Malaysia, a solar drying system has great potential to be used in drying of agricultural products which is relevant to the local climate [1]. Malaysia is located at Latitude 1.30^{o}N – 6.60^{o}N and longitude 99.50^{o}E – 103.30^{o}E with an equatorial climate received an amount of 4-5 kWh/m^2 daily solar radiation intensity [2]**.** An analysis of solar radiation at several main towns in Malaysia shows that solar radiation is possible to be used in solar drying [3]. Many studies on the performance of solar drying system have been conducted in the Green Energy Technology Innovation Park, Universiti Kebangsaan Malaysia, such as solar assisted drying systems with V-groove solar collector, the double-pass solar collector with integrated storage system, the solar assisted dehumidification system for medicinal herbs and the photovoltaic thermal (PVT) collector system [4].

Fudholi et al. [5] reviews various types' solar energy systems for agricultural and marine product. Solar drying system is one of the most attractive and promising applications of solar energy systems in tropical and subtropical countries. 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.

The solar collector is one of the most important components in a solar drying system. Various design of solar collector has been studied including multi-pass solar collector. Conventional solar collectors have inherent disadvantages is lower thermal efficiency. One way to achieve considerable improvement in collector efficiency is to use an extended heat transfer area by using corrugated surfaces, finned absorber, matrix type absorber, compound honeycomb collector, box-type absorber, absorber with slats, and porous media. A mathematical model has been developed from the energy balance equations of the solar collector system to predict the value of heat transfer coefficient. Fudholi et al. [6] concluded that V-groove collector is 7.4% more efficient than flat plate collector at volume flow rate 6.8 m^3/s. Eltief et al. [7] reported an analytical study of drying chamber performance of V-groove forced convective solar dryer. The efficiency of the system is increased if the drying chamber is well constructed and provided with good insulation. Fudholi [8,9] experimental studies on performance of the double-pass solar air collectors with finned absorber. The experiment studies show that the finned absorbers are 2-8% more efficient than flat plate absorber at solar radiation 420 W/m^2 to 790 W/m^2 and mass flow rate 0.04 kg/s to 0.08 kg/s. Sopian et al. [10] performed experimental studies on the performance of a double-pass solar collector with porous media in the second channel. They obtained a higher and stable collector outlet temperature in the system. Fudholi et al. [11] analytical studied for predicting the thermal efficiency of double-pass solar air collector with longitudinal fins absorbers. Effects of mass flow rate, number and height of fins on efficiency are studied. Fudholi et al. [12] theoretical and experimental studies on the thermal efficiency of the double-pass solar collector with finned absorber. The theoretical solution procedure of energy equations uses a matrix inversion method and making some algebraic rearrangements.

Yahya et al. [13] studied experimental and theoretical performance of a solar assisted dehumidification system for drying *Centella Asiatica* L. The results indicated that the maximum values of the pick up efficiency, solar fraction and coefficient of performance was found 70%, 97% and 0.3, respectively with initial and final wet basis moisture content of *Centella Asiatica* L 88% and 15%, respectively at an air velocity is 3.25 m/s. Good agreement was found between predicted results and measured results. Ibrahim et al. [14] studied performance of solar chemical heat pump drying system. The results show that any reduction of energy at condenser as a result of a decrease in solar radiation which in the final decrease the coefficient of performance as well as decrease the efficiency of drying. Othman et al. [15] studied of photovoltaic-thermal solar drying system. A new design of a photovoltaic-thermal (PV/T) solar drying system was fabricated. An experimental study of PV/T solar air collector has been performed towards achieving an efficient design of air collector suitable for a solar dryer. Supranto et al. [16] developed sizing of solar assisted drying system for oil palm fronds. The result equation may be used in long time performance and cost analysis for drying system of oil palm fronds. These result correlations may be used for study of auxiliary solar drying system techno economic.

This paper presents the study of an experimental solar assisted dryer for palm oil fronds. Malaysia is the world's largest producer and exporter of palm oil and accounts for more than 60% of global export. Palm oil is extracted from oil palm fruits in the mills. The waste products of oil palm mills are empty fruit bunches, fibers, shells and fronds. There are about 145 oil palm trees per hectare in Malaysia. About 25 pieces of fronds can be obtained from a single tree. The average weight of each frond is about 8 kg. Hence, about 200 kg of fronds can be obtained in a year per tree. Hence, about 30 tons of fronds can be produced in one hectare in a year. Some of the palm fronds have to be cut to facilitate the harvesting of the fruit bunches. The fronds can be converted in useful products. One way is to chip and then dry them to be used as feed stock for animal feed [17,18].

2 Description of the System

2.1 Solar Drying System Set Up

The solar assisted forced convection drying system has been installed at the OPF FELDA Kuantan, Malaysia. This drying system has capacity of drying 300 kg palm oil fronds. A general view of solar drying system is shown in Fig. 1.

Fig. 1 photograph of solar drying system

The schematic diagram of the experimental setup is shown in Fig. 2. The main components are double-pass solar collector array (Fig. 3), 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. Air enters the solar collector at ambient temperature. The oil palm fronds chips were placed in the drying chamber. Hot air from the solar collector was directed to drying chamber.

The collector width and length were 1.2 m and 4.8 m respectively. The solar collector array consists of 6 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.

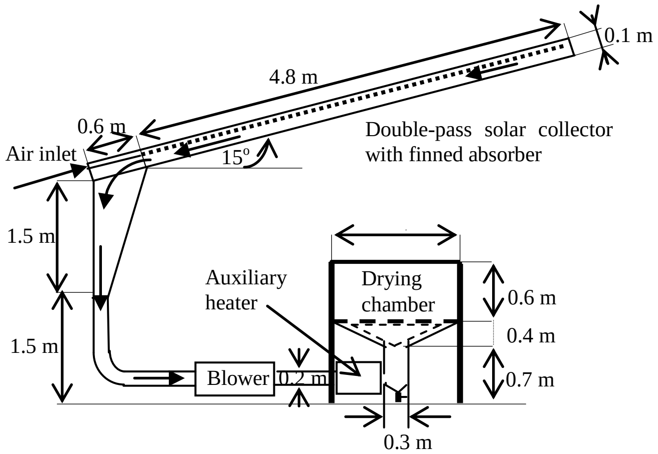

Fig. 2 schematic diagram of solar drying system

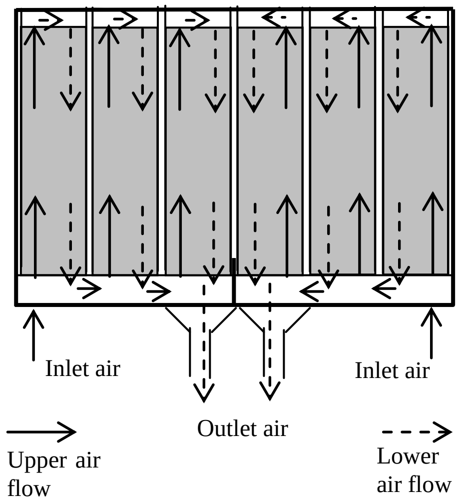

Fig. 3 the collector arrangement for the solar drying system

Fig. 4 shows the cross section of the double-pass solar collector with finned absorber. 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.

Table 1. Key parameters of the solar drying system

Parameters	Unit	Value
Collector area	m^2	17.28
Drying chamber area	m^2	4.8
Capacity of dryer	Kg	150-200
Mass flow rate	kg/s	0.05-0.13
Average drying air temperature	^{o}C	40-65

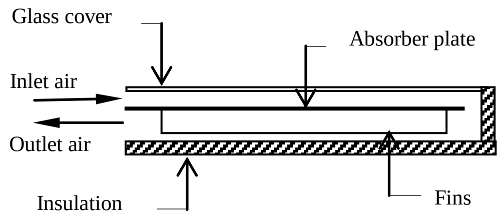

Fig. 4 the schematic of a double-pass solar collector with fins absorber in the second channel

2.2 Performance Finned Double-Pass Solar Collector

Fig. 5 and 6 shows the effect of solar radiation on the efficiency for finned double-pass solar collector. The increase efficiency is about 30% at the solar radiation of 420W/m^2 to 790W/m^2. At a mass flow rate varies from 0.04 kg/s to 0.084 kg/s, the efficiency increase is about 45%.

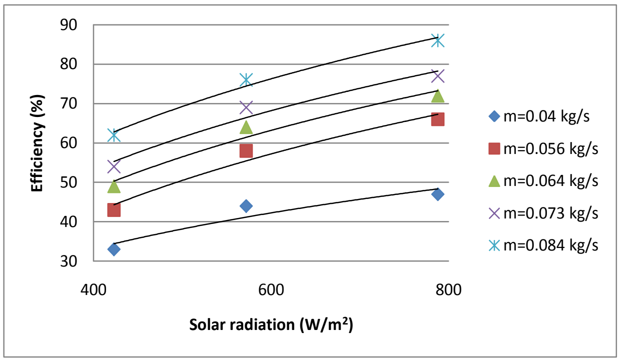

Fig. 5 the effect of solar radiation on efficiency at different mass flow rate

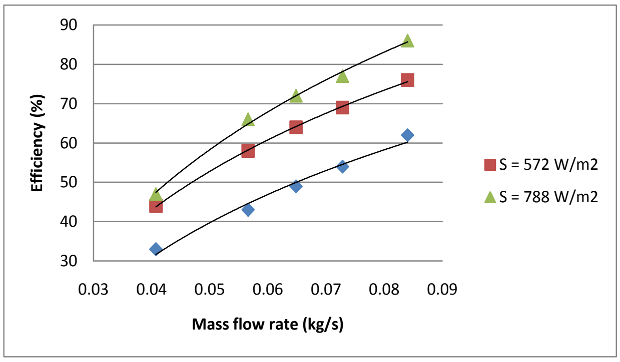

Fig. 6 the effect of solar radiation and mass flow rate on efficiency

To determine the physical characteristics of the collector, one represents effectiveness with efficiency curve, i.e. efficiency versus the reduced temperature parameters (T_o-T_a)/S in Fig. 7. As seen in the figure shows the efficiency curve decrease with increase of the reduced temperature parameters. The curve obtained is a straight line. It will results where the slope is equal to F_oU_L and the y-intercept is equal to $F_o(\tau\alpha)$. The respective efficiency equation and the physical characteristic of the collector are presented in Table 2.

Table 2. Efficiency, loss factor and efficiency equation [8]

S (W/m^2)	$F_o(\tau\alpha)$	F_oU_L	Efficiency equations	R^2
788	0.96	8.9	y=-8.9x + 96.3	0.93
572	0.85	7.5	y=-7.5x + 84.9	0.95
423	0.69	6.9	y=-6.9x + 68.9	0.99

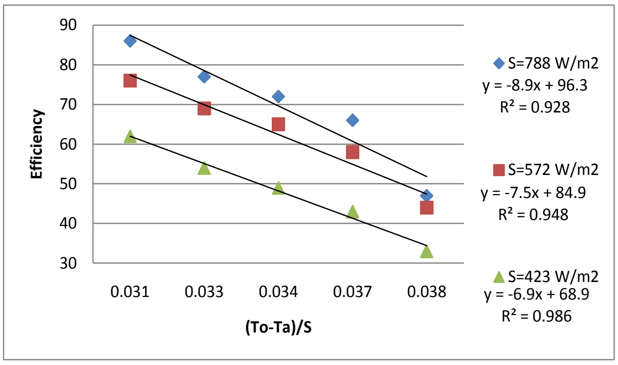

Fig. 7 combined efficiency at different mass flow rates and solar radiations

The efficiency and collector outlet temperature were an important parameter for a wide variety of applications, such as solar industrial process heat and solar drying of agricultural produce. Outlet temperature was investigated for mass flow rates from about 0.03 to 0.09 kg/s. Fig. 8 show the optimum operating condition with respect to efficiency and outlet temperature were determined for S=788 W/m^2. The optimum efficiency (70-80%) lies between the mass flow rates 0.07-0.09 kg/s. A mass flow rate of about 0.063 kg/s is considered for solar drying of agricultural produce. Minimal increase in the efficiencies occurs as the mass flow rate is increased, therefore, operating at these conditions will only increase the blower power.

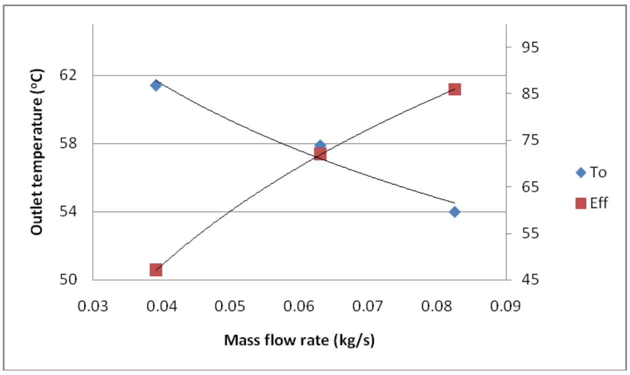

Fig. 8 variation of outlet temperature and efficiency with mass flow rate at S=788 W/m^2

Fig. 9-11 show the variation of increase temperature (T_o-T_i) and efficiency with mass flow rate for S=788 W/m2, S=572 W/m^2 and S=423 W/m^2, respectively. As seen in the figures, as efficiency increased with flow rate, increase temperature (T_o-T_i) decreased correspondingly

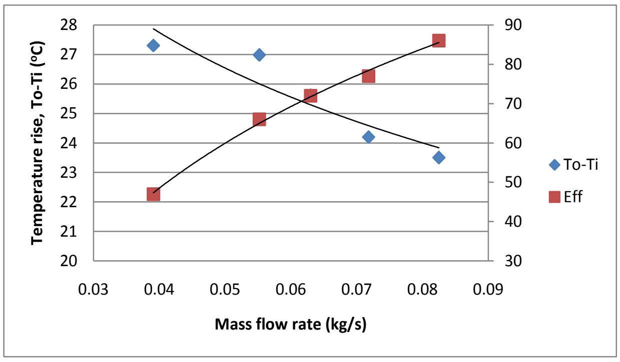

Fig. 9 variation of temperature rise and efficiency with mass flow rate at S=788 W/m^2

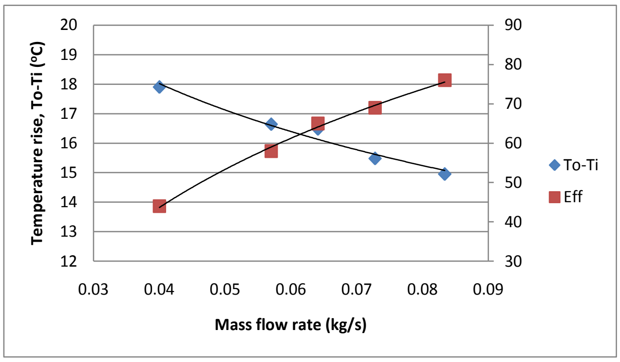

Fig. 10 variation of temperature rise and efficiency with mass flow rate at S=572 W/m^2

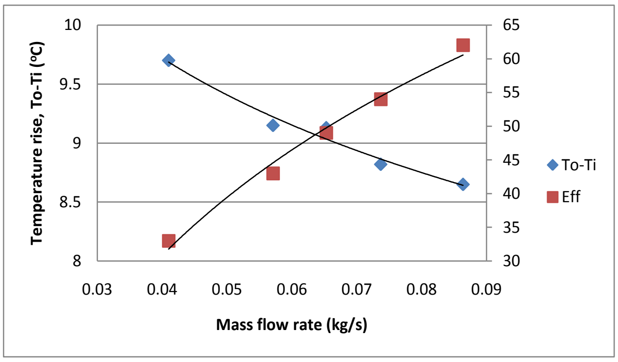

Fig. 11 variation of temperature rise and efficiency with mass flow rate at S=423 W/m^2

Fig. 12–16 shows the results of solar radiation and thermal efficiency of solar collector for the day. The average thermal efficiency of a solar collector varies from 25% to 37%. The higher thermal efficiency of a solar collector shows the result of the experiment for 27th August 2010. The fins acts as increase heat removal from first channel to the second channel and improved the overall efficiency of collector.

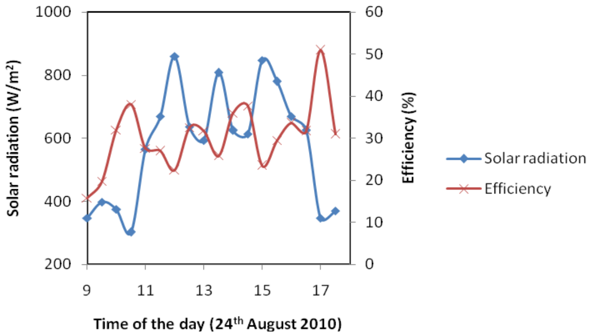

Fig. 12 the solar radiation and thermal efficiency of solar collector for 24th August 2010

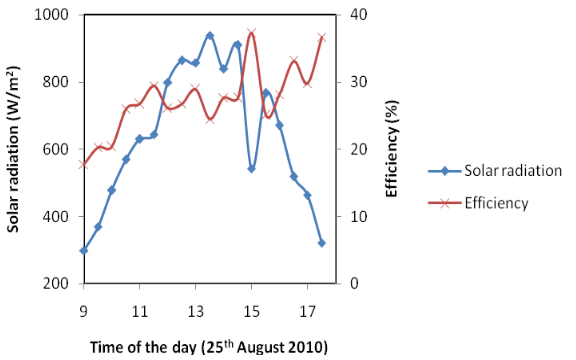

Fig. 13 the solar radiation and thermal efficiency of solar collector for 25th August 2010

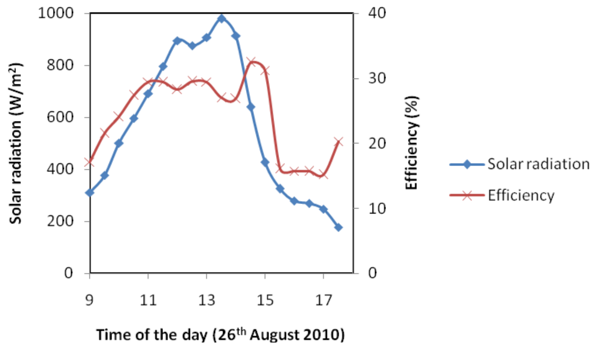

Fig. 14 the solar radiation and thermal efficiency of solar collector for 26th August 2010

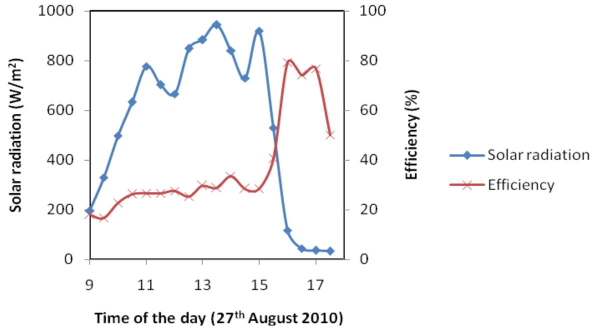

Fig. 15 the solar radiation and thermal efficiency of solar collector for 27th August 2010

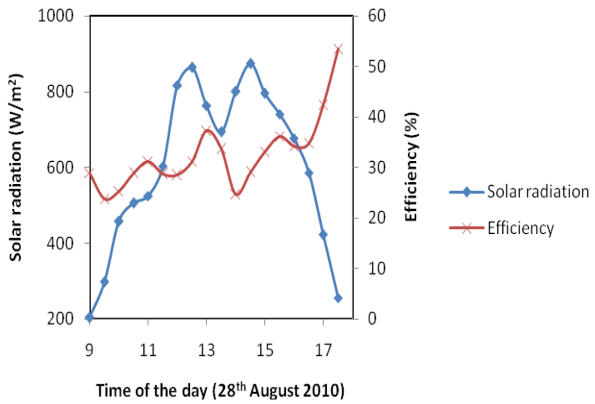

Fig. 16 the solar radiation and thermal efficiency of solar collector for 28th August 2010

3. Solar Drying Process

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.

The drying of material means removal of the moisture from the interior of the material to the surface and then followed by the removal of the moisture from the surface of the drying material. The drying process is a complex heat and mass transfer process that depends on external and internal variables. The external variables are the temperature, humidity, and velocity of the drying air. The internal variable depends on the properties of the materials such as surface characteristic (rough or smooth surface), chemical composition, physical structure, size, and shape of the products.

One of the most important parameters is the saturation vapor pressure, which is the maximum pressure of water vapor. The maximum pressure of water vapor depends on the temperature. In drying processes, it is assumed that the material surface is saturated with water vapor. The ideal saturated absolute humidity was defined as

$$Y_s = \frac{P_w^o}{P - P_w^o} \frac{M_w}{M_G} \quad (1)$$

The absolute humidity of drying air was defined as

$$Y = \frac{P_w}{P - P_w} \frac{M_w}{M_G} \quad (2)$$

The rate of evaporation can be expressed by a mass transfer coefficient and air humidity gradient

$$(\mathrm{k_g})\ w_D = k_g \left(Y_{st} - Y\right) \quad (3)$$

where Y_{st} = absolute humidity at the surface, if the surface is saturated with water than

$$Y_{st} = Y_s \quad (4)$$

where Y_s absolute humidity of air at the same temperature, so that w_D can be calculated. For drying processes a larger difference between Y_s and Y is required [17].

To calculate the mass balance in the drying process should be no assumption of data as follows:

1) Drying air conditions before entering the collection are:
   Dry bulb temperature of 30 °C
   Wet bulb temperature of 28 °C
2. Air condition hair before entering the chamber are:
   Drying air flow rate = 0.1 kg / s.
   Average temperature of drying chamber = 50 C.
3. The water content of oil palm fronds: 60% wet basis.
4. Palm fronds drying products with water content 10% weight of the base.
5. Drying occurs adiabatically.
6. Hair saturated air out of the chamber at the appropriate temperature.

From the psychometric chart in Fig. 17 obtained that the air dryer is absolutely humidity 0.024 kg of water vapor / kg dry air. The maximum drying when the drying process occurs adiabatically.

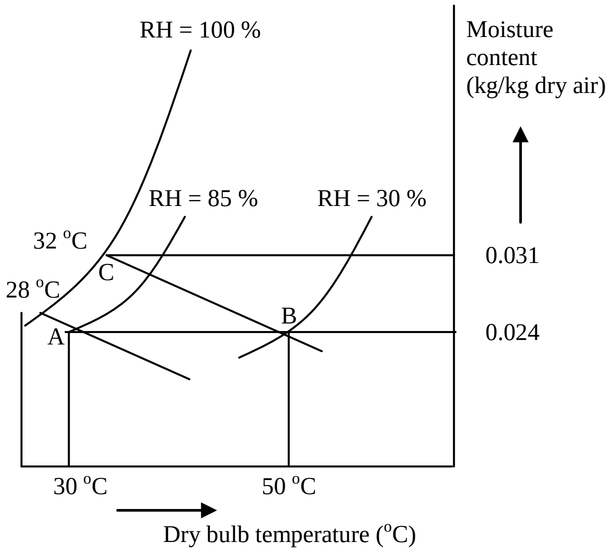

Fig. 17 simple psychometric chart of drying process

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

Palm oil fronds are used in this experiment, moisture content of the wet material is about of 60% wet basis and the dried product is 10% moisture content. For 100 kg wet material, water must be evaporated is 56 kg.

Water that can evaporated for 1 kg of dry air = (0031-0024) = 0.007 kg

Dry air required for drying = 55.56/0.007 = 7,937.14 kg

The air dryer required = 7,937.14 (1.02) = 8,095.89 kg

The period of drying = 8,095.89 / (0.1) (3600) = 22.49 hours (23 hours)

The moisture content of materials can be represented on a wet basis and expressed in percentage [19]

$$M_w = \frac{w-d}{w} \times 100\% \quad (5)$$

where,
w = mass of wet materials (kg)
d = mass of dry materials (kg)

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 [20]

$$\eta_c = \frac{mC(T_o - T_i)}{A_c S} \times 100\% \quad (6)$$

where,
m = mass flow rate (kg/s)
C = specific heat of air (J kg^{-1} $^oC^{-1}$)
Ac = collector area (m^2)
T_i = inlet air temperature (^oC)
T_o = outlet air temperature (^oC)
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 [21]. 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 [22]

$$\eta_p = \frac{WL}{A_c S + P_f} \quad (7)$$

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 [22].

$$\eta_p = \frac{h_0 - h_i}{h_{as} - h_i} = \frac{W}{v\rho t(h_{as} - h_i)} \quad (8)$$

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 Results and Discussion

During the three days of the experiment, the diurnal variation of solar radiation (S), collector inlet air temperature (Ti), collector outlet air temperature (To), drying chamber inlet air temperature (Tic), drying chamber outlet air temperature (Toc) and drying chamber air temperature (Tc) for solar dryer were plotted and are shown in Fig. 18-20. From these figures it was 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 three days, the daily mean values of air temperature at the dryer inlet vary from 49 ^oC to 55 ^oC and for solar radiations it varies from 407 to 647 W/m^2. The thermal efficiency of collector varies from 7 to 48%. The average thermal efficiency of collector is 27, 36 and 31%.

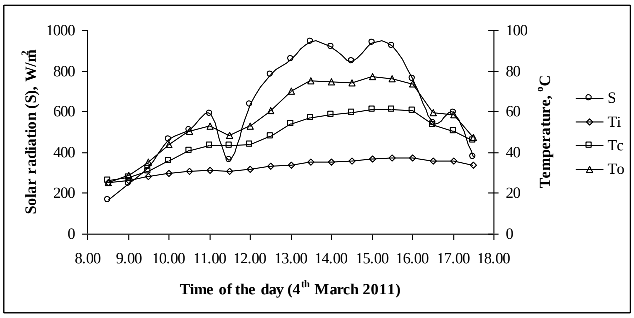

Fig. 18 temperature (inlet, outlet and chamber) and solar radiation of the 1st drying day

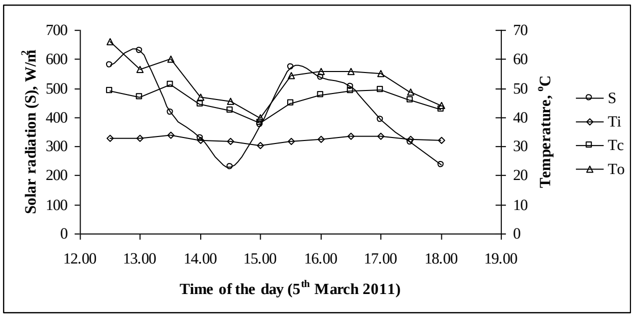

Fig. 19 temperature (inlet, outlet and chamber) and solar radiation of the 2nd drying day

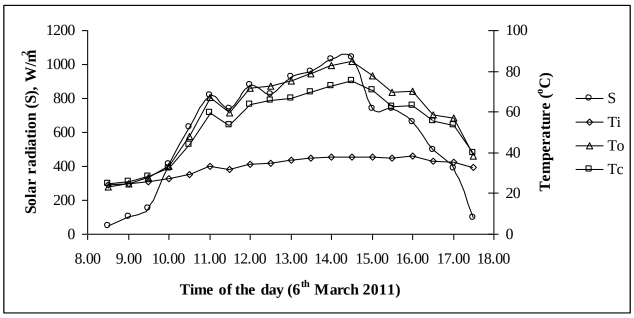

Fig. 20 temperature (inlet, outlet and chamber) and solar radiation of the 3rd drying day

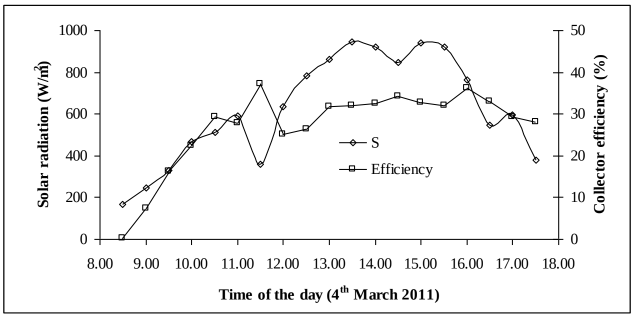

Fig. 21 thermal efficiency of collector and solar radiation for the 1st drying day

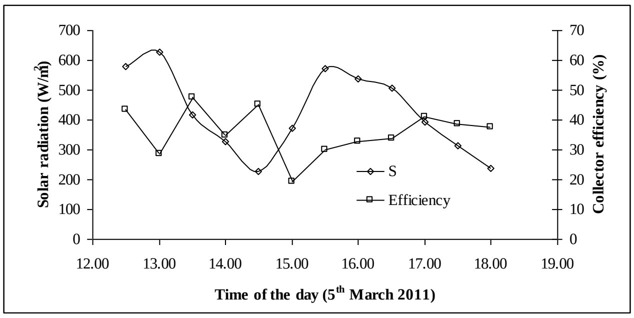

Fig. 22 thermal efficiency of collector and solar radiation for the 2nd drying day

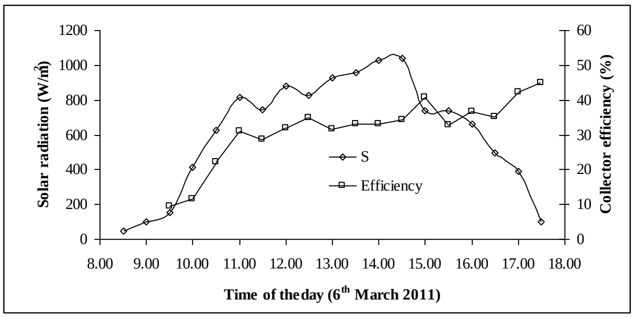

Fig. 23 thermal efficiency of collector and solar radiation for the 3rd drying day

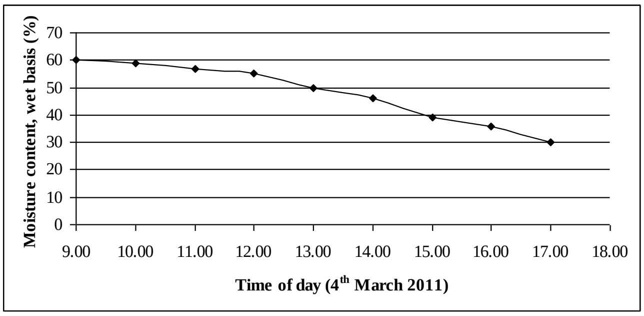

Fig. 24 variation of moisture content for the 1st drying day

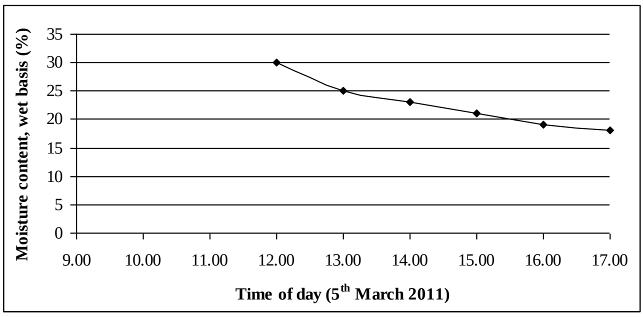

Fig. 25 variation of moisture content for the 2nd drying day

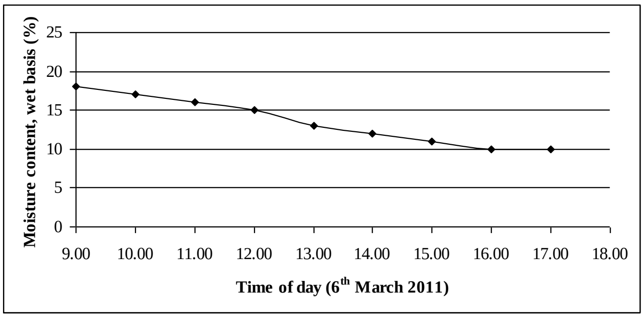

Fig. 26 variation of moisture content for the 3rd drying day

To dry palm oil fronds of the initial (58% to 70%) up to 10% final moisture content of the product required a long time, more than 10 hours. While the solar drying of the day if only 8 hours. Thus, the drying is more than one day. From the results of experimental drying characteristic curves, to dry up the water content of 10% is required within about 12 hours to 14 hours. When the weather is sunny drying by solar drying system requires two days, while the cloudy weather takes a much longer.

Experimental results of solar drying system without auxiliary heating to 100 kg dry palm oil fronds so that the average water content of about 12% is required within 21 hours (3 days drying) to yield 38 kg of dried fronds. The first day of drying up at 9.00 at 17.00, the second day of drying starts at 12:00 until 17:00, because on the second day of drying (5th March 2011) so that the electricity off starting at 12:00 am, and the third day of drying at 09.00 until 17.00. During the drying process of electrical energy supplied for blower = 5.5 kWh (cost about RM1.65). Experiments are in accordance with the previous estimate of 23 hours to 10% water content, while 22 hours to 15% water content.

From the experiments of drying 100 kg of palm fronds to the results of drying 38 kg of water content 10% weight of the base, meaning the dried palm fronds has a water content of 64% fresh weight basis. By using equations (3) obtained system efficiency is 18.89%. By using equations (4) and psychometrics chart, obtained pick-up efficiency is 66.9%. Experimental result of drying palm oil fronds that draws on the drying time shown in Fig. 24-26.

4. Conclusion

A solar dryer system was designed, constructed and evaluated for drying palm oil fronds. The initial and final moisture content of the fronds are 60% (wet basis) and 10% (product basis) respectively. The drying time is about of 22 hours at average solar radiation of about 560 W/m^2 and air flow rate 0.13 kg/s. The collector and drying system efficiencies were found to be 31 and 19% respectively. The pick-up efficiency of solar drying system was estimated to be about 67% for 100 kg palm oil fronds.

Acknowledgements

The authors would like to thank the Yayasan Felda for funding this research grant (RMK9 RS-DL-001-2007), and the Solar Energy Research Institute (SERI), University Kebangsaan Malaysia for support.

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