Development and Performance Analysis of New Solar Dryer with Continuous and Intermittent Ventilation

(Pembangunan dan Analisa Prestasi Pengering Suria Baru dengan Mod Ventilasi Berterusan dan Bersela)

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ABSTRACT

A new solar dryer has successfully developed that can be operated in two modes of ventilation which are continuous and intermittent. This paper aims to analyse and compare the efficiency of the new solar dryer with the existing dryer. Without load experiment shows that the temperature of the new solar dryer with intermittent mode can increase up to 60°C compare to 50°C and 40°C for the new solar dryer with continuous mode and the current dryer respectively. Furthermore, the intermittent mode shows a saving of 60% on the electrical energy usage compared to continuous mode. The average solar collector efficiency for continuous mode was 0.47 whereas for intermittent mode the efficiency was between 0.1 and 0.4 in no ventilation period and within 0.6 to 0.9 with force ventilation. The drying experiment of Sericite mica shows that the moisture extraction rate (MER) of the current dryer, new solar dryer with continuous and intermittent are 1.46, 1.98 and 3.07 kg/day respectively.

Keywords: Intermittent ventilation; Moisture Extraction Rate (MER); sericite mica; solar dryer; temperature

ABSTRAK

Sebuah pengering suria baru telah berjaya dibangunkan yang boleh beroperasi dalam dua mod ventilasi iaitu berterusan dan bersela. Kajian ini dijalankan bertujuan untuk menganalisa dan membandingkan kecekapan pengering suria yang baru dengan pengering sedia ada yang digunakan. Eksperimen tanpa beban menunjukkan bahawa suhu di dalam ruang pengering suria baru dengan mod bersela meningkat sehingga 60°C berbanding 50°C dan 40°C untuk pengering suria baru dengan mod berterusan dan pengering sedia ada. Selain daripada itu, ventilasi mod bersela juga menunjukkan penjimatan penggunaan tenaga elektrik sehingga 60% berbanding mod berterusan. Purata kecekapan pengumpul haba untuk mod berterusan adalah 0.47 manakala untuk mod bersela adalah antara 0.1 dan 0.4 untuk tempoh pasif dan antara 0.6 hingga 0.9 untuk tempoh aktif. Eksperimen pengeringan mika Serisit menunjukkan bahawa kadar pengekstrakan kelembapan (MER) pengering sedia ada, pengering suria baru dengan mod berterusan dan pengering suria baru dengan mod bersela masing-masing adalah 1.46, 1.98 dan 3.07 kg/hari.

Kata kunci: Ventilasi bersela; Kadar Pengestrakan Kelembapan (MER); mika serisit; pengering suria; suhu

INTRODUCTION

Drying is a process to remove moisture from a product by vaporizing moisture content in the product (Mohamed et al. 2016). Drying can be performed in many ways, including mechanical methods such as compression, chemical desiccant and also by thermal drying. Thermal drying is a popular method and used numerously in industry and agriculture process (Pirasteh et al. 2014). In thermal drying, the latent heat of vaporization was supplied to increase vapor pressure over the product. During this process, airflow is required to remove vapor away from the product. Fossil fuel is previously the main energy source for thermal dryer either for the heat source or to induce the airflow. The current global trend to reduce the greenhouse gas emissions resulting in the need to minimize the utilization of fossil fuels. This leads to extensive

research on renewable energy applications including solar drying. Compare to open sun drying, solar dryers put the product being dried in closed space which gives better and hygienic results (Mahesh et al. 2012). Solar drying is becoming a popular option to replace the mechanical thermal dryers due to costly, limited, and non-environmentally friendly of fossil fuels.

Basically, there are three types of solar dryers namely; direct solar dryers, indirect solar dryers, and mixed or hybrid solar dryers (Visavale et al. 2012). In direct solar dryers, direct heating of solar radiation on the product will produce the latent heat of vaporization. While in indirect solar dryers, the latent heat of vaporization is supplied to drying chamber from the solar collector. The solar collector absorbs the solar energy raising the temperature of the air within the collector while lowering its relative humidity. The hot air then flows by

convection through the drying chamber and exit through the outlet to the environment (Salman et al. 2014). In mix mode solar dryer, latent heat of vaporization not only supply from the solar collector but also from the direct heating of solar radiation on the product. Solar dryer was ventilated either by passive or active mode. Passive means the air movement is driven by different density inside the drying chamber while in active mode, the air movement was generated by an additional device such as pump, fan or blower. Although active mode ventilation can significantly increase the drying rate it requires higher cost compare to passive mode (Jain et al. 2004; Tiwari et al. 2004).

In this study a new mix mode solar dryer was designed and develop with active ventilation or force convection mode. As mention earlier force convection mode usually required additional cost as it need additional equipment such as fan or blower to induce the ventilation. Therefore, in order to minimize the additional cost, but at the same time to increase the drying rate, the solar dryer was designed to run in two methods or modes which are continuous ventilation and intermittent ventilation.

Intermittent drying is a technique that can reduce operating costs due to lower energy consumption and able to increase the dried product quality (Chou et al. 2000; da Silva et al. 2017; Hacıhafizoğlu et al. 2015). Intermittent drying can be applied by controlling the drying air temperature, air flow, air relative humidity, operating pressure, or by varying the energy input mode during the drying process (Kumar et al. 2014). In intermittent drying there are two phases of drying exists which are the active drying phase and tempering or resting phase. During the resting phase the moisture will migrate from the interior to the surface of the product until the moisture in the entire product is almost uniform. Therefore, in the subsequent drying period this surface moisture will be easily removed and indirectly improve the drying rate by reduction of thermal energy and air flowrate used. This phenomenon will increase the thermal efficiency of the process and product quality compared to continuous drying (Franco & Barbosa, 2016; Gan et al. 2017). Study by

Soponronnarit et al. 1999 on corn kernel drying shows that the tempering period in intermittent drying improve the quality of the dried product. The study proved that increasing the air velocity increased the stress crack and breakage of the corn kernel. Another study by Zhang et al. (2014) on municipal solid waste (MSW) bio drying process also conclude that intermittent ventilation mode is more effective to reduce moisture content compare to continuous mode. Intermittent drying of banana by varying the temperature and ventilation have been studied by da Silva et al. (2017) and reported that increasing the tempering time can decrease the final moisture content of the product.

The objectives of this study are to analyze the efficiency of the new solar dryer compared to the existing dryer and compare the efficiency between the continuous and intermittent ventilation modes of the new solar dryer. In this study sericite mica was used in the drying experiment. Sericite mica is an inorganic material belong to mica mineral group. It is inert and stable material and have an excellent smoothness with a particle size of 8-9 μm .

METHODOLOGY

A mix mode solar dryer was developed consisting of evacuated tubes, heat exchanger, blower, drying chamber and the controller (Figure 1). The size of drying chamber was 1.25 m height $\times$ 1.7 m width $\times$ 17 m long. The drying chamber was made of steel frame and insulated with polycarbonate sheet with 0.006 m thickness. The heat exchanger and blower were placed at the inlet of the drying chamber. There is an opening at the other end of the drying chamber to remove the evaporated moisture from the product to the environment which is the outlet. Water was used as a thermal fluid in the system. The evacuated tube solar collector absorbed heat from the sun and heated the water that flowing in the piping system. The hot water flowed through the heat exchanger at the inlet. The heat exchanger was then transferred the heat from the water into the air and the blower blew the hot air from the heat exchanger into the drying chamber.

FIGURE 1. New solar dryer with all the important section

The new solar dryer was built at Techcera (M) Sdn. Bhd. located at Bidor, Perak, Malaysia. Techcera (M) Sdn. Bhd. is a company that commercially produces sericite mica. Drying is one of the important process in sericite mica production not only as the requirement for the processing of the downstream product, but also to ease handling process and reduce handling cost. Techcera (M) Sdn. Bhd. already has their own dryer for the drying purposes. Nevertheless, their dryer was a simple greenhouse dryer with open wall and naturally ventilated. Drying sericite mica using the current dryer sometimes takes up to three months depending on the weather condition. For the new solar dryer, the experiment was carried out in two modes which are continuous ventilation and intermittent ventilation. In continuous ventilation mode the controller was set to manual mode. The operator need to switch on the blower at 8.30 am and switch off at 5.00 pm. Therefore, the blower was always in “on” mode during the day time. For intermittent mode, the controller was set to automatic mode where the blower will automatically switch “on” and “off” based on the temperature of the water coming from the evacuated tube solar collector. The blower will switch “on” only when the water temperature reaches 80°C. The blower will continuously be operating until the water temperature drop to 65°C and it will switch “off”.

The first experiment was carried out with no load condition. The performance of solar dryer for continuous and intermittent ventilation was evaluated, focusing on temperature in the drying chamber and electrical energy usage from the blower. Then the drying experiment for sericite mica was carried out for all three conditions of the dryer. The three conditions were current solar dryer, new solar dryer with continuous ventilation and new solar dryer with intermittent ventilation. Sericite mica used in the experiment was in the form of a round cake with a diameter of 60 mm and 45 mm thickness (Figure 2). Only 1 stack of sericite mica was dried during the experiment. As shown in Figure 3, each stack consists of 2 tiers where each tier consists of 4 pieces of sericite mica cake placed on the palate. The total weight of the sericite mica used was 100 kg. The sericite mica need to be dried until the moisture content reduce to less than 5% (dry basis).

The parameters measured during the experiment were temperature, humidity, wind speed, water flow rate and solar insolation. The air flow inside the dryer was measured using Delta OHM HD2937T airflow sensor located at the inlet and outlet of the dryer. Temperature and humidity inside the drying chamber was measured using Watchdog 450 logger. Water temperature inside the piping system was measured using Delta OHM TP878 temperature sensor located before and after the heat exchanger. The water flow rate was measured using STUF-300 ultrasonic flowmeter. For measuring the solar insolation and ambient temperature watchdog 2000 series weather station was used and located on top of the dryer. Three Delta Ohm HD3910.1 soil moisture sensor was used to measure the moisture content of the sericite mica throughout the drying experiment. Two of the sensors was placed at the center of two different sericite mica cake at the bottom tier. Another sensor was placed at the center of one sericite mica at the upper tier. Table 1 show the list of sensors used in the experiment with the respective quantity and location while Figure 3 shows the location of all the sensors used in the system. During the peak solar radiation time, which is from 12.00 pm to 1.00 pm, temperature, airflow and humidity inside the drying chamber as well as solar radiation were set to record data in a minute interval to monitor the pattern of blower “on” and “off”. The temperature and humidity sensor were also placed at the existing dryer to compare the temperature and humidity of current dryer with the newly developed solar dryer.

FIGURE 2. Arrangement of sericite mica in the experiment

FIGURE 3. Location of the sensors used in the experiment

For the new solar dryer, the solar collector efficiency was calculated for both modes of operation in order to compare the efficiency of the solar collector in both modes. The solar collector efficiency, η , was calculated using Equation (1) (Daghigh & Shafieian 2016; Venkatesan & Arjunan 2014);

$$\eta = \frac{C\Delta T}{AI} \quad (1)$$

where, W = mass flow rate of thermal fluid, C = specific heat of thermal fluid, ΔT = different between inlet and outlet temperature, A = collector area and I = solar irradiance.

TABLE 1. List of sensors used in the experiment with the respective quantity and location

Sensor name	Parameter measured	Quantity	Location
Watchdog 450 logger	Temperature and humidity inside dryer	3	2 at the new dryer inlet and outlet and 1 at the center of current dryer
Delta OHM HD2937T airflow sensor	Airflow rate inside dryer	2	New dryer inlet and outlet
STUF-300 ultrasonic flowmeter	Water flowrate	1	Inside the inlet pipe before the heat exchanger
Delta OHM TP878 temperature sensor	Water temperature inside pipe	2	Before and after the heat exchanger
Delta Ohm HD3910.1 soil moisture sensor	Moisture content inside sericite mica	3	2 at the center of sericite mica at upper tier and 1 at the center of sericite mica at the bottom layer.
Watchdog 2000 series weather station with pyranometer	Environment temperature, humidity and solar radiation	1	Outside the dryer (on top)

In the drying experiment, the drying performance of the dryer was analyzed by calculating the moisture extraction rate (MER). MER was described as the mass of moisture removal per unit time from a dryer and calculated using Equation (2) (Karabacak & Atalay 2010);

$$MER = \frac{W}{t} \quad (2)$$

where, W = mass of water evaporated from the product (kg) and t = drying time. The mass of water removed (W) from wet product can be calculated by using Equation (3) (Fudholi et al. 2016; Fudholi et al. 2014);

$$W = \frac{m_i(M_i - M_f)}{100 - M_f} \quad (3)$$

where, m_i = initial total crop mass, M_i = initial moisture content fraction on wet basis and M_f = the final moisture content fraction on a wet basis.

RESULTS AND DISCUSSION

NO LOAD TEST

Figure 4 shows the temperature and solar radiation versus time for current dryer and new solar dryer with continuous ventilation. Figure 4 shows that the temperature inside the current dryer and new solar dryer was higher compare to ambient temperature. The temperature inside the current dryer was between 28°C to 40°C and for the new solar dryer with continuous ventilation was between 31°C to 47°C. Figure 4 also shows the trend of the temperature for both drier, where it is proportional with solar radiation.

FIGURE 4. Temperature and solar radiation vs time for current dryer and new solar dryer with continuous ventilation

Due to the limitation of data acquisition equipment, the experiment for intermittent ventilation of the new solar dryer was carried out on different days. Figure 5 shows the temperature and solar radiation versus time for the new solar dryer with intermittent ventilation. From Figure 5, it shows that in the bright sunny day, the temperature inside the drying chamber increased up to 60 °C which is an increment of 56% compared to the ambient temperature. The figure also shows that in the morning the temperature inside the drying chamber increased when the solar radiation increased. In the noon time, although there was a drop in solar radiation value, there was no effect on the temperature inside the drying chamber. In the afternoon after 2.00 pm, although the solar radiation was reduced, the temperature inside the drying chamber was still maintained above 50°C for up to 4 hours before it started to decreased. This phenomenon is due to the low thermal conductivity properties of polycarbonate as the cladding material of the drying chamber that trap the heat longer in the drying chamber.

The electrical energy analysis was carried out only for the new solar dryer as the current dryer did not used any electrical energy to operate. In order to analyze the electrical energy consumption by the blower, airflow data for 1 hour at the peak solar radiation time, which was from 12.00 pm to 1.00 pm was collected in the interval of 1 minute. Data was collected only at the peak solar radiation hour because this is the most frequent time where the blower will switch on during the whole drying process. Figure 6 shows the air flow inside the drying chamber for 1 hour at the maximum solar radiation of the day.

Figure 6 reveals that during the maximum solar radiation period, the blower switch on 4 times for 6 minutes each. Therefore, for 1 hour of operation at maximum solar radiation the blower switched on for a total of only 24 minutes compared to continuous ventilation mode where the blower was switched on continuously for 60 minutes. This results in a saving of 60% in the electrical energy consumption by the blower.

FIGURE 5. Temperature and solar radiation vs time for the new solar dryer with intermittent ventilation

FIGURE 6. Air velocity vs time of the new solar dryer with intermittent ventilation

SOLAR COLLECTOR EFFICIENCY

Data of solar collector efficiency of the new solar dryer was plotted for continuous and intermittent mode as shown in Figure 7 and Figure 8. Figure 7 shows that the solar collector efficiency for continuous mode is within 0.2 to 0.6 with an average of 0.47. The collector efficiency is lower when the solar irradiance is low and increased when the solar irradiance is high. For intermittent mode, as shown in Figure 8, the efficiency of the collector is within 0.1 to 0.4 when the blower

is off (passive mode) and the collector efficiency increases from 0.6 to 0.9 when the blower is switched on (active mode). The efficiency of the solar collector for intermittent mode is low when the blower is turned off because the heat transfer rate of the heat in the water to the surrounding is lower. When the blower is turned on, the heat transfer rate of the heat inside the water through the heat exchanger is increasing. This will produce lower water temperature feed into the solar collector. As a result, the difference between the inlet and outlet water temperature of the solar collector will be higher.

FIGURE 7. Collector efficiency and solar radiation vs time for continuous mode

FIGURE 8. Collector efficiency and solar radiation vs time for intermittent mode

DRYING EXPERIMENT OF SERICITE MICA

Drying experiment of sericite mica was carried out in all three conditions of solar dryer and the graph of moisture content versus drying day was plotted. The results from the soil moisture sensor is in the volumetric water content. Volumetric water content, VWC is defined as;

$$VWC = \frac{V_w}{V} \quad (4)$$

Where, V_w = volume occupied by water and V = volume of the soil portion.

Volumetric water content (VMC) can be converted into dry base moisture content, MC_{db} by using the formula below

$$MC_{db} = \frac{VMC}{\text{Bulk density of material}} \quad (5)$$

Figure 9 shows the moisture content mean data from the three moisture sensor used. Figure 9 reveals that, the newly developed solar dryer can dry sericite mica faster compare to current drying method either in continuous or intermittent ventilation mode. The figure shows that current drying methods required 22 drying days to dry the sericite mica while in the newly developed solar drying system, the sericite mica can be dried in less than 16 days. New solar

dryer with intermittent ventilation mode shows the fastest drying periods which only took 11 days while 16 days for continuous ventilation mode.

MER for the dryer calculated by using Equation (2) obtained results of 1.46, 1.98 and 3.07 kg/day of water removed for current dryer, new dryer with continuous mode and new dryer with intermittent mode respectively. Table 2 shows the summary of the results. It was found that the new solar dryer with intermittent mode able to remove more water per unit time compare to the new dryer with continuous mode and current dryer. The new solar dryer able to remove almost double the quantity of water compared to current dryer. This was due to the higher temperature and ventilation rate inside the drying chamber of the new dryer compare to current dryer.

FIGURE 9. Moisture content (dry basis) vs drying days in three different dryer modes

TABLE 2. Experimental data for MER calculation

	Current dryer	New dryer (continuous mode)	New dryer (intermittent mode)
Initial weight (kg)	100	100	100
Initial moisture content (dry basis) (%)	M = 54.5 SD = 4.4	M = 53.8 SD = 4.3	M = 58.0 SD = 3.5
Final moisture content (dry basis) (%)	M = 4.5 SD = 0.4	M = 4.9 SD = 0.1	M = 4.5 SD = 0.4
Drying time (days)	22	16	11
Mass of water removed, W (kg)	32.3	31.7	33.8
MER (kg/day)	1.46	1.98	3.07

M = Mean data; SD = Standard Deviation.

CONCLUSION

The new solar dryer with two modes of operation was successfully developed. The new solar dryer can be operated either by continuous ventilation or by intermittent ventilation. From the experimental result of sericite mica drying, it was concluded that the intermittent ventilation mode of the new

solar dryer produced higher temperature inside the drying chamber and able to dry sericite mica faster with highest moisture extraction rate compare to continuous mode and current dryer. Furthermore, by operating in intermittent mode 60% of electrical energy can be saved compared to continuous mode. As a conclusion, the new solar dryer with intermittent mode was the best option to dry sericite mica. On the other

hand, the continuous mode can be used to dry product which is sensitive to high temperature such as food products.

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REFERENCES

- Chou, S.K., Chua, K.J., Mujumdar, A.S., Hawlader, M.N.A. & Ho, J.C. 2000. Cyclic air temperature drying of guava pieces: effects on moisture and ascorbic acid contents. 2000. *Food and Bioproducts Processing* 78(2): 72-78.
- Daghigh, R. & Shafieian, A. 2016. An experimental study of a heat pipe evacuated tube solar dryer with heat recovery system. *Renewable Energy* 96: 872-880.
- da Silva, W.P., Rodrigues, A.F., Silva, C.M.D.E. & Gomes, J.P. 2017. Numerical approach to describe continuous and intermittent drying including the tempering period: kinetics and spatial distribution of moisture. *Drying Technology* 35(3): 272-280.
- Franco, R. & Barbosa de Lima, A.G. 2016. Intermittent drying of porous materials: a review. In *Diffusion Foundations. Trans Tech Publications* 7: 1-13.
- Fudholi, A., Sopian, K., Yazdi, M.H., Ruslan, M.H., Gabbasa, M. & Kazem, H.A. 2014. Performance analysis of solar drying system for red chili. *Solar Energy* 99: 47-54.
- Fudholi, A., Mat, S., Basri, D.F., Ruslan, M.H. & Sopian, K. 2016. Performances analysis of greenhouse solar dryer with heat exchanger. *Contemporary Engineering Sciences* 9(3): 135-144.
- Gan, S.H., Ong, S.P., Chin, N.L. & Law, C.L. 2017. A comparative quality study and energy saving on intermittent heat pump drying of Malaysian edible bird's nest. *Drying Technology* 35(1): 4-14.
- Hacıhafızoglu, O., Susantez, Ç., Kahveci, K. and Akyol, E., 2015. Simulation of intermittent drying of corn. In *World Congress on Mechanical, Chemical, and Material Engineering* 1900: 323-1.
- Jain, D. & Tiwari, G.N. 2004. Effect of greenhouse on crop drying under natural and forced convection II. Thermal modeling and experimental validation. *Energy Conversion and Management* 45(17): 2777-2793.
- Karabacak, R. & Atalay, Ö. 2010. Comparison of drying characteristics of tomatoes with heat pump dehumidifier system, solar-assisted system and natural drying. *Journal of Food, Agriculture & Environment* 8(2): 190-194.
- Kumar, C., Karim, M.A. & Joardder, M.U. 2014. Intermittent drying of food products: A critical review. *Journal of Food Engineering* 121: 48-57.
- Mahesh, A., Sooriamoorthi, C.E. & Kumaraguru, A. K. 2012. Performance study of solar vacuum tubes type dryer. *J. Renewable Sustainable Energy* 4.6: 063121
- Mohamed, R., Yusop, A. M., Mohamed, A. & Nordin, N. I. 2016. Behavioral Analysis of Thermoelectric Module under Different Configurations and Temperature Gradient. *Jurnal Kejuruteraan* 28: 19-27.
- Pirasteh, G., Saidur, R., Rahman, S.M.A. & Rahim, N.A. 2014. A review on development of solar drying applications. *Renewable and Sustainable Energy Reviews* 31: 133-148.
- Salman, S. D., Kadhum, A. A. H., Takriff, M. S. & Mohamad, A. B. 2014. Heat transfer enhancement of laminar flow in a circular tube using swirl/vortex generator (Peningkatan pemindahan haba aliran lamina di dalam tabung membulat menggunakan penjana swirl/vorteks). *Jurnal Kejuruteraan* 26: 63-68.
- Soponronnarit, S., Wetchacama, S., Swasdisevi, T. & Chotijukdikuld, P. 1999. Effects of drying, tempering and ambient air ventilation on quality and moisture reduction of corn. *Drying Technology* 17(6): 1227-1238.
- Tiwari, G.N., Kumar, S. & Prakash, O. 2004. Evaluation of convective mass transfer coefficient during drying of jaggery. *Journal of Food Engineering* 63(2): 219-227.
- Venkatesan, N. & Arjunan, T.V. 2014. An experimental investigation and performance analysis of a solar drying of bitter gourd using an evacuated-tube air collector. *International Journal of ChemTech Research CODEN* 6(14): 5510-18.
- Visavale, G.L. 2012. Principles, classification and selection of solar dryers. In Hii, C.L., Ong, S.P., Jangam, S.V. and Mujumdar, A.S. (Eds.), *Solar drying: Fundamentals, Applications and Innovations*, Singapore. 1-50.
- Zhang, H.Y., Gu, J., Wang, G.Q., Hao, L.W. & Wu, X.Q. 2014. Influence of aeration modes on aerobic bio-drying of municipal solid waste (MSW). In *Advanced Materials Research. Trans Tech Publications* 1010: 934-938

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