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DRYING OF EFB BY HYBRID SOLAR/BIOMASS THERMAL BACKUP

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ABSTRACT

The Empty Fruit Bench (EFB) is very wet in its raw state and it would be an excellent for power boilers after being dried. Solar drying of EFB is highly feasible and economic, but the solar drying process is interrupted during the cloudy or rainy days and also at night. In the present paper, a combination of mixed mode dryer using solar as main heat input and biomass burner as auxiliary source of thermal energy has been investigated experimentally to dry EFB. Accordingly, an experimental model consisting of solar dryer integrated with thermal backup unit was designed and fabricated. Series of experimental measurements were carried out at four different drying modes namely, open sun, mixed solar (direct and indirect), thermal back up, and hybrid modes. The results from the four modes to dry 2.5 kg of EFB were summarized and compared. The results indicated that the solar drying mode required around 52 to 80 hours to dry EFB while it required 100 hours under open sun drying mode. Usage of the thermal back as heat source reduced the drying time to 48 to 56 hours. By the hybrid mode, the drying time was considerably reduced to 24 to 32 hours. The results demonstrate that the combined resources of solar and thermal back up were effectively enhanced the drying performance. The application of solar dryer with biomass burner is practical to be applied for massive production of solid fuels from EFB.

Keywords: Solar dryer, Hybrid solar dryer, Biomass drying, EFB, Palm oil solid waste, Thermal backup.

1. INTRODUCTION

Malaysia's palm-oil industry currently operates more than 300 palm oil mills that process palm oil from 2.5 million hectares of oil palm estates throughout the country and produce more than a million metric tons of EFB as waste material every year, (Chua 1991). Palm oil industry commonly uses its own solid waste, shell and EFB fiber as boiler fuel. The EFB is also burnt inside the incinerators to produce potash ash which is applied in the plantation as fertilizer. A stable and strong characteristic of EFB fibers was lead it into the application of mattress and cushion manufacture, soil stabilization/compaction for erosion control, landscaping and horticulture, ceramic and brick manufacture and flat fiber board manufacture, (Hasibuan and Daud 2007).

Power plant boiler requires a nonstop operation. (Brammer and Bridgwater 1999) stated that due to continuous running of an engine or turbine for example in bio-energy plants, the biomass may have to be dried. It has been used widely in palm oil mills, sawmills and wood processing factories to generate both electricity and steam and it can be transformed into both heat and electricity simultaneously through cogeneration.

The EFB, as solid waste product from the palm oil industry, is found to be very wet in its raw state, but it would be an excellent for power boilers after dried. The EFB needs to be dried before proceed into further processes and here, the application of solar dryer with biomass burner is practical to be applied since it provides high drying rate which consequently increase the production. According to (Rahim and Saffian 2006), the initial moisture content of EFB is 80% and the optimum moisture content is less than 13% for combustion.

Among EFB fibers drying technologies that has been applied are conventional rotary drum dryer with a flue gas drying medium from a diesel burner and superheated steam, (Hasibuan and Daud 2007). FASC Malaysia has installed a KDS machine in the 14 MWe TSH Biomass Power Plant in Kunak, Malaysia, for the purpose of drying EFB, Abdul Mannan 2008.

Due to high cost of diesel fuel, there are increasing demands in commercial scale on the biomass fuels since it is cheaper and available in abundant quantity. The rising utilization and highly depending on electricity to dry EFB fibers is expected to be reduced by using solar energy as the source of heat. However, one major problem which exists with these solar dryers is its capability to dry products only with the existence of solar energy enabling it to be operated only on hot days. This causes inconsistency in drying and a decrease in the production scale. To solve this problem, the usage of biomass, as a fuel of burner is relatively synonym in the drying industry. This burner extends the drying process during the cloudy or rainy days (backup heater) and even during the day and night. Several researchers have studied about the solar dryer with biomass burner. Biomass may be obtained from forests, woods and agricultural lands and commonly burned using inefficient technologies in most developing countries. Malaysia is one of the countries which taking advantage of its enormous output of biomass from oil palm residues and wood wastes. At present, biomass fuels account for about 16% of the energy consumption in the country, of which 51% is from palm oil biomass and 22% from wood waste, (EIB Malaysia, online 2013). A biomass backup heater is used to supplement the heat required for faster drying process, Bena et al 2005. Among the biomass fuel materials that has been reported in biomass burner application are coconut shells, (Serafica and Mundo 2005), woodchips, (Madhlopa and Ngwalo 2007), charcoal, (Prasad et al 2005), paddy husk, (Thanaraj 2004), fuel wood, (Prasad et al 2006, Bena and Fuller 2002, and Tarigan and Tekasakul 2005), and briquetted rice husk, (Mastekbaeva et al 1999). The biomass materials may have to be dried first in order to support a continuous running of an engine and turbine, (Brammer and Bridgwater 1999). Hence, solar and biomass are the two main renewable energy sources of energy that extremely suitable for drying application.

There is limited researchers had studied and fabricated solar dryer specifically for EFB drying. (Hasibuan and Daud 2007) had applied a hot flue gases in a diesel-fired rotary drum dryer for drying of EFB. However, the drying caused in low quality where the EFB product suffers from over-drying, browning and dust explosions. It can be concluded that the heat from direct fuel is applicable to be used as the source of heat for drying biomass product. The heat from direct fuel is expected to be higher than indirect fuel. By controlling the indirect heat for food drying, the direct heat temperature is assumed to be not too high and able to be applied for drying of biomass product. The range of supplied temperature should be observed first to prevent the over-drying. The effect of dust explosion can be avoided by using a filter which places in between the burner and solar dryer.

The objective of this study is to investigate the performance of developed hybrid solar dryer integrated with thermal backup (TBU) unit. Thermal backup biomass burner had been applied to create a 24 hours drying process. The system was used for drying EFB by four different operational modes. The results are compared in terms of drying period of 2.5 kg of the EFB. Also, the drying performance is used as comparison tool between the four cases. In addition, detailed discussion on the drying performance at each tray of the five tray levels is also included in the paper.

2. MATERIAL AND METHODS

The present investigations are carried out experimentally. The experimental implementations consist of the solar dryer, the thermal back up unit, the measuring instruments and the measurements procedure. Each is discussed separately in the following paragraphs.

2.1. Solar Dryer Model

The entire body of the dryer is made of 4 mm thickness Perspex to allow as much as possible of direct solar radiation to penetrate to inside of the drying chamber. The base is made of 1.0 m long x 1.0 m wide play wood having 10 mm thickness. The total height of the dryer model is 1000 mm and the base dimensions are 900 mm x 900 mm fixed on the wood base. A 2 m height chimney made of 102.0 mm dia. PVC pipe is installed at the upper part of the dryer to enhance the drafting of the moisture air from inside the drying chamber. Two aluminum corrugated plates painted in mat black are installed at the base. The plates are inclined with 15^o such that the lower part of both is at the center of the drying chamber. A slot is left between the plates to permit heated air from underneath the absorber plates to flow up to the trays. The dryer and the absorber plate were designed under the assumption that near collector air temperature, T_1 was around 60±5ºC at surrounding temperature outside the dryer, T_{amb} of 30ºC. The selected drying temperature, $T_{chamber}$ of 50 to 65ºC is suitable for drying all types of product and able to inactivate the growth of microorganism. The assumed outlet dryer temperature, T_{od} was 35ºC, which was slightly low since it contained the picked up moisture content. The sizes of the absorber plate and the drying chamber are designed according to the mentioned temperatures and the fabricated model is shown in figure 1. The details of the conceptual design and design calculation procedure are outlined in (Yunus 2011).

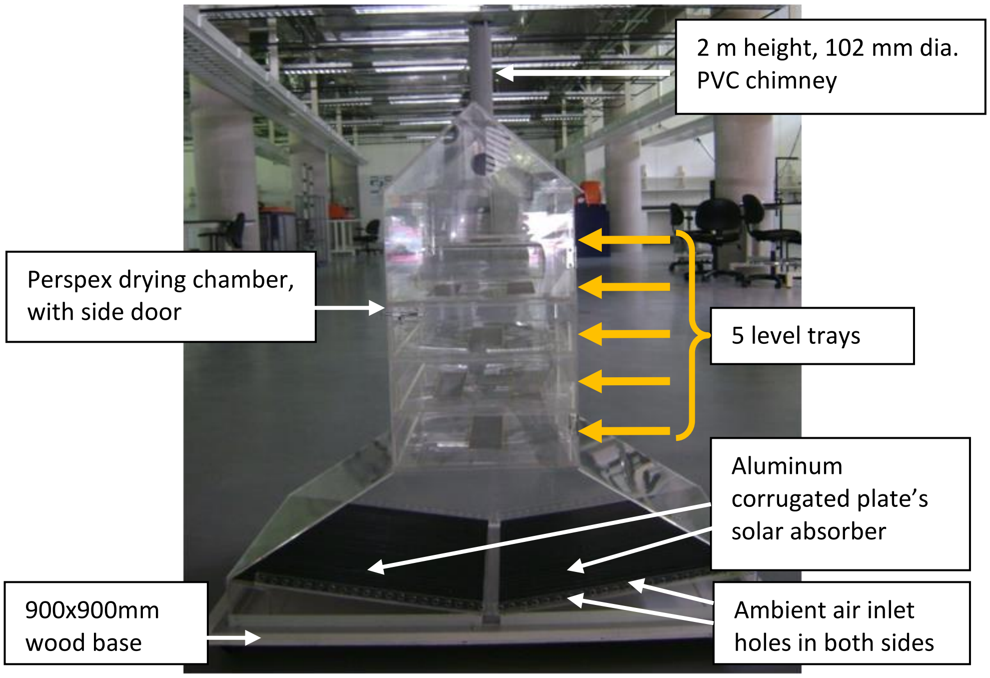

Figure 1: The parameter assumption of solar dryer

2.2. The Thermal Backup Unit (TBU)

The basic function of the thermal back up unit is to supply working fluid at 60^{o}C to 70^{o}C at the outlet from the gas-to-gas heat exchanger. This range is experienced to provide environment temperature inside the drying chamber within the selected drying temperature of 50^{o}C to 65^{o}C. This temperature is the optimum for drying of many types of products ranging from food to herbs to fish and solid agriculture wastes. In particular, for the drying of the EFB, the temperature may be as high as 65^{o}C. Similar TBU has not been found in the literature. It comprises a burner unit in the lower part and a gas–to-gas heat exchanger (G-to-G HEX) in the upper part. The solid fuel mixture of wood chips and EFB was dropped from a feeding container and positioned on a steel mesh in the burner. The produced flue flows up through a specially designed passage to exchange heat with air flow which inters at the lower part of the G-to-G HEX from outside ambient at around 30^{o}C. The air moves up under the effect of natural convection and discharge through the outlet at the top of G-to-G HEX. The design procedure of the TBU is presented in details by (Yunus et al. 2011). The sketch of TBU is shown in figure 2.

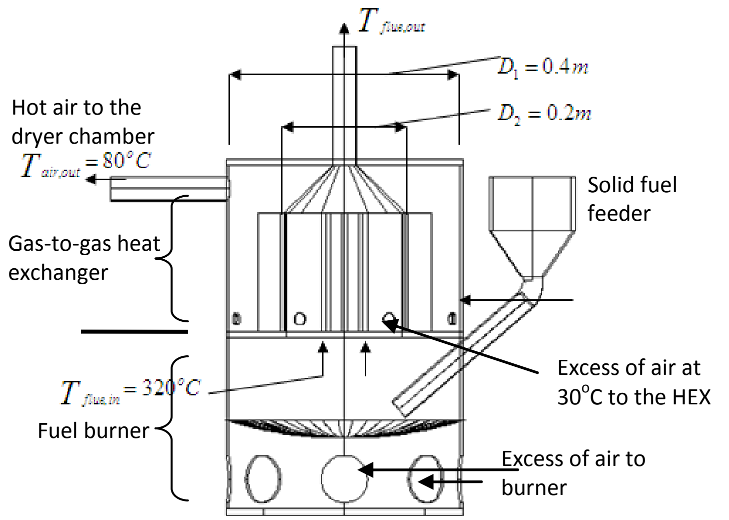

Figure 2: Sketch of the thermal backup unit comprise of slid fuel burner and Gas-to-Gas heat exchanger.

2.3. Drying Procedure and Measurements

The parameters measured during the experiment were temperature, relative humidity, weights of biomass fuel and product to be dried, speed of air flow and solar irradiation. The relative humidity and air temperature inside the chamber were measured using digital hygrometer/psychrometer (NPI 597) having accuracy of 2% of reading, while the absorber temperature was recorded using thermocouple probes, with ±0.2°C accuracy, connected to 24 channel data logger type FLUKE HYDRA. Solarimeter type SL 200 KIMO instruments with 5% of measured value accuracy was used to measure the solar radiation and anemometer (Testo 435) was used for the airflow velocities. The weight was measured using digital scale model FEJ-5000 (max 5kg with 1 gm resolution).

The initial weight of the EFB product was 2.5 kg distributed as 0.5 kg in each tray. The initial moisture content was measured and was found around 75%. The weight of product had been measured every hour until it reaches the required final moisture content which was 6% as recommended by (Rahim and Suffian 2006). The reference time of the day is 9.00am.

The EFB product was dried under four different drying modes, namely, open sun drying, solar drying, TBU drying, and hybrid solar + TBU drying.

3. RESULTS AND DISCUSSION

The open sun drying experiment was carried out by exposing 2.5 kg of EFB to the same weather conditions of solar drying in the dryer. The open sun drying is common practice in Malaysia to dry products like chilly and fish. The results of the open sun drying were used as a reference sample for comparison with other modes.

3.1. Solar Drying Mode

In this mode, the EFB was dried using the heat source from the solar radiation. The weight reductions were measured hourly in each tray until it reached around 5 to 6% final moisture content. The results are shown in Figure 3.

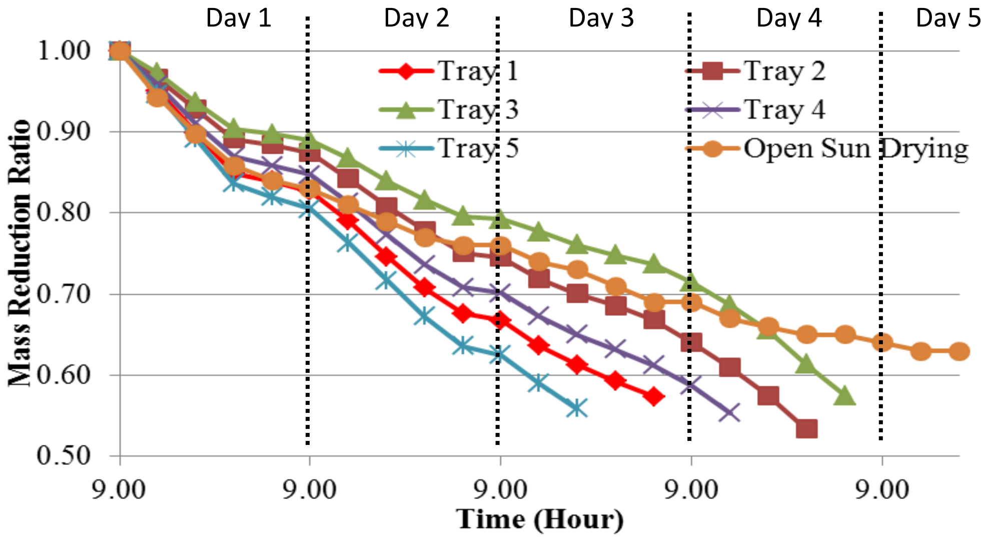

Figure 3: Drying of EFB under solar mode only

The results indicated that the solar drying mode required around 52 to 80 hours to dry the EFB according to the tray location, while it required 100 hours under open sun drying. The rate of open sun drying is slower than solar dryer as it could be observed from the slope of weight reduction results. Tray 5 took the shortest time to complete the drying since it was located at the top and it exposed to solar radiation, totally to dry mostly by direct solar drying. This followed by Tray 1 since it was located just above the solar collector and the heat flow through convection process had the highest temperature in the chamber. Tray 4 and Tray 2 stop nearly at the same drying time since it were located at the interval of the heat source. Tray 3 took the longest time to dry because it was located in the middle and portion of the solar radiation was blocked by the other trays, and also the warm air from underneath was at relatively low temperature. It could be concluded that under this mode, the trays which located below Tray 5 having problem with the shadowed area. This has caused a large difference of mass reduction ratio among the trays.

3.2. Thermal Backup Drying Mode of EFB

The EFB was dried using the hot air supplied from the TBU. The drying process was run continuously even at night since it was not affected by the presence of solar radiation. The results are shown in Figure 4. The results indicated that under thermal backup mode, the drying process took about 48 to 56 hours to dry the EFB. The ignition started at 9.00 am and the fuel feeding was continued at 2 hour interval until 11pm daily.

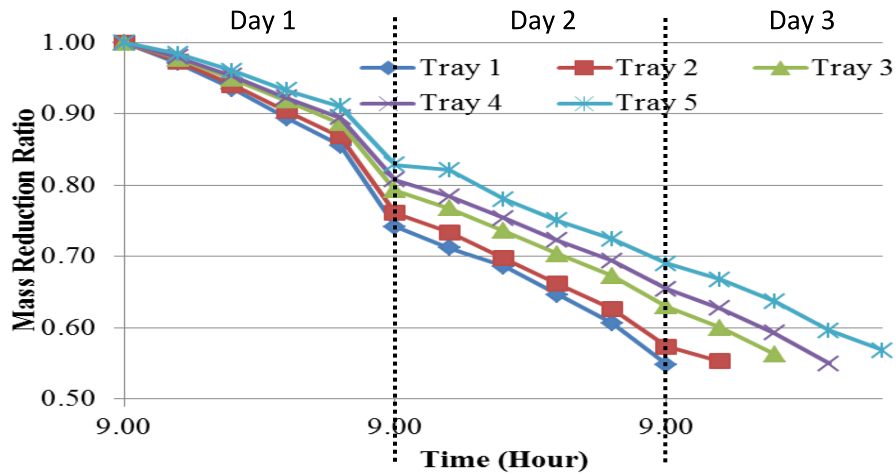

Figure 4: Drying of EFB under thermal backup mode, only

It was observed that the lower the trays, the faster the drying complete since it was exposed to the source of heat. As hot air passes through the first tray, its temperature is reduced and its moisture content becomes higher due to mass of water transfer from the product in the lower tray. The time difference between the trays to reach the final moisture content, 6% was constant at 2 hour interval from tray to another tray.

3.3. Hybrid Drying Mode of EFB

The combined drying mode was conducted using the source of heat from solar and the flue from the TBU. At night, the drying process runs continuously with the presence of biomass mode. The results are shown in Figure 5.

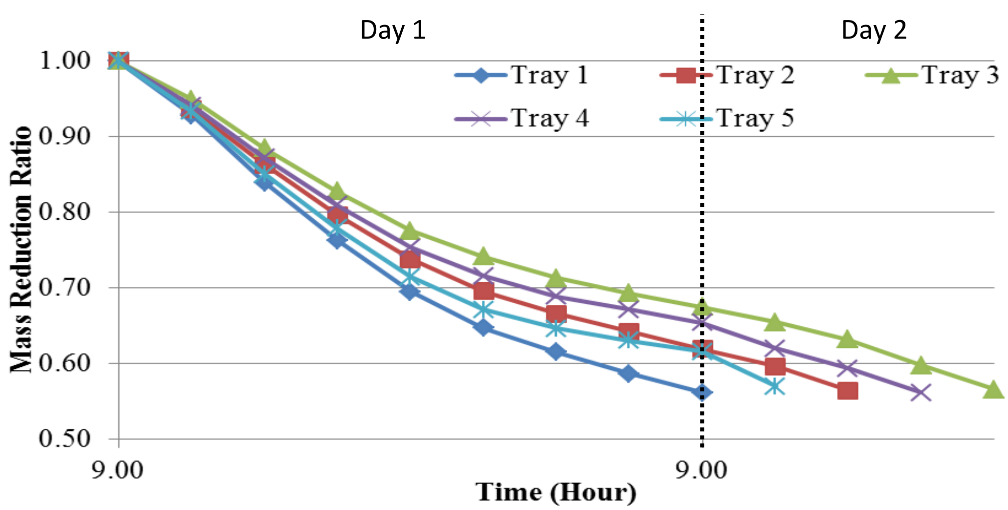

Figure 5: Drying of EFB under hybrid mode

Hybrid mode took about 24 to 32 hours to complete the drying process. Based on the results shown in Figure 5, Tray 1 requires 24 hours to dry the 0.5 kg of the EFB since it received a continuous heat from the hot working fluid and it did not rely on the availability of solar radiation. Tray 5 and Tray 2 took 26 and 28 hours respectively to complete the drying process and followed by Tray 4 and Tray 3 at 30 and 32 hours. The location of the tray and also shadowed area causes the difference of drying rate at each tray.

The overall comparisons of EFB drying modes under different modes are shown in Figure 6. It could be concluded that the hybrid mode is the best mode of drying since it took the shortest drying periods to reach the EFB final moisture content.

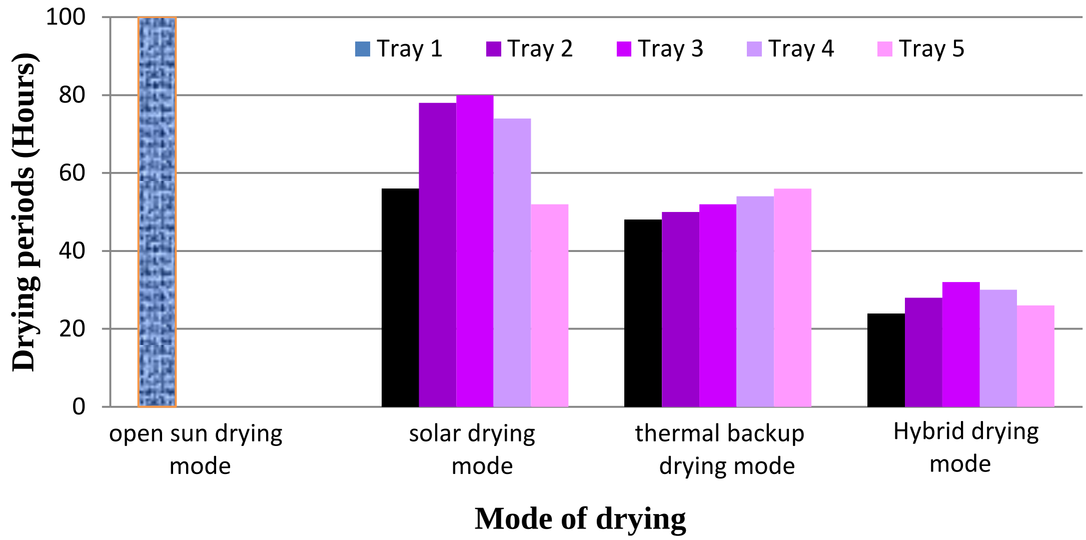

Figure 6: The overall comparison of EFB drying under different modes

3.4. The Drying Efficiency, η_d

The drying efficiency, η_d was calculated by considering the type of the thermal input whether from solar ($_s$), thermal backup ($_{tb}$) or hybrid inside the dryer. It is depending on the product mass reduction in drying time as below:

$$\eta_d = \frac{M\lambda}{t\left[\left(\Sigma I_c A_c\right)_s + \left(\dot{m}c_p \Delta T\right)_{tb}\right]}$$

where:

$\Delta T = T_{in} - T_{chimney}$ is the reduction in the hot air temperature across the dryer,
I_c, is the measured solar intensity at the absorber plate in W/m^2, and
A_c the absorber plate area in m^2

The results of drying efficiency of EFB based on different operational modes are shown in Figure 7. The efficiency increases from open sun to hybrid drying mode. The lowest efficiencies for drying of EFB was in open sun drying and followed by solar mode because the heat received is inconstant and it depends solely on the weather conditions. The drying process took longer time and interrupted especially during the cloudy days and at night. In thermal backup mode, the drying process operates continuously without affected by the weather condition and hence resulted in higher enhancement than solar mode. It was observed that the highest efficiencies were obtained in the hybrid mode.

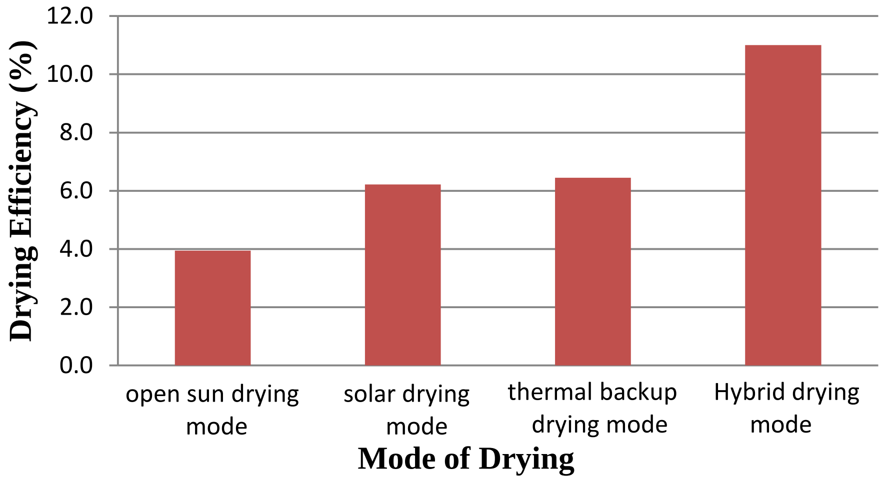

Figure7: Comparison of drying efficiencies

The drying efficiencies of EFB under hybrid mode were 11% in 1.17 days. The drying process occurred continuously even at night since it was supported with the thermal backup unit. During the day, the heat received was higher than at night since the heat from solar was extended by the thermal backup unit.

4. CONCLUSIONS AND OUTLOOKS

The design and fabrication of a solar dryer integrated with thermal back up unit is presented. The thermal backup unit comprises of solid fuel burner and gas-to-gas heat exchanger. The solar dryer operates under direct and indirect solar radiation. The thermal backup unit successfully could supply hot air at about 70^{o}C. This temperature is capable to maintain the drying chamber at around 50 to 60^{o}C.

Three different drying modes of EFB are investigated and the results have shown considerable contribution in the enhancement of the drying process by the use of the thermal backup. The time required to dry 2.5 kg of EFB requires 4.21 days under the open sun drying. This time is found to reduce to 1.33. By using the thermal backup, the drying efficiency of the EFB was enhanced by 64%. The contribution of the TBU is found to be very effective. It is highly recommended to adopt the integration of the solar dryers with thermal backup to achieve better performance.

The measurement results revealed that the location of the tray is significantly influencing the drying period. In the solar and the hybrid modes, the meddle located tray is found to take longer time to dray the product compared to the other trays.

Further investigations are recommended for other types of products, like food, fish and herbs.

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REFERENCES

Abdul Mannan. 2008. Composting EFB - Empty Fruit Bunches of Oil Palm. 22-May-2008. [Online]. Available: http://www.etawau.com/OilPalm/EFB.htm. [Accessed: 11-May-2010].

Bena, B. and Fuller, R. J. 2002. Natural convection solar dryer with biomass back-up heater. Solar Energy, vol. 72, no. 1, pp. 75-83.

Bhattacharya, S. C., Ruangrungchaikul, T., and Pham, H. L. 2000. Design and Performance of a Hybrid Solar/Biomass Energy Powered Dryer for Fruits and Vegetables. World Renewable Energy Conference, Brighton, UK, Energy Program, Asian Institute of Technology P.O. Box 4, Klong Luang, Pathumthani 12120, Thailand.

Brammer, J. G. and Bridgwater, A. V. 1999. Drying technologies for an integrated gasification bio-energy plant. Renewable and Sustainable Energy Reviews, vol. 3, no. 4, pp. 243-289.

Chua, N. S. 1991. Optimal utilization of energy sources in a palm oil processing complex. Seminar on Development in Palm Oil Milling Technology and Environmental Management, Genting Highlands, Pahang, Malaysia., May 16–17.

"Energy Information Bureau (EIB) Malaysia." [Available Online].: http://eib.org.my/index.php?page=article&item=100,136,143,152 . [Accessed: 22-Apr-2010].

Hasibuan, R. and Daud, W. R. W. 2007. Through drying characteristic of oil palm empty fruit bunch (EFB) fibers using superheated steam. Asia-Pacific Journal of Chemical Engineering, vol. 2, no. 1, pp. 35-40.

Madhlopa, A. and Ngwalo, G. 2007. Solar dryer with thermal storage and biomass-backup heater. Solar Energy, vol. 81, no. 4, pp. 449-462.

Mastekbayeva, A. G., Chandika P. B., Augustus, M.L. and Kumar, S. 1999. Experimental studies on a hybrid dryer. ISES 99 Solar World Congress, Israel.

Prasad, J., Vijay, V., Tiwari, G., and Sorayan, V. 2005. Study on performance evaluation of hybrid drier for turmeric (Curcuma longa L.) drying at village scale. Renewable Energy, vol. 30, no. 14, pp. 2097-2109.

Prasad, J., Vijay, V., Tiwari, G., and Sorayan, V. 2006. Study on performance evaluation of hybrid drier for turmeric (Curcuma longa L.) drying at village scale," Journal of Food Engineering, vol. 75, no. 4, pp. 497-502.

Rahim, S. and Suffian, M. 2006. Development of Specialty Particleboard from Oil Palm Fibre. Forest Research Institute Malaysia (FRIM), Kepong, Selangor Darul Ehsan, 2006. <hhtp://info.firm.gov.my/cfdocs/infocenter/highlight.NONIRPA_2006?08%20Rahim%20Sudin.pdf>

Serafica E. and del Mundo R. 2005. Design and Qualitative Performance of a Hybrid Solar-Biomass Powered Dryer for Fish. World Renewable Energy Regional Conference, Jakarta, Indonesia.

Tarigan, E. and Tekasakul, P. 2005. A Mixed-Mode Natural Convection Solar Dryer with Biomass Burner and Heat Storage Back-up Heater. Australia and New Zealand Solar Energy Society ***ANZSES*** Annual Conference, Dunedin NZ, 28-30 Nov.

Thanaraj, T., Dharmasena, D., and Samarajeewa, U. 2004. Development of a Rotary Solar Hybrid Dryer for Small Scale Copra Processing, Tropical Agriculture Research, vol. 16, pp. 305-315.

Yunus, Y. Md. 2011. Development and Analysis of Hybrid Solar Dryer with Biomass Backup Heater. Masters Thesis, Universiti Teknologi PETRONAS. http://utpedia.utp.edu.my/id/eprint/3060.

Yunus, Y. Md, Al-Kayiem, H. H., and. Albaharin, K. A. K. 2011. Design of a Biomass Burner/Gas-to-Gas Heat Exchanger for Thermal Backup of a Solar Dryer, Journal of Applied Science, 11 (11), Pp 1926-1936.
DOI: 10.3923/jas.2011.1929.1936.