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International Journal Of Modern Engineering Research (IJMER)

Performance Testing of The Hybrid Solar-Biomass Dryer for Fish Drying

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Abstract: *A hybrid solar-biomass dryer was constructed and tested in fish drying aiming to configure drying air temperature, drying air relative humidity and fish moisture content in drying process. The dryer was mainly consisted of drying chamber equipped with a chimney and ten trays for fish being dried, arranged in five stories inside, a furnace embedded with a heat exchanger and an exhausted funnel, and double heat collectors. The dryer was tested in three modes of drying, i.e. by solar energy, biomass energy, and solar energy followed by biomass energy. The results of experiments indicated that the higher the position of the trays, they obtained the higher drying air temperature and the lower drying air relative humidity. Utilizing fish moisture content of 20% for dry fish, the drying process was completed in 24.4 hours by the solar energy drying, 14.4 hours by the biomass energy drying, 15.4 hours by the solar energy followed by biomass energy drying, and 24.2 hours by sun drying.*

I. INTRODUCTION

Drying is commonly performed for fish preservation. Open air sun drying is widely practiced by fishermen, especially in developing countries although it faces a lot of problems such as spacious, labor intensives, and risk of product contamination and losses. To solve these problems solar dryers with various models were introduced [1] [2]. Although some models have properly performed, but solar drying works only in daylight period. To overcome this discrepancy hybrid solar dryer has been introduced. Hybrid solar dryer is a dryer that operates with solar energy and other energies such as electric energy [3] [4] [5] and biomass energy [6] [7] [8] [9]. In general hybrid solar dryer still needs or depends on electricity either as an energy substitution [10] [11] [12] [13] or drying air circulation [14] [15]. This becomes a serious handicap to operate hybrid solar dryer in remote areas where the electricity grid is not available. This article presents the results of experiments on the use of a free electricity, solar-biomass hybrid dryer with coconut shell as energy substitution, for fish drying in the form of profiles of temperature and relative humidity of drying chamber, and fish moisture content.

II. METHODOLOGY

2.1. Equipment

The main structure of the dryer was made of light steel slab covered by transparent UV12% plastic sheet having total area 5 m x 2.4 m and consisted of drying chamber measured about 2 m x 2.4 m x 1.1 m, furnace, heat exchanger, chimney, heat collectors and trays. The furnace was constructed from metal sheet with 0.42 m x 0.34 m cross area and 2 m long, its bottom was perforated to provide oxygen entries, and was provided with a front gate and a slotted box for fuel supply. The heat exchanger was embedded with the furnace and was a hollow main body made of metal sheet having 2 m x 2 m x 0.18 m in dimension, connected to 10 hollow fins (5 right and 5 left) made of aluminum sheet and measured about 2 m x 0.8 m x 0.03 m each, and all together was placed in the drying chamber. On the back side of the heat exchanger body, an exhausted funnel was placed. The Dimension of the chimney was 0.4 m x 0.4 m x 1.3 m and was situated in the center of upper end of the roof, 2.83 m from the ground. An air outlet was provided at the upper end of the chimney. The heat collector was 2.4 m x 1.6 m corrugated aluminum sheet painted in black on the upper surface while the lower surface was layered successively by used newspapers and wooden sheet as heat insulating materials. The dryer was provided with two heat collectors and each collector was equipped with air inlet at its lower end. The tray measured 0.76 m x 2 m and was constructed from anti-corrosive wires framed with metal slab. There were 10 trays, eight trays were situated between fins and two trays were placed above the top fins. The drying chamber was provided by two front doors to facilitate in-out movement of trays during drying operation. The dryer was installed in the same direction of the sun.

Utilizing solar energy, the dryer operated as follows. As soon as solar radiation struck the structure of the dryer, solar energy was collected, the drying chamber used the solar energy gain to directly heat drying air in it while the collector accumulated the solar energy and then used it to heat fresh air entering from the inlet. The entering air was also heated directly by the solar energy passing through the roof of plenum above the collector plate before it was supplied to the drying chamber. The heated drying air had a lower density than that of ambient air, and due to the closed system in the drying structure, a pressure gradient was created between a point in the plenum just after the inlet of the collector and a point before the outlet of the chimney so that continuous flow of hot air occurred from the inlet to the outlet. The hot air flow passed through the trays where the fish being dried was placed, and drying process took place. Fish moisture content continuously decreased and finally reached a certain level as an indication that the drying was completed.

The dryer was biomass energy operated as follows. The furnace door was opened and the slotted box was loaded with the fuel of known weight was loaded and the fuel fired, and then all together was introduced into the furnace and the furnace door was closed. The fuel was maintained to ember in favor to oxygen supply from the perforation at the bottom of the furnace and the existence of the exhausted funnel as a combustion gas escape. The combustion heat was distributed inside the fins and then was conducted in the drying chamber to increase the temperature of drying air that passed through from the inlet at the heat collector to the outlet of the chimney. The drying air evaporated moisture content of fish to be dried.

Supporting instruments used in this experiment were digital thermohygrometer for ambient air and drying air measurements, platform scale for fuel weighting, digital balance (0.1 gr accuracy) for fish sample weighting, freezer to preserve fresh fish, plastic boxes as fresh fish containers, oven to determine fish sample moisture content, and plastic bags to collect and to store fish samples

2.2. Materials

Pepetak Leiognatus spp. measured 12 to15 cm length, 3 to5 cm width and 13 to 18 mm thickness was utilized for experiments. Loaded with this described fish, the capacity of the dryer was about 100 kg fresh fish. The fish were taken from traditional fishermen at Teluk Sepang, Pantai Zakat, and Pulau Baai beaches, Bengkulu City. Fish were dried without splitting. Fresh coconut shell collected from daily need shops was purchased for biomass energy source. The coconut shell was sun dried to produce ready use biomass fuel having a moisture content of 9.03 (± 0.40) %.

2.3. Drying Experiments

Three series of experiments were conducted: solar energy drying, biomass energy drying and solar energy drying followed by biomass drying. The solar energy drying was carried out as follows. Five thermohygrometers were respectively placed on every storey of trays and one thermohygrometer was hung outside the dryer at a shaded area, the trays were loaded with fish, and 20 fish for every storey of tray and 20 fish for sun drying (as a treatment comparation) were prepared for observation. The experiment was run from 09.00 AM . to 16.00 PM, drying temperature, drying relative humidity, ambient temperature, ambient humidity were recorded for every 30 minutes while fish samples were weighted for every hour. The drying process was completed in three days and the experiment was repeated in three times, i.e. in 19th to 21st August 2015, in 4th to 6th September 2015, and in 8th to 10th September 2015.

In the biomass energy drying, thermohygrometers set up and fish samples preparation for drying was done in the same procedure as that of the solar energy drying. Before the experiment was proceeded, the dryer was shaded with dark color tarpaulin to avoid solar energy invasion to the dryer. Based on the preliminary experiment, the fuel supplies were 3 kgs coconut shell for first supply and 1.5 kgs for subsequent supplies in 20 minutes interval. Soon after the thermohygrometers and fish to be dried in place, the first supply fuel was fired and subsequent supplies were followed for every 20 minutes to maintain the drying s and temperature. The drying was begun at 9 AM and run for 17 hours. Recordings of temperature, humidity and weight of fish samples were conducted in the same procedure as those of the solar energy drying. The experiment was repeated in three times: in 21st to 22nd, 25th to 26th , and 28th to 29th September 2015 respectively.

In the solar energy drying followed by the biomass energy drying, the drying processes, instrument setting, fish samples preparation, and experimental parameters recording were carried out in the same procedures as the previous experiments. The experiment was taken place from 9 AM to 4 PM for the solar energy drying and then was followed by the biomass drying until 2 AM on the next day. The experiment was run for three times, i.e. 5th to 6th September 2015, 6th to 7th October 2015, and 7th to 8th October 2015.

Dried fish sample moisture contents were determined employing the gravimetric method by placing the samples in the oven having a temperature of 150^{o}C for 24 hours (SNI 01-2354.2-2006). Fish moisture content was calculated in wet basis.

Experimental data were presented in the forms of temperature, relative humidity and fish moisture content in function of drying time, and the results were then discussed, and finally the conclusion was drawn.

III. RESULT AND DISCUSSION

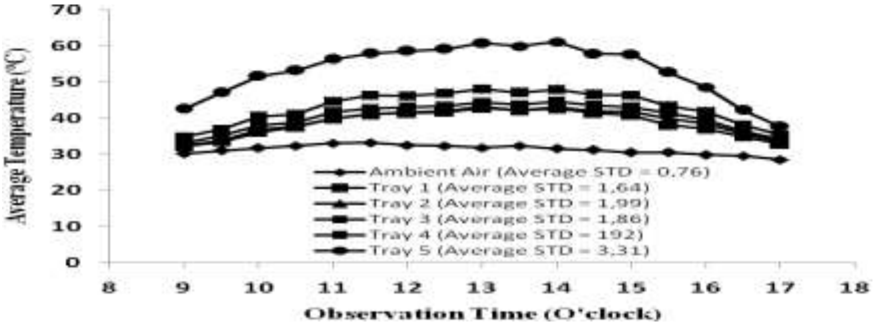

Figure 1. Average temperatures of the dryer's trays and ambient air for the solar energy drying and sun drying

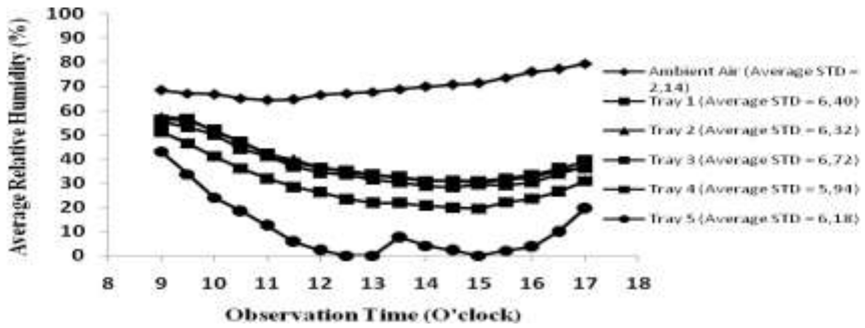

Figure 2. Average relative humidities of the dryer's trays and ambient air for the solar energy drying and sun drying

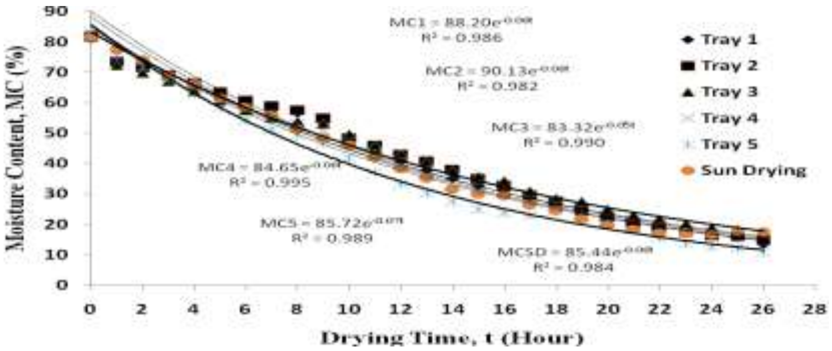

Figure 3. Curves of fish moisture contents in function of drying time for the solar energy drying and sun drying

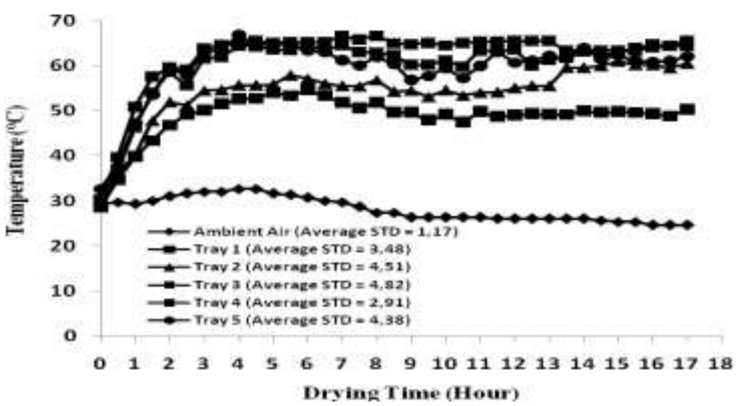

Figure 4. Average temperature values decreased against drying time during the biomass energy drying

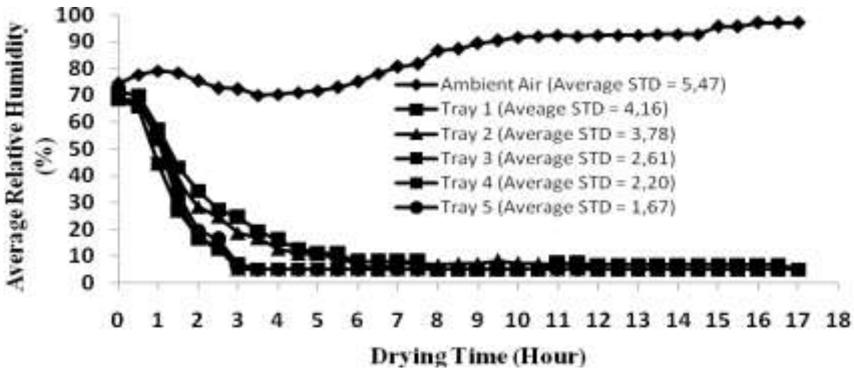

Figure 5. Average relative humidity values decreased against drying time during the biomass energy drying

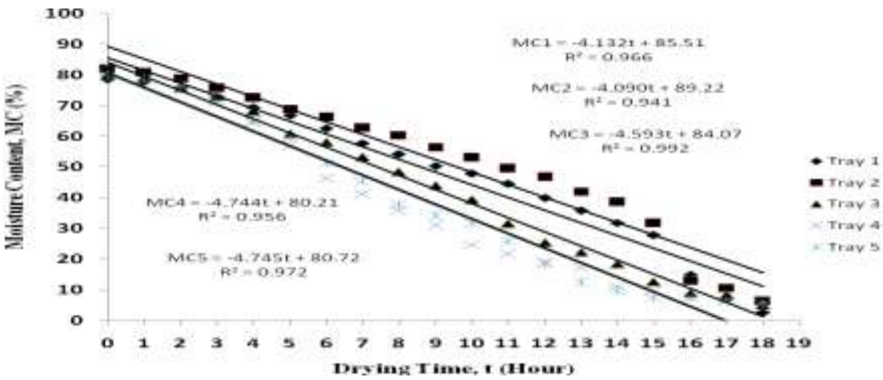

Figure 6. Fish moisture contents plotted against drying time during the biomass energy drying

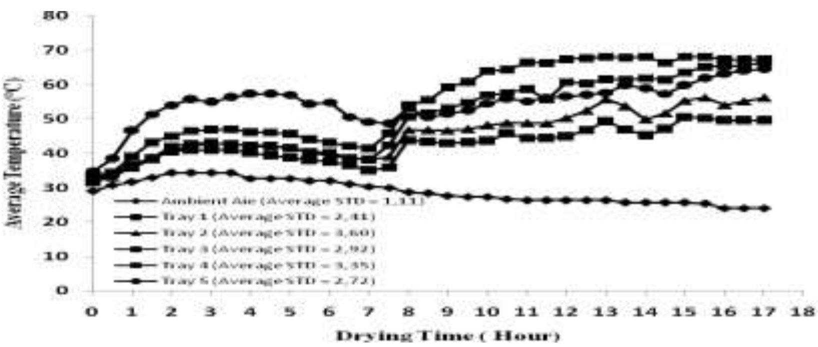

Figure 7. Average temperature values decreased against drying time during the solar energy followed by biomass energy drying

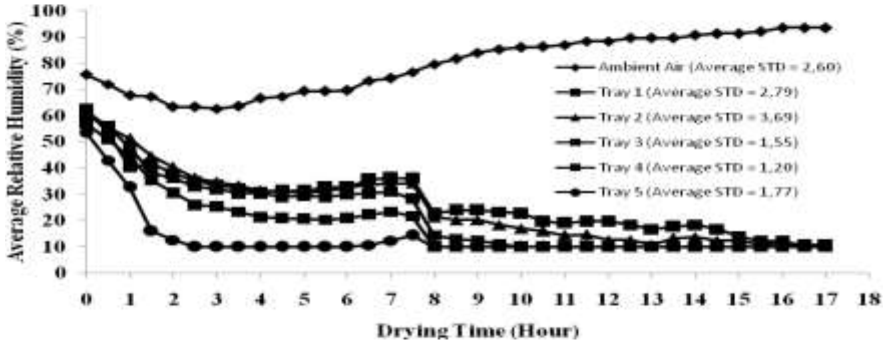

Figure 8. Average relative humidity values decreased against drying time during the solar energy followed by biomass energy drying

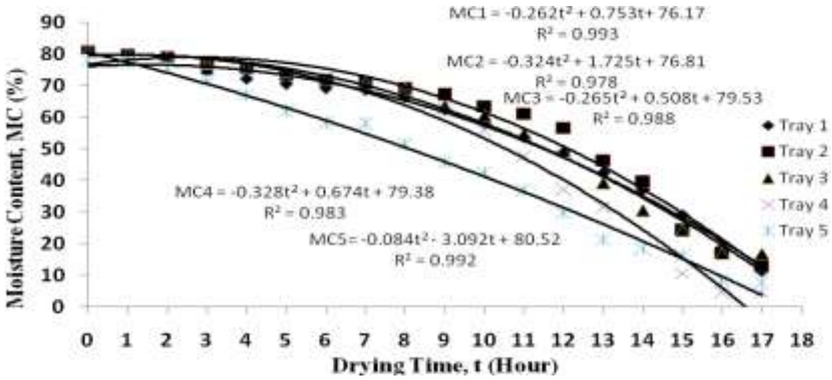

Figure 9. Fish moisture contents plotted against drying time for the solar energy followed by biomass energy drying

Table 1. Profile of drying time to complete drying process

Tray	Drying method		
	Solar energy drying (hour)	Biomass energy drying (hour)	Solar energy followed by biomass energy drying (hour)
1	23,6	15,9	16,1
2	25,1	16,9	16,2
3	28,5	13,9	16,0
4	24,0	12,7	14,5
5	20,8	12,8	14,1
Average	24,4	14,4	15,4
Std	2,81	1,88	0,98

Using the fish moisture content threshold of 20%, from curve in Figure 3, the drying time to complete sun drying was 24,2 hours. Compared to this value, the values of drying time of tray1, tray4 and tray5 of the solar energy drying were lower, whereas those of tray2 and tray3 was higher, and its average value of drying time was comparable. On the other hand the values of drying times of all the trays and the average values of drying time of both biomass energy drying and solar energy followed by biomass energy drying was lower than that of sun drying. So based on Table 1, in term of drying method, the times to complete drying process were in the order of the biomass energy drying, the solar energy followed by biomass energy drying and the solar energy drying respectively.

To justify the advantage of the dryer described here, the performance of this dryer was compared to that of the solar-biomass hybrid dryer introduced by Chavan et al. (2008). Chavan's dryer consisted of drying chamber having a similar measure which was 2 m x 2 m and similar gasifier to this dryer. The differences were Chavan'dryer was constructed from bricks and mortar, and supported by pipes as heat exchanger and automatic temperature controller, whereas this dryer dryer was constructed from metal frame and UV plastic cover as the main structure, and equipped with double heat collectors measured 1.5 m x 2 m each, hollow fins heat exchanger. Chavan'dryer was combustioned with eucalyptus wood on the other hand, this dryer was fueled with cononut shells. Tested solar energy followed by biomass energy with 25 kgs mackerel fish measured 17.7±0.33 cm length, Chavan'dryer decreased fish moisture content from 17.7±0.33 cm length, in contrast, utilizing, the same mode of drying operation and loaded with 100 kgs *Pepetak* fish measured of 15 -18 cm length, this dryer was able to reduce fish moisture content from 78.48% to 20% in 15.43 hours. This suggests that this dryer performed better than Chavan'dryer.

The uniqueness of the hybrid solar-biomass dryer presented on this occasion depicted from the overall structure, the heat exchange and free electricity consumption. This specification has been distinguished to the dryers described by several researchers [6] [8] [16].

IV. CONCLUSION

Operating with solar energy, the performance of the dryer was comparable to the sun drying, but in term of space, labor and risk of product contamination and losses, the dryer was beneficial. Operating with biomass energy and solar energy followed by biomass energy, the dryer was able to significantly speed up the fish drying suggesting that this dryer was ready to be adopted by fishermen and fish processor.

Acknowledgements

Acknowledgement is delivered to the Ministry of Research, Technology and Higher Education for providing the budget of this research.

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