

Performative Improvement of Solar-Biomass Hybrid Dryer for Fish Drying

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Abstract— The solar-biomass hybrid dryer had been developed, and recently its design was improved. The dryer was basically UV12% plastic house, equipped with a drying chamber with the trays inside, two heat collector, a furnace embedded in a heat exchanger and a chimney. The objective of this study was to investigate the performance of the dryer after the design was improved by testing it for fish drying with different modes of energy supply i.e: solar energy (SE), biomass energy (BE), solar energy followed by biomass energy (SEBE), and simultaneous solar energy and biomass energy (SEBES). Coconut shell was used as the biomass energy source, and “Bleberan” fish (*Pepetak Leiognatus spp.*) was employed as the experimental commodity. SE mode generated the average drying air temperature 10.6°C higher than that of ambient air and the average drying air relative humidity 21.9% lower than that of ambient air, and completed the drying process in 16.6 hours compared to 23.3 hours needed to finish the drying process for the sun drying. Operating with 3 kg fuel first supply and 1.5 kg fuel subsequent supplies per 20 minutes, BE mode produced the average drying air temperature 28.2°C higher than that of ambient air and the average drying air relative humidity 44.7% lower than that of ambient air, and the drying process was completed in 8.6 hours with the fuel consumption of 0.375 kg biomass per kg wet fish. In SEBE mode with the same fuel supplies as BE mode, the average drying air temperature was 27.7°C higher than that of ambient air, and the average drying air relative humidity was 45% lower than that of ambient air, and the drying process was completed in 13.4 hours with the fuel consumption of 0.19 kg biomass per kg wet fish. For SEBES mode with 3 kg fuel first supply and 1 kg fuel subsequent supplies, the average drying air temperature was 25.6°C higher than that of ambient air, the average drying air relative humidity was 43.9% lower than that of ambient air, and the dryer finished the drying process in 9.1 hours and consumed 0.29 kg biomass per kg wet fish. The uniqueness of the dryer was manifested by its shape, the heat exchanger and electricity free.

Keywords— hybrid dryer; solar-biomass; drying performance; fish; coconut shell

I. INTRODUCTION

Drying is an important process of food preservation, including fish. Sun drying has been widely exploited due to its practical application. However, this drying has many disadvantages such as the risk of product contamination by dust, dirt and other unwanted materials [1], [2], prompt to product losses caused insect attack; animal fled and rustler; space intensive [3], Labor consumptive especially during rainy season. To overcome these discrepancies, solar dryers of various types have been introduced.

According to solar energy utilization, there are direct type solar dryers [4], [5], [6], [7], indirect type dryers [1], [5], [8], [9], [10] and mix type solar dryers [11], [12]. In the direct type solar dryers, the structure of dryer comprises transparent materials like glass or plastics covering the product being dried and its moisture content is evaporated from the upper surface of the product by incoming sun rays passing through the transparent cover. In the indirect type dryers, the device is usually equipped with a heat collector

that accumulates solar energy from the sun. This energy is then used to heat drying air for evaporating the product moisture content. In the mixed type dryers, solar energy gains obtained from the sun rays passing through the transparent cover and drying air supplied by the heat collector, are utilized to evaporate moisture from the wet product. Some dryers have been equipped with heat storage to extend the drying process, but it is not sufficient to eliminate the problem of drying during bad weather and the rainy season since the source of drying energy depends completely on solar radiation.

To solve this problem, the hybrid solar dryers have been developed. These dryers operate with solar energy and other energies, such as electric energy [13], [14], [15] and biomass [16], [17], [18], [19], [20] as energy substitution or a combination. The substitution energy is usually supplied from an electric heater or a heat exchanger that transfers heat from combustion stove. Most hybrid solar dryers, demand electricity to circulate the drying air. This becomes a serious handicap for the application of the hybrid solar

dryers in the remote areas where electricity grids are not available as often experienced by majority developing countries. So it would be valuable to develop a hybrid solar dryer which is free of electricity.

On the other hand, fish has become the main source of protein in developing countries and is intensively preserved by drying. Fish has been dried by various dryers with several ranges of temperature according to fish species, for examples 32.39 to 57.69°C for Mackerel fish using solar-biomass hybrid cabinet dryer [21], 36.1°C to 51.5°C for Croaker fish, Anchovy fish and Ribbon fish using the greenhouse solar tunnel dryer [22], 36 to 55°C for Silver Jewfish using Hohenheim type solar tunnel dryer [23], 35 to 55°C for fresh Tilapia fillets using pump dryer [24], 40°C to 60°C for salted Shark fillets using horizontal air flow cabinet oven [25]), 47 to 51°C for fresh prawns using a solar dryer with electrical energy backup [26]), up to 69°C for Sardines fish using solar tunnel dryers [27]. In practice, it is important to take account of tolerable temperature for fish drying to obtain a good dry fish. Caprio noted that 49.5 to 70.4°C had experienced drying temperature in the Philippines [28].

In the previous study, the solar-biomass hybrid dryer was developed and tested by using a coconut shell as a fuel for fish drying [29]. This research aimed to explore the performance of the dryer after the design had been improved.

II. MATERIAL AND METHOD

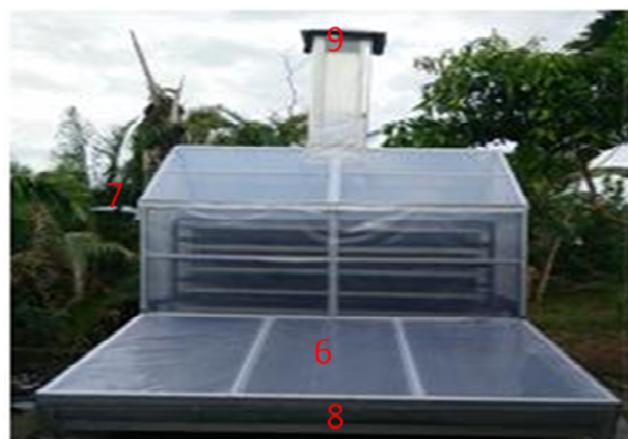
A. Equipment

The general design of the dryer was basically the same as described by Yuwana and Sidebang [29] in term of structure and dimensions, whereas the modification was made especially on the inclination of the roof of drying chamber and the surface heat collector, and the interior of the heat exchanger. The version is presented in Figure 1. The roof drying chamber and the surface of heat collector were inclined in 45° from the ground to improve the distribution of drying air inside the structure. Furthermore, laths were adhered inside the wall of the main body of the heat exchanger to improve the distribution of the combustion gas into the hollow fins. The modified dryer was constructed from light steel slabs and covered with UV12% transparent plastic and consisted of the main body functioned as drying chamber and supported by two wings as a heat collector, a furnace together with a heat exchanger, a chimney, and trays. The drying chamber measured of 2.4 m length 1.9 m width and 1.26 m height and two front doors were provided to accommodate in and out movement of the trays. Each heat collector had a horizontal area of 2.4 m length and 1.5 m wide and was made of corrugated zinc sheet painted in black on the surface facing into the sun, whereas the opposite surface was insulated successively with used newspaper and plywood. At the lower end of the heat collector, a clearance of 0.25 m and covered with nylon net as the inlet of fresh air. This clearance was gradually increased up to 0.35 m at the lower end of the wall of the drying chamber and functioned as a plenum. The furnace was situated beneath the drying chamber had 0.42 m x 0.34 m cross area and 2 m long, and perforations were made in its bottom to facilitate fresh air entry. The furnace was also equipped with a front gate and a slotted box for biomass fuel supply.

The heat exchanger comprised a hollow main body made of a metal sheet having 2 m x 2 m x 0.18 m in dimension, connected to 5 pairs hollow fins (right and left) made of aluminum sheet and measured about 2 m x 0.8 m x 0.03 m each.



Front View



Side View

Fig. 1. Photo of the dryer, showing the chimney (1), drying chamber (2), fin of heat exchanger (3), tray (4), furnace (5), heat collector (6), exhaust funnels (7), inlet air (8), outlet moist air (9)

The heat exchanger embodied in the drying chamber and embedded in the furnace. An exhaust funnel was mounted on the back side of the main body of the heat exchanger for smoke escape. The chimney was 0.4 m x 0.4 m x 1.3 m in dimension and was paled 2.83 m from the ground, the center of the upper end of the roof of drying chamber. The chimney was equipped with an outlet of air at its upper end. The dryer was provided with 10 trays made of anti-corrosive wire and fringed by metal slabs and measured about 0.76 m x 2 m each. The whole structure of the dryer occupied a horizontal area of 11.76 m². The dryer was installed in a free shading area and oriented parallel to the sun.

The mode of operation of the dryer can be described according to the types of energy used, i.e., solar energy and biomass energy. The dryer operates with solar energy as

follows. As soon as the sun lights penetrate the cover of the dryer, the drying chamber and the plenum of the heat collector collect solar energy and directly use it to heat the drying air in it while the black surface of the heat collector accumulates solar energy and also uses it to heat drying air in the plenum. Accumulating solar energy, the temperatures of the drying air in both the drying chamber and the plenum increases and its density decreases, and because of this, the drying air flows from the plenum of the heat collector passing through the trays and finally escapes from the drying chamber through the outlet of the chimney. The flow of drying air is followed by fresh air entering from the inlet. So as long as the sun rays are available, there is a continuous flow of drying from the inlet passing through the trays in the drying chamber to the outlet. The drying air evaporates moisture of the fish placed on the trays and the fish moisture content gradually decreases as a function of drying time.

Utilizing biomass energy, the dryer works as follows. The gate of the furnace is opened, and the slotted box is slid out and loaded with biomass fuel of known weight. The fuel is fired, then the slotted box is slid into, and the gate of the furnace is closed. Due to oxygen supply through the perforation of the furnace bottom and combustion gas escape through the exhaust funnel, the fuel is maintained to ember. The combustion heat is distributed in the hollow fins and is then conductively transferred into the drying chamber to heat the drying air supplied from the inlet. The temperature of the drying air increases and heats the wet fish on the trays and evaporates its moisture. Finally, the moist air is exhausted from the drying chamber through the outlet.

The other instruments used in the experiments were digital thermo-hygrometers to measure temperature and relative humidity values of both drying air and ambient air; digital platform scale (1 g accuracy) to weigh the biomass fuel; digital balance (0.1 g accuracy) for weighing the fish samples; a freezer for fresh fish preservation; an oven for moisture content determination of the fish samples; plastic bags for collecting and preserving the dry fish samples.

B. Materials

"Bleberan" fish (*Pepetak Leiognatus spp.*) measured about 13.4 (± 0.25) cm length, and 7.6 (± 0.57) mm width were prepared for the experiments. With these specified measures, the capacity of the dryer was about 100 kg wet fish. The fish was freshly bought from traditional fishermen at Pulau Baai, Pantai Zakat and Teluk Sepang shores, Bengkulu. The fish were kept fresh in the freezer before using and were dried intact. Fresh coconut shell purchased from stalls was prepared as a biomass energy source for the experiments. To be ready for use as combustion fuel, the fresh coconut shell was sun-dried to obtain a moisture content of 9.04 (± 0.3) %.

C. Experiments

Four series of drying experiments were carried out according to the drying energy used, i.e., solar energy (SE) drying, biomass energy (BE) drying (BE), solar energy drying continued by biomass energy (SEBE) drying, and simultaneous solar energy and biomass energy (SEBES) drying done simultaneously. Each series of experiments were repeated three times.

Within all series of drying, experiment preparation was done as follows. All of the trays were loaded with fish, and a sample of 20 fish was prepared for each story of the trays, so there were 100 fish for observation for every run of drying experiment. Five thermo-hygrometers were installed on each story of trays to measure drying air temperature and relative humidity, and one thermo-hygrometer was hung in the shading area outside the dryer to measure ambient air temperature and relative humidity. Temperature and relative humidity value were recorded for every 30 minutes while the fish samples were weighed regularly for every hour.

After the drying process was completed the dry fish samples were taken to the laboratory for dry weight determination. These samples were placed in the oven having a 105°C temperature for 24 hours. Obtaining the dry weight and the wet weight, the moisture of the fish samples along the drying process was calculated on a wet basis using the following equation.

$$MC = \frac{W_w - W_d}{W_w} \times 100\% \quad (1)$$

where

MC = moisture content of sample (%)

W_w = sample wet weight (kg)

W_d = sample dry weight (kg)

In the first series of experiment, the solar energy (SE) drying was conducted in three times within a two-day period, i.e., July 20th to 22nd, 2016, September 25th to 26th 2016, and September 27th to 28th. The drying process was run from 9 AM to 4 PM. As a comparison sample of 20 fish was sun-dried near the dryer. The fish sample was weighed in the same manner as those of the solar drying.

In the second series of experiments, the biomass energy (BE) drying was done in three replications on August 6th, 7th and 8th 2016. The dryer was protected from solar radiation by shading it with dark color tarpaulin. Three-kilogram fuel first supply and 1.5 kg subsequent supplies per 20 minutes were in the furnace. The drying process was completed in 10 hours from 8 AM to 6 PM.

The next series of experiments where the solar energy drying was continued with the biomass energy (SEBE) drying. The solar energy drying was performed in the same method as the first series of experiments while the biomass energy drying followed the same procedure as the second series of experiments. The drying process started at 8 AM and terminated at 11 PM. The experiments were carried out in three replications on October 7th, 9th and 10th 2016.

In the fourth series of experiments, the dryer was operated by solar energy and biomass energy simultaneously (SEBES). In this mode, the dryer was solar energy operated in the same manner as the first series of experiments, and the dryer was biomass energy operated by feeding the furnace with 3 kg fuel first supply and 1 kg fuel subsequent supply per 20 minutes. The drying process was run from 6.30 AM to 5 AM, and the three replications were taken place on 9th, 11th and 12th 2016.

The results of the experiments were presented in the forms of graphs which were drying air temperature, drying air relative humidity, ambient air temperature, ambient air

relative humidity and moisture content of fish in function of drying time. The fish was judged to be dry when its moisture content reached 20% wet basis (wb) [30].

III. RESULTS AND DISCUSSION

The results of the first series of experiments, where the dryer was solar energy operated, are presented in Figure 2 and 3.

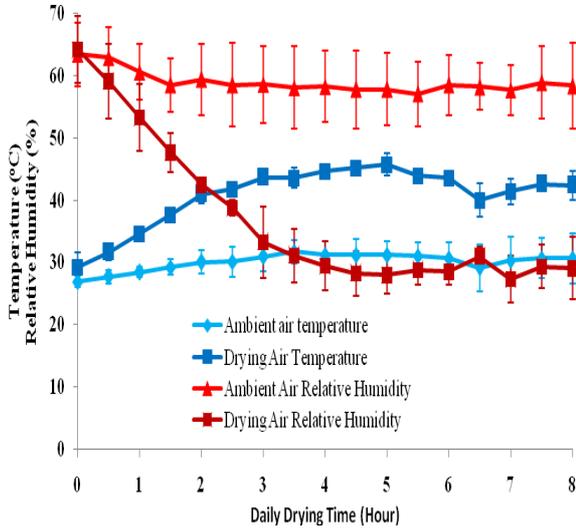


Fig. 2. Daily temperature and relative humidity plotted against daily drying time for both the solar energy drying and the sun drying

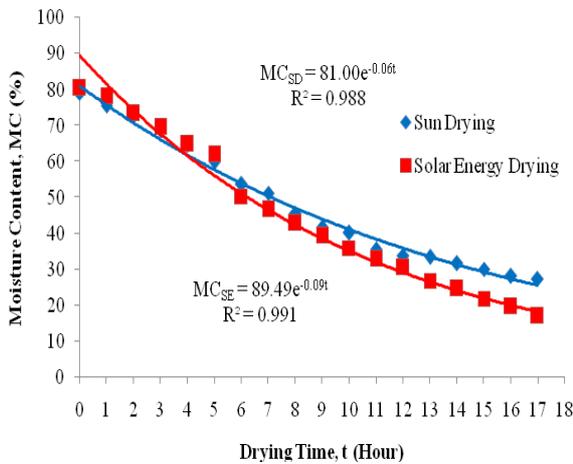


Fig. 3. Fish moisture content plotted against drying time for both the solar drying and the sun drying

The experimental data also indicated that the average ambient air temperature and drying air temperature were 30.1°C and 40.7°C, respectively, while the average ambient air relative humidity and drying air relative humidity were 58.9% and 37%, respectively. So the dryer was able to generate the drying air temperature 10.6°C higher than the ambient air temperature and the drying air relative humidity 21.9% lower than the ambient air relative humidity. This temperature gain was higher than the temperature gain of Doe tent solar dryer (6.2°C) reported by Olorok and Omojowo[4] and passive solar dryer (8°C) reported by Dasin et al. [31]. The ability of the dryer to decrease the drying air relative humidity was better than Kainji type solar

dryer (14.3%) and Doe type solar dryer reported by Olorok and Omojowo [4].

The curves in Figure 3 indicate that the fish moisture contents decreased exponentially with the drying time for both the solar energy drying and the sun drying, the drying process was completed (fish moisture content of 20%) in 16.6 hours for the solar energy drying and 23.3 hours in the sun drying. These typical curves were also found in the solar drying of Sardines fish [32], in the greenhouse tunnel solar drying of salted and unsalted Croaker fish, Anchovy fish and Ribbon fish [22]. The performance of this dryer was also better than that of the dome type solar dryer with multiple trays tested by Sablani et al. [32] since this dryer was equipped with 5 stories of trays and completed the drying process faster than that of the sun drying whereas the dome dryer had only 3 stories of trays and finished the drying process in comparable time to that of the sun drying. Compared to the greenhouse tunnel solar dryer which generated the drying air temperature of 40°C to 45°C and decreased the moisture content of freshwater fish from 226.95% - 296.05% (dry basis) to 17.64% - 25% (dry basis) in 24 to 32 hours depending on the fish species, the performance of this dryer also seemed to be better.

The results of the second series of experiments, when the dryer was biomass energy operated, are presented in Figure 4 and 5.

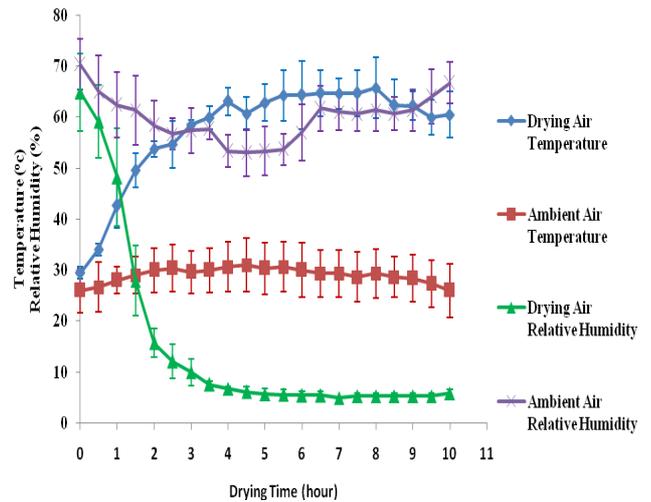


Fig. 4. Drying air temperature, ambient air temperature, drying air relative humidity, ambient air relative humidity plotted against drying time for the biomass energy drying

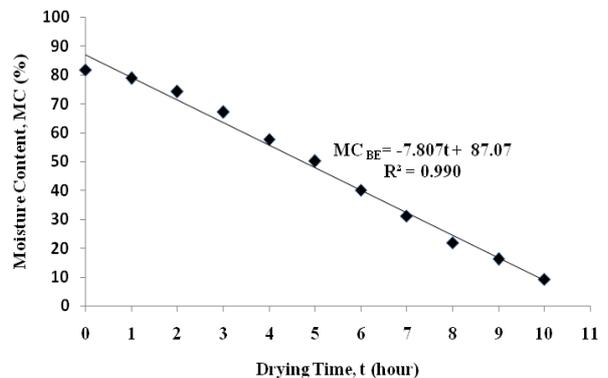


Fig. 5. Fish moisture content plotted against drying time for the biomass energy drying

The dryer produced the average drying air temperature about 57.2°C which was 28.2°C higher than the average temperature of ambient air, and the average drying air relative humidity of 15.1%, which was 44.7% lower than the average relative humidity of ambient air. The fish moisture content decreased linearly with the drying time; the 20% fish moisture content was obtained in 8.6 hours, the dryer consumed 37.5 kg fuel. In this case, the biomass fuel needed by the dryer to dry the fish was 0.375 kg per kg wet fish. The linear drying curve was also observed by Sengar et al.[33] in the solar energy drying for the prawn with the drying temperature ranged from 32.4°C to 57.7°C, and by Chavan et al. [21] in the solar-biomass hybrid cabinet drying for Mackerel fish working in the temperature range of 32.4°C to 57.7°C, the relative humidity range of 23.9% to 85.8%, and the drying air velocity of 0.20 ms⁻¹ to 0.6 ms⁻¹.

Figure 6 and 7 presents the result of the third series of experiment, in which the dryer was solar energy operated and continued by biomass energy operated.

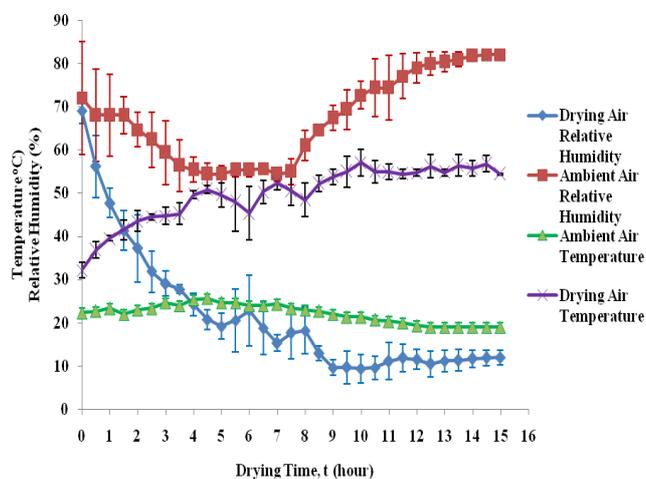


Fig. 6. Drying air temperature, ambient air temperature, drying air relative humidity, ambient air relative humidity plotted against drying time for the solar energy drying continued by the biomass energy drying

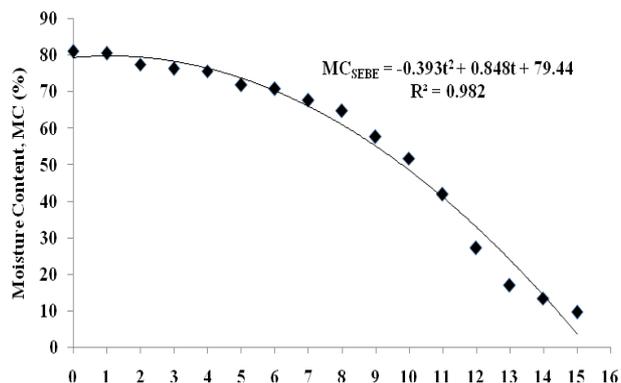


Fig. 7. Fish moisture content plotted against drying time for the biomass energy drying for the solar energy drying continued by the biomass energy drying

The dryer generated the average drying air temperature about 49.8°C which was 27.7°C higher than the average temperature of ambient air and the average drying air relative humidity of 22% which was 45% lower than the average relative humidity of ambient air. The fish moisture

content decreased quadratically with the drying time, and the dryer completed the drying process in 8.6 hours with the total fuel supply of 19 kg so that the fuel consumption was 0.19 kg biomass per kg wet fish.

Figure 8 and 9 shows the results of the fourth series of experiment, where the dryer was operated by solar energy and biomass energy simultaneously.

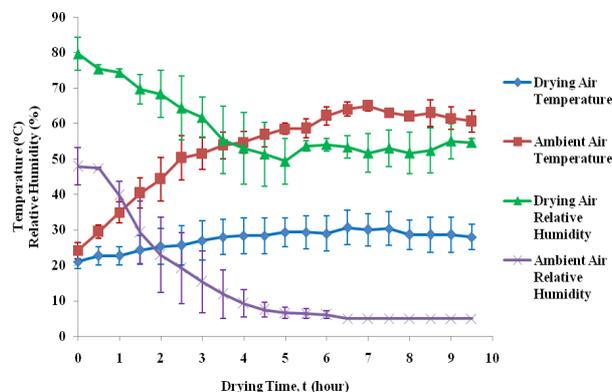


Fig. 8. Drying air temperature, ambient air temperature, drying air relative humidity, ambient air relative humidity plotted against drying time for the simultaneous solar energy and biomass energy drying

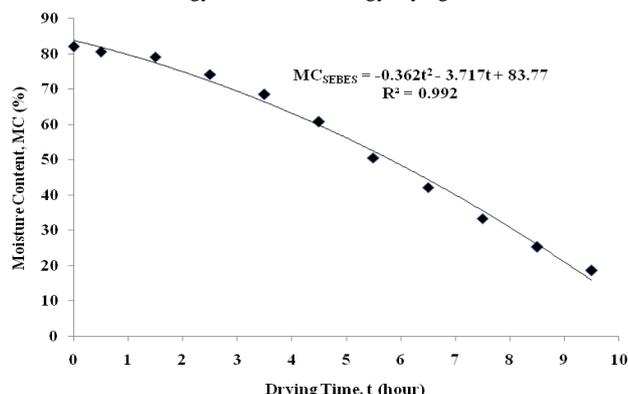


Fig. 9. Fish moisture content plotted against drying time for the biomass energy drying for the simultaneous solar energy and biomass energy drying

The dryer produced the average drying air temperature about 52.9°C which was 25.6°C higher than the average ambient air temperature, the average drying air relative humidity of 15.2% which was 43.9% lower than the average ambient air relative humidity. The drying process was completed in 9.1 hours, and the dryer consumed total fuel of 29 kg. Therefore the fuel consumption was 0.29 kg biomass per kg wet fish.

The quadratic curve found in the drying process, when the dryer was solar energy operated and continued by biomass energy operated, and the dryer was solar energy, and biomass energy operated simultaneously, have not been reported in fish drying by other researchers, but this typical curve was similar to the curve of convective heat transfer coefficient versus drying time reported by Das and Tiwari [34] in the prawn drying process employing greenhouse type solar dryer.

The results of the dryer performance testing according to the type drying operation are summarized in Table 1.

TABLE I.
THE PERFORMANCE OF THE DRYER ACCORDING TO THE TYPE OF OPERATION

Performance Indicator	Type Operation			
	SE	BE	SEBE	SEBES
Ta (±Std) ^o C	30.1 (±2.3)	29.0 (±0.6)	22.1 (±1)	27.3 (±4.4)
RHa (±Std)%	58.9 (±5.4)	59.8 (±1.3)	67.0 (±4)	59.1 (±5.2)
Td (±Std) ^o C	40.7 (±1.4)	57.2 (±1.6)	49.8 (±2.2)	52.9 (±3)
RHd (±Std)%	37.0 (±3.6)	15.1 (±2.9)	22.0 (±4)	15.2 (3.2)
td (h)	16.6	8.6	13.4	9.1
fc (kg fuel /kg fish)		0.375	0.19	0.29

Note: Ta = temperature of ambient air, RHa = Relative humidity of ambient air, Td = temperature of drying air, RHd = Relative Humidity of drying air, td = time to complete drying process, fc = fuel consumption, Std = standard deviation

This Table indicates that the highest drying air temperature was produced when the dryer was biomass energy operated and was in the range of drying air temperature for fish reported by Caprio [28] which was 49.5-70.4^oC.

The superiority of the dryer can be distinguished by comparing its performance to the performance of the solar-biomass hybrid cabinet dryer introduced by Chavan et al. [21] when these dryers were run by solar energy and biomass energy operated subsequently, after describing their important parameters. Both dryers comprised 2 m x 2 m drying chamber and the furnace having similar working principle, but this dryer was structured by metal slab as a frame and UV12% transparent, and equipped with double heat collectors and the heat exchanger in the form of hollow fins whereas Chavan's dryer was constructed from bricks and mortar, and equipped with the heat exchanger made of pipes, a fan, and a temperature controller. As a source of biomass energy, this dryer used coconut shell, on the other hand, Chavan's dryer utilized Eucalyptus wood. Operating with the drying air temperature of 49.8(±2.2)^oC and relative humidity of 22(±4)%, and loaded with 100 kg wet fish Bleberan measured about 13.41 (±0.25) cm long, this dryer reduced the moisture content of fish from 81.04% to 20% in 13.4 hours, in contrast working with the drying air temperature ranged from 32.39^oC to 57.69^oC, relative humidity ranged from 23.9% to 85.8% and drying air velocity of 0.20-0.60 m/s, and loaded with 25 kg of fish Mackerel measured of 17.7±0.33cm long, Chavan's dryer decreased the fish moisture content from 72.5±0.44% to 16.7±0.52% in 24 hours.

The design of the solar-biomass hybrid dryer introduced here was also unique compared to those reported by other researchers [16], [21], [17], [18]. The uniqueness of this dryer relied mainly on the shape of the structure as depicted in Figure 1, the design of the heat exchanger as described in detail above, and free from electricity dependence which makes it possible for application in remote areas. Furthermore, the performance of the heat collector may be improved by adopting a solar tracking system [35] while the efficiency of the furnace can be increased since it was found

that the gasifier efficiency for biomass was between 50-80% [36]. Finally, the operation of the dryer may be optimized seeing that a device for future solar irradiance prediction may soon be available [37].

IV. CONCLUSION

Based on the above results the conclusion can be formulated as follows. Operating with solar energy, the dryer generated the average drying air temperature 10.6^oC higher than that of ambient air and the average drying air relative humidity 21.9% lower than that of ambient air, and completed the drying process in 16.6 hours compared to 23.3 hours needed to finish the drying process of the sun drying. When the dryer was biomass energy operated with 3 kg fuel first supply and 1.5 kg fuel subsequent supply per 20 minutes, the dryer produced the average drying air temperature 28.2^oC higher than that of ambient air and the average drying air relative humidity 44.7% lower than of ambient air, and the drying process was completed in 8.6 hours with the fuel consumption of 0.375 kg biomass per kg wet fish. In the case of the dryer was solar energy operated, and followed by biomass energy operated with the same fuel supplies as the previous experiment, the average drying air temperature was 27.7^oC higher than that of ambient air and the average drying air relative humidity 45% lower than that of ambient air, and the drying process was completed in 13.4 hours with the fuel consumption of 0.19 kg biomass per kg wet fish. When solar energy and biomass energy with 3 kg fuel first supply and 1 kg fuel subsequent supply were employed to operate the dryer, the average drying air temperature was 25.6^oC higher than that of ambient air temperature, the average drying air relative humidity of 15.2% was 43.9% lower than that of ambient air. The dryer completed the drying process in 9.1 hours and consumed 0.29 kg biomass per kg wet fish. The uniqueness of the dryer was identified by its shape, the heat exchanger characteristic, free electricity dependence.

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