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DEVELOPMENT OF A HYBRID ENERGY GREENHOUSE SOLAR DRYER WITH A VERTICAL ROTATING RACK SYSTEM FOR DRYING FISH

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Abstract

This study aimed to evaluate the performance of a greenhouse solar dryer with a vertical rotating rack system (GHSD-VRR), integrated with an air recirculation system and a biomass furnace with air preheater. This GHSD-VRR was able to reduce the weight of fish from 88.6 kg with a wet basis moisture content of 68.5% (2.18% on a dry basis) to 34.4 kg with a wet basis moisture content of 20% (0.21% on a dry basis) at an average air temperature of about 57.0°C and an average sunlight of 629 W/m² in 10.8 hours. The average drying rate (DR) and specific moisture extraction rate (SMER) reached 4.44 kg/s and 0.211 kg/kWh, respectively. The average specific energy consumption (SEC), specific thermal energy consumption (STEC), and specific electrical energy consumption (SEEC) were 7.724 kWh/kg, 6.408 kWh/kg, and 1.315 kWh/kg, respectively. The efficiency of biomass furnace, dryer, and exergy were recorded at 66.9%, 38.7%, and 80.5%, respectively. The contribution of heat energy from sunlight and biomass to the dryer system was 19.18% and 64.7%, respectively.

Keywords: Drying, fish, greenhouse, rotating rack, performance.

INTRODUCTION

Indonesia is one of the largest fish producing countries in the world, with fish production coming from catches in sea waters, inland public waters, and fish farming. Every year, capture fisheries production from the sea and inland public waters reaches around 7.7 million tons and 3.03 million tons respectively, while fish farming produces around 5.54 million tons [1].

Fish is one of the most popular foods in Indonesia because it is high in protein, vitamins, and minerals but low in calories [2]. After being caught, fish generally have a high moisture content, around 70-80% wet basis, which makes it difficult to store for a long time. Post-harvest technology, like the application of drying methods, is needed to preserve fish for this reason [3].

In general, there are two popular methods used by fishermen to dry fish, namely the traditional method and the use of a greenhouse dryer with a static rack system. In the traditional method, fish are dried on bamboo mats or nets using direct sunlight. This simple and easy-to-do method has low drying quality and the process takes a long time.

A number of researchers have conducted research on the static rack type greenhouse solar dryer (GHSD-SR) to dry various fishery and agricultural products, silver jewfish [3], tilapia [4], medium size queenfish [5], cambodian fish species [6], bombay duck [7], wild ginger [8], fenugreek leaves [9], chili [10]) banana slices [11], and *Eugenia caryophyllus* [12].

Several studies have indicated that GHSD-SR is very suitable for drying in large quantities, producing hygienic products, and accelerating drying time. However, both systems have several weaknesses, namely (1) the distribution of air temperature is uneven along and in each rack in the drying chamber, causing the final moisture content (MC) of the material to vary, with some parts having high moisture content that allows microorganisms or fungi, which can reduce the quality of dried fish, to grow, (2) high air temperature that comes out through exhaust air from the drying chamber causes a lot of heat energy to be wasted into the environment, automatically increasing energy consumption and reducing the performance of the dryer, (3) the dryer function is not optimal when the weather is cloudy or overcast, or when sunlight is low, and (4) solar energy collectors (greenhouses) ability to absorb solar energy is low, so that the air temperature produced in the drying chamber is also limited. In addition, the drying process requires a lot of energy to evaporate water in the dried material. The drying process consumes about 12% of the total energy needed in the agricultural and food industries [13, 14].

To overcome the limitations of traditional drying methods and greenhouse dryers with static rack systems, innovation in drying technology is needed. Therefore, the purpose of this study is to develop a greenhouse dryer with a vertical rotating rack system (GHSD-VRR) integrated with an air recirculation system and a biomass furnace.

RESEARCH METHODS

2.1. Experimental set-up

A greenhouse solar dryer with vertical rotating rack system (GHSD-VRR) integrated with an air recirculation system and a biomass furnace has been designed and fabricated for drying fish, as shown in **Fig.1**. The GHSD-VRR comprises several essential components: a greenhouse (drying chamber), racks, a biomass furnace, an air recirculation system, an air distributor, and a rotating rack transmission system.

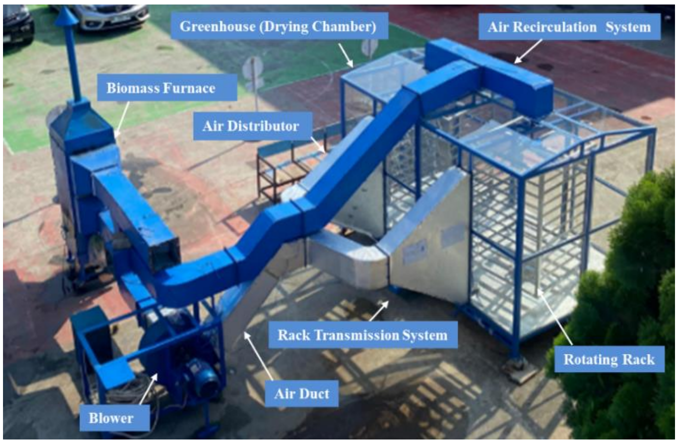


Fig. 1. Photo of the GHSD-VRR.

2.2. Experimental procedure

The researchers conducted a two-day experiment to evaluate the performance of a hybrid energy greenhouse solar dryer with a rotating rack system, designed to dry up to 90 kg of fish. On the first day, drying took place from 9:00 a.m. to 4:00 p.m., and on the second day from 9:00 a.m. to 2:00 p.m. Fresh tilapia fish sourced from local farmers in Padang were cleaned, split in half, and about 4.5 kg of fish were placed on each of the 20 trays in the drying chamber.

During the experiment, air temperature at various points in the dryer (GHSD-VRR), as shown in **Fig. 2**, was measured using thermocouples. These thermocouples and fish samples were placed in different locations within the chamber (see **Fig. 3**). Solar radiation was measured using a pyranometer, and air mass flow was measured with an anemometer. A data logger recorded air temperature and solar radiation, while sample weights were measured using scales. All measurements temperature, sunlight, and sample weight were taken every 60 minutes.

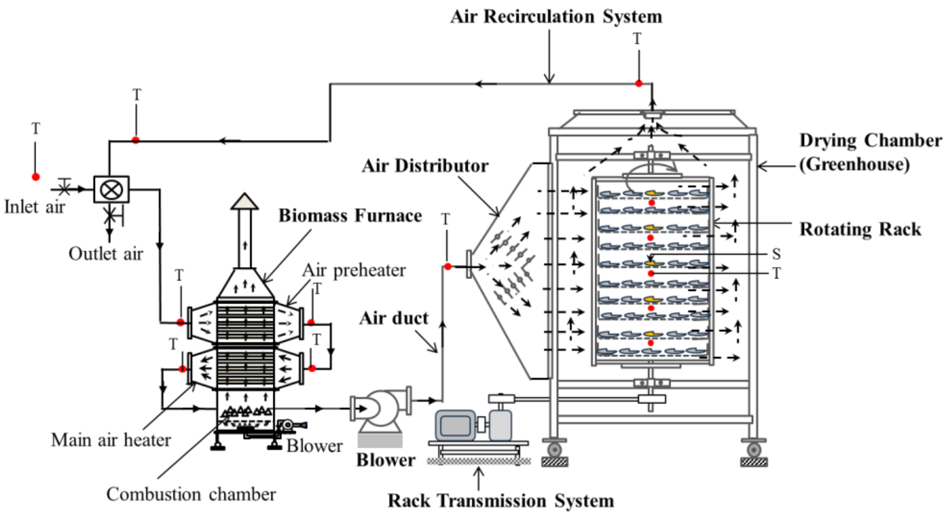


Fig. 2. Schematic of the GHSD-VRR.

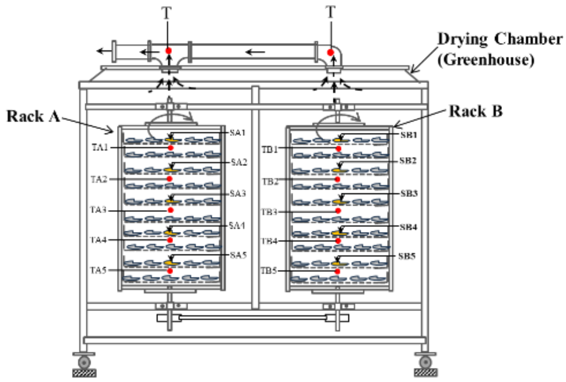


Fig. 3. The positions of thermocouple and fish samples in the drying chamber.

2.3. Analysis of performance

The equations in **Table 1**. are used to calculate the performance of the greenhouse solar dryer with a vertical rotating rack system (GHSD-VRR) for drying fish and the efficiency of the biomass furnace.

Table 1. The equations used to calculate the performance of the dryer and the efficiency of the biomass furnace.

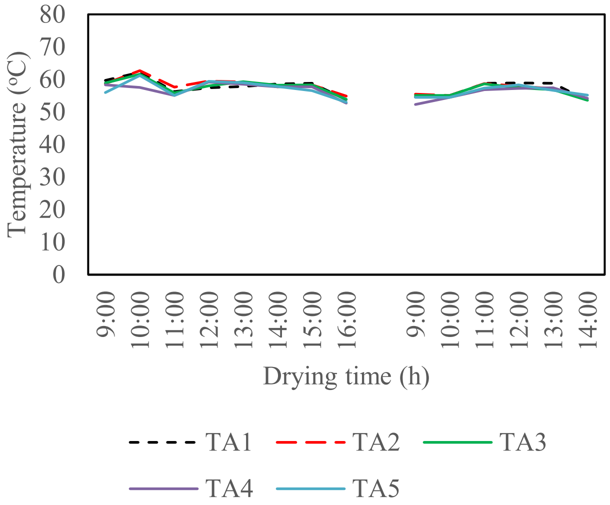
Parameter	Formula	Eq.no.	Ref.
Efficiency of biomass furnace	$\eta_{thbf} = \frac{Q_{ubf}}{Q_{Ibmf}}$	(1)	[15]
Useful heat from biomass furnace	$Q_{ubf} = \dot{m}_{da} C_{Pda} (T_{o,BF} - T_{i,BF})$	(2)	[15]
Heat energy input of biomass furnace	$Q_{Ibmf} = \dot{m}_{bf} CV_{bf}$	(3)	[15]
Moisture content (db)	$M_{db} = \frac{m_{wet} - m_d}{m_d}$	(4)	[16]
Moisture content (wb)	$M_{wb} = \frac{m_{wet} - m_d}{m_{wet}}$	(5)	[16]
Drying rate (DR)	$DR = \dot{m}_{water} = \frac{M_{db,t+dt} - M_{db,t}}{dt}$	(6)	[17,18]
Specific energy consumption	$SEC = \frac{Q_{Ise} + Q_{Ibmf} + W_{Tee}}{\dot{m}_{water}}$	(7)	[19,20]

Specific moisture extraction rate	$\mathrm{SMER} = \dfrac{\dot{m}_{water}}{Q_{Ise} + Q_{Ibmf} + W_{Tee}}$	(8)	[19]
Solar energy input	$Q_{Ise} = I_T A_{SC}$	(9)	[19]
Total electrical energy input for drying system	$W_{Tee} = W_{Mrts} + W_{Bdr} + W_{Bbf}$	(10)	[20]
Specific thermal energy consumption	$\mathrm{STEC} = \dfrac{Q_{Ise} + Q_{Ibmf}}{\dot{m}_{water}}$	(11)	[21]
Specific electrical energy consumption	$\mathrm{SEEC} = \dfrac{W_{Tee}}{\dot{m}_{water}}$	(12)	[21]
Contribution of biomass fuel energy	$CE_{BF} = \dfrac{Q_{Ibmf}}{Q_{Ise} + Q_{Ibmf} + W_{Tee}} \times 100\%$	(13)	[15]
Contribution of solar energy	$CE_{SE} = \dfrac{Q_{Ise}}{Q_{Ise} + Q_{Ibmf} + W_{Tee}} \times 100\%$	(14)	[15]
Thermal dryer efficiency	$\eta_{th} = \dfrac{\dot{m}_{water} H_{fg}}{Q_{Ise} + Q_{Ibmf} + W_{Tee}}$	(15)	[22]
Exergy efficiency of drying chamber	$\eta_{Ex} = \dfrac{Ex_{DCi} - Ex_{loss}}{Ex_{DCi}} = 1 - \dfrac{Ex_{loss}}{Ex_{DCi}}$	(16)	[22,23]
Exergy losses	$Ex_{loss} = Ex_{DCi} - Ex_{DCo}$	(17)	[22,23]
Exergy inflow of drying chamber	$Ex_{DCi} = \dot{m}_{da} C_{Pda} \left[(T_{i,DC} - T_{amb}) - T_{amb} \ln \dfrac{T_{i,DC}}{T_{amb}} \right]$	(18)	[22,23]
Exergy outflow for drying chamber	$Ex_{DCo} = \dot{m}_{da} C_{Pda} \left[(T_{o,DC} - T_{amb}) - T_{amb} \ln \dfrac{T_{o,DC}}{T_{amb}} \right]$	(19)	[22,23]
Power input of blower biomass furnace	$W_{Bbf} = VI \cos \varphi$	(20)	[24]
Power input of dryer blower	$W_{Bdr} = \sqrt{3} VI \cos \varphi$	(21)	[24]
Power input of rack transmission system motor	$W_{Mrts} = \sqrt{3} VI \cos \varphi$	(22)	[24]

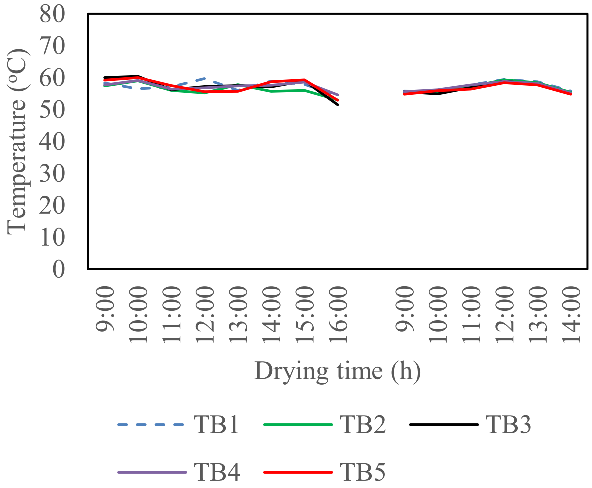
RESULTS AND DISCUSSION.

The variations of air temperature at various positions on rack A (TA1, TA2, TA3, TA4, and TA5) and rack B (TB1, TB2, TB3, TB4, and TB5) in the drying chamber are shown in Figs. (4a) and (4b). From these two graphs, it can be seen that the air temperature has the same trend at the same time, caused by the effect of the rotation of the racks.

Furthermore, the variations of the weight change of fish samples at different positions on rack A (SA1, SA2, SA3, SA4, and SA5) and rack B (SB1, SB2, SB3, SB4, and SB5) are also shown in Figs. (5a) and (5b). These two graphs show that the weight change of fish samples at the same time also shows the same trend, because the samples receive almost uniform heat energy from the air.

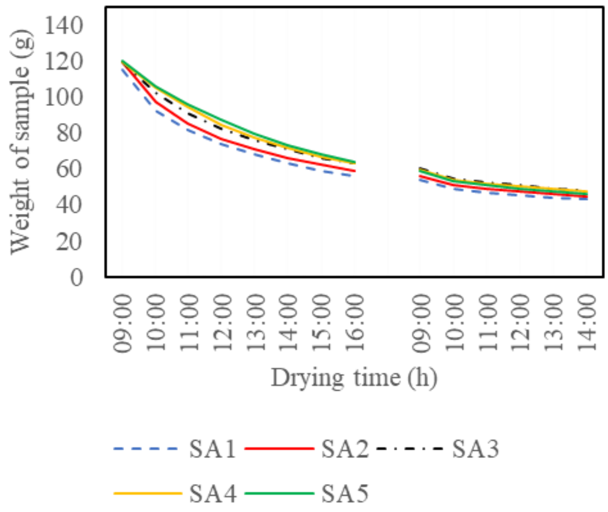


(4a). Air temperature on rack A.

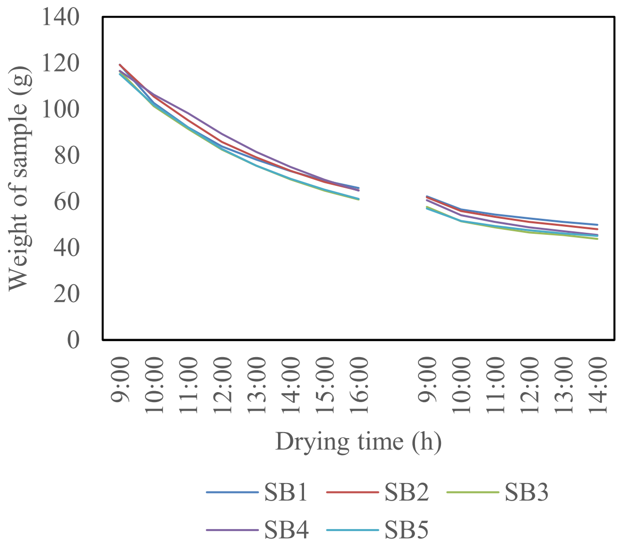


(4b). Air temperature on rack B.

Fig. 4. Air temperature on rack A (4a) and rack B (4b) versus drying time.



(5a). Weight change of fish samples on rack A.



(5b). Weight change of fish samples on rack B

Fig. 5. Weight change of fish samples on rack A (5a) and rack B (5b) versus drying time.

In this dryer (GHSD-VRR), the air coming out of the drying chamber, or exhaust air, is reused for the drying process by circulating it through the air recirculation system and biomass furnace. Before being used for the drying process, this air is first heated in the air preheater and the main air heater of the biomass furnace according to the desired temperature. The variations of air temperature entering, inside, and leaving the drying chamber against drying time are shown in Fig. 6. The temperature of the air entering the drying chamber is maintained in the range of 56.0°C-59.3°C with an average of 57.7°C using a biomass furnace. Meanwhile, the average temperature of the air inside the drying chamber is recorded at 57.0°C (range: 53.5°C-60.0°C), and the average temperature of the air leaving the drying chamber was 54.4°C (range: 50.0°C-57.1°C). **Fig.6** also shows the variations of sunlight, ambient temperature, and air temperature entering the biomass furnace. The average sunlight received by the greenhouse (drying chamber) during the drying process reaches 629 W/m². The average temperature of the ambient air and the air entering the biomass furnace are recorded at 33.8°C (range: 31.5°C-36.2°C) and 47.7°C (range: 43.5°C-50.5°C), respectively. The graph shows that the temperature of the air leaving the drying chamber is higher than the ambient air temperature. Utilizing this exhaust air for the drying process can save energy or reduce biomass fuel consumption by 58.2% compared to using ambient air.

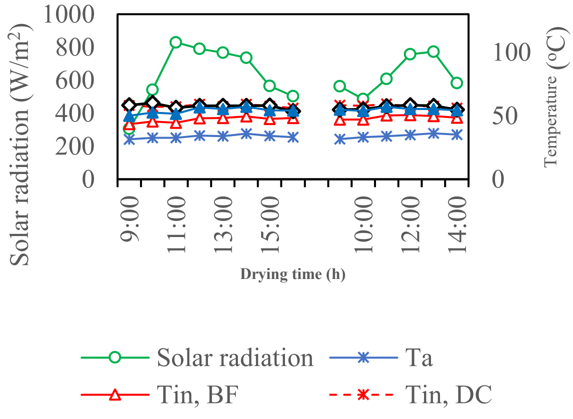


Fig. 6. Solar radiation and temperature versus drying time.

Variations in fish weight changes, as well as changes in moisture content on a wet basis and a dry basis during the drying process are shown in **Fig.7.** The figure expresses that the weight and moisture content of the fish decrease continuously as the drying time increases due to a decrease in the driving force for the mass transfer of water from the inside of the material to the surface. In this GHSD-VRR, the time required to reduce the weight of the fish from 88.6 kg with a wet basis moisture content of 68.5% (2.18% dry basis) to 34.4 kg with a wet basis moisture content of 20% (0.21% dry basis) is 10.8 hours, with an average air temperature of around 57.0°C and an air mass flow rate of 0.676 kg/s.

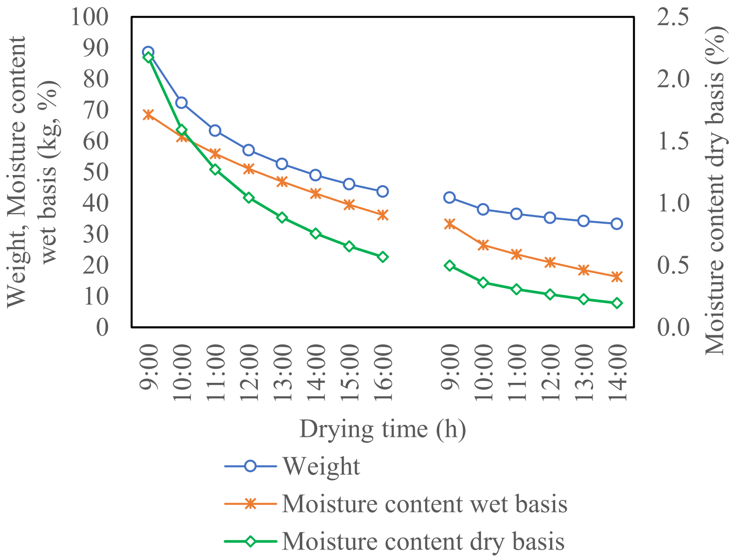


Fig. 7. Weight and moisture content (wet basis and dry basis) vs drying time

Fig. 8 shows the variations of DR (drying rate) along with drying time, with an average reaching around 4.44 kg/s (in the range of 0.89-16.26 kg/s). From the figure, it can be seen that the DR value is high at the beginning of drying and decreases at the end of drying. This is due to the high moisture content of the fish at the beginning of the drying process, which gradually decreases to low at the end of drying. **Fig. 8** also shows the variations of SMER (Specific Moisture Extraction Rate) with drying time, where the average obtained is around 0.211 kg/kWh (in the range of 0.060-0.585 kg/kWh). The SMER value is highly dependent on the rate of water evaporation from the material and the energy input into the drying system. The higher the rate of water evaporation from the material, the higher the SMER value obtained, and vice versa.

Fig. 9 shows the variations of SEC (Specific Energy Consumption), STEC (Specific Thermal Energy Consumption), and SEEC (Specific Electrical Energy Consumption) along with drying time. The average values for these three energy consumption variables are obtained at 7,724 kWh/kg (in the range of 1,710-16,586 kWh/kg), 6,408 kWh/kg (in the range of 1,533-13,342 kWh/kg), and 1,315 kWh/kg (in the range of 0.178-3,243 kWh/kg). From the figure, it can be seen that the values of these three types of energy consumption are quite large at the end of the drying process. This is due to the low rate of water evaporation from the material in the final phase of drying. **Fig. 9** also shows the variations of the thermal efficiency of the dryer, where the average value reaches 14.0% (in the range of 4.0-38.7%).

Fig. 10 shows the exergy variations (inflow, outflow, and loss) during the drying process. The average values for each of them are 3988.3 W (in the range of 3036.6-5037.4 W) for inflow, 3171.1 W (in the range of 2641.7-4081.9 W) for outflow, and 817.1 W (in the range of 235.6-2265.5 W) for loss. Fig. 10 also shows the exergy efficiency variations during the drying process, with values ranging from 54.3-93.1%, and the average exergy efficiency reaches about 80.5%.

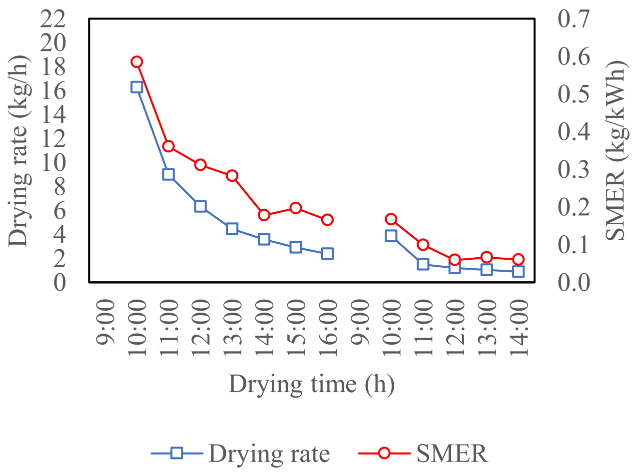


Fig. 8. Drying rate and SMER versus drying time

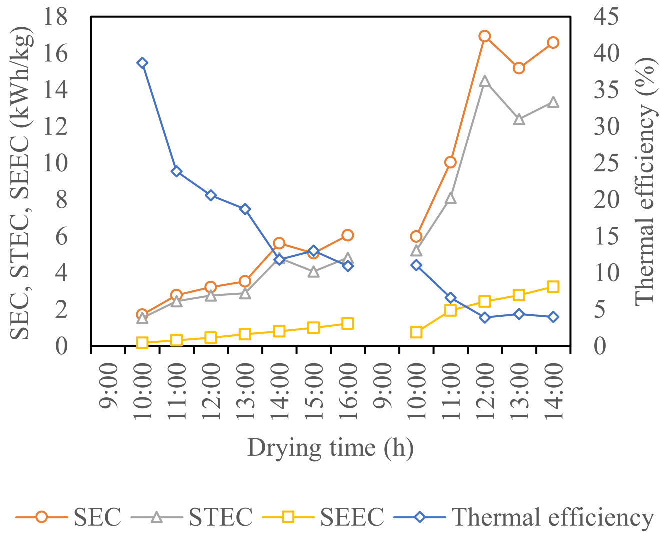


Fig. 9. SEC, STEC, SEEC, and thermal efficiency of dryer vs drying time

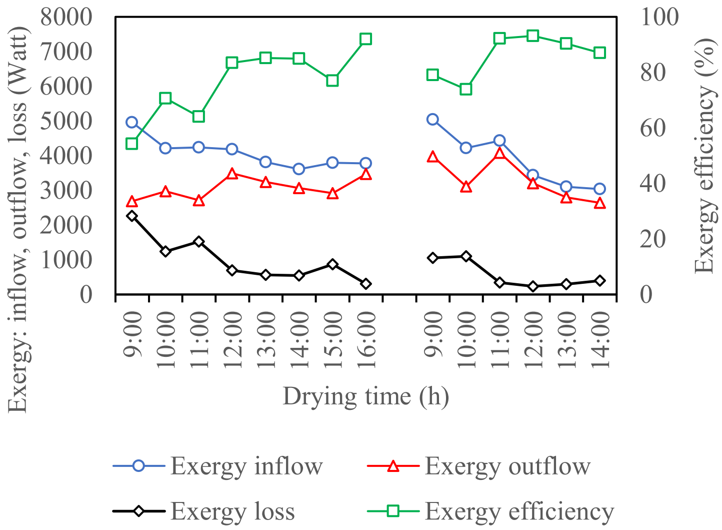


Fig.10. Exergy (inflow, outflow, and loss) and exergy efficiency versus drying time.

The variations of input energy and energy used in biomass stoves and the thermal efficiency of biomass stoves are shown in Fig. 11. The average values of input energy and energy used in biomass stoves are 12.51 kW (range: 8.83-22.08 kW) and 7.85 kW (range: 6.27-9.93 kW), respectively, while the thermal efficiency of biomass stoves reaches 66.9% (range: 40.9-87.1%) with an air mass flow rate of 0.676 kg/s. From the graph, it can be seen that input energy significantly affects the efficiency of the biomass furnace. When the input energy is low, the efficiency of the biomass furnace tends to be higher, and vice versa.

The variations of the contribution of heat energy from sunlight and biomass fuel during the drying process in GHSD-VRR are shown in Fig.12. The average contribution of these two energy sources is 19.18% (range: 10.2-25.7%) for sunlight and 64.7% (range: 56.0-79.4%) for biomass fuel. From Fig. 12, it can be seen that the contribution of heat energy from sunlight during the drying process is lower than the energy consumption from biomass fuel. This is due to the limitations of the solar collector or drying chamber in absorbing solar energy optimally.

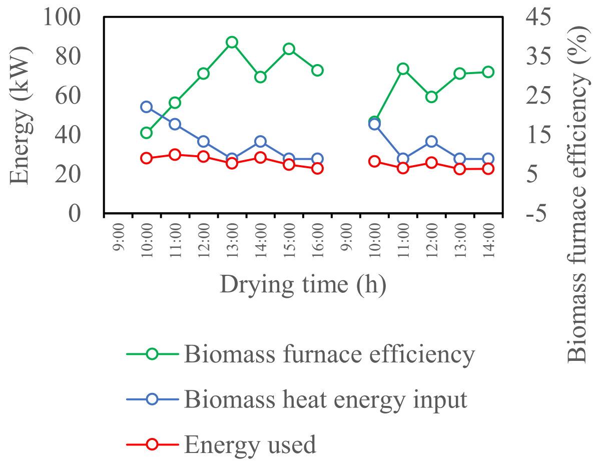


Fig. 11. Energy and biomass furnace efficiency versus drying time.

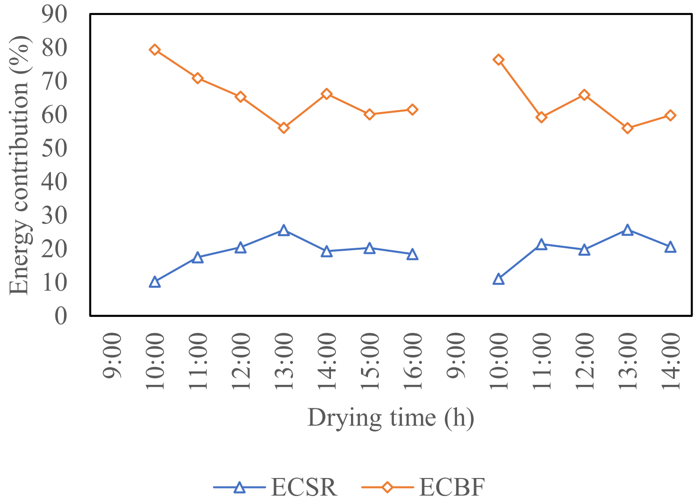


Fig.12. Energy contribution versus drying time.

CONCLUSIONS.

Research on the performance of a greenhouse dryer with a vertical rotating rack system (GHSD-VRR) integrated with an air recirculation system and a biomass furnace for drying fish has been conducted at Institut Teknologi Padang (ITP), Indonesia. From the research results, the following conclusions can be drawn:

1. The weather during the drying process was quite sunny, with an average sunlight intensity of 629 W/m².
2. The drying time to reduce the weight of fish from 88.6 kg with a wet moisture content of 68.5% (2.18% dry basis) to 34.4 kg with a wet moisture content of 20% (0.21% dry basis) at an average air temperature of 57°C and an air mass flow rate of 0.676 kg/s was 10.8 hours.
3. The average DR and SMER were 4.44 kg/s (range: 0.89-16.26 kg/s) and 0.211 kg/kWh (range: 0.060-0.585 kg/kWh), respectively.
4. The average specific energy consumption (SEC) was 7.724 kWh/kg (range: 1.710-16.586 kWh/kg).
5. The average STEC and SEEC were 6.408 kWh/kg (range: 1.533-13.342 kWh/kg) and 1.315 kWh/kg (range: 0.178-3.243 kWh/kg), respectively.
6. The average efficiency of the biomass furnace reached 66.9% (range: 40.9-87.1%).
7. The average thermal efficiency of GHSD-VRR and exergy efficiency were 14.0% (range: 4.0-38.7%) and 80.5% (range: 54.3-93.1%), respectively.
8. The average contribution of heat energy from sunlight and biomass fuel in the drying process was 19.18% (range: 10.2-25.7%) and 64.7% (range: 56.0-79.4%).
9. The average exergy inflow, exergy outflow, and exergy loss are 3988.3W (range: 3036.6-5037.4 W), 3171.1W (range: 2641.7-4081.9 W), and 817.1W (range: 235.6-2265.5W), respectively.

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