Harvesting Solar Energy by Combining Thermal and Photovoltaic System in Fish Dryer

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***Abstract*— Indonesia is a tropical maritime country, has abundant of sea product including in the Gresik Regency which has aquaculture products of 79 thousand tons per year and marine catches of 18 thousand tons per year. Drying is one of the methods to store fishery products longer. Conventional drying carries out with the medium of wind and sunlight. However, contamination of dust and other impurities cannot be avoided from conventional drying. Therefore, fish drying research will be carried out using a hybrid method with thermal collectors and solar panels to harvest solar energy which lead to increase efficiency and overcome the disadvantages of conventional fish drying. This tool model refers to the design of solar powered fish dryers with the development of additional thermal aisles and solar panels. The design of this study uses solar energy that is converted to heat through thermal collectors and cabinet spaces that resemble the greenhouse effect. Photons in solar energy are converted into electricity and become mechanical energy that will move the blower, that converted by photovoltaic. Air enters from the blowers to the thermal tunnel whose base is made of black plate as a thermal collector and the envelope is made of glass. Then hot air is brought to the cabinet drying chamber containing fish. The fish receives heat from the thermal collector and the cabinet system which also receives heat from the mirror installed on all three sides of the cabinet. Hot air containing moisture will come out on the cabinet's top shelf. The performance of dryers is measured by the value of efficiency and the quality of the fish. Based on experimental study, the efficiency of solar dryer is 43.15% and the bacteria test is 45 x 10^7 CFU/ml.**

Keywords— solar energy, thermal collector, photovoltaic, fish dryer

I. INTRODUCTION

Indonesia is an archipelago where 70% of the territory in Indonesia is in the form of water [1]. The area of water owned by Indonesia has its own advantages, especially in abundant marine biota. In general, coastal areas and oceans in Indonesia are the source of livelihood for the surrounding community. This is because coastal and marine areas have a variety of natural resources that can be used as a source of livelihood for the community. The fisheries sector is one of the natural resources in coastal and marine areas that supports the economy in Indonesia. Results from aquaculture and marine catches can be processed into a variety of products with various methods of processing carried out. The process of processing and preservation is an effort to improve the quality of storage and the durability of post-harvest fishery products. The purpose of processing and preservation of fish in principle is an attempt to overcome excess production and at the same time maintain the quality of fish before being marketed or consumed, increase the selling value of fish, as a food diversification material and to extend the shelf life of fish. There are various ways to preserve fish such as salting, drying, scanning, infiltration, fermentation and cooling of fish. One of the most preservative products found in Indonesia is salted fish. On a national scale, salted fish is a fishery product that has an important position, almost 65% of fishery products are still processed and preserved by salting. In the salting process there is also a drying process using solar energy which converted to thermal energy.

Fish drying can be done conventionally or using a dryer. In conventional dryers, fish are plate on an open container which is expected to be exposed to the sun. Conventional drying does not consider various factors, namely the heterogeneity of heat received by each part of the dried fish so that the drying of the fish is not evenly distributed. As a result, the water content contained in dried fish can differ both between parts and between the dried ones. Hygienic factors are difficult to avoid from contamination of dust and other impurities, and technical drying factors such as temperature, air flow rate, and humidity are difficult to control. This can reduce the quality of drying results [2]. Based on Indonesian standard SNI 8273: 2016, the quality of fish can be seen from the value of water content and the level of bacteria found in the body of the fish. In salted fish, the level of bacteria can grow when the fish is wet and vice versa when dry the bacteria cannot grow on the body of the fish. To decrease the moisture, a drying system is needed that can be controlled according to its needs. Therefore, it is necessary to do research and development of drying systems.

Dryers are continuously being developed with the aim to simplify and accelerate the process of drying fish. Experimental studies of simple fish dryers have been carried out by making fish dryers using solar power to optimize the drying process of fish using solar energy. This dryer uses a light reflection system using a mirror located under the dryer. This fish dryer has 3 levels, using a glass-coated cover to increase the temperature in the drying chamber. The highest efficiency is achieved using a base in the form of black wire with a 30^o mirror angle of 34.94% and the dryer temperature can reach 48.8^{o}C. The number of bacteria in both samples A (using designed dryers) and K (conventional) had differences bacterial values, which showed that conventional drying had a higher number of bacteria which was equal to 25.1x10^6 when compared to drying using a designed dryer which was 19.5x10^6[3].

Dryers design with the blower are found in Refuse Derived Fuel (RDF) dryers. In RDF type dryers the best efficiency

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results are obtained by using two additional blowers. 21 watt blower used to dry RDF which has capacity of 20 kg [4]. Addition of blowers used by RDF dryers can be applied on fish dryers using a hybrid method with thermal collectors and solar panels. However, the number of blowers used in drying was 2 watts for 1 kg capacity of dried fish.

The type of dryer that is almost the same design is a meat dryer which has heating aisle that utilizes the sun's heat. The heater aisle with the black plate base material is connected to the rack of meat to be dried. In addition, this dryer also uses a blower that is connected to a solar panel. The capacity of the dryer is 50-100 kg of meat with a size of 10-15m. The temperature in the drying chamber can reach 55^oC during the day, and 30^oC in the morning and evening. The humidity in the drying chamber is 20% lower than in the environment [5]. Drying hybrid systems utilize solar energy with additional energy sources (electricity, fuel, etc.). Hybrid methods of fish dryers use two or more power energy, the main purpose of a hybrid system is basically to try to combine two or more energy so that they can increase efficiency and achieved economical at certain costs .

Based on the description of the problems above, as an alternative development from previous research for the fish drying process is designed dryer which increase efficiency by maximize harvesting solar energy in two method: thermal collectors and solar panels. This dryer utilizes the sun's heat received by the thermal collector's aisle to raise the temperature in the drying chamber and reduce the humidity. In addition, solar photons are used by solar photovoltaic to drive blowers mounted on thermal aisles. Solar energy is used optimally both from thermal and photon in the hope of increasing the efficiency of this research.

II. Literature Study

A. *Fish Drying*

Drying is one of fish processing method by removing the moisture content from the fish, the objective is extending the shelf life. Most of fish have 56-80% moisture content and according to Indonesian National Standard SNI 8273: 2016 the maximum moisture content of salted fish is 40% [6]. The condition with moisture levels less than 40% could reduce microbial activity and even lead to their inactivation. To calculate the moisture content of fish body during drying process, equation (1) and (2) could be used [6]:

$$(\%\ \text{wet basis}) = \frac{Mwater}{Mwater+Msolid} \times 100\% \quad (1)$$

$$(\%\ \text{dry basis}) = \frac{Mwater}{Msolid} \times 100\% \quad (2)$$

Moisture content could observe from drying mass per hour. The drying rate can be calculated with the equation below [7] :

$$\frac{dw}{dt} = \frac{Wt-W(t+\Delta t)}{\Delta t} \quad (3)$$

B. *Dryer Design*

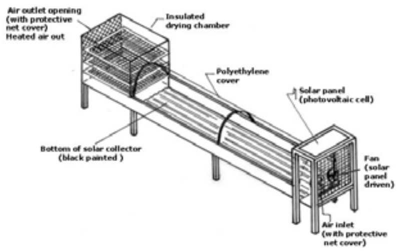
Simple food dryers in the form of tents have a design like a greenhouse roof. This dryer coating material is transparent plastic and dark plate as base. Transparent plastic is placed facing the sun while the dark material is placed across it. Experiments in the form of houses that adapt the greenhouse shape are done to dry the vanilla seeds. Drying is carried out for 49 to 53.5 hours with temperature variations ranging from 33°C to 65°C and 34% humidity during daylight hours (Tiwari, 2016). This design also applied in tent solar dryer for RDF which have capacity of 20 kg. 21-watt blower used to remove vapor from the chamber [8].

The design of the next food dryer uses a model of a rack or cabinet. This form makes it possible to dry food without the need for large land. Experimental studies of simple fish dryers have been carried out by making fish dryers using solar power to optimize the drying process of fish using solar energy. The dryer in Figure 1 uses a light reflection system using a mirror located under the dryer and mirror that is on the second and third levels. This fish dryer has 3 levels, using a roof and glass-coated cover to increase the temperature in the drying chamber, so that the drying process of fish can be faster. It used 3 types of base: ventilated glass, black wire, and black plate. The highest efficiency is achieved using a base in the form of wire rang with a 30^o mirror angle of 34.94% and the dryer temperature can reach 48.8 ^oC. Bacterial counts in both samples A (tools) and K (conventional) have differences from bacterial values which indicate that on conventional drying has more bacterial amounts of 25.1×10^6 compared to drying using a tool that is equal to 19.5×10^6 [3].

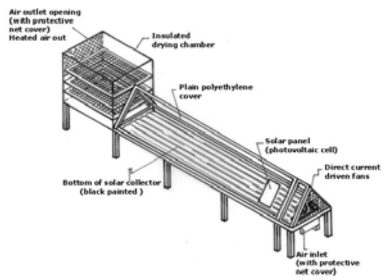
Figure 1 Cabinet type fish dryer with reflector [3].

Food dryers with a rack system are designed with the addition of thermal aisles and chimney vents. Thermal aisle extends on the bottom shelf and has a black base to capture the sun's heat. The heat from the thermal passageway was forwarded into the cabinet. In India, this system is used to dry coriander seeds and carrots. Drying with this method produces the same coriander oil as the frying process. While this type of dryer is not suitable for carrots because it can eliminate the element of vitamins[8]. Meanwhile, [7] in an experiment to determine the length of drying of salted stalk fish using an artificial dryer (cabinet dryer) with a duration of 4 hours drying resulted in the highest average value of water content was 50.30%, while the lowest moisture content was 20.91% with long drying 16 hours.

Heinz [5] designed hybrid dryers use solar heat and solar panels are applied to dry meat. This dryer uses a cabinet system, thermal aisle, and solar panels that shown in Figure 2. The three-compartment shelf uses the base and the transpran outer part. On the shelf side there are ventilation holes on one side. The thermal aisle is installed at the bottom of the rack and has a dark base. The thermal passageway connects between the blower hole and the drying chamber. The heat in the thermal passageway will be carried to the drying chamber. The capacity of this design can accommodate meat weighing 50-100 kg with a collector length of 10-15 m.



(a)



(b)

Figure 2 Food dryer (a) low cost (b) high cost)

TABLE I. COMPARISON LOW AND HIGH COST DRYER

Variable	Dryer A (Low cost)	Dryer B (High cost)
Thermal tunnel	11.5 m	15 m
Width of thermal tunnel	1.5 m	1.85 m
Thermal tunnel area	17 m^2	28 m^2
Volume	1.6 m^3	1.6 m^3
Material	Aluminum roofing sheet painted with ordinary, black oil paint	Polyurethane (PU) panel coated with metal, painted with black absorber paint
Collector	Transparent high-density polyethylene sheet	Transparent UV-stabilized polyethylene sheet
Structure	Wood	Concrete
Plane	Slightly sloped (2°)	Horizontal (level)
Blower	2	3

III. METHODOLOGY

The fish dryer designed to get the optimum solar energy, which can reduce the water content of fish according to the Indonesian National Standard, which is 40%. This design refers to former research [3] with the development of adding thermal aisle and solar panels as in the [5].

The design uses solar energy which is converted to heat through thermal collectors and glass cabinet spaces that resemble the greenhouse effect. In addition, photons in solar energy are converted into electricity and become mechanical energy that will move the blower, which is 2 Watt/blower. Air enters from blower to the thermal aisle whose base is made of black plate as a thermal collector and the casing is made of glass. Then hot air is brought to the cabinet drying chamber containing fish. The fish receives heat from the thermal collector and the cabinet system which also receives heat from the mirror mounted 30° on all three sides of the cabinet. Hot air containing moisture will come out on the cabinet's top shelf. This research also observed the effect of photovoltaic blower number. Each experiment repeated 3 times in May, located in Gresik, Indonesia.

TABLE II. EXPERIMENT VARIATION

Experiment	Number of blowers	Figure
1	0	3
2	3	4
3	6	5

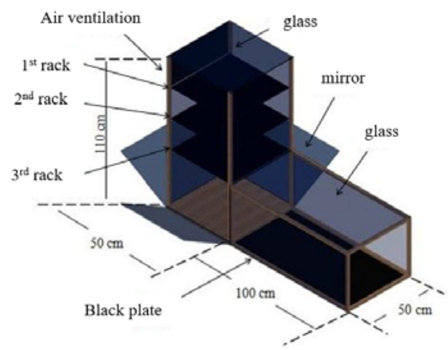


Figure 3 Experiment 1, 0 blower dryer.

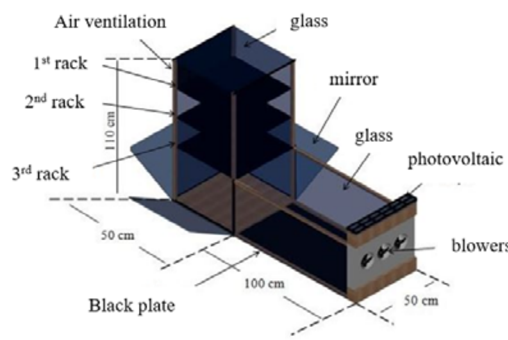


Figure 4 Experiment 2, 3 blower dryer.

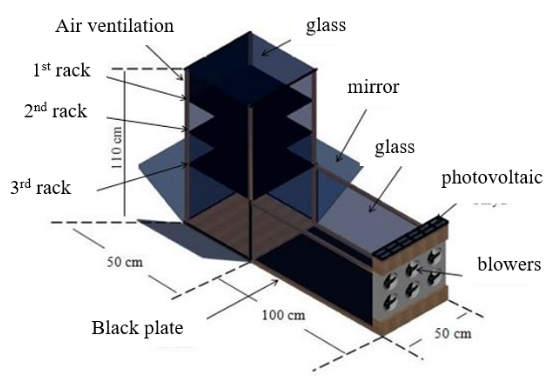


Figure 5 Experiment 3, 6 blower dryer

On drying process, several test and measurement are conducted as follows:

a. Temperatures, thermometer is utilized to measure environment and drying room temperature for every 60 minutes.
b. Solar radiation measured by luxmeter. The output value is converted into W/m^2 unit
c. Air moisture (RH), the hygrometer is utilized to measure air moisture
d. Air velocity, anemometer is applied in outside and inside room.
e. Moisture content measured every 60 minutes and by weighing the fish mass at the end of process.

The dryer performance analyzes from drying rate, moisture content, and efficiency. The performance calculation process as followed:

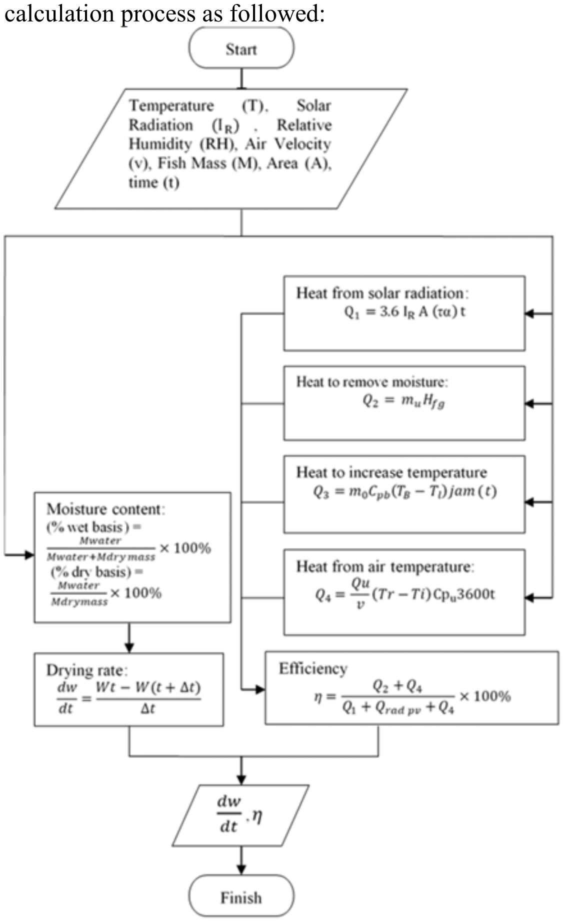


Figure 6 Equation for dryer performance analysis.

IV. RESULT AND DISCUSSION

A. *Environmental and Product Temperature*

Environmental temperature measurements and product temperature are carried out to determine the ratio of environmental heat energy and heat energy trapped in the drying chamber. The ambient temperature and product temperature are measured using a thermometer that is placed in the environment and inside the drying chamber, ie, at each level of the drying rack. Based on the results of the measurements, data on the ambient temperature and product temperature are obtained as shown in Figure 7.

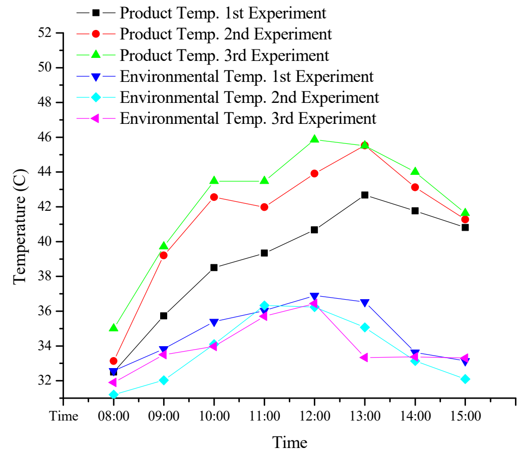


Figure 7 Comparison between environmental and product temperature.

From these results it can be concluded that the average value of the product temperature in 0, 3, and 6 blowers in sequence is 39, 41.3, 42.3 °C. The average of temperature difference between product and environmental temperature is 6.7 °C. Meanwhile, the temperature difference between aisle/ thermal collector and environmental temperature could reach 29.6°C. Compared to the previous dryer design by [3], the design in this study experienced an increase in temperature difference. This reinforces that the addition of a thermal collector can increase the temperature of the drying chamber [5].

B. *Drying Rate*

Measuring the drying rate is done to determine the amount of water evaporated in the drying process. The drying rate is carried out by measuring the initial weight and moisture content of drying. Measurements are made from 08.00 to 15.00 with an interval of 1-hour sampling. Based on the results of measurements that have been made, the drying rate data is obtained as shown in Figure 8.

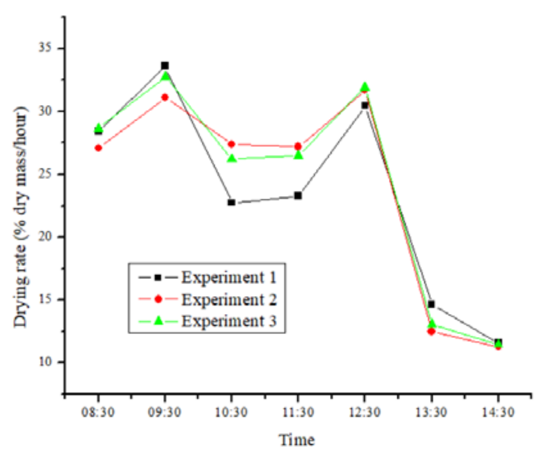


Figure 8 Drying rate (% dry mass/hour).

From these results it can be concluded that the average drying rate at blower 0 is 23.54% dry mass / hour, on blower 3 is 24.04% dry mass / hour, and on blower 6 is 24.37% dry mass / hr. This happens because the fish mass decreases every hour. The decrease influenced by temperature, RH humidity, and the speed of air entering the drying chamber. On the graph shows that from 8:00 to 9:00 the initial drying begins, then at 9:00 a.m. to 10:00 a.m. it can be seen in the graph of the rising drying rate, this occur because there is a air velocity entering through the collector and influencing the drying rate of 1st, 2nd, and 3rd experiment which use 0, 3, and 6 blower respectively. Furthermore, between 10:00-11:00 the drying rate decreases, this occur because there is a vapor from fish trapped in the drying chamber. Then between 11:00-13:00 the drying rate rose, this happens because the existing solar thermal utilized properly and get help by the presence of blowers. Furthermore the drying rate drops steadily at 13:00 to 15:00.

C. Dryer Efficiency

The efficiency of the fish dryer conducted to find out the best level of drying of fish and to show the heat energy used by each variation. In this case, the calculation of the efficiency of a fish dryer is done by looking for a comparison between the total energy input in the drying system and the total energy output used by the dried product as shown in Figure 6. The energy input used is heat from the sun, while the energy output is used to vaporize water and raise the temperature of the product. In Figure 9, it shows that the highest efficiency is 43.15% in experiment 3 or using 6 blowers.

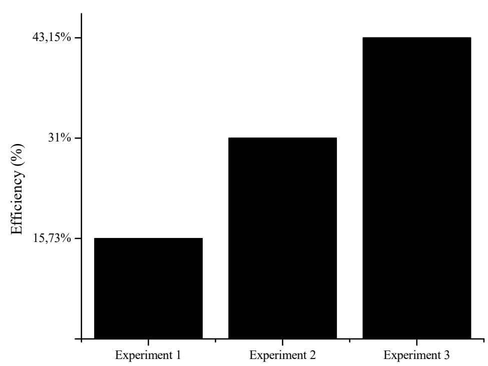


Figure 9 Dryer efficiency in each experiment.

D. Quality of Fish Product

1) Moisture Content

The objective of moisture content test is to determine the water content in fish. Measurements are carried out in every hour, from 08.00 to 15.00 WIB with a capacity of 3 kg of fish in the drying chamber. Based on the results of the measurements, water content data shown in Figure 10.

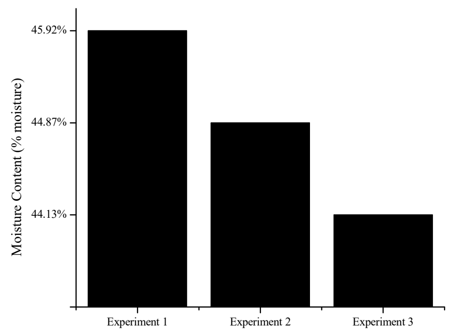


Figure 10 Water content in each experiment.

From these results it can be concluded that the average value of water content in blowers 0, 3 and 6 is 45.92%, 44.87%, and 44.13%. The results of the calculation of the moisture content are linear with the results obtained at the drying rate, where the highest drying rate is 3rd experiment (blower 6) and results in high evaporated water. This occurred because the air flow generated from the use of 6 blowers entering through the collector to the drying chamber. Compared to other, the maximum blower gave the maximum air velocity inside of the dryer, so the steam exits faster. According to SNI 8273: 2016 the maximum fish water content is 40%. However, in the experiment of drying fish the water content did not meet the SNI standard of 40%. So that for further research changes can be made to the design of the shape of the collector / thermal aisle, so that it can produce a moisture content that meets the SNI standard of 40%.

2) Bacterial Test

Testing of fish bacterial levels is done after the drying process in the fish has been completed. Testing the levels of fish bacteria aims to determine the number of bacteria contained in fish after drying. Testing the levels of fish bacteria using laboratory tests with the determination of ALF (Total Plate Figures) by comparing the number of conventionally dried fish bacteria and using tools. According to SNI 8273: 2016 explained that the maximum requirement limit for ALF is 10^5 CFU/ml. Based on the results of testing the levels of bacteria carried out, data has been obtained as shown in Table III.

TABLE III. BACTERIAL TEST RESULT

TYPE OF DRYER	TOTAL BACTERIA (CFU/ml)
Conventional	75 x 10^7
Experiment 1	59 x 10^7
Experiment 2	52 x 10^7
Experiment 3	45 x 10^7

In bacterial test, the highest bacterial results were found in conventional samples of 75 x 10^7 with a unit value of CFU / ml (Colony Forming Unit). This can happen because the sun's heat in the cabinet dryer not spread uniformly. While the lowest bacteria found in the 3rd experiment is 45 x 10^7 CFU / ml. This happens because the sun's heat obtained by fish can be fully utilized. However, the results of bacterial testing on each sample are still above the maximum of 10^5

CFU/ml. These results do not meet the optimal value of bacterial levels. This can be influenced by the existence of several factors such as fish washing, fish shelters, and fish storage. So that the research that will be carried out can then be given a recommendation at the stage of washing fish using clean water with several washings so that the levels of bacteria in the fish body can reach an optimal value of 10^5 colonies / g.

E. Comprehensive Performance of Dryer

Recommendations for fish dryers are used to give advice or consider so that in the next research, they can find out which is the best for a variety of fish dryers Fish dryer has 3 variations, namely, experiment 1 (without blower), experiment 2 (3 blowers), and experiment 3 (6 blowers). The following is a table of recommendations for each variation of the dryer as shown table IV.

TABLE IV. COMPARISON BETWEEN 3 EXPERIMENTS

Value	Experiment 1	Experiment 2	Experiment 3
Drying rate (% dry mass/hour)	23.54	24.04	24.37
Efefficiency η (%)	15.73	31	43.15
Moisture content (%)	45.92	44.87	44.13
Bacterial test (CFU/ml)	59 x 10^7	52 x 10^7	45 x 10^7

Based on the results of the dryer test table above, the best drying of fish occurs in blowers 6 with the highest drying rate value of 24.37% dry mass/ hour, this can occur because when drying, fish get air through 6 blowers which are then forwarded to drying room. The highest efficiency value is 43.15%, which indicates that a fish dryer with 6 more maximum blowers utilizes solar energy when drying. The lowest water content value of 44.13%, the lower the water content, the faster the mass of water in the body of the fish to dry. The lowest value of bacterial fish content was 45 x 10^7, indicating less bacterial content in the body of the fish because the conditions that occur in fish drier faster so that the levels of bacteria that exist in fish bodies do not develop.

V. CONCLUSION

Harvesting solar energy by combined thermal and photovoltaic collectors was applied in fish dryer. Thermal collector in dryer build from glass envelope, black plate base, and mirror on the three side of dryer to maximize solar thermal. Besides, photovoltaic installed to drive blower which help to remove moisture. Three variations of the blower were investigated to determine its effect on drying rate, efficiency, moisture content, and bacterial test. Based on experiment, more blower will increase significantly on efficiency and bacterial test. Air velocity which drive from blower will accelerate evaporation process which lead to maximum efficiency. Six blowers in experiment 3 dryer has the highest efficiency at 43.15% and the lowest bacterial value at 45 x 10^7 CFU/ml.

APPENDIX

Mwater : Mass of water (gram)
Msolid :Mass of solid (gram)
$\frac{dw}{dt}$: Drying rate (%bk/hour)
Wt : Moisture content at t (%bk)
W(t+Δt) : Moisture content at t + Δt (%bk)
Δt : Duration (hour)
Q_1 : Solar energy absorbed by dryer (kJ)
I_R : Solar irradiation (W/m^2)
A : Solar dryer area (m^2)
τ : Transmisivity of dryer material
α : Absorpsivity of dryer material
t : Drying duration (hour)
m_u : Mass of evaporated water (kg)
H_{fg} : Latent heat of evaporation at temperature Tb (kJ/kg)
C_{pb} : Capacity heat of a product (kJ/kg^{o}C)
M_o : Moisture content of a product in the beginning (%)
m_0 : Mass of a product in the beginning (kg)
T_B : Temperature of product after drying (^{o}C)
T_l : Temperature of product before drying (^{o}C)
Q_4 : Heat absorbed by dry air (kJ)
Qu : Air volumetric flow rate (m^3/s)
v : Volume specific of air (m^3/kg)
Cp_u : Heat specific of air (kJ/kg^{o}C)
Tr : Dryer room temperature (^{o}C)
Ti : Environment temperature (^{o}C)
m : mass flow rate (kg/s)
A : area (m^2)
V : wind velocity (m/s)
ρ : air density (kg/m^3)

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