Experimental Analysis of Solar Cabinet Dryer for Fish Processing in Gresik, Indonesia

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***Abstract*—Most fishermen in Gresik, East Java, Indonesia used open air bamboo wicker as a conventional solar fish dryer. However, the dryer has weakness such as need long time to dry and cleanliness issue. The condition raises the idea of designing and manufacturing solar cabinet dryer to improve efficiency and overcome the weaknesses in a conventional fish dryer. The solar cabinet dryer contains 3 kg fish and designed in 3 shelf collectors which are equipped with mirror to maximize solar radiation. The fish dried to below 40% of moisture content based on Indonesian National Standard. Dryer performance is measured from drying rate and efficiency. It found that the drying rate per hour was 18.93%, 20.81%, 20.92% mass/hour for 30º, 45º and 60º mirror angle respectively. Highest efficiency performance of solar cabinet dryer was 34.94%. In cleanliness issue showed a decrease of 25.1 x 10^6 bacteria colonies/gr on conventional drying to 19.5x10^6 bacteria colonies/gr on designed solar fish dryer.**

***Index Terms*--Cabinet, drying rate, efficiency, fish, solar dryer.**

I. Introduction

Indonesia as an archipelagic country, consist of 64,97% sea and the rest is land area by total ± 5.8 million km^2. This condition has its own advantages, especially on the underwater biota. The fishery product is one of community effort to achieve welfare by managing or utilizing fish resources and other biota that have economic value. Many coastal areas located in Java Island, with the development of fishery industrialization sector is quite abundant, one of which is in East Java, especially in Gresik. Gresik Regency has a cultivation of fishpond of 79x10^3 tons per year and sea catch of 18x 10^3 tons per year (Gresikkab.co.id, 2016).

Fish processing is important stage in the fish industry, thus fish will be decayed if this process failed. It occurs because of bacteria activity and enzyme reaction [1]. To face this problem, innovation on fish processing is needed to increase the fish quality, extend product shelf life and increase the selling value of fish product [2].

There are various methods of fish processing, i.e drying, salting, freezing, canning, and smoking. The amount of fish processing product in Indonesia is 65% which belongs to salting process. In those conventional process, the fishers need sun as heat source to dry fish [3]. Drying process will remove the moisture content of fish [4]. Commonly, they put the fish product above the bamboo webbing. However, this method has limitations regarding to the hygiene problem on the fish surface. It occurs since the fish surface contaminated with dust, dirt, bird and insect. Moreover, it takes longer time to dry fish [2]. Most of fisherman in Gresik, Indonesia where the research was done, using the conventional dryer.

Based on the problem, an idea to design fish solar dryer was explored. The design has three racks with reflecting and absorbing heat system using a mirror and a glass, the cabinet design will useful in small land area. The objective of this experiment is to fabricate a solar cabinet dryer, analyze the performance in terms of moisture content, drying rate, efficiency and the number of bacteria cells in the fish body. The scope of the problems is the capacity of the prototype is 3 kg and the maximum moisture content of fish follows the Indonesian National Standard (SNI) 8273:2016 is 40%. This experiment was done in Gresik on April 2017.

II. Literature Study

A. Fish Drying

Drying is one of fish processing method by removing the moisture content in the fish body as much as possible. Most of fish species have 56-80% moisture content. According to Indonesian National Standard the maximum moisture content of salted fish is 40% wet basis[5]. 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]:

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

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

Where,
Mwater : Water mass (gram)
Msolid : Solid Mass (gram)

The drying rate can be calculated with the equation below [7]:

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

Where,

$\frac{dw}{dt}$: Drying rate (%bk/hour)
Wt : Moisture content at t (%bk)
W(t+Δt) : Moisture content at t + Δt (%bk)
Δt : Duration (hour)

B. *Solar Cabinet Dryer*

The cabinet is a large wooden or metal box and the product located in trays or shelves inside a drying cabinet. If the chamber is transparent, the dryer is named as integral-type or direct solar dryer. If the chamber is opaque, the dryer is named as distributed type or indirect solar dryer. Mixed-mode dryers combine the features of the integral (direct) type and the distributed (indirect) type solar dryers. The combined action of solar radiation incident directly on the product to be dried and hot air provides the necessary heat required for the drying process. In most cases, the air is warmed during its flow through a low pressure drop solar collector and passes through air ducts into the drying chamber and over drying trays containing the crops. The moist air is then discharged through air vents or a chimney at the top of the chamber [8].

The advantages of this system are simple in construction, low labor costs, simply load and unload, heat storage systems can be applied and protect the product from unwanted dust, insect and bacteria. This simple system suitable for traditional fisherman, which cheap and easy to construct.

C. *Dryer Efficiency*

Solar dryer efficiency calculates from energy used and energy received. The system received heat from solar radiation and environment by the air circulation. The received energy used for raising temperature of product and remove the moisture.

Solar energy is one of alternative energy that efficient and environment friendly. The objective of solar energy system is to collect the solar radiation and change into heat in drying process (fish processing) [8]. To calculate the solar energy absorbed by surface, Equation (4) could be applied [6]:

$$Q_1 = 3.6\, I_R\, A\, (\tau\alpha)\, t \qquad (4)$$

Where,

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)

Heat used to evaporate the water on a product could be analyzed using the equation below [6]:

$$Q_2 = m_u\, H_{fg} \qquad (5)$$

Where,

m_u : Mass of evaporated water (kg)
H_{fg} : Latent heat of evaporation at temperature Tb (kJ/kg)

Equation (6) explains heat to increase the temperature on a product [6]:

$$C_{pb} = 0.837 + 0.034\, (M_o \qquad (6)$$

$$Q_3 = m_0 C_{pb} (T_B - T_I) \qquad (7)$$

Where,

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_I : Temperature of product before drying (^{o}C)

Heat absorbed by dry air could be calculated by equation below [7]:

$$Q_4 = \frac{Qu}{v} (Tr - Ti)\, Cp_u\, 3600t \qquad (8)$$

Where,

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)
t : Drying duration (hour)

The efficiency of solar dryer shows below:

$$\frac{Q_2 + Q_3}{Q_1 + Q_4} \times 100\% \qquad (9)$$

III. METHODOLOGY

A. *Design of fish dryer*

The design only utilizes wind energy and solar energy, without any addition energy (electric).

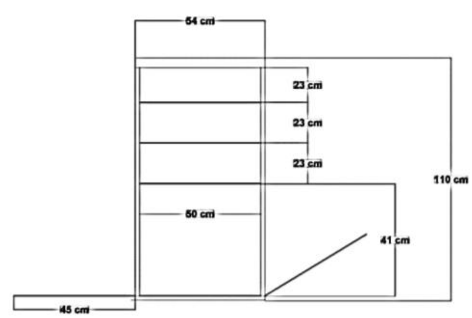

Figure 1. Fish solar dryer (side view).

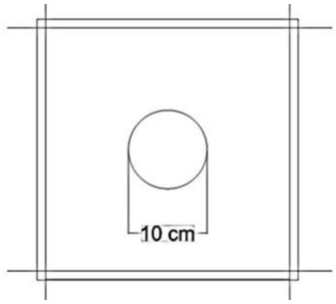

Figure 2. Fish solar dryer (Upper view).

There are three racks to put 3 kg of fish. On the bottom surface, there are four mirrors each side. The mirrors are used to reflect the sun light. This plat has three different plats, i.e. black plat, black plat with ventilation, and wire rang.

B. *Experiment Step*

The measuring instrument used in this study were thermometer, anemometer, luxmeter, hygrometer, scale, and timer. The experiment order can be explained as follows:

1. At the beginning, fish is weighed. The initial weight should be 3 kg.
2. Three kinds of plats with different position angle are tested. The material and the angle applied in the experiment are described in Table 1.

TABLE I. EXPERIMENT SET UP

Experiment number	Surface material	Angle
1	Rang	30º
2		45º
3		60º
4	Black plat	30º
5		45º
6		60º
7	Black plat + Ventilation	30º
8		45º
9		60º

3. 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 30 minutes.
   b. Solar radiation
   Solar radiation is measured by luxmeter. The output value is converted into W/m^2 unit.
   c. Air velocity
   To measure the velocity, anemometer is applied in outside and inside room.
   d. Moisture content
   The moisture content is measured every 30 minutes and by weighing the fish mass at the end of process.
   e. Drying duration
   The drying process starts at 08.00 to 13.00
4. Performance calculation
   Equation (1)-(9) are used to calculate the dryer performance
5. Bacteria test

This test is conducted in laboratory to find out the amount of bacteria on fish surface after drying process

IV. RESULT AND DISCUSSION

A. *Solar Irradiation*

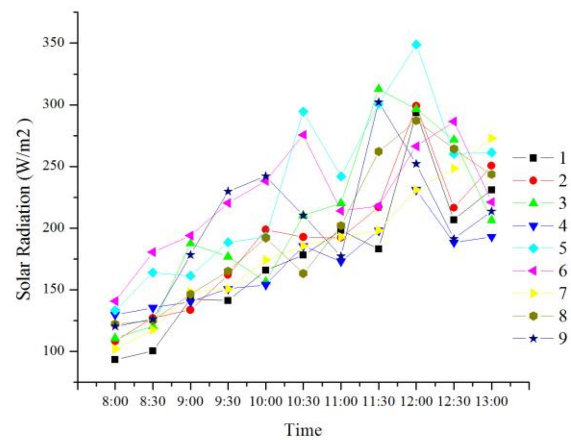

Figure 3. Solar Irradiation.

In Figure 4 the first experiment to the nine experiments obtained that the highest solar irradiation value occurred at 11.30 to 13.00 with the highest value of 338.21-510.83 W/m^2 and the lowest solar irradiation value occurred at the beginning of drying with the value of 136.31-206.15 W/m^2.

B. *Environmental Temperature*

In the graph below from the first experiment until the ninth experiment, the ambient temperature appears to fluctuate. The highest environmental temperature occurs at 11.30 to 13.00 with a temperature value of 36.2-39.6 ºC.

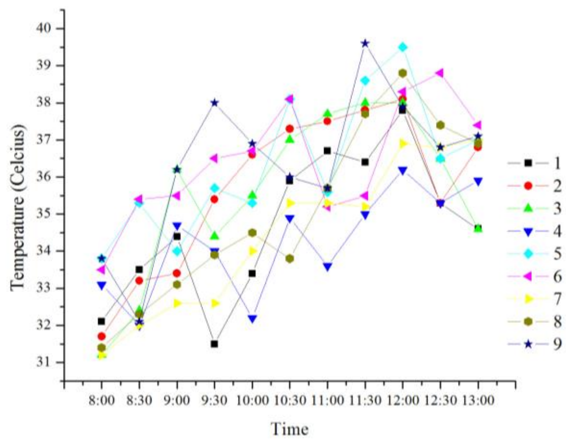

Figure 4. Environmental Temperature.

C. *Dryer Experiments*

1. Dry Room Temperature

The room temperature shows table below, the temperature higher than environmental temperature around 2 ºC-6 ºC. The highest dry room temperature is 45,43ºC.

TABLE II. ROOM TEMPERATURE

Experiment	Temperature Range	Average Temperature
1	33.0-42.7 ºC	38.04 ºC
2	33.4-43.7 oC	39.36 ºC
3	33.2-45.8 ºC	40.02 ºC
4	37.1-48.3ºC	42.72ºC
5	40.0-51,9ºC	45.40ºC
6	38.2-51.5ºC	45.43ºC
7	35.7-45.0 ºC	40.77ºC
8	36.1-47.5 ºC	41.06ºC
9	38.4-48.8 ºC	42.85ºC

The first experiment until the ninth experiment, the highest room temperature occurred between 10:30 to 12:30, this is because the high environmental temperature and the heat absorbed by the dryer room also increased. In experiments using wire pad, the temperature of the drying chamber and the ambient temperature did not have an excessive distance. This is because the air environment can enter through the cavities on the shelf. While experiments using black plate mats, room temperature and the environment has a large difference, because in addition to direct sunlight trapped into the room and the use of black plate can also absorb the heat so that the temperature in the room higher.

Experiment using black plate plate ventilation, room temperature is not too high when compared with using black plate, because environmental air circulation can enter through ventilation.

2. Humidity in Solar Dryer

In Table 3 the highest humidity in solar dryer measurements were achieved at 08.00 am because the fish entered into the drying chamber were still in humid conditions and the room temperature was still relatively low. While the lowest RH was reached at 11:00 to 13:00 owing to the high temperature in the chamber.

TABLE III. HUMIDITY

Experiments	Humidity Range	Humidity Average
1	26-38%	32%
2	26-35%	30%
3	21-38%	27%
4	33-42%	39%
5	31-44%	37%
6	28-43%	33%
7	33-43%	38%
8	34-42%	38%
9	29-45%	36%

3. Moisture Content

The result of initial and final moisture content shows in table 4. The initial moisture measure and calculate from 1 kg fish in laboratory.

TABLE IV. MOISTURE CONTENT

Experiments	Dry Mass (Kg)	Initial Moisture Content (%wet basis)	Final Moisture Content (%wet basis)
1 (30R)	1.21	70.37	31.57
2 (45R)	1.12	70.37	31.25
3 (60R)	1.11	70.37	30.70
4 (30P)	1.38	70.83	38.09
5 (45P)	1.36	70.83	36.80
6 (60P)	1.31	70.83	35.70
7 (30PV)	1.28	70.00	35.29
8 (45 PV)	1.20	70.00	34.78
9 (60 PV)	1.17	70.00	33.30

Based on Table 4, the lowest final water content was found to be 30.70% on the use of wire base rang and the highest end grade with 38.09% on black plate plate. The use of wire pad on the dryer bed will make the fish dry evenly on the top and bottom of the fish. This is due to the moisture released in the fish can be exposed to air circulation. While the use of black plate on the dryer will make dry fish uneven, because the bottom of the fish is not exposed to air circulation, so the bottom of the fish is still sweating.

The use of black plate ventilation on the dryer bed is also less efficient, because the bottom of the fish is still a little sweating caused by the bottom of the fish is also not exposed to air circulation evenly. However, from nine experiments the final water content of fish is in accordance with SNI 8273: 2016 that is below 40%.

4. Drying Rate

In the first experiment until the ninth experiment, the highest drying rate occurred during the day which ranged from 11.30-12.30 and occurred on the first shelf. This is because on the first rack directly exposed to sunlight and relatively high temperature, so the rate of drying faster.

TABLE 1. DRYING RATE

Experiments	Highest Drying Rate (dry mass /hour)	Average		
		Plate1 (dry mass/hour)	Plate 2 (dry mass/hour)	Plate 3 (dry mass/hour)
1	32.40 %	20.74 %	17.49 %	18.56 %
2	36.41 %	23.61 %	19.59 %	19.23 %
3	35.85 %	23.09 %	19.16 %	20.50 %
4	32.66 %	18.02 %	15.03 %	15.98 %
5	31.09 %	16.96 %	16.04 %	16.86 %
6	36.48 %	18.88 %	16.67 %	16.71 %
7	33.40 %	19.85 %	16.88 %	16.91 %
8	30.15 %	19.71 %	18,.9 %	19.12 %
9	31.07 %	20.10 %	19.51 %	19.82 %

D. *Solar Drying Efficiency*

Efficiency in the drying process is the ratio between the total energy inputs in the dryer system and the energy output used by the dried product. The higher the efficiency it will be the less energy required to dry the product.

In the graph below the efficiency of the drying apparatus using wire pads rang are 34.94%, 33.65% and 27.56% respectively. The efficiency of drying apparatus using black plate plate are 12.31%, 11.44% and 11.89%, respectively, while dryer efficiency using black plate plate velvet are 17.21%, 18.67% and 17.64%. The highest efficiency was achieved in the first experiment of 34.94% ie using a base of wire rang with a 30^o.

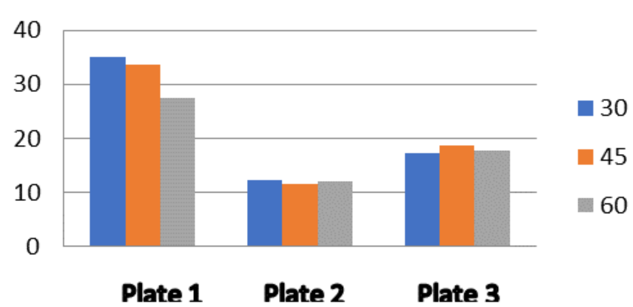

Figure 5. Solar Dryer Efficiency.

E. *Bacteria Test*

TABLE VI. BACTERIA TEST

No	Parameter	Unit	Result	Method
1	Total bacteria in solar cabinet dryer	CPU/ml	19,5 x 10^6	Coloni Counter
2	Total bacteria in conventional dryer	CPU/ml	25,1 x 10^6	Coloni Counter

The number of bacteria in both sample A (tool) and K (conventional) is not eligible because the value is above the maximum limit of 1 x 10^5 colony / gr, but the number of fish bacteria dried by drying is less than the conventional drying. Growth of bacteria found in salted fish can be caused by several factors such as washing fish only once, not using clean running water, dirty fish shelter.

V. CONCLUSION

Based on the results of the experiment, as for the conclusions obtained are:

1. The final moisture content in the first experiment until the ninth consecutive trial was 31.57%, 31.25%, 30.70%, 38.09%, 36.80%, 35.70%, 35.29%, 34 , 78% and 33.30%. The final drop in water content is generated by wire ranges at an angle of 60 °.
2. Average drying rate is 18.93%, 20.81%, 20.92%, 16.34%, 16.62%, 17.42%, 17.88%, 19.20% and 19, respectively, 81% in the first trial until the ninth experiment in sequence. The highest average drying rate is on the wire base rang with an angle of 60^o.
3. The efficiency of dryers in the first to ninth experiments was 34.94%, 33.65%, 27.56%, 12.31%, 11.44%, 11.89%, 17.21%, respectively, 18.67% and 17.64%. The highest efficiency was achieved in the first experiment of 34.94% ie using a base of wire rang with a 30^o angle.
4. The number of bacteria in both sample A (tool) and K (conventional) has differences from the bacterial value indicating that the conventional drying has a larger number of bacteria that is 25.1x10^6 when compared with drying using tool that is equal to 19.5x106.

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