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Design and Fabrication of Tilted Hot-Air Fish Dryer Using Heat Sensor

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Abstract

The tilted of hot-air fish dryer using the heat sensor were designed and constructed to ease the problems of fish drying in Palawan. The machine was composed and assembles of five components namely; drying chamber, furnace, frame, chimney, and tilted heat exchanger. There are four trays inside the drying chamber in which is the container of the product. The heat exchanger of the fish dryer forming 40 degrees tilted and also has operated as a chimney of the furnace. A The heat sensor placed in the drying chamber to monitor the desired temperature and controls the feeding of fuel in the furnace. The dryer operates by the combustion of fuel for heating the air that enters the drying chamber and temperature could be achieved from 29 to 70 degree Celsius. The study was conducted by performing three trials. During the testing of the performance of fish dryer, the temperature was checked in every hour. The initial weight of the dried fish before the five hours drying was 6.0 kilograms and the final weight after drying was at an average of 2.23 kilograms. The product produced of good and clean dried fish with a drying efficiency of 85%. In terms of cost analysis, the machine has a payback period of 2 years. This drying system could be a substitute for local drying methods, especially in poor weather conditions. The hot air fish dryer is highly recommended used for fish produces and a local community of coastal and sub-urban areas, however, further changes were needed.

Keywords: dryer, fish, heat, hot-air, tilted,

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1. Introduction

In the developing countries, fish is a very important foodstuff due to its nutritional value [5] particular in the Philippines and Sri Lanka, dried fish is an important source of protein [12]. Globally, the total amount of dried fish produced estimates indicates that 10% catch is dried. However, 50% is dried in some areas of Africa and Asia [12]. In the Philippines, Palawan is the biggest producer of fish according to the Bureau of Fisheries in 2008. One out of every five fishy tons came from Palawan (A fishy ton is a metric ton of fish.) [4]. According to the Fisheries Statistics of the Philippines (2014-2016), Palawan is the largest area and location of major fishing grounds and the MIMAROPA region, Palawan also the biggest production of fish [3].

Fish rapidly spoils and within a few hours capture, it becomes putrid unless processes and preserved in some way [12]. The very important factor to prevent the process of spoilage is the temperature where the reactions connecting the death of the fish proceed at a very rapid rate [5]. The bacteria cannot survive and autolytic activity will be greatly reduced if the moisture content of fish from 80% reduces to around 25% [2]. Further stated that a moisture content reduces of 15% and stored under right condition less mold will cease to grow and can be kept for several months [2]. Some of the method and techniques for preservation of fish such as cooking (boiling or frying), salting, smoking, and drying are collectively known as curing (lowering the moisture content) and fermentation (lowering the pH) [10].

In the developing countries, the problem is the reduction of post-harvest losses of the availability of food [9]. Generally, an estimate of these losses cited to be of the order 4% but can under very undesirable conditions, be nearly as high as 100% [9]. These losses are associated with improper and untimely drying.

Sun drying is one of the popular methods of preservation of fish in the Philippines and province of Palawan, which plays a significant role in additional providing income to the people in coastal areas. This is capable to make in preserving fish because of the simplest and cheapest method. But some disadvantages of this method are the exposure of the fish to dust and rain which cause uncontrolled dying, etc. According to Bassey [1], the use of solar drier have some disadvantages technically economic unviable and inadequate and inappropriate designs due to the materials used, and mostly the intensity of solar energy from the sun which usually collected to produce the temperature that dries the foodstuff during the rainy season which occupies 6-7months in a year. Also the use of convective fish dryer using heating elements in Nigeria under no load condition that used in fish processing, it only shows the temperature of drying chamber reached 110oC from which fish drying temperature 60 to 900C by an installed thermostat in 30 minutes using heater at 9000 Watts at speed of 280 rpm which is expected higher drying rate than the natural sun drying and open-fired drying methods but no evaluation test of the fish drying temperature for good quality product. This drying system is capable of supplying 110oC temperature of the drying chamber. Also, the use of this method does not cite the cost economic analysis because of the materials used and high electrical energy input.

In Palawan, there is an application for utility model of hot air fish dryer using biomass fuel. This drying system the hot air was generated from the furnace and conveyed to the drying chamber. By means of fire, air absorbed the heat from the pipe and forced into the drying chamber through ducting flowing from the heat exchanger to the said drying chamber that serves as the container of the product. This drying system is locally available in the market but it is not a movable type and was a hook type. Because of the duct where the hot air from the furnace flows through drying, there was a possibility to decrease the temperature onto the drying chamber and drying efficiency was affected. The performance of this drying system the hot air was not evenly distributed inside the drying chamber so the product was not equally dried because of the angle of the damper was not adjusted.

Today, there is no existing portable conventional machine of fish dryer used by fish producers in Palawan. Due to high demand for fish and the preservation were needed to prevent spoilage. The design and fabrication of tilted hot-air fish dryer using heat sensor could be a substitute for local drying methods during the wet season. This is the improvement of sanitarily and hygiene, preserving economically, ease of operation and product quality. This study is the improvement of the mechanical fish dryer to rectify the heat exchanger into tilted from the horizontal heat exchanger to accumulate heat in the drying chamber at the upper part of the dryer and there is a complete system in one device.

The improvement of the machine was lead to a high production rate with less time and the availability in areas which needs it most. It is also a great help to fish producers to have this dryer because they can produce dried fish anytime in the fastest way.

This paper presented the detailed design, fabrication and preliminary experimental results carried out on the tilted hot-air fish dryer using heat sensor.

2. Objectives of the Study

The general objective of this project was to designed and fabricated fish dryer which tilted heat exchanger using heat sensor. Specifically, this aimed to determine: the components of the fish dryer; the significant difference of the performance of fish dryer in terms of time, temperature, and mass; and the drying efficiency of the machine. Also, determine the cost of fabrication and analyze the profitability of the machine.

3. Materials and Methods

The accomplishment of the project comprises the following methods as shown in Figure 1.

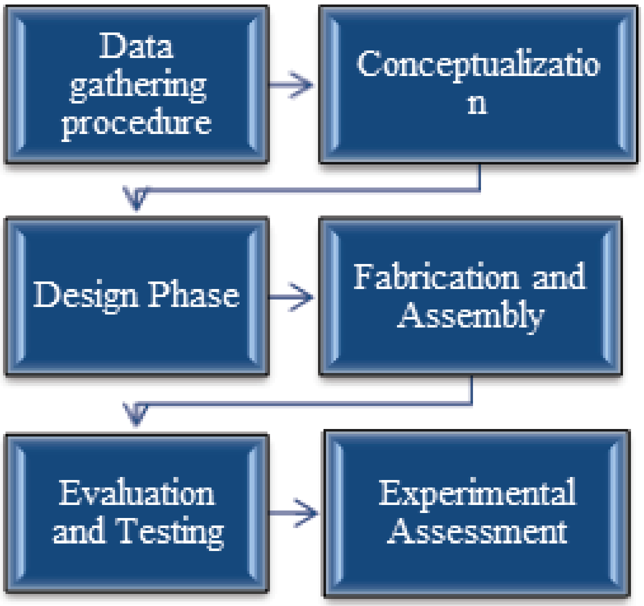

Figure 1: Methods for development research project.

3.1. Data gathering procedure

The improvement and development of the fish dryer are a product of research and the developmental process was used by prototyping technique to prove the different concept, theories, and ideas. This technique aimed continuously improving the design of the project for commercialization. The research begins with data gathering procedure where the fish producers were thoroughly considered. The process starts with the preliminary researches of literature from the articles and journals, periodicals, brochures, and internet, books, etc. regarding the existing methods of drying and considering the design of heat exchanger, furnace, blower and drying chamber.

3.2. Conceptualization

Through preliminary research of existing drying system and fish dryer, were done to resolve the issue about the method of drying in a shorter time that produce good quality dried fish that could be substitute during poor weather condition. The development on similar dryer were gathered through internet and latest design of fish dryer that was conducted in Palawan in order to determined the improvements that could be done on related design.

3.3. Design phase

The detailed design of the project has been visualized using software application for mechanical design (Solidworks). In the design function, it can operate in different weather condition without affecting the quality of its product. The design requirements are the hot-air dryer must remove 85% moisture content of fresh fish, the use of coconut shell as fuel, the drying time approximately of five hours, and low construction cost. The selection of materials was based in the design and the availability of materials in the market.

3.4. Design computation

Mass of water to the product [11]

Weight of initial moisture in the fresh fish, W_{mf}

$$W_{mf} = W_f \times m_{ci}$$

where:

W_f = weight of fresh fish

m_{ci} = initial moisture content in the fresh fish

Bone dry weight of product, W_d

$$W_d = W_f - W_{mf}$$

where:

W_f = weight of fresh fish

W_{mf} = Weight of final moisture in dried fish

Weight of final moisture in dried fish, W_{mf}

$$W_{mp} = \frac{W_d}{\frac{1}{m_{cf}} - 1}$$

where:

W_d = Bone dry weight of product

m_{cf} = The final moisture content in the fresh fish

Weight of dried fish, W_P

$$W_p = W_{mp} + W_d$$

Moisture need to evaporate at the fresh fish, ΔW_{mf}

$$\Delta W_{mf} = W_{mf} - W_p$$

Rate of moisture need to evaporate, ΔW_{mf}

$$\Delta W_{mf} = \frac{W_{mf} - W_p}{t_d}$$

where:

t_d = drying time

Heat required for raising the temperature of fresh fish

$$Q_1 = m_{cp} \Delta t$$

Heat required for evaporating moisture

$$Q_2 = \Delta W_{mf}(hfg)$$

Heat required for raising the temperature of the moisture in the product forms

$$Q_3 = m_{cp} \Delta t$$

Therefore, the total heat entering the drying chamber;

$$Q_T = Q_1 + Q_2 + Q_3$$

$$\text{Dying efficiency} = \frac{\text{mass of moistured remove x latent heat of water}}{\text{total heat enter to the chamber}}$$

Computing the mass of fuel needed, m_f

$$Q_F \ =_F \ (HHV)_F$$

where

$$m_F = \frac{Q_F}{(HHV)_F}$$

$(HHV)_F$ = higher heating value of fuel

3.5. Fabrication and assembly

The selection of materials based on the availability in the market. It is also based on the design requirements and functions for every component of the machine.

Frame Assembly: The frame assembly of the machine is made up of an angle bar to support the whole machine and it has a dimension of (28x24x48) in. as shown in Figure 2.

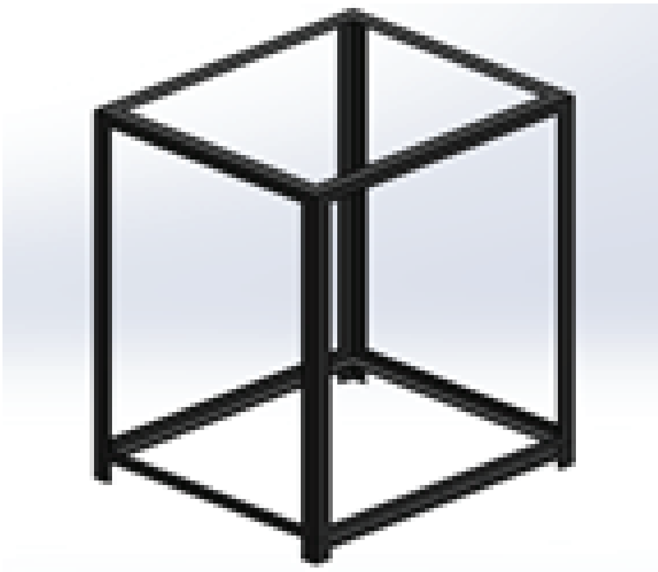

Figure 2: Frame assembly.

Furnace: The furnace has a dimension of (24x18x27) in. with a fan on both sides, it is made up of bricks coated with cement to minimize heat loss. Its frame is fabricated by an angle bar as shown in Figure 3.

Titled heat exchanger. The tilted heat exchanger is composed of 15 pieces of 1.5 in diameter tube forming an elbow of 40 degrees to accumulate heat in the upper part. It is installed on top of the furnace and serves as an exhaust for the product of combustion as shown in Figure 4.

Chimney. The chimney is (10x24x33) in. it is made up of a plain sheet and a riveted joint as shown in Figure 5.

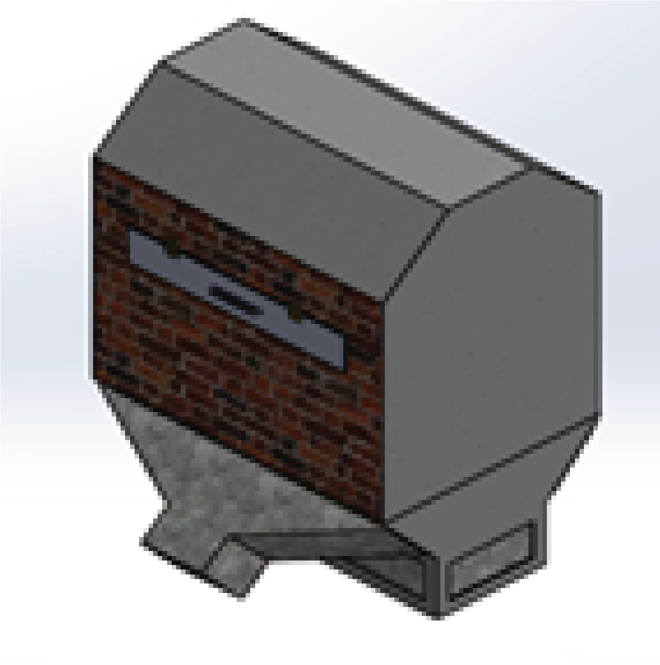

Figure 3: Furnace assembly.

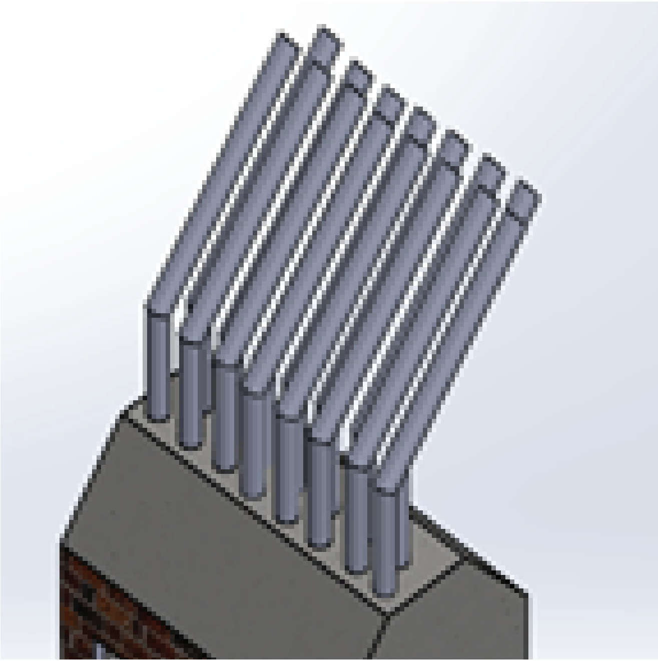

Figure 4: Heat exchanger assembly.

Drying chamber. The chamber is (24x24x 26) in. it is made up of plywood, plain sheet, angle bar for the frame and double insulation foam. Plywood, plain sheet, and insulation foam are used to minimize the heat loss in the chamber. The chamber has (5x5) in. chimney in upper back side.

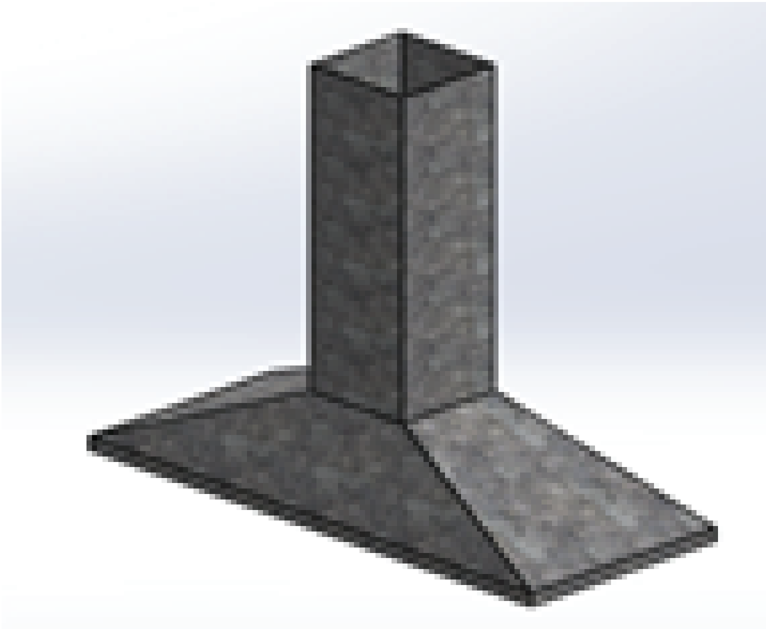

Figure 5: Chimney assembly.

3.6. Evaluation and testing

After the Fabrication, the dryer was preliminarily tested to determine the errors and problems that might be encountered during the final testing. The following data was collected during the test:

Temperature. During testing the temperature was checked in every 1 hour. A heat sensor was placed inside the chamber to monitor the temperature inside to control the feeding of fuel.

Mass of fuel. The weight of fuel mass should be considered before feeding to a furnace to determine the fuel consumption in every trial.

The weight of dried fish. A weighing scale was used to weight the fish before and after drying and its weight should be checked in every hour to determine the moisture content. The total weight per batch was recorded.

3.7. Experimental assessment

The data analysis that corresponds to the overall performance and results of the test analyzed using Analysis of Variance (ANOVA) of two-factor without replication.

3.8. Payback period

The economic analysis of the prototype machine is the period of time recovering the investment cost. This is the cost of the initial cash outflow of the machine to the cash inflows generated by the investment of prototype machine.

3.9. Results and discussion

The findings of the study and the discussion as follows: the components of the fish dryer; the significant difference of the performance of fish dryer in terms of time, temperature, and mass; and the drying efficiency of the machine. Also, determine the cost of fabrication and analyze the profitability of the machine.

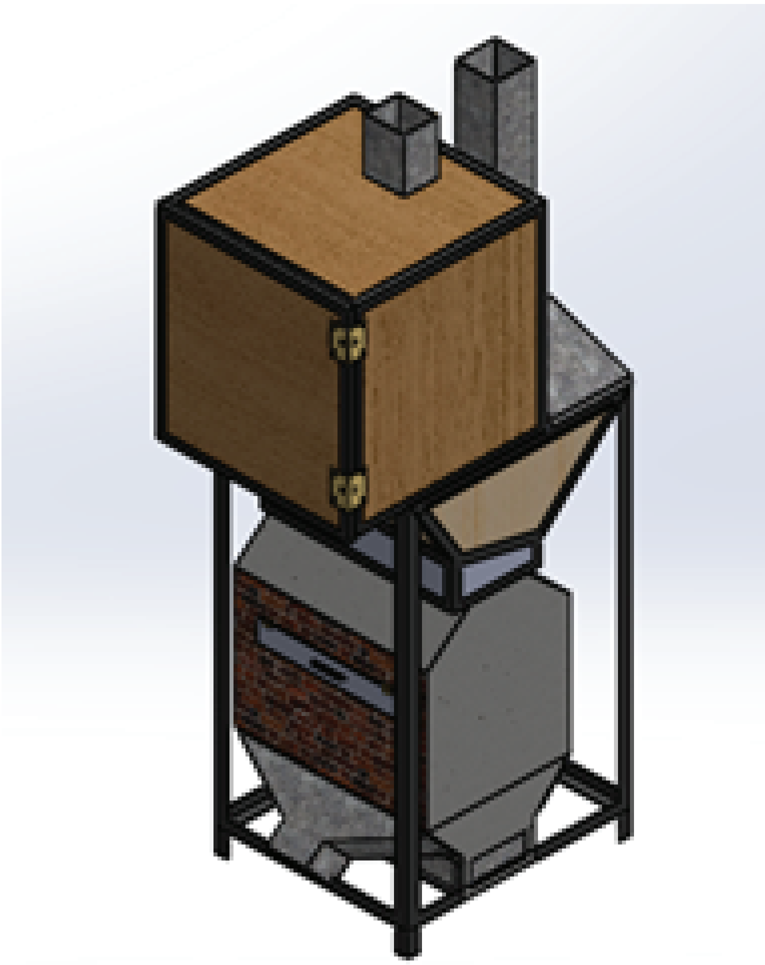

Figure 6: Isometric View of Salt Maker Machine Design.

Figure 6 presents the designed and fabricated of tilted hot-air fish dryer composed of five main parts namely: drying chamber, furnace, frame, chimney and tilted heat exchanger. The chamber maximum load is 6kg of fresh fish, there are four layers of the chamber which will be used to place the fish inside. The furnace can be fuel up to 1.5 kg of coconut shell which will be consumed up to 20 to 30 minutes. The dryer has fifteen heat exchanger inside and acts as a chimney of the furnace. The machine uses three (3) fans, two of the fan was placed in the lower front and back side of the furnace and act as a blower while the other one was placed in the upper backside and act as a blower for the heat exchanger. When the blower on the upper back of the furnace run the air it blows goes directly to the heat exchanger and produces a hot air that goes directly to the chamber which will be the air to dry the fish.

Table 1: The weight of finished product OF each trial in every hour.

Time (hr)	Result of trials per hour					
	Trial 1		Trial 2		Trial 3	
	Wt. (kg)	Fuel (kg)	Wt. (kg)	Fuel(kg)	Wt. (kg)	Fuel (kg)
1	4.75	3	4.6	3	5	3
2.5	3.25	3	3.25	3	4.75	3
3.5	2.75	3	2.275	3	4.25	3
4.5	2.5	3	2.5	3	3.5	3
5	2.25	3	2.2	3	2.25	3

In Table 2 shows the weight of finished product each trial. In every trial, a total of 6kg of fresh fish was used in each trial. Trial 1 dried 6kg of fresh fish and reduced into 2.25kg. In trial 2,6kg of fresh fish is also used and reduced it into 2.2kg while on trial 3 it reduced into 2.26kg with the same 6kg of fresh fish. Each trial consumed 15 kg of fuel in five hours, a total of 45 kg of fuel in three trials.

Figure 7 and 8 according to the statistical analysis, there is no significant difference between sample 1, 2, and 3 in terms of mass. There is a significant difference between time, temperature, and mass. The mass in each time depends on temperature. The temperature is dependent on time, when the time increased, temperature changes. The mass is dependent on time when the time increased the mass decreased. The mass is dependent on temperature, when the temperature changes the mass also changed. This shown linearity of the time, temperature and mass.

$$\text{Drying efficiency, (\%)} = \frac{\text{mass of moisture} \times \text{latent heat of water}}{Q_T} \times 100$$
$$= \frac{0.86kg/\text{hr} \times 2260.4kJ/hr}{2279.2kJ/hr} \times 100$$

Drying efficiency = 0.85 or 85 %

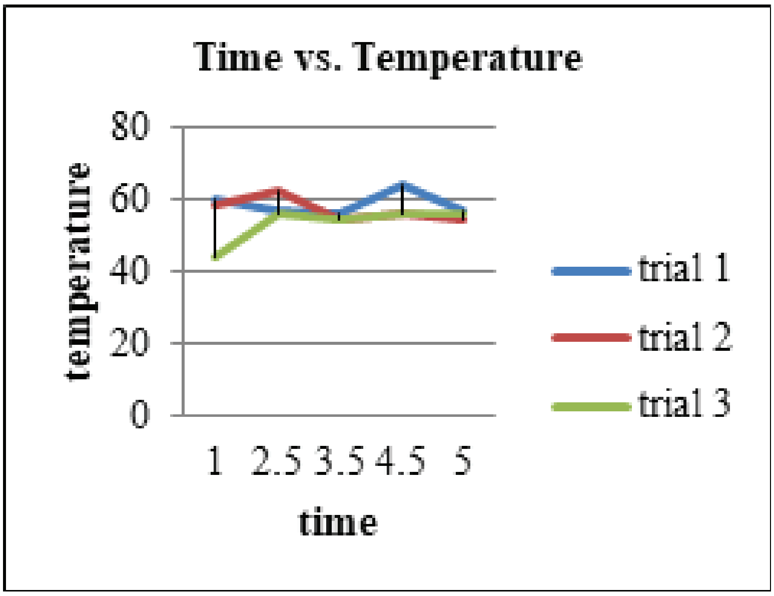

Figure 7: The time versus temperature of the three trials.

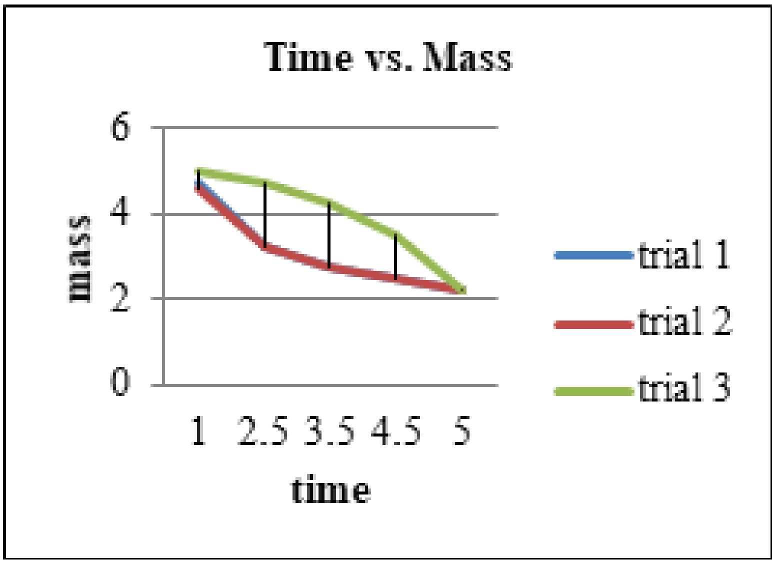

Figure 8: The time versus mass of the three trials.

The drying efficiency of tilted hot air fish dryer was 85% based on the design computation. Therefore the machine was capable to dry the fish for every five hours to reach the moisture content of 15%.

Table 2

Summary	Time	temp	mass	Total
T1A				
Count	3	3	3	9
Sum	7	173	10.9	190.9
Average	2.333333	57.66667	3.633333	21.21111
Variance	1.583333	4.333333	0.985833	749.6092
T1D				
Count	3	3	3	9
Sum	10.5	180	9.35	199.85
Average	3.5	60	3.116667	22.20556
Variance	4.75	13	1.665833	808.3678
T2B				
Count	3	3	3	9
Sum	10.5	174	8.6	193.1
Average	3.5	58	2.866667	21.45556
Variance	1	19	0.140833	756.3272
T2E				
Count	3	3	3	9
Sum	8.5	155	11.85	175.35
Average	2.833333	51.66667	3.95	19.48333
Variance	4.083333	44.33333	2.5825	595.6025
Count	3	3	3	9
Sum	13	167	10	190
Average	4.333333	55.66667	3.333333	21.11111
Variance	0.583333	0.333333	1.020833	672.3455
Total				
Count	15	15	15	45
Sum	49.5	849	50.7	949.2
Average	3.3	56.6	3.38	21.09333
Variance	2.207143	20.11429	1.068857	652.1315
ANOVA				
Source of Variation	*SS*	*df*	*MS*	*F*
Sample	35.77078	4	8.942694	1.349558
Columns	28366.32	2	14183.16	2140.406
Interaction	92.90156	8	11.61269	1.752492
Within	198.7917	30	6.626389	
Total	28693.79	44		

3.10. Payback period

The cost analysis based on the capacity of machine usage of 21 liters salt wat6 kilogram if fresh fish. Thus, the payback period:

$$\text{Payback Period} = \frac{\text{Php } 19{,}000{+}1{,}072{,}512.00}{\text{Php } 744{,}760.463}$$

$$\text{Payback Period} = 1.8 \approx 2\ years$$

- Initial Investment (Machine Cost),

  Php $19,000$.

- Total Annual Gross Income,

  Php $744.760.463$ (5 hours drying rate)

- Prevailing price of Big-eye scad " Matambaka", in kilogram (https://www.bfar.da.gov.ph/files/img/photos/Luzon.1.4.15.pdf), Php 133.00

4. Conclusion and Recommendation

The proponents had proven that tilted hot air fish dryer can be dried up of fish in a shorter time due to the heat exchanger arranged at 40 degrees to ease accumulating the heat in the drying chamber. Based on the result of the test conducted, it can be produced 2.23 kilograms in an average weight of dried fish for 6 kilograms of fresh fish in five hours operation. Based on the design computation that the gross weight of dried fish was 4.08 kilogram in 15% moisture content and weight of the moisture content of dried fish was 0.72 kilogram and the bone dry weight was 3.36 kilogram. In the comparison of actual drying, almost 56% decreases the value the bone dry weight. Therefore, the fish was over dried within 5 hours of drying rate. However, the machine can be dried up the fish up to 2 and half hours to reach the desired moisture content. Therefore, it signifies that the tilted fish dryer was acceptable in the fastest way of drying. The drying efficiency was 85 %, therefore the heat loss of this machine was minimal. For further improvements of performance of the dryer the proponents recommend the improvement of the fan in the heat exchanger and use two fans in order to distribute the hot air more effectively; determination of minimum energy (fuel) requirements;improvement the fuel feeder for faster operation; and use much thick bricks for more heat resistance and insulation. For the further and future direction of this study, some parts should be added to improve the mobilability of the machine (e.g. use of the wheel to easily move the machine). This machine was effective to dry the fish in a shorter time produced the good quality and clean product, therefore this machine highly recommended for piloting in some coastal areas in Palawan however, minimal improvement were needed

Appendix

Figure 9: During the fabrication and assembly the components.

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Figure 10: Dried fish at the drying chambe.

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