Design and Fabrication of a Convective Fish Dryer.

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ABSTRACT

A simple convective fish dryer was designed and constructed to alleviate the problems associated with fish processing in Nigeria. It is made up of five main parts namely; the base frame which is fabricated from 40 x 40 x 3 mm angle iron bar with dimensions of 865 x 498 x 770 mm.; the drying chamber measuring 808 mm (length), 438 mm (width), and 648 mm (depth).; the drying cage/net measuring 720 x 350 x 36 mm which is constructed with a stainless wire mesh of 2.8mm diameter; the fan housing consisting of 3 fan blades measuring 520 x 100 x 2 mm; and three electric heating elements (3000 w, 6000 w, and 9000 w, respectively). The no–load evaluation (temperature profile) of the dryer showed the highest temperature of 110°C/drying chamber temperature in 30 minutes which is expected to give higher drying rate than the natural sun drying and open–fired drying methods.

(Keywords: convective, fish dryer, drying rate, drying temperature, food preservation, local construction)

INTRODUCTION

Reduction of post harvest losses in developing countries can significantly contribute to the availability of food. Estimation of these losses according to Michael [1] are generally cited to be of the order of 4% but can under very adverse conditions, be nearly as high as 100%. A significant percentage of these losses are related to improper and/or untimely drying of foodstuffs such as fish, meat, cereals, cassava, tomatoes, etc.

Fish, being an important component of the diet for people throughout the world, has high protein content and nutritional value. According to Ayyappan and Diwan [2], it supplies approximately 6% of global protein. Fish may be classed as either white, oily, or shell fish. Table 1 shows the average mineral composition of fish. In most developing countries where there is high rate of malnutrition, fish provides nutritious food which is often cheaper than meat and therefore available to a larger number of people Ogunleye and Awogbemi [3].

Fish being an extremely perisable food which in most cases according to Clucas [4] become inedible within twelve hours at tropical temperature. Spoilage therefore begins as soon as the fish dies and processing should therefore be done quickly to prevent the growth of spoilage bacteria.

Peter and Ann [5] stated that fish is a low acid food and is therefore very susceptible to the growth of food poisoning bacteria. This is another reason why it should be processed quickly. Clucas [6] affirmed that the moisture content of fish is 80%; if this is reduce to around 25%, bacteria cannot survive and autolytic activity will be greatly reduced. Clucas [6], further stated that at moisture content of 15 per cent or less mould will cease to grow; well dried fish if stored under right conditions can be kept for several months.

Table1: Average Mineral Composition of Fish.

Composition	White Fish (e.g. Haddock)	Oily Fish (e.g. Herring)
Energy (kg)	321	970
Protein (g)	17	17
Fat (g)	0.7	18
Water (g)	82	64
Calcium (mg)	16	33
Iron (mg)	0.3	0.8
Vitamin A (pg)	0	45
Thiamine (mg)	0.07	0

Source: Peter and Ann [5]

Ogunleye [7] said the use of appropriate methods of preservation creates the possibility of having greater increase in the amount of fish available for human consumption. The purpose of preservation is to reduce the moisture content of the fish because micro-organisms that are responsible for spoilage and wastage cannot survive without moisture. Some of the preservation methods/techniques according to Peter and Ann [5] include: cooking (boiling or frying), salting, smoking and drying collectively known as curing (lowering the moisture content) and fermentation (lowering the pH). However, it should be noted that the scope of this paper is basically on drying as a means of fish preservation.

Drying is a dual process of heat and mass transfer of moisture from the interior of the product to the surrounding air Hall [8]. Mclean [9] stated that drying involves the abstraction of moisture from the product by heating and the passage of air mass around it to carry away the released vapor. The basic essence of drying is to reduce the moisture content of the product to a level that prevents deterioration within a certain period of time normally regarded as the "safe period" (Ekechuckwu [10]).

There are basically two common methods (traditional) of drying fish namely: open air/sun drying and smoking. Open air/sun drying is probably the oldest method use for preserving fish and other foodstuffs such as meat, fish, vegetable, cereals, etc. used in the developing countries because it is the simplest and cheapest methods of conserving fishes. This traditional drying method involves spreading of products on the ground or on rack in the open air/sun or on local three stone stove for smoking. Some disadvantages of open air/sun drying and smoking are: exposure of the fish to rain and dust, uncontrolled drying; exposure to direct sunlight which is undesirable for some foodstuffs; infestation by insect; attack by animal, etc. Also the use of solar drier has not gained popularity in the developing countries. The reasons which according to Bassey [11] can be attributed to: poor problem definition which makes the developed dryers technically inadequate and economically unviable; inappropriate dryer designs due to the choice of construction materials; inadequate understanding of the operation of solar dryers and lack of design procedures. One of the disadvantages of solar drier is that the intensity of solar energy insolation from the sun which is usually collected and concentrated to produce elevated temperature that dries the foodstuff is relatively low during rainy season which occupies 6-7months in a year (i.e., April – October) thus lead to longer drying duration cum low rate of drying.

Due to increasing demand for fish because of its nutritional value, practical ways of cheaply, sanitarily and economically preserving it are needed. The design and fabrication of a convective dryer which does not depend on weather will definitely takes care problems associated with the traditional drying methods. This paper present design detail, fabrication and preliminary experimental results carried out on the convective dryer for fish under no load conditions.

MATERIALS AND DESIGN METHODS

The design of a convective fish dryer is presented as follows. The materials for the fabrication which includes galvanized metal sheets, angle iron stainless steel, etc. were obtained from Araromi metal sheets /spare parts market in Ibadan, Nigeria.

Operation Description of the Convective Dryer

The dryer is designed to dry ten pieces of common Tilapia fish of average weight 4.6 kg per batch is to be operated by one horse power (1 hp) electric motor as its source of power. It has drying chamber and cage capacities of about $182x10^{-3}m^3$ and $9.1x\ 10^{-3}m^3$, respectively. It is made up of five main parts namely; the base frame, the drying chamber, the drying cage/net, the fan housing and the electric heating element (Figure 1).

The Base Frame

It is fabricated from (40x40x3) mm angle iron bar with dimension (865x498x770) mm. The frame is welded to shape and provides support for other component parts of the dryer (No. 7, Figure 1).

The Drying Chamber

The drying chamber which is rectangular in shape .It has double walls made up of a plain galvanized metal sheet (gauge 18) measuring 808mm (length), 438mm (width), and 648mm (depth) with fiberglass (insulator) in between to reduce heat loss across the wall . It has an air inlet which is located by one side of the chamber at the bottom end. This provision allows air into the chamber. At the top of the chamber is a hinged main door which permits easy access to the drying cage. On this main door are 15mm diameter holes which allows the moist air out of the drying chamber (No. 6, Figure 1).

The Drying Cage

To hold the fishes in place is a drying cage/net measure (720x350x36 mm) which is constructed with a stainless wire mesh of 2.8mm diameter. The cage has a removable drying tray (718x 348x35 mm) on which fishes are spread for pretreatment and handling during and after drying process to prevent contamination. It has also a hinged door which permits easy access inside the cage for loading and unloading the fishes before, during and after drying (No 1, Figure 1).

The Fan Housing

In order to effectively force ambient air into the drying chamber across the heating elements and at the same time expel moist air form the chamber, there exists a fan of 3 blades measuring (520 x100 x 2 mm) inside an housing mounted in front of the air inlet opening created at bottom part of the drying chamber. (No. 3 and 4, Figure 1).

The Heating Element

This consists of three loop like electric heating elements of 3000 w capacity each, (9000 w in all) arranged in parallel to one another to heat the incoming air. It is connected in such a way that each can be switched on separately (No. 5, Figure 1).

Design Preliminary Survey

The preliminary investigation were carried out on different sizes of common Tilapia fish family (Mackerel, Pilchard, and Herring) selected in the market to serve as data base for the design and fabrication of the dryer component parts. Highlighted below are the results of the investigation obtained by physical measurement.

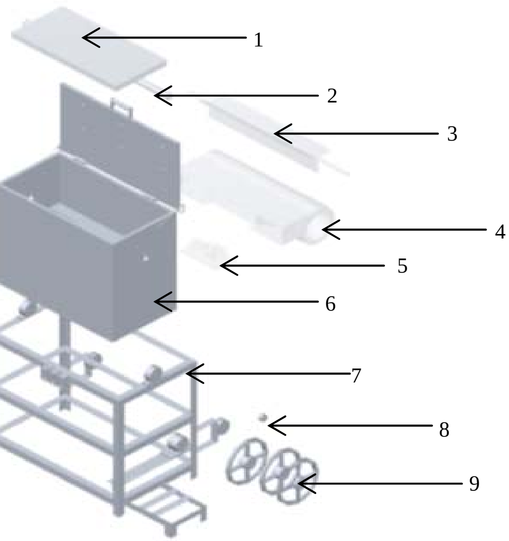
Mass of a fish = 0.4625kg
Length of a fish = 360mm
Width of a fish = 70 mm
Thickness of a fish = 36mm

Components Design

The major components were designed based on the following equations:

(i) Volume (space and material) of the drying cage (V_c) = $L_c \times B_c \times D_c$ **(1)**

Where,
L_c = length of the cage
B_c = breadth of the cage
D_c = Depth of the cage.



LEGENDS

1. Drying cage
2. Main shaft
3. Fan blades with shaft
4. Fan housing
5. Heating element
6. Drying chamber
7. Base frame with bearings and switches

Figure 1: CAD Components Drawings of the Convective Fish Dryer.

(ii) Power requirement for rotating the drying cage shaft only with full load (pc)

P_c = torque x angular velocity **(2)**

(iii) Total Power required for rotating the cage and fan shaft (P_{cf})

$P_{cf} = P_c + P_f$ **(3)**

where,

P_c = power required for rotating the drying cage shaft (kw)

P_f = power required for rotating the fan shaft (kw)

(iv) Open belt length

$$L_{open} = 2xCD_1 + \frac{\pi(D_1 + D_2)}{2} + \frac{(D_2 - D_1)^2}{4CD_1} \quad \textbf{(4)}$$

Hall et al., [12]

(v) Belt tension

$$\frac{T_1 - MV^2}{T_2 - MV^2} = \ell^{\mu\alpha / Sin(\theta/2)} \quad \textbf{(5)}$$

Hall et al ,[12]

where,

T_1 = tension in the tight side

T_2 = tension in the slack side

M = $bt\ell$

b = belt width (mm)

t = belt thicknes (mm)

ℓ = belt density = 970 kg/m^3 for leather belt

μ = coefficient of friction between belt (0.115 for leather belt on steel)

α = angle of wrap

θ = groove angle

(vi) Shaft diameters

$$D^3 = \frac{16}{\pi S_s}\sqrt{(k_b M_b)^2 + (k_t m_t)}^2 \quad \textbf{(6)}$$

Hall et al, [12]

where,

S_s =Allowable combine shear stress for bending and torsional = 40MN/m^2

k_b = Combine shock and fatigue factor applied to bending moment for minor shock =1.0 to 2.0

m_t = Maximum torsional moment (Nm)

m_b = Maximum bending moment(Nm)

k_t = Combine shock and fatigue factor applied to torsional moment for minor shock 1.0 to 1.5

Fabrication and No-load Testing of the Convective Fish Dryer

Fabrication: The dryer components (Figure 1) were measured, machined, welded, bolted and assembled as shown in the sectional front view (Figure 2) according to the design specification. The dryer was then test run to effect all necessary adjustment, alignment, tensioning, greasing etc. where necessary.

No–load Testing: A no-load test was conducted for the thermal profile, which could be suitable for fish drying. This is important in order to determine the maximum temperature each heater with capacity 3000 w (heater I), 6000 w (heater II) and 9000 w (heater III) would give and also the time it will take each to reach these temperatures at different fan speeds. This idea was borne out of minimum and maximum drying temperatures 60°C and 90°C considered suitable for fish drying by Rahaman [13].

However, Mujumdar [14] opines that the drying period may be significantly shortened by blowing air through the drying chamber provided this air has been heated to 102 – 105°C by electricity. In reference to the latter, three actual fan speeds 280rpm (speed 1), 340rpm (speed 2) and 400rpm (speed 3) capable of supplying air at 1.5 – 2m/s as suggested by Mujumdar [14] to be an ideal air velocity in mechanical fish dryer. These fan speed were obtained by tachometer as a result of motion transmitted from a selected 3-step-pulley.The dryer was allowed to run by switching on each heater at these speeds on separate days when the heaters were in the same ambient state with the environment. A k-type thermocouple was installed to measure the temperature attained by each heater at different fan speeds at interval of 5 minutes until the maximum temperature is reached.

The no-load testing was carried out at the Federal College of Agriculture, Moor Plantation, Ibadan Nigeria, latitude 7^0 22½ ^{1}N and Long 3^0 50½ ^{1}E between April 15th and 25th, 2010. The velocity of the ambient air within the period was between 1.3 to 1.5 m/s.

RESULTS AND DISCUSSION

Results

The results are presented in Table 1 and Figures 3 to 5. Under no load condition of convective drying, temperatures of the heated air from three heating source (3000, 6000, and 9000 w) tagged heater I, II and III inside the drying chamber were measured at three fan speeds (280, 340 and 400 rpm) and plotted against time.

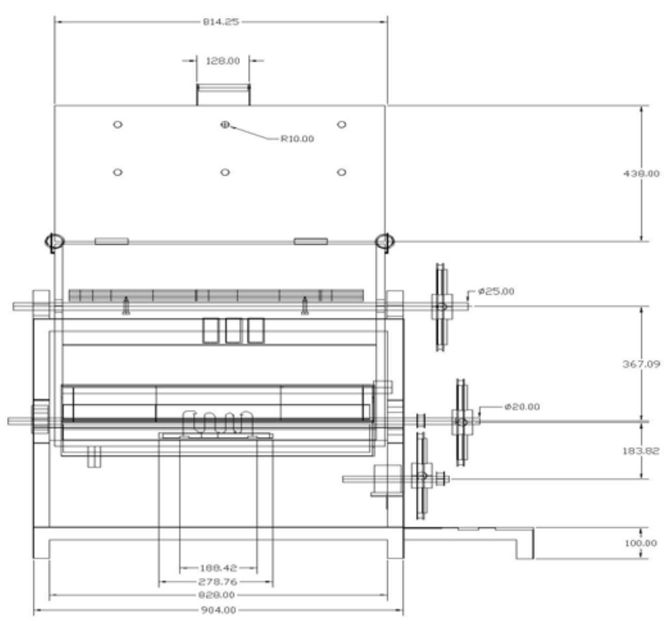


Figure 2: CAD Sectional Front View of the Convective Fish Dryer.

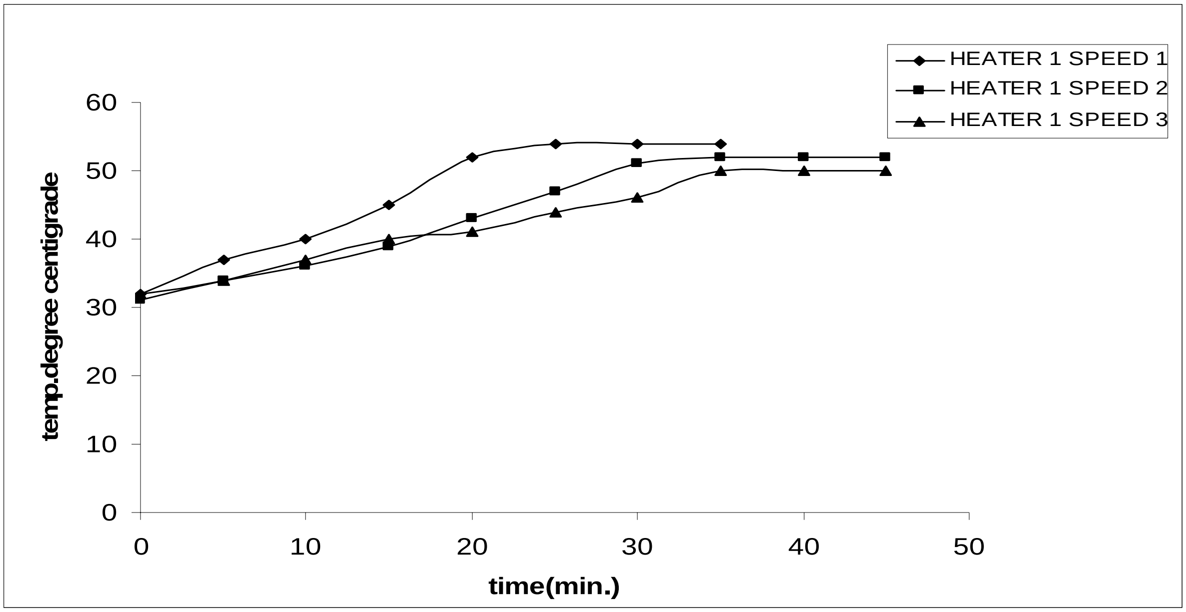


Figure 3: Temperature Profile under No-load Test with Heater 1 at Different Fan Speeds.

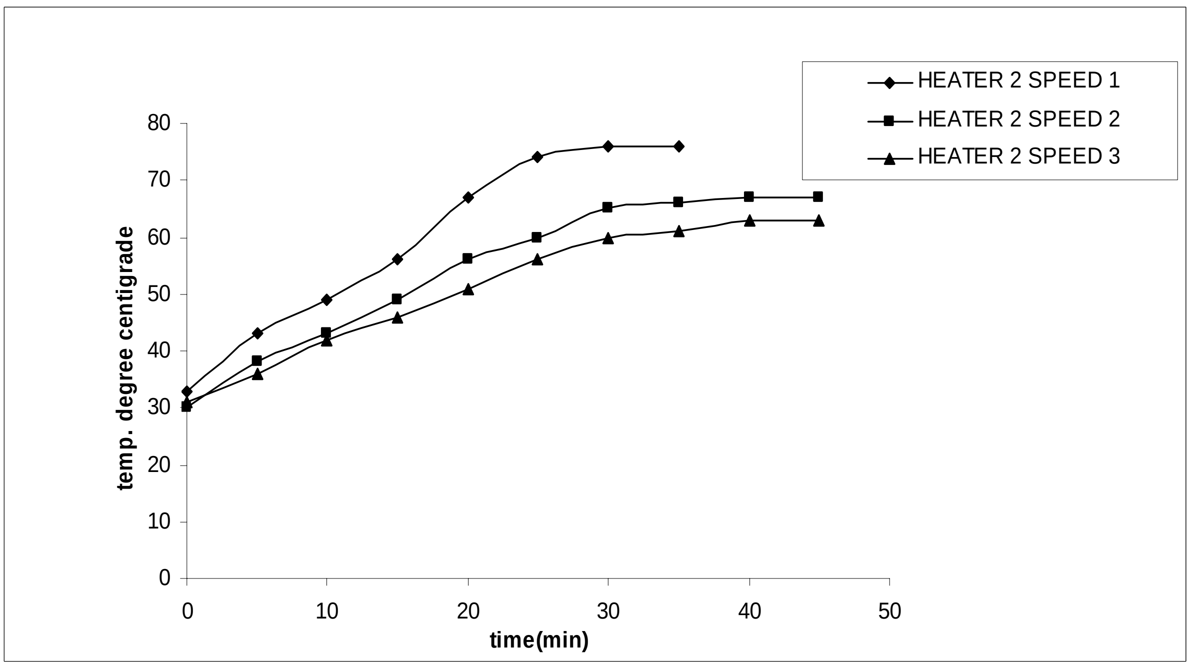


Figure 4: Temperature Profile under No-load Test with Heater 2 at Different Fan Speeds.

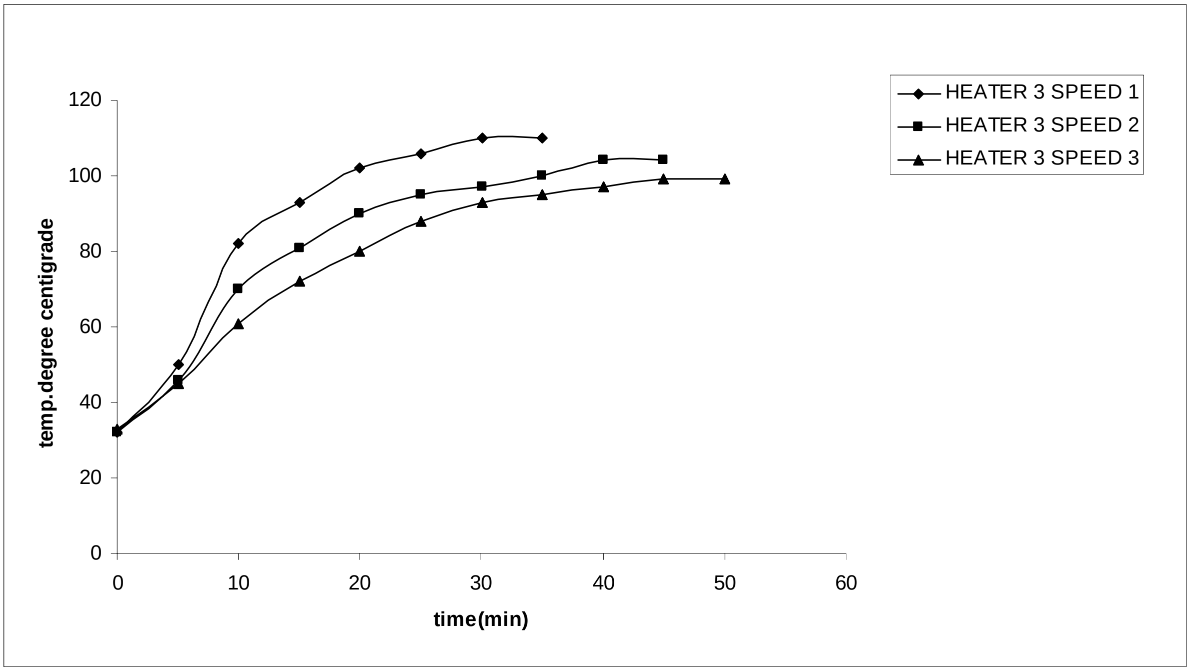


Figure 5: Temperature Profile under No-load Test with Heater 3 at Different Fan Speeds.

Figure 3 indicates temperature profile observed with heater I (3000 w) at speed I, II, and III (280, 340 and 400 rpm), respectively. With heater I (3000 w) at fan speed I (280 rpm), the maximum temperature of 54°C was attained in 25 minutes. With heater I (3000 w) at fan speeds II (340 rpm) and III (400 rpm), the maximum temperature 52°C and 50°C of the heated air were attained in 35 and 38 minutes, respectively.

Similarly, in Figure 4, the maximum temperatures attained with heater II (6000 w) at fan speeds (280, 340, and 400 rpm) as above were 76°C, 67°C, and 63°C in 30, 35, and 40 minutes of testing, respectively.

Also in Figure 5, the maximum temperatures 110°C, 104°C, and 99°C of heated air with heater III (9000w) at these same fan speeds (280, 340, and 400 rpm) were reached in 30, 40, and 45 minutes of testing.

Discussion

From Figures 3-5, it is observed that maximum temperature increases with increase in the heat source. However, the maximum temperature decreased with fan speed. Heater III (9000 w) at speed I (280 rpm) gave the highest drying chamber temperature while heater I (3000 w) at fan speed III gave the lowest drying chamber temperature. Thus, these figures can be used to predict the temperature of heated air in the chamber at a specific drying time and speed under no load.

The results obtained from heater III (9000w) at fan speeds I (280 rpm) and II (340) were very close to that (102 -105°C) reported by Mujumdar [14] , but the latter (heater III at fan speed I) with heated air temperature 110°C was preferred for full load test. The reason being that it took shortest time (30 minutes) to reach this drying chamber temperature and also in support of Mujumdar [15] opinion that the hotter the air temperature, the faster the moisture evaporation.

CONCLUSION

A designed and constructed convective fish dryer consisting of a drying cage, drying chamber, fan/ fan housing, and a base frame was subjected to no–load testing under Ibadan climate to ascertain suitable fish drying temperature for good quality product. From the results, it took heater I (3000

w) at different fan speeds I (280 rpm), II (340 rpm), and III (400 rpm) to attain the maximum drying chamber temperatures 54°C , 52°C, and 50°C, respectively in 25, 35, and 36 minutes .

The maximum drying chamber temperatures attained with heater II (6000 w) at these same fan speeds (I, II, and III) were 76, 67, and 63, respectively, in 30, 35, and 40 minutes.

Also it took heater III (9000 w) 30, 40, and 45 minutes to reach the maximum drying chamber temperatures 110, 104, and 99°C, respectively at different fan speeds (I, II, and III). The results shows that heater III (9000 w) at speed I (280 rpm) attained the highest temperature 110°C from which fish drying temperature 60 to 90°C considered suitable by drying experts could be selected or regulated by an installed thermostat in 30 minutes. This suggests that this convective drying system capable of supplying as high as 110°C drying chamber temperature, could be a substitute for local drying methods especially in poor weather conditions.

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SUGGESTED CITATION

Komolafe, C.A., I.O. Ogunleye, and A.O.D. Adejumo. 2011. "Design and Fabrication of a Convection Fish Dryer". *Pacific Journal of Science and Technology*. 12(1):89-97.

Pacific Journal of Science and Technology