Development of A Dual-Fired Dryer for Augmentation of Fish Preservation

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Abstract
Food serves as one of the basic requirements for the well-being of every living being, but improper handling during post-harvesting stage to cater for the rainy day in the midst of insufficient energy source, is one of the factors responsible for food insecurity, especially in the developing countries. This study focused on the construction and evaluation of an adaptable dual-fired fish dryer. The dryer, designed to reduce moisture content of fish from 80% to 8% for proper product shelf life, has a rated drying capacity of 12 kg of fish per period of 4 hours per batch, while working on either electricity or natural gas as source of heat energy. Locally available materials were used in the construction of the device. The rig developed cost one hundred and forty-eight thousand eight hundred and twenty Naira (₦148, 820.00). It was evaluated using salmon fish. The dryer is more efficient when electrically fired than when gas-fired and has the maximum drying and thermal efficiencies of 84.67 % and 92.93 % when operated at 85^{o}C while the corresponding values when operated on gas are 36% and 62.65% respectively.
Keywords: Food insecurity, Fish, dryer, Performance evaluation, Preservation, Income

1. Introduction

Food is fundamentally required by all creatures for survival. Food provides the body with the needed requirements to keep the body healthy, apart from being served as the energy source to do useful work. Food exists in various forms and the time (period) together with rates of their consumption varies. Whilst some are considered as desserts, consumed wholly, used to seasoning or supplementing other foodstuff when consumed, some are used in all these cases. One of these kinds of food is fish.

Fish exist in various species (e.g. Tilapia, catfish and salmon) and consume in variety of ways; they are either used to prepare: pepper soups or barbecues at inns to enjoy the coolness of the day, at homes to seasoning foods and soups or processed as canned food (like Geisha and Sardine), but when unprepared as ready-to-eat meals and are stored as frozen food, they gradually toughen, develop an off-flavour and off-odour likened to boiled clothes or wet cardboard at a rate which varies widely between species. The consumptions of fish and their allied products (such as fish oils) have significant effects on the well-being of consumers. Fish constitutes a reasonable percentage of protein, lipid, minerals and minerals to human diets when processed (Andrew *et al.*, 1993) and it accounts for more than 60 % of the world supply of protein, most especially in the developing country (FAO, 2017). Rice (2007) reported that consumption of fish or intake of fish oil reduces blood pressure and viscosity, the contributory factors to stroke and cardio-vascular related diseases. It serves as a unique source of essential nutrients, such as long-chain omega-3 fatty acids, Vitamin-D, and Calcium, the essential ingredient of bone formation and development (Rice, 2007). Fish provides: 0.48% to the national GDP of Nigeria (NBS, 2017), more than 6% of Namibia, Uganda, Ghana and Senegal (World Bank, 2015), 3.69 % of Bangladesh (FAO, 2016) 1.07 % in India between 2003-04 (FDF, 2007)

Fish production from tropical waters accounts for about 17 % of the world's total catch (Eyo, 1999); its stands at 2.7 mmt in Nigeria (NBS, 2017), 1.0 mmt in Ghana, and 0.3 mmt in Coted'Ivore; these represent about 30 % in Nigeria, 0.5 % in Ghana and 0.3 % in Cote d'Ivore of the demand (World Bank, 2015) with some of the difference being sought from neighbouring countries, (NBS, 2017).

In spite of the various strategies put in place by concerned stakeholders (Government, producers and consumers) to increase fish production and make them available as food or food substitute, losses are still incurred. Studies carried out by Swedish Institute for Food and Biotechnology (FAO, 2016) for the Food and Agriculture Organization of the United Nations (FAO) revealed that: roughly one-third of food produced for human consumption is lost or wasted globally, which amounts to about 1.3 billion tons per year (FAO, 2007). UNEP (2010) estimated that abandoned, lost or otherwise discarded fishing gear in the oceans make up approximately 10 % (640,000 tonnes) of all marine litter Ugochukwu (2017) reported that about 30 – 50 % of fish harvested are wasted due to poor handling in Nigeria. More so, according to FAO (2017) about 27 % to 39 % of total fish caught is wasted each year due to these similar reasons. A significant percentage of these losses are related to: untimely drying of foodstuffs (Bassey, 1989); Improper preservation techniques, poor transportation and retail, and factors which also apply to all foodstuffs (Adewuyi et al., 2010; Andrew et al., 2016). One of the activities uses to add value is drying.

According to Fellows (2002) drying is defined as the application of heat under controlled conditions to remove the majority of the water normally present in a food by evaporation, or in the case of freeze, by sublimation. The main purpose of dehydration is to extend the shelf life of foods by a reduction in the water activity. Drying inhibits microbial growth and enzyme activity, but promotes physical changes. Physical changes that may occur include: shrinkage, puffing, crystallization, glass transitions. In some cases, desirable or undesirable chemical or biochemical reactions may occur leading to changes in colour, texture, odour or other properties of the solid product. Water which exist as moisture in food items are either chemically bound or physically held water. Therefore any increase in moisture content during storage, for example due to faulty packaging, will result in rapid spoilage.

Emmanuel *et al.*, (2015) developed a smoking kiln capable of drying about 70 pieces of catfish (Clarias Gariepinus) using coal or wood as the heat energy source. The coal pot, valued at ₦ 178,000, was designed to carry a load of 3.0 kg at a time

Komolafe *et al*., (2011) developed a convective drier that could dry ten pieces of common Tilapia fish of average weight 4.6 kg per batch while operated by one horse power (1 hp) electric heating element as its source of power. Their findings showed that this convective drying system is capable of supplying heat as high as 110°C drying chamber temperature which could be a substitute for local drying methods especially in poor weather conditions

Zomorodian *et al* (2009) discussed a new method of using a direct solar dryer, i.e., cabinet dryer, in which solar radiation is the main source of energy for drying the products. The dryer has three parts: the collector, the drying cabinet, and the air blower. Direct convective temperature losses were reduced to ambient levels with the aid of a glass cover, the drier is advantageous for increasing crop and chamber temperature. But the shortcomings of the solar dryer are that the crops may become discoloured because of direct exposure to solar cell radiation and moisture compression inside the glass cover decreases its transitivity

More so, many food industries dealing with commercial products employ state-of-the-art drying equipment such as freeze dryers, spray dryers, drum dryers and steam dryers. The prices of these dryers are significantly high and only commercial companies generating substantial revenues can afford them. Therefore, because of the high initial capital costs, most of the small-scale companies dealing directly with farmers, and even some of the farmers, are not able to afford the price of employing such high-end drying technologies that are known to produce high quality products. Instead cheaper, easy-to-use and practical drying systems become appealing to such companies or the rural farmers themselves. In addition, the pollution threat due to under-utilization of natural gas is another challenging factor. These shortcomings justify the need for dryer that is less expensive, could make use of the unused flare natural gases and not climate-dependent as in the case of solar driers

Thus, owing to the problems of incessant power outages that has been rocking the boats of economic breakthrough of the developing nations coupled with under-utilization of the naturally abundant gases which ought to have been diversified into various usage, not only at large and medium scales but small scale instead of allowing it flaring to pollute the available natural resources hence, there is a need to develop a dryer that could work on both electricity and gases so that when there is an outage it can be operated on a gas mode to meet the needs of concerned stakeholders in this profession and at the same time finding additional means of increasing the sources of protein and source of revenue to the Government. be used to alleviation. Therefore, the concern of this study is to develop and evaluate the performance of a dual-fired fish dryer. The type of fish chosen for the evaluation of the is red Salmon fish (*Oncorhynchus nerka*).

2. Materials and Methods

2.1 Description of the dual fish Dryer

The basic components of the dryer include: heating chamber, heat source, dryer trays Exhaust unit and Temperature controller/regulator. The heating chamber is a rectangular shaped housing unit with coned head to enhance proper circulation of heat and discharge of heat and flue gas (moisture, CO_2) to the ambient air .the heating cabinet measures 600 mm long, 600 mm wide and 800 mm high was made from 1.5 mm stainless sheet, cladded round with 50 mm thick fibreglass (Rockwool) as insulation material and walled externally with 2.5 mm thick mild steel plate to have external dimensions of 712 x 712 x 812 mm. The heating/drying chamber is divided into two shelves, formed with the aid of 30 x 30 x 3 mm angle bar welded (leftward and rightward) inside it to form rail tracks for smooth loading and off-loading of the the trays. Each of the 2 trays, which was formed with 30 x 30 x 3 mm angle bar made from steel and wire-gauzed with 5 mm diameter stainless steel; these are the unit on which the intended sample to be dried are arranged. Each of the trays has 24 pieces of U-shaped hook welded underneath them for hanging bent fresh samples. .In operation drying is achieved by: 2 pieces of 3.5 Kw (or 7.0 kW) heating elements when electrical fired and Cormet industrial gas burner, that utilizes NLG gas, when gas fired. Air is drawn into the dryer through the gas burner air hole and exhaust air exits through the exhaust hood formed from 125 mm diameter and 150 mm long cylinder pipe welded to one side of the coned head of the dryer. The exhaust hood is capped with Chinese cap developed from 2.0 mm thick mild steel plate for prevent ingress of contaminants and proper dispersion of flue gas. The required set temperature is done using a temperature controller mounted on the rear side of the dryer. Figures 1 and 2 show the pictorial and isometric views of the developed adaptable dual fired fish dryer while Table 1 shows its materials specifications

Figure 1: Pictorial View of the dual-fired fish Dryer

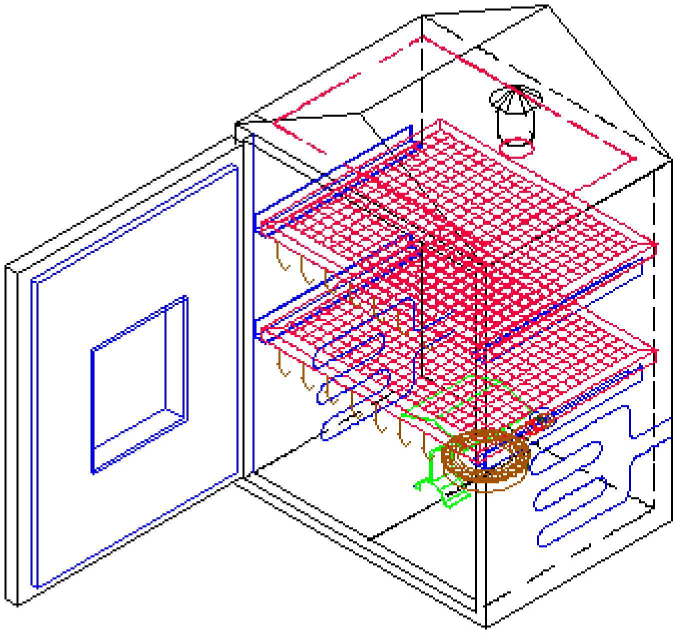

Figure 2: Isometric view of dual-fired Fish Dryer

Table 1: materials specifications of the developed dual-fired fish Dryer

Material	Specification	Quantity
Mild Steel plate	2 mm thick	2 sheets
Stainless plate	1.5 mm	1 sheet
Galvanised pipe	19 mmØ	1 length
Mild steel rod	6.35 mmØ	7 lengths
Mild Steel plate	1.5 mm thick	½ of a sheet
angle iron	50 x 50 x 5 mm	1 length
Mild Steel Electrode	G12	12 dozens
Stainless Steel Electrode	G12	4 dozens
Cutting and grinding disc	flexovite	2 Nos
Castro Tyre		4 Nos
Square pipe	19 x 19 x 2 mm	2 lengths
Fibre glass		147 kg
Refractory Glass	320 x 480 mm	1 piece
Heating Element	3.5 KW	2Nos
Temperature control switch		1 No
Plug and socket	15 Amps	1 No each
Wire (Cable) for connection		450 mm length
Gas Burner	Cormet (industrial)	1 No
Gas Cylinder with regulator	5.0 kg sized	1 Bottle
Silver paint		1 Gallon
Black paint		½ Gallon
Sand (MEE cloth) paper		1 ½ yard

2.2 Design Parameters of the Dual fired dryer

The design parameters of the dual-fired fish dryer were calculated from the mathematical relations described below (Horner, 1997; Rajput, 2007;) and the following assumption were considered in designing while designing the dryer

(i) density of water to be 1000 kg/m3
(ii) moisture content of salmon fish is 80 %, according to the result of the findings of Horner (1992) and average specific heat of salmon fish is 1.4 kJ/kg-K since the value ranges between 0.8 -1.6 kJ/kg-K

(Sabramaniam, 2005)

(iii) moisture contents of fish to prevent spoilage is 25 %, to prevent formation of mold is 15 % and lengthen the shelf life is 8 % (Horner, 1997 and Barbosa et al.,, 2007)
(iv) prevailing air velocity is 0.2 m/s
(v) Design temperature is 27 °C
(vi) Mass of each piece of salmon fish is 0.25 kg and total number of fish design for is 48 pieces
(vii) The efficiency of the Heating element is 100 % and the Gas burner is 90 %
(viii) Calorific value (CV_{fg}) is 11800 kcal/kg or 49.4042 MJ/kg ()
(ix) Complete combustion (no soot, and more blue like flame is the key)
(x) Probable size of a piece of fresh fish is 175 x 72 mm (Length x width)

2.3 Design Analysis of dual-fish Dryer's Components

The fish dryer was designed using conventional engineering principles and standard equations. Components of the dryers include: the electrical element heating rate, rating of the Gas burner starting from the determination of the various moisture contents to prevent spoilage, formation of mold and lengthen the product shelf life and heat energy required for the drying operation

2.3.1 Determination of Moisture of fresh Fish

5 In view of the fact that water accounts for certain fraction of the body weight, proper estimation of this body water mass would assist in determining the size of heat energy that would be needed to remove this associated water mass. Considering N pieces of fresh fish of individual mass m (kg) with initial moisture content T % to be dried to: (1) r % water content to prevent spoilage, (2) y % water content to prevent mold formation, and (3) z % water content to lengthen the shelf life; On wet basis water content, according to Hall et al (1997), is given in equation (1) as

$$M_w = \frac{100\ m_{wd}}{m_t} \quad (1)$$

Also, on dry basis is expressed with equation (2) as:

$$M_d = \frac{100\ m_{wd}}{m_t}\ \% \quad (2)$$

Hence, the relation between the mode of expression, according to Horner,(1997) becomes equation (3):

$$M_w = \frac{100M_d}{100-M_d} \quad (3)$$

At initial water content of T %, the composition of the fish sample is

$\frac{TM}{100}\ kg$ of water + $\frac{(100-T)M}{100}\ kg$ solid fish

At z % water content for proper shelf life, the $\frac{(100-T)M}{100}$ (kg) of mass of solid sample represents $(100 - z)$ % of z % water content can be derived as $\left[\frac{(100-T)M_f}{(100-z)}\right]$, which is equal to: $\frac{(100-T)M_f}{100}$ kg of solid fish + $\frac{z}{(100-z)}\frac{(100-T)M_f}{100}$ kg of water. Therefore, the amount of water to be removed to ensure proper shelf life of the fish sample (M_{WS}) is given in equation (4) as:

$$\left[\frac{(T-z)}{(100-z)}\right] M_f \text{ kg} \quad (4)$$

when values are substituted the mass of water to be removed is 9.39 kg and the mass of the solid fish is 2.61 kg

2.3.2 Heating Element Capacity

The capacity (Q_H) of the heating element required for the drying process consists of the heat to reduce the water content of the fish from its moisture content to the desired level for proper shelf life (Q_{ev}) and heat gained by the solid part of the (Q_s), this can be obtained usimg equations (5) and (6)

$$Q_{ev} = M_{WS}\left|(c_p(T_f - T_{ic}) + h_{fg}\right| \quad (5)$$

$$Q_s = M_S\left|(c_{ps}(T_f - T_{ic})\right| \quad (6)$$

So that $Q_H = Q_{ev} + Q_s$

when value substituted, the capacity of the heating element at 100 % efficiency is 7.0 kW (approximately)

2.3.3 Gas Burner Capacity

The burner capacity Q_B at burner efficiency of η_{OB}, according to Oilon (2015), is given by equation (7) as:

$$Q_B = \frac{Q_H}{\eta_{OB}} \quad (7)$$

The fuel flow of the burner (m_{fb}) can be obtained using equation

$$m_{fb} = Q_B \frac{3.6}{CV_f} \quad (8)$$

when values substituted, the gas flow of the burner is 0.547 kg/h (or 0.547 m^{3}n/h) and the appropriate burner adapted for these specifications from Gas Burner Brochure is i-Ring Comet Delux model or its equivalent.

2.3.4 Burner Air flow rate

The system is designed to draw in air by natural draft via the air hole of the burner, the air flow rate (m_a) of the burner, according to Baukal (2003) and Oilon (2015), is estimated with equation (9) as

$$m_a = \frac{1.3r}{\Delta h_f G_f} Q_b \tag{9}$$

2.3.5 Determination of heating area of dryer

The dryer tray is the platform on which the sample to be dried are arranged. The tray is to have a shape which facilitates loading, maximum volume utilization and effective heat transfer of heat between the heat source and sink. Hence, to achieve this, the tray is made rectangular in shape. For a piece of fresh fish or sample, the heating area required is obtained with equation (10)

$$A_h = L_s W_s \tag{10}$$

For N_s pieces of fish sample the total heating area required becomes

$$A_{th} = N_s L_s W_s \tag{11}$$

The theoretical area required for drying 48 pieces of salmon fish of dimension 175 mm (length) and 72 mm (width) is 604800 mm^2. Thus, in order to make the system compact and increase its economy, the dryer is made to have two compartments with tray of heat transfer area of 302400 mm^2 so that the dimension of the tray becomes 700 x 500 mm.

Also, to ensure proper circulation of heat, loading of fresh and off-loading of dried samples, the distance between the compartments is half the width of the dryer (250 mm) so that the entire height of the heating chamber is 750 mm.

Hence, the entire dimension of the heating chamber is 700 x500x750 mm

2.4 Sample Preparation

Samples of fresh pieces of salmon fish popularly called *Panla* (native language), were sourced from Cold-stores at King Adesida Market in Akure, Nigeria. The procured samples were stocked inside a 100 Litre-sized upright shelf-type freezer and refrigerated for 24 hours (1 day) to ensure initial uniform temperature and prevent thawing of sample prior to the commencement of each of the experimentations.

During the preparation of the samples for experimentation, 48 pieces of the sample were picked, defrosted, washed in bucket of water salted with little quantity of salt and coiled into rings with the aid of sticks of tooth pick. The ringed samples were then hung with the pieces of U-like hooks located under the dryer trays. The charged dryer was closed and allowed to rest for a period of 30 minutes so that certain fraction of the unbound water could drain off from the test samples and also, to allow both the samples and the drying chamber to attain same initial temperature. The test samples were then off-loaded into a known weighed container and weighed on a digital ADAM weighing scale to know the mass of the charged samples. The weighed samples were then re-loaded into the dryer for onward drying. The initial temperature of the charged dryer and the ambient temperature were measured with infra-red laser thermometer (UT300 Series) and Multi-Thermometer (H-9283 Series) and recorded. The dryer was switched on with the drying temperature set to 50 ^{o}C using the mounted temperature controller to drying the sample at intervals of 30 minutes. Data as regards the instantaneous losses in weight of samples to determine the moisture contents were taken at each of these intervals and the process was done until when no significant difference in mass was obtained. The procedure was repeated at 75 ^{o}C, 85 ^{o}C and 100 ^{o}C drying temperatures.

In the case of when the dryer was gas-fired, the drying operation was carried out at same set combustion rate and air velocity of 0.2 m/s (FUTA Meteorological Data, 2017) Owing to the fact that it was hard to vary the drying temperature and to ensure credibility in experimental data, the drying process was done twice and average values of each recorded data were used in evaluating the thermal performance of the system, The procedure was done until when constant moisture content was obtained. Data as regards the difference in mass were done similar manner using the same procedure like when it was electrically powered

The four batches of the experimentations when electrically fired were conducted on 12th, 20th, 26th and 27th October, 2017 between 14.00 h and 21.00 h. and the two batches when gas-fired done on 25th and 28th October 2017 between 7.30 h and 11.30 h.

2,5 Performance Evaluation of the dual-fired Dryer

Evaluation of the performance of the dryer was done based on the following two parameters, thermal efficiency and drying efficiency. .Each of the these parameters were determined from the data obtained during the experimentations

2.5.1 Thermal Efficiency

The thermal efficiency is the ratio of the energy used to evaporate the moisture present in the test sample to the quantity of energy incorporated into the drying process for the length of the drying time. Thermal efficiency focuses mainly on the moisture removal rate without the material temperature. From the equation adopted from

Rajput (2007) and Dincer (2003), the thermal efficiency during the drying process is given by equation (12) as:

$$\frac{M_{WS}|(c_p(T_f - T_{ic}) + h_{fg}|}{M_a CV_f} \quad (12)$$

2.5.2 Drying Efficiency

This describes how efficiently the input energy to the dryer is used in the product drying. The heat supplied to it is the power rating of the heat source (heating element or heat rate of the fuel) used to fire the system. The drying efficiency of the dryer can be calculated as follows, using equation (13):

$$\eta_d = W\frac{h_{fg}}{CV_f} \quad (13)$$

where W is the quantity of the moisture evaporated from the sample calculated using equation adapted from Hubackova *et al*.(2014) as:

$$W = \frac{m_s[M_{iw} - M_{fw}]}{100 - M_{fw}} \quad (14)$$

Table 1 shows the performance of the dryer when electrically powered.

Table 1: Performance of Dryer when electrically powered

	Dryer Temp (°C)	Drying Efficiency (%)	Thermal Efficiency (%)
1	50	74.26	75.48
2	75	75.69	77.95
3	85	84.67	92.93
4	100	70.68	79.86

From Table 1, it was observed that the dryer is most efficient when drying at 85 °C set temperature and least at 100 °C.

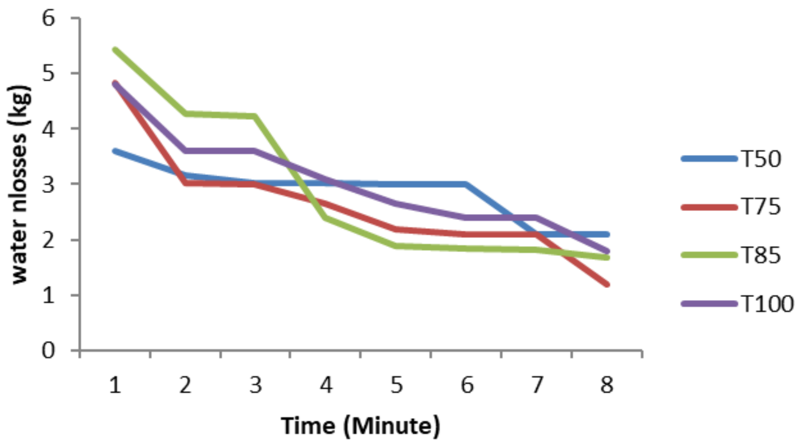

Figure 1 shows the plot of moisture (water) loss with time at the 4 levels of temperatures considered.it was observed that maximum rate of water losses occurred when drying at 85 °C followed by at 75 °C and least at 100 °C

Table 2 shows the performance characteristics of the dryer when gas-fired

Table 2: Performance of dryer when gas-fired

Time (Minute)	Test-1 (kg)	Test-2 (kg)
30	5.400	3.640
60	4.200	2.856
90	3.960	2.220
120	3.500	1.350
150	1.800	0.922
Thermal efficiency (%)	62.650	67.410
Drying efficiency (%)	64.200	36.740

Table 2 shows the variation of the moisture losses/ drying rate with time when gas fired; it was observed that the thermal efficiency and drying efficiency increase as the charging load increases.

3 Conclusion

This paper presents a study on the conceptual design and performance evaluation of an adaptable dual-fired fish dryer that is suitable for producing high quality dried fish throughout the year; a best solution to cushion fish preservation problems due to incessant power outages or traditional techniques which are characterized by seasonal variation in solar energy, the commonest drying method, in developing countries. Specifically, the design removes idle time caused by epileptic power supply and utilizes removable trays, components that could be improved on to cater for other agro-allied products (e.g. grains, mash) The adaptable dual-fired fish dryer capable of drying 48 pieces (12 kg) of fish per batch, was developed at a cost of one hundred and forty-three thousand, eight hundred and twenty Naira (₦143, 820.00) with locally sourced materials. The machine, which was evaluated using salmon fish, is more efficient when electrically powered as it has higher efficiencies than when gas-fired

Based on the evaluation, it is obvious that the developed unit has a capacity greater than the traditional means

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