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Development of a Forced Convection Electric Fish Drying Machine

[1*]Isinkaye J. T, [2]Oghenekaro J. S & [3]Isinkaye O. D

[a] Department of Mechanical Engineering, Federal University of Technology, Akure
[b] Department of Electrical and Electronics Engineering, Federal University of Technology Akure[c] Department of Agriculture and Bio-Environmental Engineering, Federal Polytechnic, Ado Ekiti
*Correspondence: joshuaisinkaye@gmail.com

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A forced convection electric fish dryer was developed in this study to provide an efficient means of drying fish in urban and rural areas and serve as a substitute for the largely inefficient local means of drying fish. The machine was designed to accommodate 126 kg of fish distributed accordingly within the drying chamber. Six flat electric coils of 3 kW capacity each and a fan blower were provided to induce a saturating forced convective current within the drying chamber. The machine was evaluated at a drying temperature of 60ºC with a total of 126 kg catfish, 21 kg on each tray. The result showed that percentage moisture contents of 81.8%, 72.7%, 62.7%, 54.1%, 47.7%, and 40.9 % were evaporated from the fish on the sixth to the first tray respectively in one hour. The mean percentage of moisture evaporated from all the trays was 60 %.

Keywords: convection, electric, drying, fish, moisture, chamber

INTRODUCTION

Fish can be considered as one of the most important and prominent components of people's diet throughout the world. Containing all the amino acids essential for human health, it is a nutrient storehouse that provides more than 20% of the average per capita animal protein intake for 3 billion people in developed countries, and more than 50% in some less developed countries (Elavarasan, 2018). Fish may be classed as either white, oily, or shellfish. In most developing countries with a high malnutrition rate, fish provides nutritious food that is often cheaper than meat and therefore available to a larger number of people (Wijkström, 2009).

Fish and seafood are traded and transported in different forms around the world. For example in 2010 the proportions traded and transported were as follows:

- live, fresh or chilled: 46.9%;
- deep-frozen: 29.3%;
- prepared and preserved: 14.0%;
- smoked, dried, cured: 9.8%. (Charles, 2010).

Preservation is a very important attribute of fish processing due to its perishability. The purpose of preservation is therefore to reduce the moisture content of the fish because micro-organisms that are responsible for spoilage and wastage cannot survive without moisture. Modibbo (2014) determined the moisture content of fish to be 80% and that when reduced to 25% and less, bacteria activities will be greatly reduced. The use of appropriate methods of preservation opens up the possibility of having a greater increase in the amount of fish available for human consumption (Ogunleye, 2006). According to Peter and Ann (1992), some of the preservation methods include cooking (boiling or frying), salting, smoking, drying, and fermentation (lowering the pH). This study is focused solely on the drying method of fish preservation. Drying is one of the essential unit operations performed to increase the shelf life of agricultural or horticultural produce and it is one of the most practical methods of preserving food and the quality of agricultural produce (Ashok *et al.*, 2015). Drying involves the abstraction of moisture from the product by heating and the passage of air mass around it to carry away the released vapour. Drying reduces the moisture content of the product to a level that prevents deterioration within a certain period usually regarded as the "safe period".

Sun-drying of fish has been the traditional and most prominent method of fish preservation in most countries of the world. It entails the drying of fish by spreading in open sun in thin layers. Open sun drying and smoke processing drying require a longer drying time. Product qualities are usually difficult to control because of inadequate drying, high moisture, fungal growth, and encroachment of insects, birds, and rodents, as well as the economy of space (Idi-Ogede *et al.*, 2018). Owing to the ever-increasing demand for fish as food, there is a need to develop a cheap, safe, and efficient method to preserve fish to ensure the retention of its nutritional value, sanitary compliance, and economic viability. This paper puts up a design that utilizes a forced convective heat transfer approach whereby heat is circulated evenly through the entire volume of the system to dry up fish arranged on trays inside the system.

MATERIALS AND METHODS

Materials Selection

The materials used in the fabrication of the machine include:

- Plain galvanized metal sheet (gauge 18) for the Drying Chamber and Cover
- Fiberglass for Insulation
- Angle iron bar for the Trolley
- Stainless steel wire mesh for the Drying tray
- Electric Coils for the Heat source
- Air blower
- Fabrication equipment: These include measuring tools, setting and marking out tools, cutting tools, Driving tools, and Metalwork machine tools

Fabrication Procedure

The fabrication procedure for the machine includes;

i. Measurement: The metal sheets used for the machine parts were first measured to determine their dimensions. The measuring tools used are measuring tape and steel rule.

ii. Setting and Marking out: The metal sheets for the drying chamber and dryer cover were marked out according to specifications. The major hand tools used in the marking out process is Scriber, Combination set, and Centre punch

iii. Cutting: After marking out the various measurements according to specification, the marked out materials were cut using the appropriate cutting tools such as hacksaw, plier, and chisel

iv. Drilling and Drive-in: The drilling of holes for bolts and nuts was done with the aid of both hand and pillar drilling machines. The holes were first marked with a center punch before drilling.

Bolts and Screws were driving in with the aid of tools such as hammer, mallet, screw-driver and so on

v. Welding: Various parts of the machine such as the dryer body, trolley, and dryer cover were welded together using an electric arc welding machine.

Other tools used in the fabrication includes: Clamps, Angle Iron for mounts, Sliders, Flat bar, Tap and Die set, Drill bit, Drill, and Grinder

The empirical principle used to produce the design framework is the Conceptual generation method using morphological analysis and design matrix.

The functional objectives of the design and the selected mechanisms are listed in

Table 1

Table 1. Functional objectives of the design and the selected mechanisms to achieve the objectives.

S/N	Functional Objectives	Mechanism
1	Heating	Electric heater
2	Feeding	Hand
3	Air circulation	Blower
4	Power supply	A.C
5	Discharge	Hand
6	Feedback	Humidity
7	Safety	Temperature Monitor
8	Lagging	Fiber Glass

Design Analysis

The moisture content of different fish types differs, but Catfish is the reference sample for this design.

According to Solomon and Oluchi (2018), the moisture content of Catfish is 78.70% and upon drying, to maintain/improve the nutritional composition, an average reduction to the recommended safe moisture content of dried fish (6% to 8%) with an average of 7% should be established (Olayemi *et al*., 2011).

Therefore, the percentage of water required to be removed upon drying is:

$m\,\% = 78.70 - 7 = 71.7\%$

From physical measurement, it was discovered that the average weight of a yellow bullhead catfish is 0.7kg and this was adopted for the drying system.

From the tray dimension, a maximum of thirty (30), 0.7kg fishes can be accommodated and there are 6 trays in total in the system,

Therefore the **total weight of the fish on the system** is

$m_f = 30 \times 0.7 = 21kg$

The mass of water required to be removed to dry the fish is gotten as the product of the percentage moisture to be removed upon drying and the total weight of fishes on the system.

$m_w = 0.71 \times 21 = 14.91kg$

Drying requires the vaporization of water from the material to be dried. The heat supplied for drying to occur is equivalent to the **heat required for vaporization of water from the material** as given by equation (1)

$$H = m_w L \quad (1)$$

Where L is the latent heat of vaporization of water given as 2260kJ/kg (Datt, 2011) and m_w is the mass of water present in the material. Substituting the values gives;

$$H = 14.91 \times 2260 = 33{,}696.6kJ$$

The power required for drying is given by equation (2)

$$P_d = H/\eta t \quad (2)$$

Where η is the heating efficiency of the system when considering heat transfer and t is the allotted time required for drying.

The heaters used for the system are each 3kW, and the total number of installed heaters is six (6). Therefore, the total power of heaters P_h is 3KW x 6 = 18KW

For drying to occur evenly, the heat has to be circulated evenly through the entire volume of the system. A forced convection heat transfer approach is used

The heat transfer of the mass of air circulating the system is given by equation (3)

$$H = m_a c_{pa}(\theta_a - \theta_o) \quad (3)$$

Where m_a is mass of air, c_{pa} is the specific heat capacity of air at constant pressure, θ_a is the drying temperature of the material and θ_o is the exit temperature of the system.

To obtain the capacity of the blower required to supply the required volume of air, first the **mass of air required** is inferred from equation (3);

$$m_a = H/(c_{pa}(\theta_a - \theta_o)) \quad (4)$$

Rahman (2006) posited 60ºC as the minimum temperature suitable for fish drying and 40ºC as the consequential exit temperature. Therefore,

$$m_a = \frac{33{,}696.6}{1.005(60-40)} = 1676.4478kg$$

The mass flow rate of air required is given by equation (5)

$$\dot{m} = m_a/t \quad (5)$$

$$\dot{m} = \frac{1676.4478}{2 \times 3600} = 0.2328kg/s$$

While the **volumetric flow rate** is given by equation (6)

$$\dot{V} = \dot{m}/\rho \quad (6)$$

Where m is the mass flow rate of air, and ρ is the density of pure water. Therefore,

$$\dot{V} = 0.2328/1 = 0.2328m^3/s$$

The **power required by the blower** motor to provide the required volumetric flow rate is given by equation (7)

$$P_b = 0.1175\left(\dot{V}\Delta p/\eta_m\right) \quad (7)$$

Where Δp is the differential pressure of the blower and η_m is the mechanical efficiency of the blower.

The mechanical efficiency of the blower from the product specification is 80% while the average differential pressure is 0.8bar.

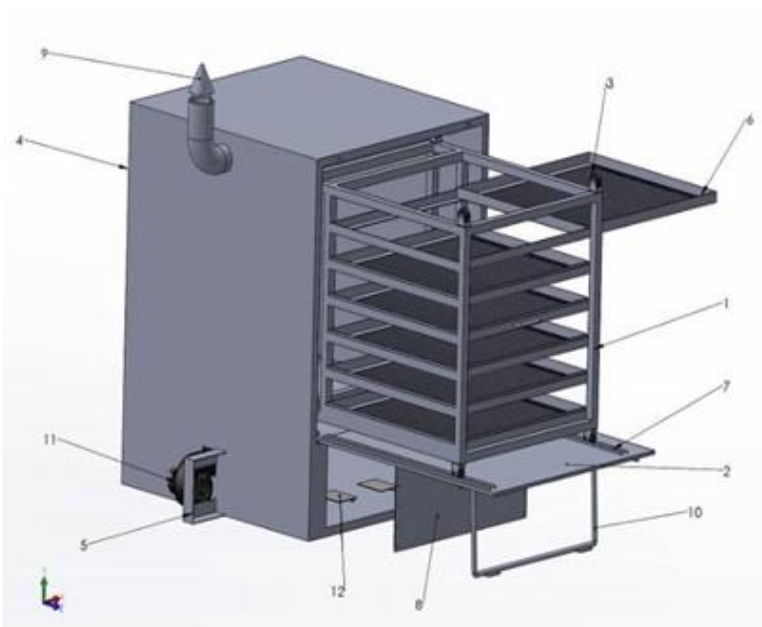
$$P_b = 0.1175\left(\frac{0.2328 \times 0.8 \times 10^5}{0.8}\right) = 2.7\text{kW}$$

The overall electrical power required to drive the system is given by equation (8)

$$P_t = P_h + P_b \quad (8)$$

$$= 18 + 2.7 = 20.7\text{kW}$$

$$\cong 21\text{kW}$$



ITEM NO.	PART NUMBER	QTY.
1	Trolley	1
2	Dryer Cover	1
3	Roller	8
4	Drying Chamber	1
5	Blower holder	1
6	Tray	6
7	Trolley Rail	1
8	heater chamber cover	1
9	Chimney	1
10	Dryer cover stand	1
11	Blower Fan	1
12	Heater	6

Figure 1: Design drawing of the fish drying machine

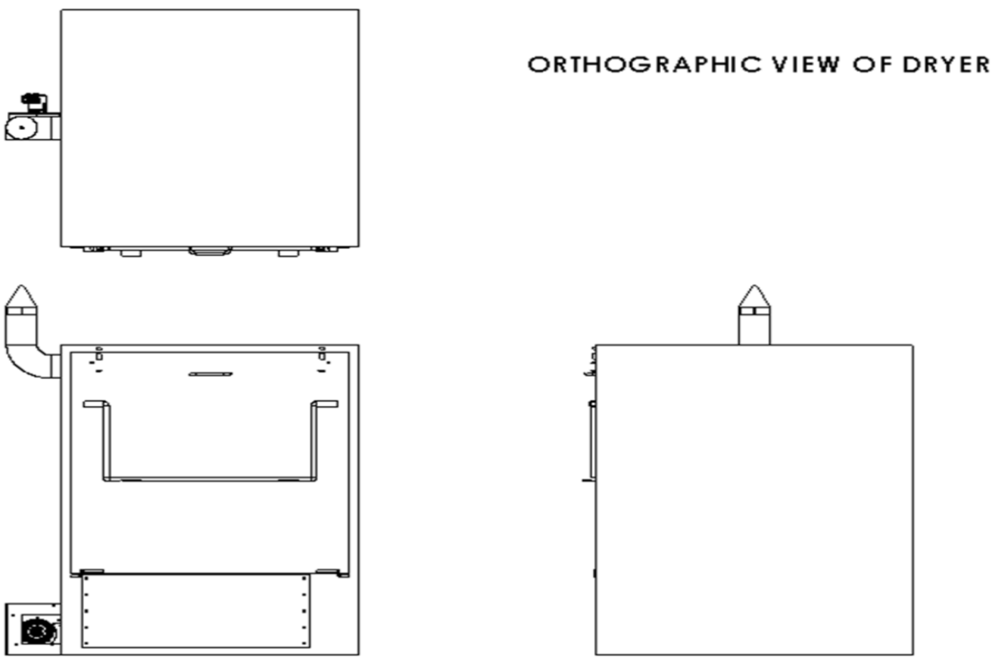


Figure 2: Orthographic view of the fish dryer

Working Principle

The dryer is designed to dry catfish with the aid of forced convection heat transfer. Six perforated heating trays are fixed on a trolley rail that sets in and discharges the fish from the heating chamber. Three electric heaters are attached to the base of the heating chamber, from which hot air rises and circulates through the chamber aided by the fan blower. The convection current sustained within the chamber evaporates the fishes' moisture through the chimney. Figure 2 shows the setup of the machine in the top, side, and front views

Parts description

The drying chamber (No. 4, Figure 1)

The drying chamber (Figure 3) is rectangular. It has outer walls made of plain galvanized metal sheet (gauge 18) and stainless steel sheet interior walls with fiberglass (insulator) sandwiched in between to reduce heat loss to the surroundings. It has an attached fan blower at its left side, which induces hot air generated from the embedded heating elements to rise. At the top of the chamber is a chimney through which moisture is made to escape.

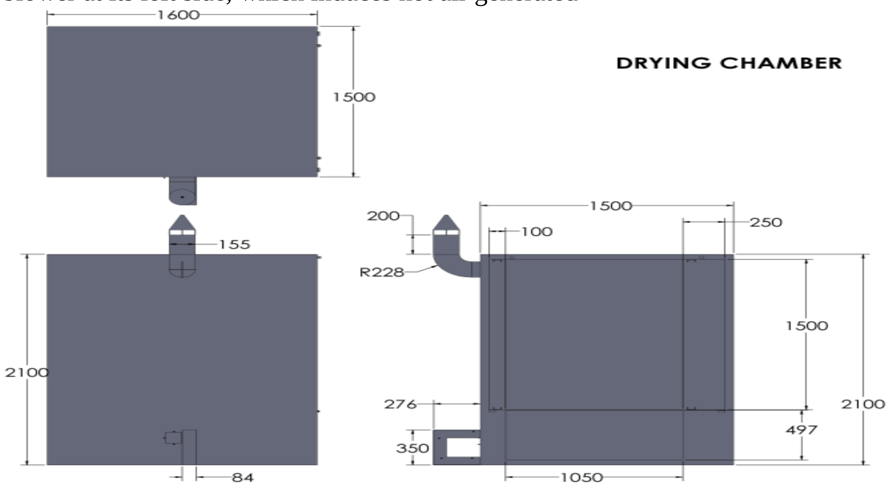


Figure 3: Dimension drawing of the drying chamber

Trolley (No. 1, Figure 1)
This (Figure 4) is the support device upon which the drying trays are suspended. It is made of (40x40x3) mm angle iron bar and it is situated within the drying chamber with the ability to slide in and out on a trolley rail that double functions as the dryer cover.

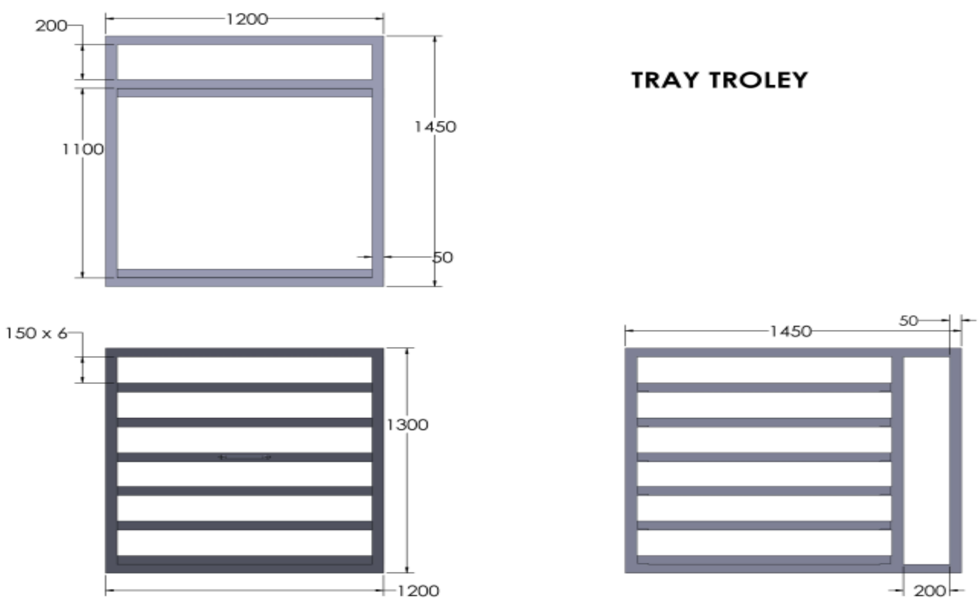


Figure 4: Dimension drawing of the tray trolley

Tray (No. 6, Figure 1)
This (Figure 5) is the component upon which the fish to be dried are Placed. It is rectangular and made of stainless steel wire mesh with 6*6mm apertures. There are a total of six trays set on the trolley.

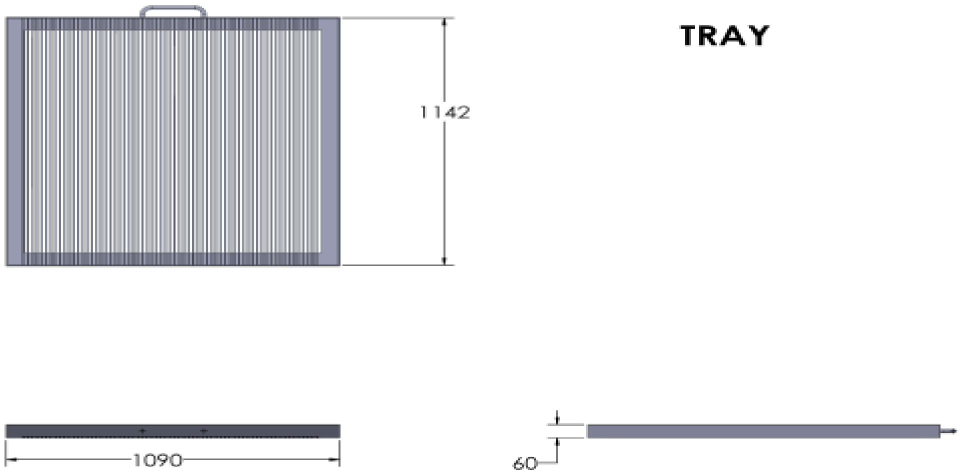


Figure 5: Dimension drawing of the tray

Blower (No. 11, Figure 1)
This part of the machine forces ambient air into the drying chamber across the heating elements and in turn dissipates most air through the respirator attached to the top of the drying chamber.
Dryer cover (No. 2, Figure 1)
This (Figure 6) is a hinged door that permits the opening and closing of the drying chamber. It also acts as a support base for the trolley when it is to be loaded or discharged. It is rectangular and also made of plain galvanized metal sheets.

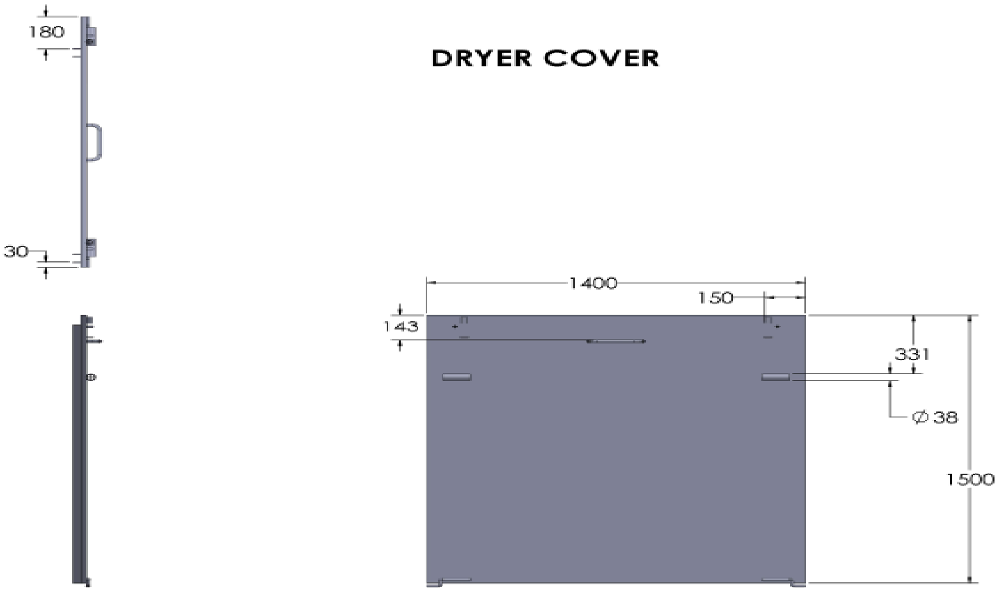


Figure 6: Dimension drawing of the dryer cover

Heating elements (No. 12, Figure 1)
This consists of six flat electric coils of 3kw capacity each that glow red hot and gives off heat which they radiate out in all directions aided by the blower when electric current flows through them. The choice of 3kw coils was made so that the intensity of heat in the chamber does not become extreme as to burn off the fish within a short time.

RESULTS AND DISCUSSION

The results are presented in Table 2. The catfish samples were thoroughly washed, drained, weighed, and spread on each of the six trays. The total moisture content of the fish was recorded before and after drying on each tray to determine the drying efficiency as given in equation (9).

$$\text{Mc (dry basis)\%} = \frac{\text{Initial weight } (w1) - \text{Final weight } (w2)}{\text{Final weight}} x100 \qquad (9)$$

Where Initial weight is the weight of tray + fish before drying and

Final weight is the weight of tray + fish after drying

Dry basis moisture content (designated M_c in the formula) describes the percentage equivalent of the ratio of the weight of water to the weight of the dry matter. Dry basis moisture is usually used for describing moisture changes during drying.

Table 2 showing the fish's Initial weight on each tray before drying, the time taken to dry, and the final weight of the fish on each tray after drying. %Mc is the percentage moisture content evaporated from the fish on each tray after drying.

Table 2: Drying performance

Tray no	Initial weight (w_1) kg	Time taken (min)	Final weight (w_2) kg	%Mc
1	22	60	13	40.9
2	22	60	11.5	47.7
3	22	60	10.1	54.1
4	22	60	8.2	62.7
5	22	60	6	72.7
6	22	60	4	81.8
Mean value	**22**	**60**	**8.8**	**60**

The average values of the above parameters were calculated as shown in Table 2. The result shows that the drying performance increases when moving from tray to tray starting from the first tray downward. This can be attributed to the fact that hot air rises from below the sixth tray upwards and therefore will lose moisture faster than overlaying trays till a state of saturation is achieved within the system. This state of saturation is also aided by the time-bound shuffling of the trays within the chamber to avoid overheating the fish on the tray closest to the heat source. This aligns with the Theory of Convection which is a process by which heat is transferred by the movement of a heated fluid such as air or water. Natural convection is usually induced by the upward movement of fluids when heated, coupled with the increased buoyancy the fluid possesses as it becomes less dense. However, Forced convection is achieved when fluid motion is induced by an external agent such as a pump, suction device, or fan as in this case. Forced convection creates a more uniform temperature throughout the entire system. This reduces cold spots in the system, reducing the need to increase the intensity of the heat applied (Donev *et al*., 2021).

CONCLUSION

A forced convection fish drying machine was developed in this study. The machine was tested with 21kg of fish on each tray of the machine (Table 2). The result showed that drying was achieved on the trays from the bottom up based on closeness to the heaters. At an average time of 60 minutes and an average initial weight of 22kg, a mean value of 60 % moisture content evaporation was achieved on the trays within the drying chamber. When compared with the pneumatic charcoal kiln dryer developed by Idi-Ogede *et al*. (2018) which had a maximum drying temperature of 83.6^{o}c, and the convective fish dryer developed by Komolafe *et al.* (2011) which had a maximum drying temperature of 110^{o}c, it is noted that this design will suffice as a non-intense drying alternative for fish. It is also expected that the total drying efficiency can be amplified by reversing the order of the trays in the drying chamber after one hour. This machine is found suitable as a substitute to the local method of smoking and sun drying fish that usually spans a long time in addition to being labour-intensive and detrimental to human health.

Declaration of Competing Interests: The authors declare that they do not have any competing interests that are relevant to this research.

REFERENCES

Ashok K., Moses C.C. and Kalay K. (2015). A survey on the design, fabrication, and utilization of different types of food and vegetable dryers. *IOSR Journal of Agric and Veterinary Science*, **8**(8), 59–68.

Charles, A. (2011). Good practices for governance of small-scale fisheries. World small-scale fisheries: Contemporary visions.

Datt, P. (2011). Latent heat of vaporization/condensation, in Singh V.P., Singh P., Haritashya U.K. (eds) *Encyclopedia of Snow, Ice and Glaciers. Encyclopedia of Earth Sciences Series. Springer, Dordrecht.* https://doi.org/10.1007/978-90-481-2642-2_32

Elavarasan, K. (2018), Importance of fish in human nutrition. *Training Manual on Seafood Value Addition*: *ICAR-Central Institute of Fisheries Technology*.

Idi-Ogede, A.M., Ogori, A.F., Omoniyi, S.A. (2018). Design and fabrication of pneumatic charcoal kiln drying characteristics and residence temperature for catfish smoking. *African Journal of Food Science and Technology*, 8(6) 085-089, DOI: https://doi.org/10.14303/ajfst.2017.100

J.M.K.C. Donev *et al*. (2021). Energy Education - Forced convection [Online]. Available: https://energyeducation.ca/encyclopedia/Forced_convection.

Komolafe, C. A., Ogunleye, I. A., & Adejumo, A. O. D. (2011). Design and Fabrication of a Convective Fish Dryer. *The Pacific Journal of Science and Technology*, *12*, 95–96.

Modibbo, U. U., Osemeahon, S., Shagal, M. H., & Halilu, M. (2014). Effect of Moisture content on the drying rate using traditional open sun and shade drying of fish from Njuwa Lake in North Eastern Nigeria. *IOSR Journal of Applied Chemistry*, 7(1), 41–45. https://doi.org/10.9790/5736-07114145

Ogunleye, I.O. (2006). Preservation of fish through solar drying. *Journal of Science and Technology Research*, 5(3): ISSN 1596- 9649.

Olayemi, F. F, Adedayo, M. R., Bamishaiye, E. I. & Awagu, E. F. (2011). Proximate composition of catfish (Clarias gariepinus) smoked in Nigerian stored products research institute (NSPRI): Developed kiln. *International Journal of Fisheries and Aquaculture*, 3(5), 96-98.

Peter, F. & Ann, H. (1992). Small Scale Food Processing. Intermediate Technology Publication, 103 – 105 Southampton Row, London WciB4HH, UK. 60-64.

Rahman, M.S. (2006). Drying of fish and seafood. In: *Handbook of Industrial Drying*. Mujumdar, A.S., editor. Taylor and Francis Group LLC: London, UK.573 -587.

Solomon, R. J. & Oluchi, A. R. (2018). Proximate Analysis and Nutritional Value of African Catfish (Clarias Gariepinus) Fed with Local (Telferia Occidentales and Moringa Olefera) and Industrial Feed (Coppens). *Rep Opinion*, 10(4), 1-8. https://doi.org/10.7537/marsroj100418.01.

Wijkström, U.N. 2009. The use of wild fish as aquaculture feed and its effects on income and food for the poor and the undernourished. In M.R. Hasan and M. Halwart (eds). *Fish as feed inputs for aquaculture: practices, sustainability, and implications*. Fisheries and Aquaculture Technical Paper. No. 518. Rome, FAO. pp. 371–407