Design, Fabrication and Characterization of a Solar Fish Dryer

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Abstract

Herein, a forced convection solar fish dryer is designed, constructed and characterized to yield a better mains of drying fish. The designed dryer incorporated a heat storage unit which complimented the drying rate of the product during off sunshine hours. The device was characterized during raining and dry seasons and results clearly indicated the influence of seasonal variation on the performance of the device. Average hourly variation of the dryer and ambient temperatures measured on the selected days of the different months of measurement during the two seasons, clearly indicated that temperatures were significantly enhanced by the device. This was due to the high ability of the designed solar collector to trap large amount of long waves. Maximum dryer and ambient temperatures during raining season were measured to be (58.9±2) °C and (40±2) °C whereas, (73.5±1.3) °C and (45±1.8) °C respectively, were measured during the dry season. Average daily moisture loss from the drying fish was notably high, especially during dry season which was due to the high dryer temperatures and decrease in atmospheric humidity. The efficiency of the solar dryer was estimated to be 76 %. The fishes with initial moisture content of 87 % was dried to 13 %. This moisture content is in range with the United Nations Economic Commission for Europe (UNECE) Standard DDP-19 concerning the marketing and commercial quality control of dried fish.

Keywords: Solar fish dryer, forced convection, raining and dry seasons, dryer and ambient temperatures, collector absorber, heat storage unit.

1. Introduction

Considering the high rate of global population increase (projected to be more than 9 billion by 2050), there must be a proportional increase in food production in order to curtail the menace of food insecurity (Food and Agriculture Organization, FAO, 2009). A greater percentage of the world population that is most vulnerable to the menace of food insecurity and malnutrition is found in the sub-Saharan Africa (SSA) region with high rate of post-harvest loss (Divo *et al.*, 2014). Hence while increase in food production is critical, reducing the existing high rates of global food loss and waste, including post-harvest loss, along the various production and supply chains, will play a key role in tackling the problem of food insecurity in SSA. Globally, close to 1.3 billion tonnes of food produced for human consumption are lost annually (FAO, 2011). Hodges *et al*. (2010) reported that the critical factors influencing food loss in developed countries occur at the consumption stage, whereas in less developed countries, most losses mainly occur early in the value chain, especially in post-harvest handling and processing (Chegere, 2018; Patchimaporn *et al.*, 2020). It is obvious that high rates of food loss contribute to food shortages, leaving millions in low-income countries suffering from malnutrition (FAO, 2010; Munesue *et al.*, 2014).

Solar food drying is one of the ancient and common means of preserving agricultural products worldwide; however, inappropriate and sub-optimal drying practices along the food value chain have led to significant income losses among farmers, food distributors, processors, and exporters in Nigeria and SSA region (Patchimaporn *et al.,* 2020). Beyond income losses, poor solar drying has also contributed to aflatoxin contamination, which is a major food safety and public health concern in developing countries (World Health Organization, WHO, 2005). In this regard, the use of appropriate drying technologies can potentially enable small-scale producers to significantly reduce post-harvest losses, improve the quality of food, and generate income and employment opportunities (Patchimaporn *et al*., 2020).

Solar drying is an energy-intensive and cost-effective method to improve the storability of various types of agricultural products. During a simultaneous transfer of heat and mass, moisture is evaporated near the surface by several mechanisms such as liquid and vapor diffusion, capillary and gravity flows, and flow caused by shrinkage and pressure gradients (Tomar *et al*., 2017). A reduction of the moisture content prevents the risk of micro-organism growth, minimizes many of the moisture-intermediated, deteriorative reactions such as enzymatic reactions, non-enzymatic browning, and oxidation of lipids and pigments, and substantially reduces weight and volume (Kumar and Tiwari, 2007; Barnwal and Tiwari, 2008).

Among numerous available methods of drying, open-air sun drying is the most preferred method in tropical countries such as Nigeria, due to its affordability, especially for smallholder farmers in rural areas. However, the drying process completely relies on ambient conditions and is very prone to contamination by dust, rain, wind, pests, and rodents (El Hage *et al*., 2018; Singh *et al.*, 2018), leading to low-quality products and a loss of farmers' income. To overcome these problems, several systems such as the greenhouse dryer (Janjai *et al*., 2007; Azaizia *et al*., 2017; Hamdi *et al*., 2018; Iskandar *et al.*, 2017) and the hybrid solar dryer (Amer *et al.*, 2018; Eltawil *et al.*, 2018) have been introduced. These systems are faster, more efficient, and more hygienic, resulting in lower crop losses relative to the traditional open-air sun drying method (Muehlbauer, 1986; Chua and Chou, 2003; Karim and Hawlader, 2004; Tomar *et al*., 2017).

In general, solar dryers for agricultural products can be classified based on their size, design of the system, and mode of solar energy utilization. Herein, the passive, active, and hybrid solar dryers focusing on the method of air movement (natural or forced convection) and mode of heat transfer (direct or indirect) are the commonly available classes. The direct passive solar dryers (natural convection) such as cabinet and greenhouse dryers have a simple and cheap construction. A drying chamber usually consists of an insulated box with inlet and outlet holes and a transparent glass/polyethylene/polycarbonate sheet (Seveda and Jhajharia, 2012; Kumar *et al*., 2016; Sivakumar and Rajesh, 2016). The solar-heated air is circulated through the agricultural materials either by buoyancy forces or as a result of air pressure or a combination of both (Tomar *et al*., 2017; Müller *et al*., 2012; Tiwari *et al.,* 2016). The indirect passive dryer (forced convection) contains a drying unit with a separate solar collector and three main components: solar collector, drying unit, and air duct for circulation. The air is heated while flowing through a low-pressure drop solar collector and then passes through air ducts into the drying chamber and over the drying trays. The moist air is discharged through air vents or a chimney at the top of the chamber. Active dryers have a ventilation system to circulate heated air inside the drying chamber or from the solar collector to the drying chamber. Fans or blowers are run by electricity, which can be harnessed from a photovoltaic (PV) module or grid (Tiwari *et al*., 2016). In a hybrid dryer, agricultural materials are dried under direct solar radiation and/or back-up energy or stored heat in the absence of sunlight. The air is pre-heated by another auxiliary source of energy such as a solar PV module, electricity, liquefied petroleum gas (LPG), diesel, or biomass. This dryer can be used in both single and mixed modes (direct and indirect types of drying) (Bala and Woods, 1994). Different types of solar dryers have been designed, constructed, developed and tested in the different regions of the tropics and subtropics.

Fish is a very important component of the diet for people throughout the world because of its high protein content and nutritional value. Ayyappan and Diwan (2003), reported that fish supplies approximately 6% of global protein. Ogunleye and Awogbemi (2008), reported that 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. Fish is an extremely perishable foodstuff. It invariably become putrid within a few hours of capture unless they are preserved or processed in some way to reduce this microbial and autolytic activity and, hence, retard spoilage (Komolafe *et al.,* 2011). Spoilage therefore begins as soon as the fish dies and processing should therefore be done as quickly as possible to prevent the growth of spoilage bacteria. Spoilage occurs as a result of the action of enzymes (autolysis) and bacteria present in the fish, and also chemical oxidation of the fat which causes rancidity. At the high temperatures prevalent in tropical countries, bacterial and enzymic action is enhanced (Komolafe *et al.,* 2011).

Consequently, the use of an efficient solar drying technology for fish drying will not only preserve it but will yield better quality and nutritious dry fish. Smoking, salting and open sun drying are traditional methods commonly used to preserve fish; they have been used for centuries and dried salted products are still popular in many areas, particularly in Africa, South East Asia and Latin America (Mohanraj and Chandrasekar, 2009). Reducing the moisture content of fresh fish to about 25 % during drying, inhibits bacteria growth and autolytic activity will be greatly reduced. However, to prevent mould growth, the moisture content must be reduced to about 15 % (Sandip and Yashwant, 2009). The presence of salt retards bacterial action temporary and in addition, it aids the removal of water by osmosis though not to the desired level. Smoking could significantly reduce moisture content in fish, but to a great extent it is an unhygienic method since the product is exposed to contamination by smoke, flies and other open air contaminants. In order to improve the drying techniques, the use of solar dryers has been investigated as an alternative to traditional sun drying. Debashree *et al* (2017) designed, fabricated and evaluated an indirect solar dryer which has a maximum drying temperature of 55°C. Duraisamy *et al* (2019) also unstudied a natural convection solar dryer with an efficiency of 58 %.

In this paper, a solar fish dryer utilizing forced convection mode of heat circulation has been designed, constructed and characterized. This solar dryer is found to be highly efficient, and demonstrates a good preference over several existing ones including those of Debashree *et al* (2017) and Duraisamy *et al* (2019) and also the traditional methods of fish drying earlier mentioned because it yielded better quality and nutritious dry fish. The design is novel in the sense that it integrated a separate Heat Storage unit which utilized rock pebbles as heat storage materials for Chilli Drying.

2 Design, Fabrication and Characterization

2.1 Design specifications and analysis

A scheme of the stationary forced convection solar dryer for drying fish using solar energy is presented in Figure 1. It consists of four distinct parts; a flat plat solar collector, a drying chamber, a heat storage unit and a chimney. In this work the solar dryer was designed considering various system parameters such as area of the solar energy collector absorber, the air inlet vent and collector-drying chamber air vent, air outlet vent and the capacity of the heat storage unit.

The dimensions of the collector absorber were chosen to be 670.0 mm x 500.0 mm with a focus to maximize heat absorption by the collector while the dimensions of the entire collector space were 670.0 mm x 500.0 mm x 250.0 mm. This is to enable adequate air space (7cm) between the absorber and the glass and to allow free flow of the heated air within the collector chamber and into the drying chamber. For effective performance of the flat plate solar collector, a 4 mm thick transparent glass with thermal conductivity of k = 0.96 W/m.K was chosen due to its high transmittance to short waves (of 0.7) and opaque nature to long wave radiation (Raju *et al*., 2013). A mild steel sheet of 2.0 mm thickness was chosen and coated black for the collector absorber plate with a focus to maximized solar absorption (Irtwange and Adebayo, 2009).

Two air vents are provided in the dryer; the air inlet vent and air outlet vent. The air inlet vent allows air into the collector chamber where it is heated before been transported to the drying chamber. The dimension of the air inlet vent was chosen to be approximately 350 mm x 60 mm, in order to allow free flow of air into the collector chamber. It is positioned between the absorber plate and the bottom of the collector, which forms the airflow duct. The air outlet vent is the chimney, constructed with a folded ply wood of 15 mm thickness and a diameter of 20 mm and a height of 400 mm in order to minimize heat loss.

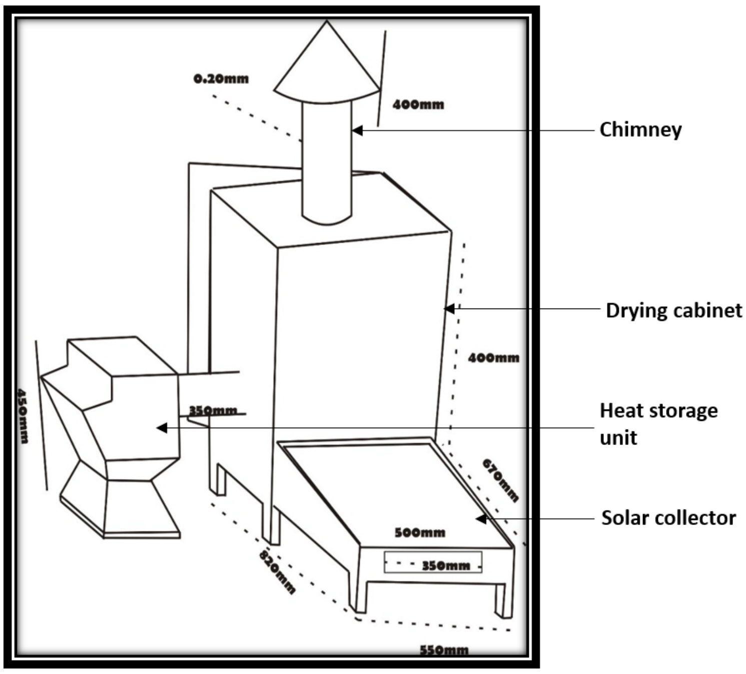

Figure 1: A Scheme of the Stationary, Indirect Passive Solar Fish Dryer

It was positioned on top of the drying chamber. The collector chamber is connected to the drying cabinet through a 350 mm x 60 mm vent, created in the front base of the drying chamber. The heat storage compartment is a box-shaped unit, designed to contain black coated rock pebbles of volume 300 mm x 250 mm x 130 mm, and connected to the drying cabinet through as short pipe duct of diameter 25 mm as shown in Figure 1. The storage unit stores heat trapped by a 4 mm thick transparent glass and the excess heat from the drying chamber. It also removes excess heat from the drying chamber for storage and to return the stored heat to the drying chamber during off sunshine hours. Ply wood was used for the entire casing of the dryer in order to minimized heat loss, whereas, aluminum sheet of 1 mm thickness was used to coat the entire inner surface of the dryer system to prevent heat absorption by the wood.

The collector was oriented at 45° and facing the equator according to Weiss and Buchinger, (2004). This inclination is to allow easy run off of water during raining seasons, prevent heat backward flow and to enhance air circulation. An effective fish drying temperature of 60.5 °C was chosen as a working temperature for the dryer from an optimum range of 37.7°C – 75.5 °C (Tibebu, 2015). An average drying efficiency of 35 % was considered as a design parameter, which is in line with the 25 % to 45 % recommended by Struckmann, (2008) for forced convection dryers. As a result, the daily expected energy output from the collector considering solar insolation of 14. 00 $MJ/m^2/day$ in Makurdi (Latitude 7°43" 35.75" N and longitude 8°32" 20.92" E) for the month of May 2018 (PP Nigerian Meteorological Agency, Tactical Air Command, Makurdi Airport 2018) will be:

$14.00\ MJ/m^2/day \times 0.35$

$= 4.90\ MJ/m^2/day$

For the five days which is the maximum estimated drying period per batch of fish, the energy output will be

$5 \times 4.90 = 24.50\ MJ/m^2$.

7 cm was chosen as the air gap between the absorber and the glass cover. This choice is within the 4 -10 cm range suggested by Irtwange and Adebayo, (2009) for free flow of the heated air. Hence,

$$Vent\ Area = width\ of\ collector\ \times air\ gap \quad (1)$$

$$Vent\ Area = 50\ cm\ \times 7\ cm = 350\ cm^2 = 0.035\ m^2$$

Given air velocity of 0.51 m/s (Scanlin, 1997);

$$Volume\ flow\ rate = Vent\ Area\ \times Air\ Velocity \quad (2)$$

$$Volume\ flow\ rate = 0.035\,m^2\ \times 0.51\ \text{m/s} = 0.01785\,m^3/s$$

The mass flow rate of air M_a is given as (Bolaji and Olalusi, 2008);

$$M_a = V_a\rho_a \qquad (3)$$

where V_a is the volume flow rate of air and ρ_a, is the density of air. Density of air ρ_a is taken as 1.2252 kg/m^3 at S.T.P. Therefore,

$$Mass\ flow\ rate(M_a) = 0.01785\,m^3/s \times 1.2252\ kg/m^3 = 0.02142\,kg/s$$

Hence, the mass flow rate value is within the range of 0.02 – 0.9 kg/s as recommended by Forson *et al.* (2007) for forced convection dryers.

The amount of moisture removed from the drying fish in kg (M_w) is given by (Brown, 2000);

$$M_w = \frac{m_i\,(M_i - M_e)}{1 - M_e} \qquad (4)$$

where m_i is the initial mass of the food item (kg), M_e is the equilibrium moisture content, M_i is the initial moisture content. The solar dryer has three trays which are used to determine the quantity of fish to be dried and an initial amount of 10 kg is considered for the design of the dryer. The heat energy required to remove this amount of moisture H_r is given by (Duraisamy *et al.*, 2019);l

$$H_r = (M \times H_k) + (H_L \times M_W) \qquad (5)$$

where M is the dryer capacity per batch (10 kg), $H_K = C_T\,(T_2 - T_1)$, is heat inside the dryer where, T_1 is the ambient temperature and T_2 is the dryer temperature and C_T is specific heat of fish

= 3.18 KJ/kg^{o}C and $T_2 - T_1 = 60.5^o - 35.0^o$ = 25.5^{o}C. Therefore,

$H_K = C_T\,(T_2 - T_1)$, = 3.18(25.5) = 81 kJ/kg^{o}C

$H_L = h_g - h_f$, is the latent heat of vaporization. The values for h_g (enthalpy of water as a vapour) and h_f (enthalpy of water as a liquid). h_g = 2618 kJ/kg and h_f = 272 kJ/kg

H_L = 2618- 272 = 2346 kJ/kg;

and M_w is the amount of moisture to be removed (kg) = 2.820 kg. Hence

$$H_r = (10 \times 81) + (2346 \times 2.820) = 7{,}425.7\ \text{kJ}$$

The constructed solar dryer is shown in Figure 2.

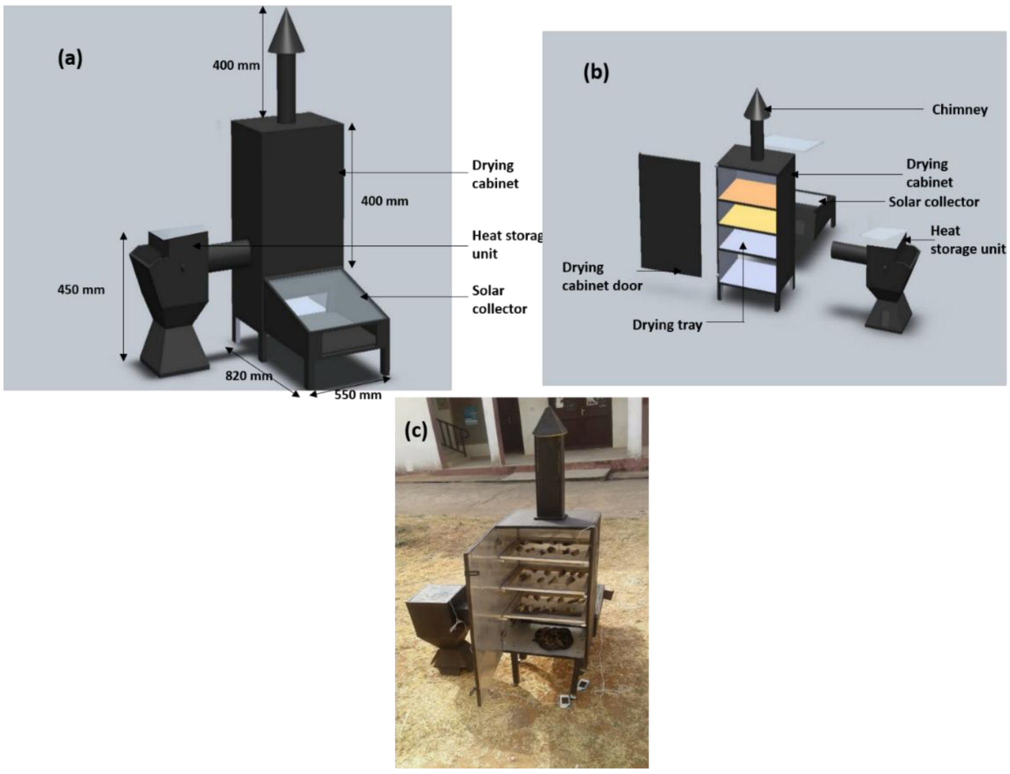

Figure 2. *(a) The Designed Solar Dryer (B) Internal Structures of The Solar Dryer and (C) Photograph of the Constructed Solar Dryer During Characterization.*

2.2 Characterization of the solar dryer

A total number of 240 tilapia fishes weighing about (30.0 ±3) kilograms were used for this test. The fish was dried in batches of 20 each considering the size of the dryer and in order to achieve proper circulation of air in the drying cabinet. The drying test was carried out in the months of May – October, 2018 which represent raining season, during which the drying was conducted in the first five days of each month. Whereas, the months of November, 2018 – February, 2019 represent dry season and during this period, the drying was done in the first four days of every month. Within these days (five and four days for raining and dry seasons respectively) the fish samples were well dried. The drying was done from 8 A.M to 5 P.M daily. The following performance evaluations were carried out on the constructed solar dryer in order to evaluate its performance.

i. Temperature

The variation in ambient and dryer temperatures were measured using a digital thermometer at intervals of one hour throughout the test period, beginning from 8 am to 5 pm daily over a period of May, 2018 to February, 2019.

ii. Moisture loss

Daily moisture loss, M_L was estimated from Eq. 6 (Umayal, *et al*., 2013).

$$M_L = M_i - M_f \tag{6}$$

where, M_i is the initial mass of the sample and M_f is the final mass of the sample. A digital weighing balance was used to measure the initial weight of the fish samples before drying and during the drying process, the fish samples were re-weighed after three hours interval, beginning from 8 AM to 5 PM daily, the result is then subtracted from the initial weight of the fish samples which gives the daily moisture loss.

iii. Drying rate

Drying rate is the amount of evaporated moisture over time, this was estimated using Eq. 7 (Duraisamy *et al*., 2019);

$$D_R = \frac{M_i - M_d}{t} \qquad (7)$$

where M_d is the mass of sample after drying and t is the drying period. This was done for each batch of the fish samples that were dried, the readings were taking at interval of three (3) hours, beginning from 8 AM to 5 PM daily over the period of May, 2018 to February, 2019.

iv. Drying efficiency

The dryer efficiency, η_d was estimated from Eq. 8 (Umayal, *et al.* 2013),

$$\eta_d = \frac{MH_L}{IAt} \qquad (8)$$

where M is the total mass of fish (kg), H_L is the latent heat of vaporization (kJ/kg), A is the collector area (m^2), I = rate of total radiation incident on the absorber's surface (Wm^{-2}), hence

$$\eta_d = \frac{30\ kg\ X\ 2346}{124.6\ X\ 0.30\ X\ 2484\ sec} = 76\ \%$$

v. Amount of moisture removed

The amount of moisture, M_w removed from the drying fish in kg is determined from Eq. 4;

$$M_w = \frac{30\ \text{kg}\ (0.89 - 0.15)}{1 - 0.15} = 26.\ 12\ \text{kg}.$$

3. Results and Discussions

3.1 Results

The solar fish dryer in this work was evaluated with Tilapia (Nile tilapia, Oreochromis niloticus) fishes obtained from markets within Makurdi metropolis, Benue State, Nigeria. The evaluation of the dryer spanned across two seasons; rainy and dry seasons with a target to ascertain seasonal impact on the drying rate. The months of May to October, 2018 were considered raining season, during which the drying was conducted in the first five days of each month; whereas, dry season months were November, 2018 to February, 2019 in which case drying was carried out in the first four days of every month. Results obtained from all the measurements carried out are presented in Figure 3-17.

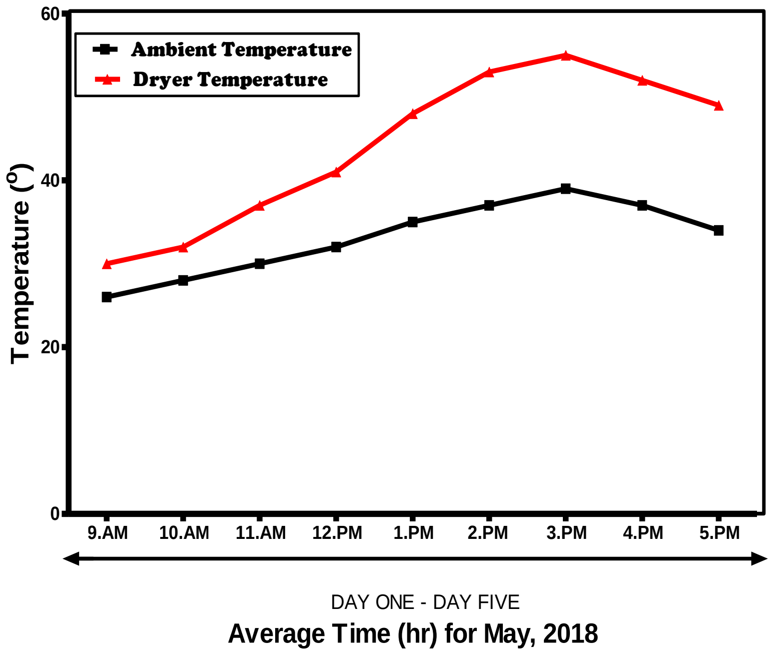

Figure 3: *Average Hourly Variation of Ambient and Dryer Temperature with Time for the Month of May, 2018*

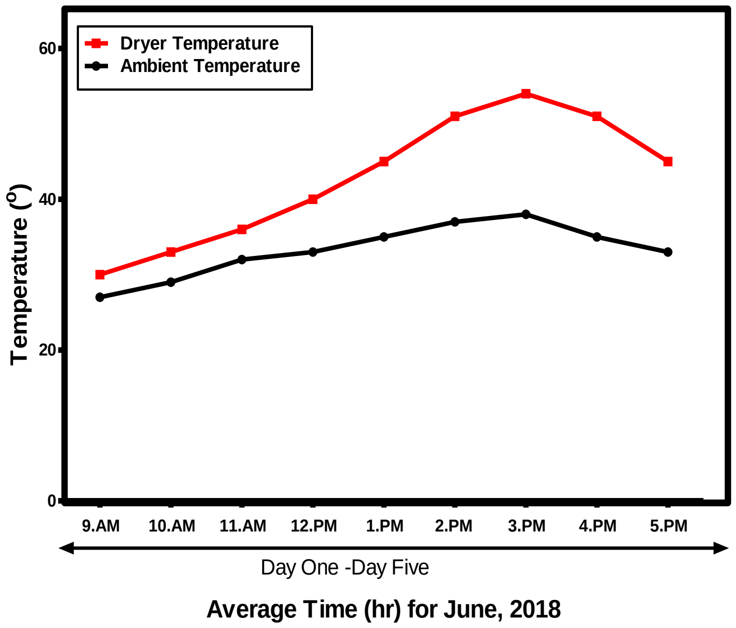

Figure 4: *Average Hourly Variation of Ambient and Dryer Temperature with Time for the Month of June, 2018*

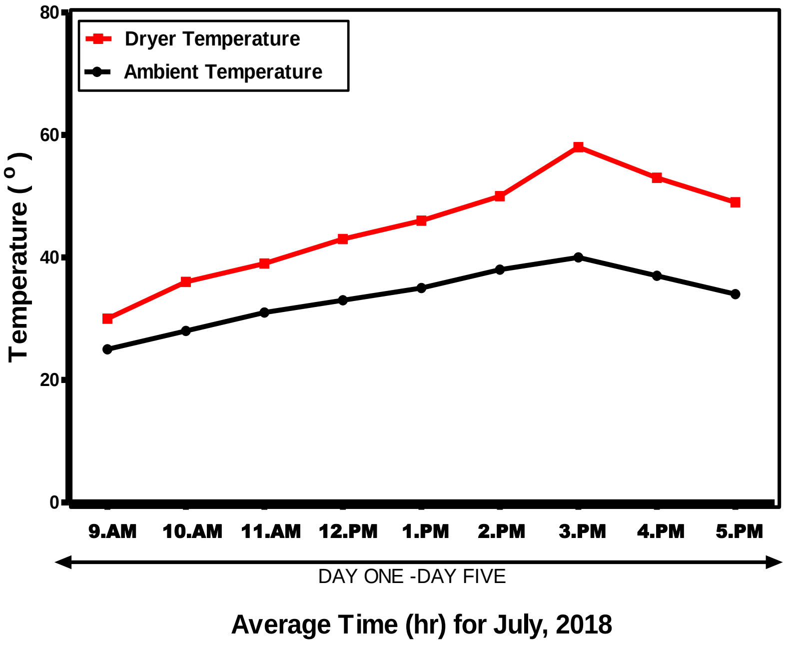

Figure 5: *Average Hourly Variation of Ambient and Dryer Temperature with Time for the Month of July, 2018*

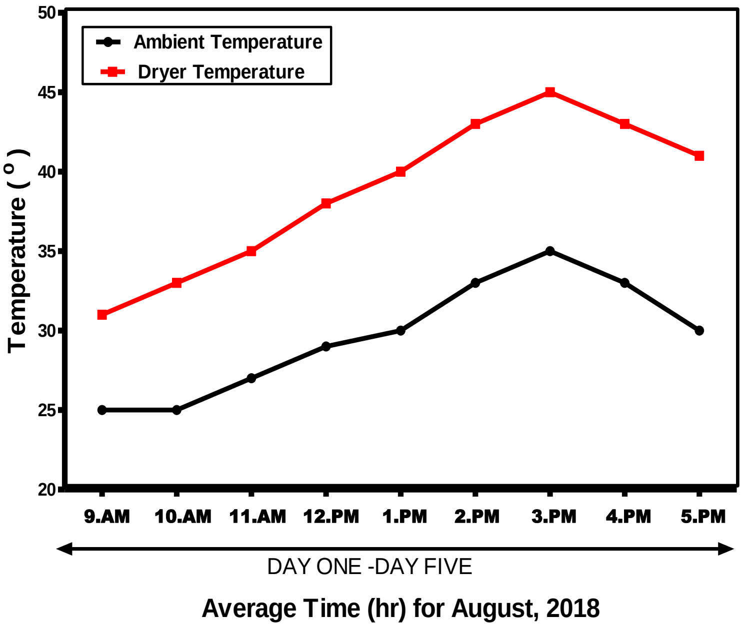

Figure 6: *Average Hourly Variation Ambient and Dryer Temperature with Time for the Month of August, 2018*

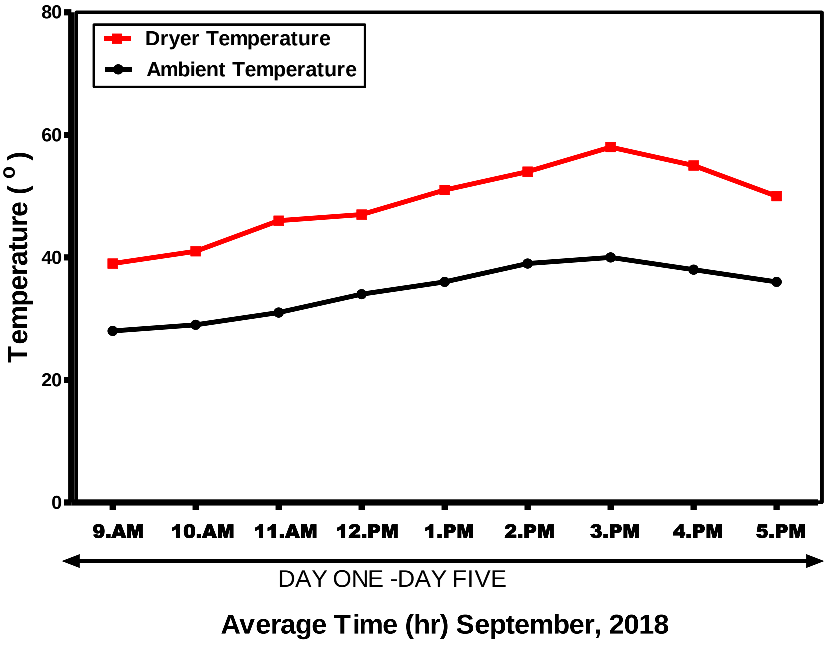

Figure 7: *Average Hourly Variation of Ambient and Dryer Temperature with Time for the Month of September, 2018*

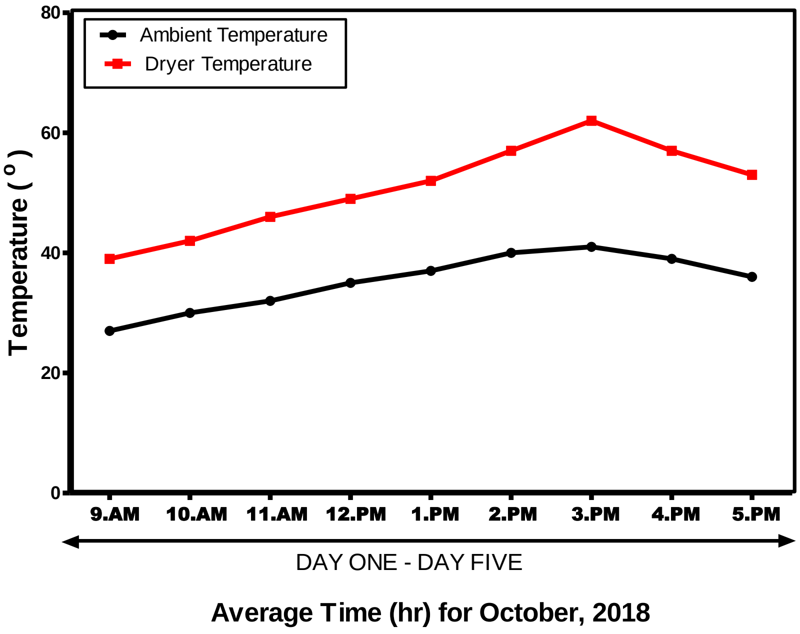

Figure 8: *Average Hourly Variation of Ambient and Dryer Temperature with Time for the Month of October, 2018*

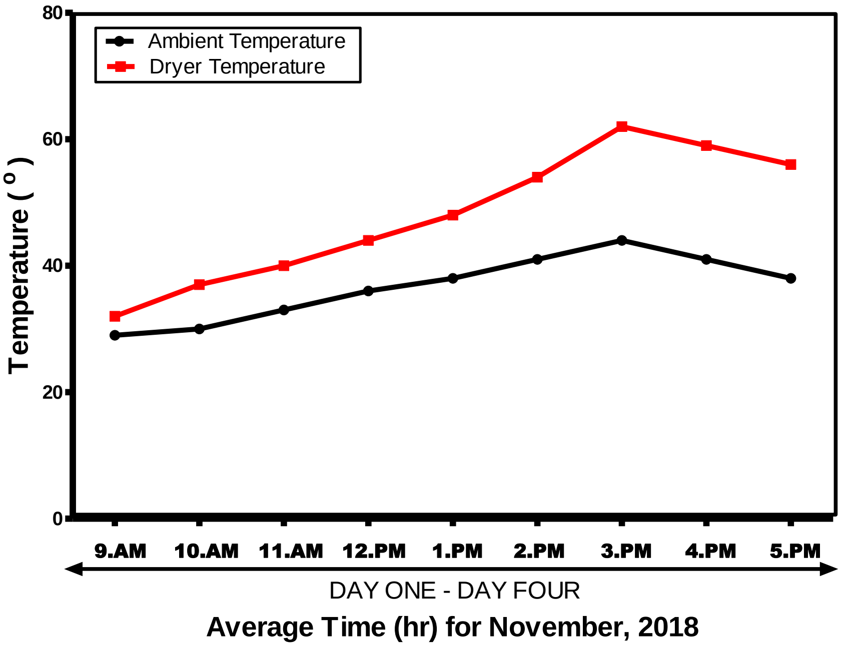

Figure 9: *Average Hourly Variation of Ambient and Dryer Temperature with Time for the Month of November, 2018*

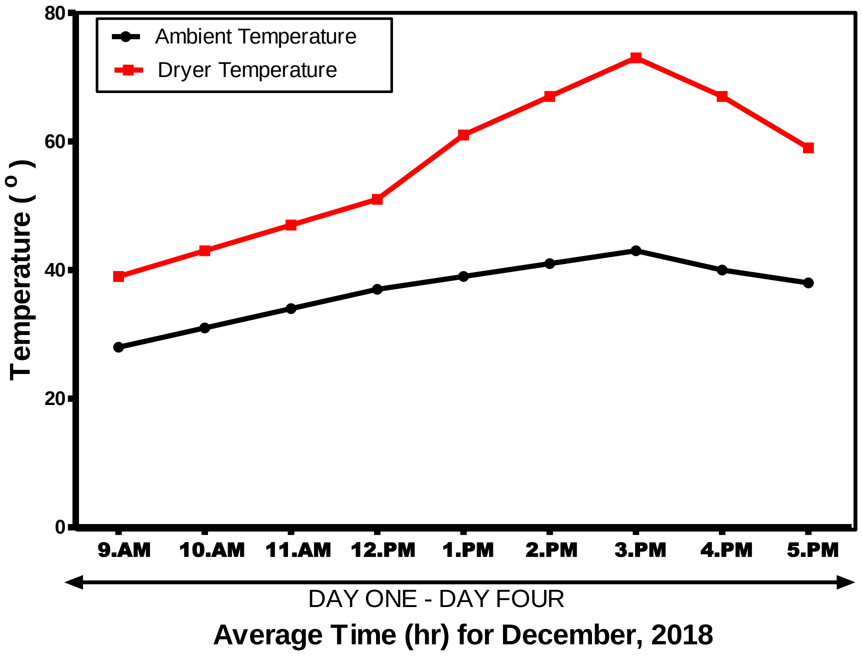

Figure 10: *Average Hourly Variation of Ambient and Dryer Temperature with Time for the Month of December, 2018*

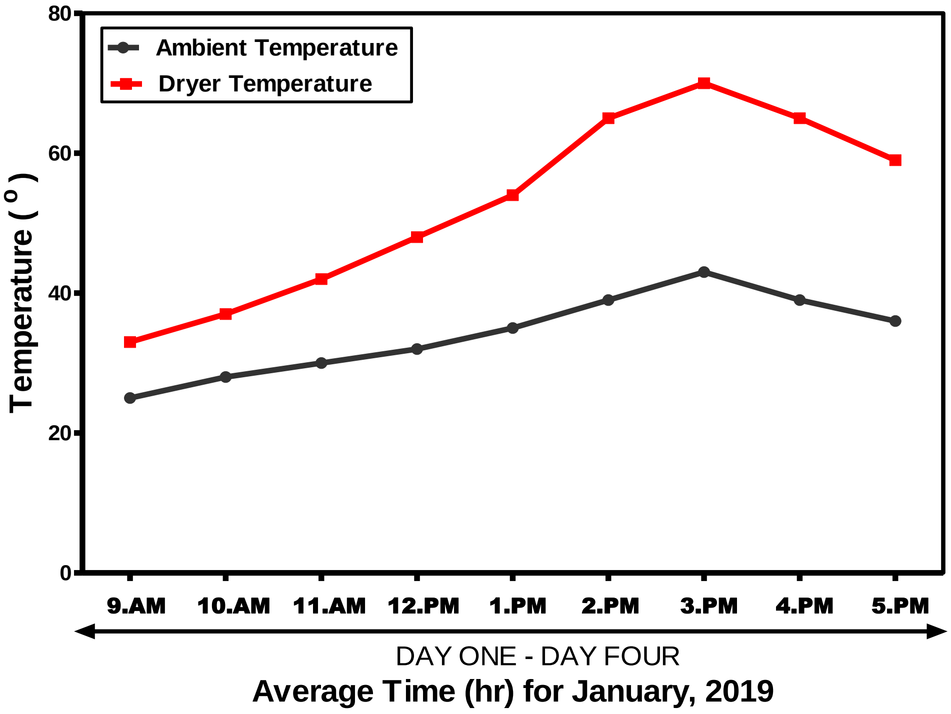

Figure 11: *Average Hourly Variation of Ambient and Dryer Temperature with Time for the Month of January, 2019*

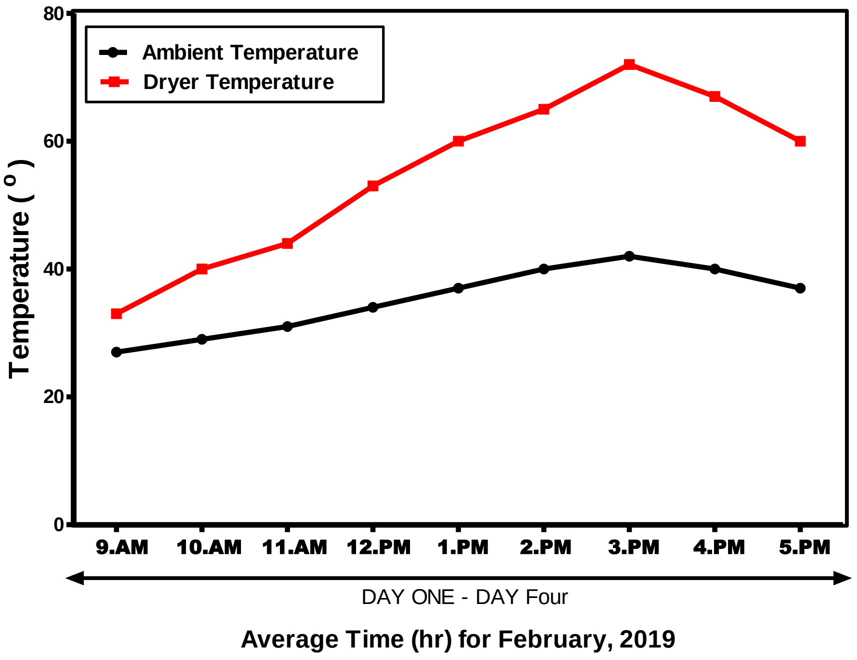

Figure 12: *Average Hourly Variation of Ambient and Dryer Temperature with Time for the Month of February, 2019*

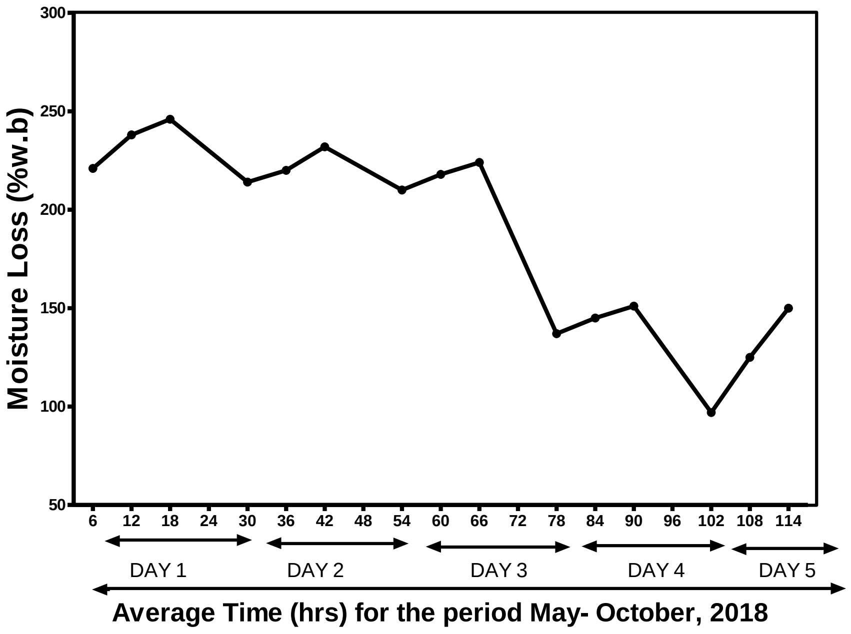

Figure 13: *Average Daily Moisture Loss from the Fish During the Drying Period, (May,2018- October, 2018)*

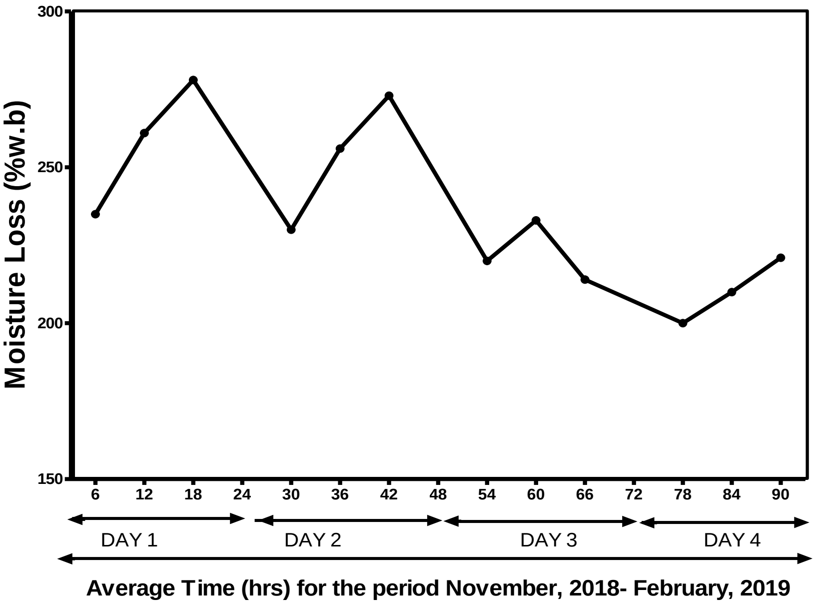

Figure 14: *Average Daily Moisture Loss from the Fish During the Drying Period, (November, 2018 -February, 2019)*

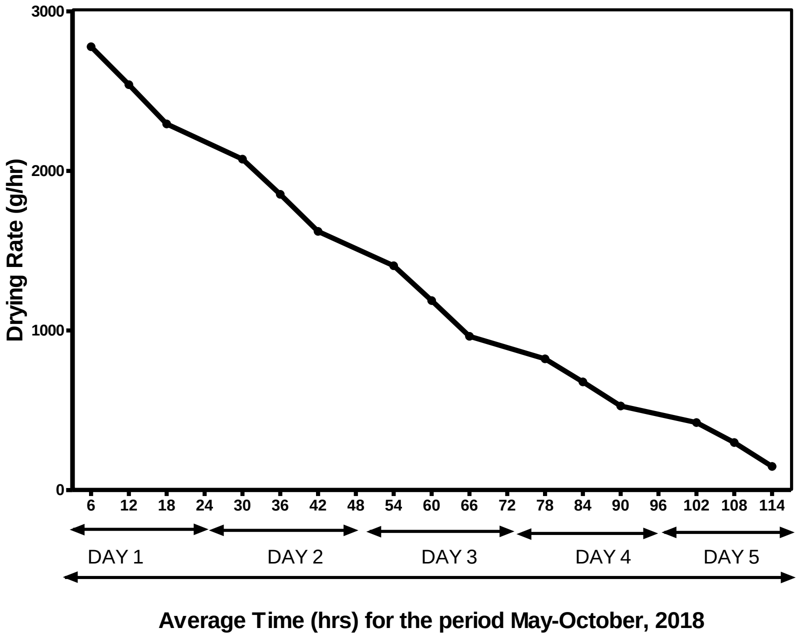

Figure 15: Average daily drying curve with time during the period, May-October, 2018.

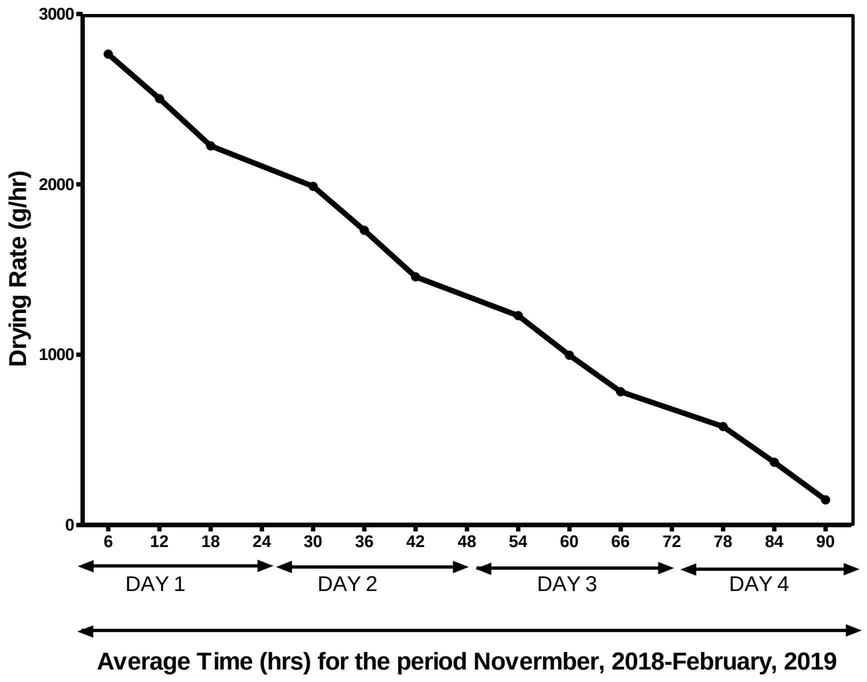

Figure 16: *Average daily drying curve with time during the period, November, 2018-February 2019.*

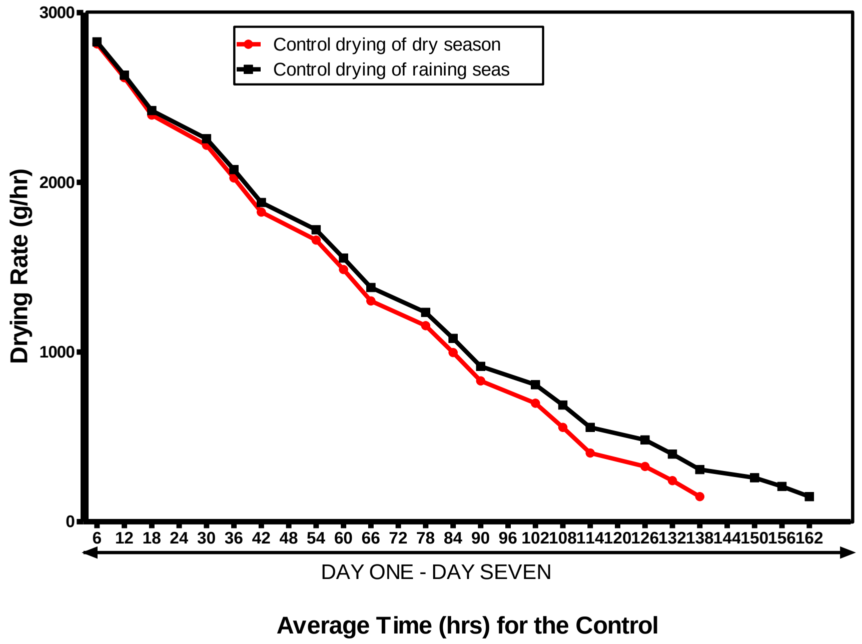

Figure 17: *Drying curve with time for the control*

3.2 Discussion

Figures 3-8, represent~~s~~ the dryer and ambient temperatures achieved during the raining season for drying 120 fishes. The drying was carried out in batches of 20 fishes with an average weight of about (3.0±1) kilograms per batch per drying period of 5 days. The maximum dryer temperature achieved during this period was (58.9±2) ^{o}C with ambient temperature of (40±2) ^{o}C. Similarly, Figures 9-12 depicts the dryer and ambient temperatures obtained during the dry season for drying 120 fishes in batches of 20 fishes with average weight of (3.0±1) kilograms per batch. The maximum dryer and ambient temperatures obtained during the dry season were (73.5±1.3) ^{o}C and (45±1.8) ^{o}C respectively, for a maximum drying period of 4 days for each batch. It is seen in both cases (raining and dry seasons) that the dryer temperatures are much higher than ambient temperatures which is a clear indication that the designed solar collector is effective, trapping much heat as is necessary. Furthermore, it could be noted that higher temperatures were recorded during the dry seasons (both ambient and dryer temperatures), which could be attributed to the overhead position of the sun within the experimental region during this period and to the low humidity of the atmosphere. It is also observed that the drying period changed from 5 days (Figures 3-8) during the raining season to 4 days (Figures 9-12) with the dry season. This may be assigned to the less humid atmosphere and high moisture evaporation rate during dry season. This is similar to the report of Raji *et al*. (2013).

Figures 13 and 14, illustrates the average daily moisture loss from the fish during the drying periods considered (raining and dry seasons). It is seen that the average daily moisture removed during dry season was higher compared to that removed during raining season (25 % against 23 %), thus, indicating a faster rate of drying during this period as depicted in Figures 13 and 14. The fishes with initial moisture content of 87 % (measured using moisture meter) was reduced to 13 % after drying. This moisture content is in range with the United Nations Economic Commission for Europe (UNECE) Standard DDP-19 concerning the marketing and commercial quality control of dried fish, 2007 edition given as 10 % - 19 %.

From the temperature curves (Figures 3-12), it could be deduced that the highest temperatures were recorded between 12 noon to 3 P.M. At these times, the angle of incidence of the sun rays striking the earth surface within the tropics is almost overhead (at 90^{o}, measured from the horizon). Also, from the temperature variation curves in Figures 3 – 12, it is seen that the average temperatures obtained when using the solar dryer were significantly higher than the maximum ambient temperatures. This implies that there would be higher drying rates with the use of the solar dryer as compared to open sun drying. This is in line with the reports of Dare *et al.* (2016). In addition, the incorporation of the heat storage unit which utilizes energy from the same energy source, facilitates higher drying rate with the dryer, which is a novelty in this work.

Figures 15 and 16 illustrates the average daily drying curves. It is clearly observed in both cases that, as the drying process approaches the maximum drying days, the rate of moisture loss becomes slower thus, indicating that the fish moisture content is approaching the desired level. This observation is in agreement with earlier reports found in several literatures (Tomar *et al*., 2017; El Hage *et al*., 2018; Ogunleye and Awogemi, 2008; Raju *et al*., 2013) and also in tandem with the natural law of drying.

Open sun drying was considered as control experiment during the period as shown in Figure 17. During the raining season, (May to October, 2018), it took seven days for the fishes to dry in contrast to the five days using the solar dryer in the raining season, whereas, open sun drying took six days for the fishes to be well dried as compared to the four days with the solar dryer during dry season. These results indicate the advantage of using the solar fish dryer over the traditional open sun drying.

Finally, the dryer efficiency was estimated to be 76 % which is much higher than that achieved by Debashree *et al* (2017) and Duraisamy *et al* (2019). This value is in accordance with the range 35-80 % recommended by Longwe and Kapute, (2016) for forced convection solar dryers with high drying efficiency.

Conclusions

Herein, a forced convection solar fish dryer is designed, constructed and characterized to yield a better mains of drying fish; this method is hygienic and provides good quality dry fish. The characterization of the device spanned across two seasons; raining and dry seasons (months of May to October, 2018 were considered for raining season, while

November, 2018 to February, 2019 were considered for dry season) and results clearly indicated the influence of seasonal variation on the performance of the device. Average hourly variation of the dryer and ambient temperatures measured on the selected days in the different months of measurement during the two seasons, clearly indicated that the device temperatures were significantly enhanced. This was due to the high ability of the designed solar collector to trap large amount of long waves. Average daily moisture loss from the drying fish was notably high, especially during dry season which was due to the high dryer temperatures and decrease in atmospheric humidity. The designed dryer incorporated a heat storage unit which complimented the drying rate of the product during off sunshine hours. The efficiency of the solar dryer was estimated to be 76 %.

In conclusion, the designed solar dryer showed very high drying rates, with highly hygienic fish products. The fishes with initial moisture content of 89 % was dried to 16 %. This moisture content is in range with the United Nations Economic Commission for Europe (UNECE) Standard DDP-19 concerning the marketing and commercial quality control of dried fish.

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