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Empirical Modelling of Drying Characteristics of Elongate Glassy Perchlet (*Chanda nama*) (Hamilton, 1822) in Solar Hybrid Dryer

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Abstract

This study was conducted to evaluate the performance of solar dryer with electrical back-up to produce quality dried Glassy perchlet (*Chanda nama*). Insolation of the experimental region varied from 25 to 1025 W m^{-2}. Atmospheric temperature showed a variation between 29.5 to 34.5°C. Relative humidity outside the dryer ranged from 56 to 76.5% showing a direct relationship with temperature. Drying experiment was carried out for 10 h at drying air temperature of 60°C. Relative humidity and velocity of drying air inside the drying chamber was 68% and 0.8 m s^{-1} respectively. Drying conditions were maintained inside the dryer by electrical back-up. Weight loss of pre-processed *C. nama* during drying was measured at 1 h duration. Drying characteristic data were fitted into empirical drying models. Two-term model was found to be the best fit for the drying characteristic data under specified conditions (R^2=0.998, RMSE=0.016 and χ^2=0.00027).

Keywords: Solar electrical hybrid dryer, drying performance, drying models

Introduction

Fish is a highly perishable food, the quality of which starts deteriorating without proper storage (Fellows & Hamptum, 1992). Fresh fish contains up to 80% of water by mass that contributes to microbial spoilage and reduction in shelf life when left unprocessed (Bala & Mondol, 2001). Various preservation methods are aimed at reducing the water activity of fishes, thereby, inhibiting undesirable microbial growth and enzyme activity (Duan et al., 2004). Among processing methods, drying is very effective in terms of extending the shelf life of fish by reducing the microbiological activity. The most commonly practiced method of drying is open air sun drying, as it does not require any investment.

However, open air sun drying has several disadvantages like larger area requirements, exposure of the products to dust, infestation by predators, uncontrolled drying conditions and higher drying times, resulting in dried products with inferior quality (Suzuki et al., 1988). An alternative to traditional open air sun drying is solar drying by which solar energy is harnessed in a more effective way. Due to seasonal and daily fluctuations in availability of sunlight there is a need for an alternative source of energy to achieve complete drying. Thus, hybrid solar dryers are characterized by an additional source of heating other than solar collectors that renders continuous drying (Boughali et al., 2009). An alternative electrical back up is automatically actuated when the optimum temperature required for drying is not attained within the drying chamber.

The drying kinetics describes the moisture variation profile of the material with time. Models that represent the drying curves have been proposed based on the variables that may interfere on product drying (Pacheco et al., 2011). Newton, Page, Henderson and Pabis, Logarithmic and Two-term models are commonly used empirical models to explain thin layer drying characteristics. *C. nama* (Glassy perchlet) is consumed in local markets due to high nutritive content, and low price. The objective of the work was to examine the thin layer drying behaviour of the *C. nama* fish in solar assisted electrical dryer and to model the drying characteristics of similar fishes in the dryer.

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Materials and Methods

The solar hybrid dryer (20 kg) is a solar dryer with electrical back-up designed and fabricated at engineering division of ICAR-Central Institute of Fisheries Technology, Cochin, India. Dryer dimension is 1.85 m × 0.85 m × 1.3 m. It has solar flat plate collectors with an area of 8 m^2 for harnessing solar energy to heat the air at top. This hot air is brought into the drying chamber by means of a blower for drying the product. It consists of 10 trays stacked one over the other with a total area of 5.4 m^2. The dimensions of the trays were 1.60 m× 0.75 m × 0.03 m. All the food contact surfaces of the dryer was made up of stainless steel (SS 304 Food grade). Drying was carried out under controlled temperature and humidity conditions with the help of Programmable Logic Controller (PLC) system. Dryer also had two electrical coils of 1000 W each which acted as supplementary heating sources, which are kept at the centre of drying chamber. Technical details of the solar hybrid dryer is shown in Table 1. The schematic representation and technical details of the solar dryer with electrical back-up is shown in Fig. 1 and Table 1 respectively.

Table 1. Solar hybrid dryer – Technical details

Heat absorbing area	8 m^2
Total tray area	5.4 m^2
Alternate energy back up	Electrical
Tray material	SS 304 Food Grade
Total drying time	6-8 h
Loading capacity	20 kg

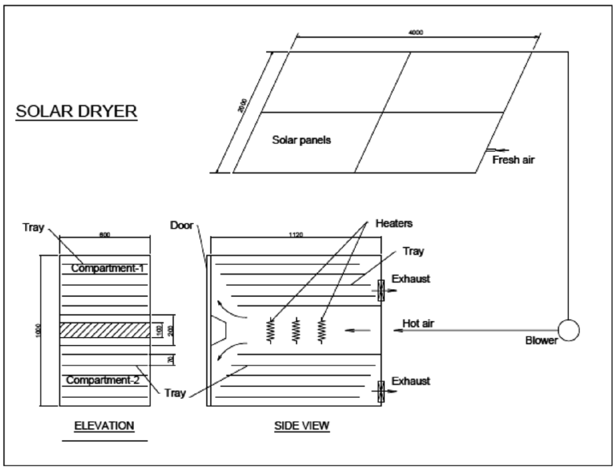

Fig. 1. Solar dryer with electrical back-up

Performance of the dryer was analysed by conducting drying studies on *C. nama*. The fishes were thoroughly washed in potable water and cleaned fishes were dry salted in the ratio of 1:8 (1 kg salt for 8 kg fish) and kept overnight for proper salt penetration. The excess salt was drained off next day before drying. The parameters observed were drying air temperature, drying air velocity, relative humidity and weight loss of fish with respect to time. Air velocity was measured using anemometer (Horio Keiki, Japan) and relative humidity using renewable energy monitoring system (Emcon, Kerala). Experiments were conducted in triplicate and the average values were taken for calculations. Based on the data obtained on hourly basis, drying characteristic curves were plotted.

Moisture contents of fresh and dried fish were determined according to the method of AOAC, 1990. Five grams of samples in triplicate were dried for eight hours in a hot air oven at 105°C in preweighed crucibles. Then crucibles were transferred immediately to desiccators, cooled and weighed. The loss in weight represented the moisture content of the samples (AOAC, 1990)

$$MC\ \%(db) = \frac{w}{Wd} \ X\ 100 \qquad \text{... (1)}$$

$$MC\ \%(wb) = \frac{w}{W} \ X\ 100 \qquad \text{... (2)}$$

MC % (db) - moisture content, per cent dry basis

w - Weight of water evaporated, g

W_d - weight of dry matter content present in fish, g

MC % (wb) - moisture content, per cent wet basis

W - total weight of the fish, g

$$MR = \frac{M-Me}{Mo-Me} \qquad \text{... (3)}$$

MR - moisture ratio

M - moisture content at any time t, % (db)

M_e - equilibrium moisture content, % (db)

M_o - initial moisture content, % (db)

Results and Discussion

Solar dryer with electrical back up was tested for performance under no load conditions. Difference of

Table 2. Thin layer drying curve models for variation of moisture ratio (MR) with time (t)

Model No.	Model name	Model	References
1	Newton	$MR = e^{-kt}$	Ayensu (1997)
2	Page	$MR = e^{-kt^n}$	Page (1949)
3	Henderson and Pabis	$MR = ae^{-kt}$	Henderson & Pabis (1969)
4	Logarithmic	$MR = ae^{-kt} + c$	Akpinar et al. (2003)
5	Two-term	$MR = ae^{-k1t} + be^{-k2t}$	Henderson (1974)

Where,
MR: moisture ratio; a, b, c : dimensionless empirical constants; k, k1, k2: drying constants based on physical properties of drying process

temperature vis-à-vis tray positions in the drying chamber was observed. A uniform temperature of 60±0.5°C was attained inside the drying chamber within 35 min of operation. The relative humidity and velocity of drying air was observed to be 68% and 0.8 m s^{-1} respectively under stabilized drying conditions.

Initial moisture content of salted *C. nama* was found to be 68.50% (wb). Changes in moisture content with time during drying of *C. nama* in solar dryer with electrical back up is presented in Fig. 2. The moisture content declined at a rapid rate during first three hours of drying, further it showed a gradual decline to the final moisture content of 11.05% (wb). This can be accounted due to higher moisture content and lower salt content of fish, thus causing rapid moisture removal at initial stage of drying. Similar results were reported by Chavan et al. (2011) for solar tunnel drying of mackerel.

It is evident from Fig. 3 that initially under stabilized drying conditions, the moisture migration from the free water of the fish to the drying air occurred very rapidly. As time progressed, water vapour diffusion gradient between the drying air and the drying material decreased, resulting in reduced drying rates. Similar results were reported Hossain et al. (2013) for microwave drying of sardine.

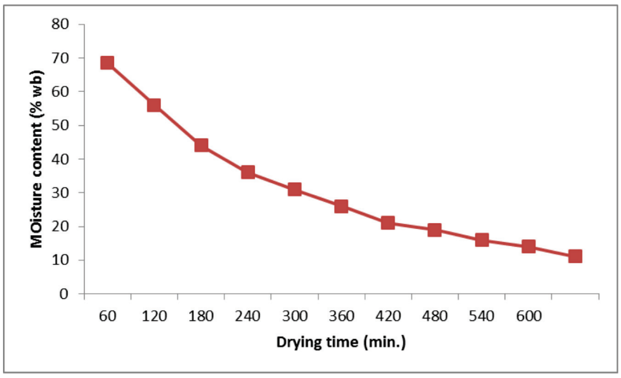

Fig. 2. Drying curve of *Chanda nama*

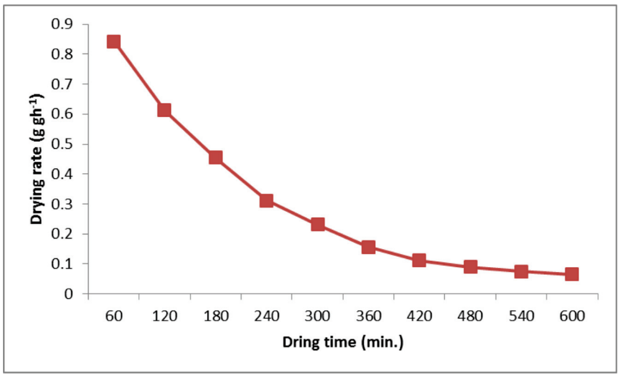

Fig. 3. Drying rate curve of *Chanda nama*

Drying characteristic study revealed that drying of *C. nama* falls with time (Poernomo, 1986). A final moisture content of 11.05% was obtained after 10 h of drying. During drying of salted fishes, movement of water from interior of fish to the surface occurs by osmosis. On the surface, evaporation of water results in formation of a crust which is more evident when initial salt concentration is higher. This layer in turn reduces the rate of water loss by making the surface less permeable. There is a significant decrease in moisture content every one hour during drying. This further confirms that drying occurs under falling rate period.

From the drying characteristics data, moisture ratio values were calculated. The initial moisture ratio was 1.00 before drying and a moisture ratio value of 0.0571 was observed at the time of equilibrium moisture content for the given drying conditions. Moisture ratio showed a gradual and continuous decrease in its value.

Modelling of drying data was done using MATLAB™ software. Results of modelling studies (regression analysis) using drying models namely, Newton, Page, Henderson and Pabis, Logarithmic and Two term for *C. nama* at a temperature of 60±0.5°C and drying air velocity of 0.8 m s^{-1} are presented in Table 3.

The goodness of fit of each model was evaluated based on values of coefficient of determination (R^2), root mean square error (RMSE) and chi square x^2 value. The best fit model was selected based on the highest R^2 value and the lowest RMSE value followed by the lowest x^2 value. Even though, the models showed close similarity among R^2 values, based on comparative advantages, two term model was selected as the best to explain the drying characteristics.

Drying behaviour of products with very high moisture content are better explained by two term model as it assumes uniform product temperature and diffusivity throughout the drying process. Also, it describes the moisture transfer of the drying process, with constants representing the physical properties of drying process. From Table 2 it can be seen that two-term model has maximum R^2 value (0.9973), minimum RMSE value (0.016) and the lowest x^2 value (0.00026). The best fit two-term model is as follows.

$$MR = 0.6221e^{-03042t} + 0.4047e^{-0.01329t} \quad \dots (9)$$

The first term of the model represents the last part of the drying process and the second term describes the beginning of the drying process.

No-load testing of the solar dryer with electrical back-up revealed that the maximum drying temperature of 60±0.5°C could be obtained within 35 min. of initial operation. The electrical back-up system helped to ensure uniform drying temperature irrespective of changes in incidence of solar radiation. Drying characteristics study of *C. nama* indicated that entire drying process occurred under falling rate drying period. The moisture content declined at a rapid rate during first three hours of drying and subsequently showed gradual decrease. The dryer takes 10 h for complete drying of *C. nama* from a moisture content of 68.50 to 11.05% (wb). Out of the different models tested, two-term model was found to be most appropriate for describing the drying kinetics of *C. nama* under solar electrical hybrid dryer (Hii et al., 2009). Thus it can be further concluded that two term model can be used to predict information regarding ideal drying time, temperature, air velocity and relative humidity of similar products.

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Table 3. Results of modelling studies on solar dryer with electrical back-up

Model name	Parameters	RMSE	R^2	Chi-square
Newton	k = 0.00539	0.0337	0.9868	0.001135
Page	k = 0.01349 n = 0.8304	0.01792	0.9963	0.000321
Henderson and Pabis	a = 0.9669 k = 0.005198	0.03318	0.9872	0.001101
Logarithmic	a = 0.9254 k = 0.006557 c = 0.07009	0.01862	0.996	0.000346568
Two-term	k1 = 0.3042 k2 = 0.01329 a = 0.6221 b = 0.4047	0.01616	0.997	0.000261301

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