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Development of an Energy Efficient Portable Convective Fish-Dryer

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Abstract

A portable multipurpose electrical dryer of 10 kg capacity was designed and developed for drying of fishe and other agricultural products. The dryer consists of a drying chamber with total drying area of 2.8 m^2, fan, heating element and exhaust vent. The dryer was fabricated using locally sourced materials. Under 'no-load' conditions, the drying chamber attained highest temperature of 50±5°C within 60 min of operation. Relative humidity and velocity of drying air inside the drying chamber were observed to be 65% and 0.8 m/s respectively. The study of energy consumption pattern indicated a drying efficiency of 21.42%. A performance evaluation study of the dryer was done for sardine and the maximum drying time required for complete drying was eight hours. Results showed that the entire drying processes occurred under falling rate period. A logarithmic model fitted to the drying data very well for the specified range of drying conditions.

Keywords: Convective dryer, fish drying, sardine drying, drying efficiency

Introduction

Fish is a highly perishable product that serves as an elementary source of animal protein (Ayyappan & Diwan, 2003). Fish production in India is around 10.06 million metric tonnes which constitutes to 6.5% of world fish production (DADF, 2016). Spoilage of fish starts at an early stage soon after it dies and so processing measures needs to be executed immediately (Peter & Ann, 1999). Drying is an important method of processing that preserves fish by arresting microbial growth, inactivating enzymes and other chemical reactions by removal of moisture from the fish (Duan et al., 2004). It is a combined heat and mass transfer process through which moisture content of products are brought down to predetermined levels for safe and longer storage period (Hall et al., 1988). Open air sun drying is an age old practice adopted by fisherfolk to preserve fish and fishery products, to combat seasonal glut and fluctuating market prices (Chakrabarti & Varma, 1999). Although this practice is inexpensive, quality of dried products are inferior due to unhygienic handling and improper drying conditions (Balachandran, 2001). The method relies solely on availability of solar radiation; moreover losses caused by predators are also high. This unhygienic method of drying make the fish vulnerable to infestation with insect larva and contamination, results in 10-40% post-harvest wet weight losses (Wall et al., 2001). In order to minimize these losses it is necessary to optimize the drying conditions, machine design and product quality. Even though innumerable dryers are available commercially for drying fish, cost is one of the major constraints that prevent the fishermen from adopting it. Thus a low cost, multi-purpose, portable type electrical dryer is designed and developed for micro and small scale fish processing units, households, laboratories for in-house drying of fishes and other agro products. Modelling the drying characteristics and predicting the drying time of perishable products are important. There is limited information available on modelling of drying characteristic data for fish in electrical dryers. This paper presents the design details, fabrication, performance evaluation and empirical modelling of drying characteristics during drying of fish.

Materials and Methods

Materials which were used for dryer fabrication such as galvanized metal sheets, angle iron, stainless steel, etc. were sourced locally. Sardine (*Sardinella*

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gibbosa) were collected from Kalamukku fish landing centre, Kochi. The mean weight and length of fish were 64±0.71 g and 8.74 ±.44 cm, respectively. Fishes were kept in polystyrene boxes with crushed ice and carried to laboratory for further processing. The dryer is designed for a capacity of 10 kg of fish per batch. The dryer is comprised of a base frame, fan housing, two heating coils of 1.5 kW each and drying chamber with ten stainless steel mesh trays stacked one over the other with an exhaust system. The base frame for dryer is fabricated using an angle iron bar with dimensions 865 mm × 498 mm × 770 mm. The frame is welded into shape to provide support for other components of the dryer. A fan is essential for forcing the ambient air into the drying chamber across the heating elements and also to expel the moist air from the chamber. The fan comprised of three blades with each of dimensions 520 mm × 100 mm × 2 mm. The air heating arrangement of dryer consists of two loops of heating coils with 1.5 kW capacities, aligned parallel to each other for heating the incoming air. Thus the total capacity of the heating elements of dryer is 3 kW.

The drying chamber is made up of marine plywood of thickness 19 mm which can withstand humid and wet conditions. The chamber is rectangular in shape with dimensions of 880 mm × 590 mm × 1650 mm. The inner side of the drying chamber is coated with aluminium foil sheet of 0.5 mm thickness for insulation purpose. As the air inlet to the chamber is located at the bottom of the chamber the moisture laden air escapes through the exhaust at the top end. The chamber consists of ten trays with aluminium frames and stainless steel mesh. The trays are stacked equidistantly with a spacing of 50 mm. Dimensions of each tray is 560 mm × 500 mm × 25 mm amounting a total tray area of 2.8 m^2. The chamber has provisions for a hinged door which permits easy access for loading and unloading of fishes and other agro products.

Energy required to dry the food is calculated by (Brenidorfer et al., 1995).

$$Q = MC_p\Delta T + m\lambda \qquad \text{… (1)}$$

Q: Total heat required for drying, kJ

M: mass of material to be dried, 10 kg

C_p: specific heat (above freezing point for fishes), 3.68 kJ/kg°C

ΔT: Temperature change between ambient and drying conditions, 20°C

m: mass of water to be evaporated (considering fish with 75% initial moisture content)

λ: latent heat of vaporisation of water, 2260 kJ kg^{-1}

Mass of hot air required to supply the required heat energy (Q) can be obtained by equating the heat content of hot air with the total heat to be removed (Brenidorfer et al., 1995)

$$Q = M_{air}Cp_{air}''T_{air} \qquad \text{… (2)}$$

Where = M_{air}, Cp_{air} and ΔT_{air} are mass, specific heat and temperature difference between drying and exhaust air respectively (Brenidorfer et al., 1995).

$$\text{Cp of hot air} = 0.24+0.45\ H \qquad \text{…(3)}$$

Where H is the humidity obtained from Psychometric chart corresponding to the inlet ambient conditions (Temperature =30°C, Relative humidity = 70%)

The performance of the developed dryer was analysed by conducting drying studies on medium sized sardine (*Sardinella gibbosa*). About 10 kg of sardine was thoroughly washed in potable water after evisceration. Cleaned fish is dry salted in the ratio of 1:6 (1 kg salt for 6 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 sardine fish with respect to time. Air velocity was measured using anemometer (Horio Keiki, Japan) and the relative humidity by hygrometer (Emcon, Kerala). Moisture content of the samples was calculated by hot air oven method. Experiments were conducted in triplicate and the average values were taken for calculation and based on the data obtained on hourly basis, drying characteristics curves were plotted.

The moisture content of drying sample at time 't' can be transformed to be moisture ratio (MR):

$$MR = \frac{Mt - Me}{Mo - Me} \qquad \text{… (4)}$$

Where M_t, M_o and M_e are moisture content at any time of drying (kg water/kg dry matter), initial moisture content (kg water/kg dry matter) and equilibrium moisture content (kg water/kg dry matter), respectively. The moisture ratio was simplified to M_t/M_o instead of equation (1) by some investigators (Doymaz, 2005) due to continuous fluctuation of relative humidity of the drying air during convective drying process.

The drying rate of the samples was calculated using the following equation:

$$DR = \frac{Mt - Mt{+}dt}{dt} \quad \dots (5)$$

Where DR is the drying rate (kg water /kg dry matter.min); *Mt+dt* is the moisture content at t+dt (kg water/kg dry matter) and t is drying time (min).

The drying data obtained were fitted to four thin layer drying models detailed in Table 1 using the non-linear least squares regression analysis. Statistical analyses of the experimental data were performed using the software MATLAB (version 2012). The coefficient of determination (R^2) is one of the criteria for selecting the best model to define the drying curves.

Drying efficiency of the dryer was estimated by considering the amount of water evaporated and the total heat supplied to the dryer and is given by (Chavan et al., 2008)

$$\textit{Drying efficiency \%} = \frac{\textit{Energy required to evaporate water}}{\textit{Energy supplied to the dryer}} \quad \dots (6)$$

Cost of construction of the dryer takes into account the material costs for various dryer components whereas the operational expenses were calculated based on the energy requirement for drying.

Results and Discussion

The mass flow rate of hot air and volume of drying chamber for dryer was calculated to be 0.023 kg s^{-1} and 0.496 m^3 respectively. Then, ten trays were selected with dimensions of 0.56 m × 0.50 m × 0.025 m, amounting to a total tray area of 2.8 m^2. The schematic representation of the portable, multipurpose dryer is shown in Fig. 1.

The designed and fabricated dryer was tested without any load condition. A uniform temperature of 50±0.5°C was attained inside the drying chamber within 60 min of operation. The relative humidity

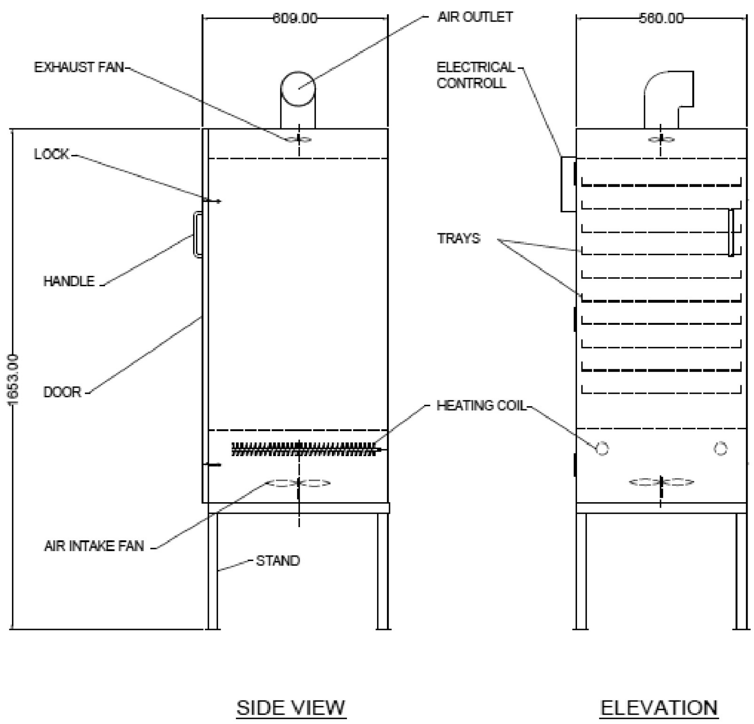

Fig. 1. CAD Sectional view of portable convective dryer

Table 1. Mathematical models for drying curves

Model name	Model	References
Newton	$MR = e^{-kt}$	Ayensu (1997)
Page	$MR = e^{-kt^{n}}$	Page (1949)
Henderson & Pabis	$MR = ae^{-kt}$	Henderson & Pabis (1969)
Logarithmic	$MR = ae^{-kt}$	Akpinar et al. (2003)

Where, k is the drying constant and a, c, n are equation constants

and velocity of drying air was measured to be 65% and 0.8 m/s respectively under stabilized drying conditions.

Initial moisture content of salted Sardine was found to be 65.43%. Drying characteristic study revealed that drying falls under falling rate drying period. The product was obtained after eight hours of drying with a final moisture content of 29.60%. Salted dried fish has an average value of moisture content higher than unsalted dried fish as a result of seepage of salt solution into the flesh of the fish which holds the residual fluid in the body through ionic interaction. This lowers the amount of free water contained in fish meat to be removed during drying process (Fetriyuna et al., 2017). Thus, dry salting resulted in both slower rate of moisture reduction and higher final moisture content during drying (Bellagha et al., 2002).

During drying of salted fishes, movement of water from interior of fish to the surface occurs by osmosis process. 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. Thus, the drying kinetics of salted sardine comes directly under falling rate period (Poernomo, 1986; Zuggaramundi & Lupin, 1980). There is a significant decrease in moisture content at every one hour of drying process. This further confirms that drying occurs under falling rate period.

It is evident from Fig. 2 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 decreases, resulting in reduced drying rates. Similar results were reported by Hossain et al., 2013 for microwave drying of sardine fishes.

The overall drying efficiency of convective electrical dryer was 21.42% for drying of Sardine. Gyanvali et al. (2014) reported an efficiency of in similar range of 20-30% for electrical dryer with capacity of 25 kg with 40 kWh of electric power. The convective dryer developed is capable of supplying uniform temperature of 50±0.5°C within the drying chamber for

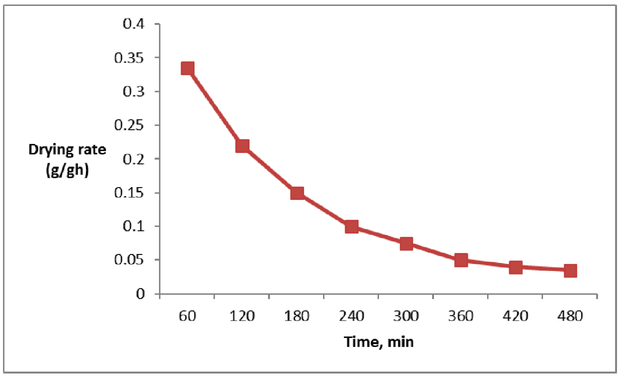

Fig. 2. Drying curve of sardine

Table 2. Drying efficiency of convective dryer

SI. No.	Parameters	Value
1	Total weight of fresh Sardine (kg)	10
2	Total weight of dried Sardine (kg)	4.2
3	Initial moisture content (%)	65.43
4	Final moisture content (%)	29.60
5	Water evaporated during drying (kg)	7.5
6	Total energy required to evaporate water (kJ)	18,511
7	Latent heat of evaporation of water (kJ/kg)	2370
8	Specific heat capacity of fresh Sardine (kJ/kg°C)	3.68
9	Duration of drying (h)	8
10	Energy supplied by heating element (kWh) or (kJ)	86,400
11	Total energy supplied to evaporate water (kJ)	86,400
12	Drying efficiency (%)	21.42

Table 3. Results of Statistical analysis on the modelling of moisture content and drying time for convective dried sardine fish

Model	Model constants	R^2	RMSE	χ2
Newton	a=0.002901	0.9976	0.01285	0.000165
Page	k=0.001893n=1.075	0.9990	0.007059	0.0000525
Henderson and Pabis	a=1.012k=0.002948	0.9978	0.01244	0.000155
Logarithmic	a=1.158k=0.00229c=-0.1601	0.9993	0.002482	0.00000626

hygienic drying of fish and it can be a substitute for local drying of fish under poor weather conditions.

From the drying characteristics data, moisture ratio values were calculated. The initial moisture ratio was 1.00 just before drying and a moisture ratio value of 0.2225 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.

The best fit model was selected based on the highest R^2 value and the lowest RMSE value followed by the lowest ë^2 value. From Table 3 it can be seen that logarithmic model has maximum R^2 value (0.9999), minimum RMSE value (0.002482) and the lowest ÷^{2} value (6.29E-06). The best fit Logarithmic model is as follows. Observed and predicted values of moisture ratio for the best fit logarithmic model is depicted in Fig. 3.

Assuming 200 effective drying days in a year, the operational cost for drying 1 kg of sardine was found to be INR 3.96 (assuming the tariff of 1 unit of electricity to be INR 8).

A portable electrical dryer suitable for drying of fishes and other agricultural products was designed and developed. No load testing of the dryer revealed that the maximum drying temperature of 50±0.5°C can be obtained after 60 min of operation. Drying characteristics study of Sardine in the developed dryer indicated that entire sardine drying process occurred under falling rate drying period. The developed dryer required eight hours for complete drying of sardine from moisture content of 65.43 to 29.60%.

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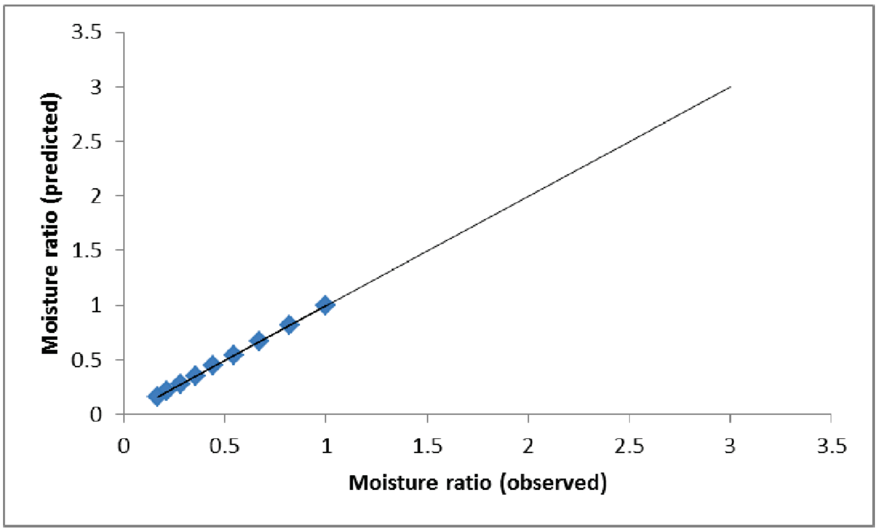

Fig. 3. Plot of observed and predicted values of moisture ratio for the best fit logarithmic model

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