Drying characteristics of shrimp (*Metapenaeus dobsoni)* in electrical dryer

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ABSTRACT: This study was conducted to investigate the drying characteristics of shrimp (*Metapenaeus dobsoni*) in an electrical dryer. Initial moisture content of shrimps was decreased from 73– 79% (wb) to 8 – 10% (wb) final moisture in 8 h. Drying was performed at drying air temperature and air velocity of 55±2°C and 0.8±0.04 m/s respectively, and drying parameters were recorded at 1 h interval. Drying rate was found to be reduced with drying time and drying followed the falling rate drying period. Drying characteristics curves were plotted and various drying models were fitted to describe drying kinetics of shrimps. Drying models suitability was analysed based on higher coefficient of determination value (R^2), lower root mean square error and reduced chi-square values (χ^2). Midilli model was selected as the best fit model with highest R^2 (0.999), lowest χ^2 (0.00002) and root mean square error (0.004) values. Results proved that hot air drying using electrical dryer has many advantages over sun drying like better control over drying temperature and moisture content, uniformity in drying and less drying time.

Key words: Drying, electrical dryer, mathematical modelling, Shrimp

Shrimp is a delicate and highly priced seafood commodity. Shrimp is the most commonly consumed and the highly traded seafood in the world. According to a report from the Food and Agriculture Organization (FAO), India is the largest shrimp exporter to the international market in 2016 with 438,500 metric tons. Shrimps contain 78 – 80% water and 20% protein. Shrimp lipids are having the essential fatty acids which are vital to human (Sriket *et al*., 2007). Shrimps are highly perishable because of its high moisture content. Hence preservation is an important issue for shrimp to extend its shelf life significantly.

Among the various preservation methods *viz.,* freezing, low temperature storage, drying and canning, the oldest and common preservation method for shrimps is drying and dehydration. Drying is an efficient and cheap method for food preservation. Drying is removal of water from substances to certain levels in order to protect it from microbial contamination and other spoilage. Shrimps in dried form are an important value-added product and it is commonly used in foods for protein source and the delicious flavour. Generally, dried shrimp products are prepared by natural sun drying and take around 3– 5 days. Even though natural sun drying is a cheap technique, it has limitations such as weather uncertainties, larger area requirement, spoilage by insects and birds and other forms of contamination (Jain and Pathare, 2007). Moreover severe deterioration in shrimp quality often occurs during the open sun drying process. Hence development of various alternative drying techniques to dry shrimps is essential in order to reduce the degradation and enhance the quality of dried shrimp. Also, seafood producers and exporters require dryers with higher efficiency, uniform drying and quality dried product.

Various mathematical models are available for the optimization of drying characteristics and to support dryers design (Kiranoudis *et al*., 1992). These available models can be used for the estimation of drying parameters and to represent the generalized drying curves (Midilli *et al*., 2002). Drying kinetics models are essential for the design and operation of dryers, drying process optimization and to obtain good quality products. The aim of the present study was to analyse the drying characteristics of shrimps in electrical dryer and to simplify the drying characteristics of shrimp using selected models.

MATERIALS AND METHODS

Drying experiments were conducted using fresh shrimps *(M. dobsoni)* of length, width and thickness as 50, 27 and 10 mm, respectively which were procured from the fish market at Cochin, Kerala, India and transported using ice box. Initially shrimps were cleaned using potable water and then immersed in salt solution (3% w/v) at 80°C for 5 min to avoid the microbial contamination. Hot air oven method (AOAC, 1990) was used to determine the initial moisture content of shrimp. Moisture content was determined by keeping five grams of shrimps in triplicate in a hot air oven at 105°C for 8 h. Weight loss was recorded for the moisture content analysis and calculated by the following formula:

$$\text{Moisture content (wet basis),\%} = \frac{\text{Weight of water removed (g)}}{\text{Weight of sample taken (g)}} \times 100 \quad \text{..........(1)}$$

$$\text{Moisture content (dry basis),\%} = \frac{\text{Weight of water removed (g)}}{\text{Weight of dry matter in sample (g)}} \times 100 \quad \text{.........(2)}$$

Drying experiments

Shrimp drying experiments were conducted in electrical dryer developed by Engineering Division, ICAR-Central Institute of Fisheries Technology, Cochin. The capacity of electrical dryer (Fig. 1) is 5 kg and consists of base frame, drying chamber, heating element, air inlet and exhaust. Base frame is fabricated using angle iron bar which provides support for other parts of dryer. The drying chamber is rectangular in shape with dimension of 1275×705×1000 mm and made up of marine plywood which is coated with aluminium foil internally to avoid heat loss. Drying chamber has two air inlet fans located at the bottom of chamber which forces air into the chamber. One heating element of 1000 W capacity is fixed at the air inlet to heat the incoming air. Inside the drying chamber 5 numbers of perforated trays (SS 304) (L×B×H - 950×700×25 mm) are placed with the spacing of 102 mm to place the samples for drying. At the top of drying chamber, air outlet provision is provided for the escape of moist air from chamber.

During drying experiment, 5 kg shrimps were spread on trays and placed inside the chamber. Temperature and relative humidity (RH) inside the chamber were observed in three different points inside the dryer at initial stage of drying and found to be 55±2°C and 75±5% respectively, using the renewable energy monitoring system (EMCON, Cochin, India) and RH was reduced to 50-55 % during drying. Anemometer (HORIO KEIKI, JAPAN) was used to measure the drying chamber air velocity and recorded as 0.8±0.04 m/s. Shrimp drying experiments were conducted in triplicate and the mean values are reported for the temperature of 55±2^{0}C with the aim of improving dryer design. Weight loss in shrimps was observed at one hour interval for 8 h to determine the moisture content values. Drying curves were plotted against time vs. moisture content, drying rate and moisture ratio. Dried shrimps were stored in polyethylene bags at room temperature.

The drying rate (DR) is expressed as the amount of evaporated moisture over time. The drying rate of samples was calculated using the following equation (Darvishi *et al.*, 2013):

$$DR = \frac{M_t - M_{t+\Delta t}}{\Delta t} \quad \text{............(3)}$$

Where DR is the drying rate (kg water/kg dry matter/h), M_{t+t} is moisture content at t = t+"t (kg of water/kg of dry matter), M_t is the moisture content at time t (kg of water/kg of dry matter) and "t is time difference in hour.

Mathematical modelling for shrimp drying

Drying kinetics of shrimps can be represented by various empirical or semi-empirical models. Drying data obtained during experiments were fitted in various thin layer drying models which are shown in Table 1.Mathematical modelling was carried out to describe the drying curve of shrimps.

MR represents the moisture ratio and is calculated as follows:

$$MR = \frac{M - M_e}{M_o - M_e} \quad \text{...........(4)}$$

Where M is the moisture content (% db) at time t, M_0 is the initial moisture content (% db) and M_e is the equilibrium moisture content (% db). Since the equilibrium moisture content (M_e) is very less compared to M and M_0 values it can be neglected and the moisture ratio can also be expressed using equation 5:

$$MR = \frac{M}{M_o} \quad \text{...........(5)}$$

The drying data experimentally obtained during shrimp drying are fitted in the models listed in Table 1. MATLAB (R2017b, The MathWorks, Inc, USA) software was used for the non-linear regression analysis of shrimp drying data. Coefficient of determination (R^2), reduced chi-square (χ^2) and root mean square error (RMSE) are the important parameters to find out the best equation for prediction of drying data and fitness of the models to data. Goodness of fit can be selected based on the higher R^2 and lower chi-square and RMSE values (Goyal *et al.*, 2006). The parameters can be calculated as follows (Yaldýz *et al.*, 2001; Togrul and Pehlivan, 2004; Doymaz and Ýsmail, 2011):

$$x^2 = \frac{\sum_{i=1}^{n} (MR_{(exp.1)} - MR_{(pred.1)})^2}{N - z} \quad \text{.......(6)}$$

$$RMSE = \left[\frac{1}{N}\sum_{i=1}^{n}(MR_{(exp.1)} - MR_{(pred.1)})^2\right]^{1/2} \quad \text{......(7)}$$

Where $MR_{exp,i}$ and $MR_{pred,i}$ are experimental and predicted moisture ratios at i^{th} observation, respectively; N is total number of observations; z is number of constants.

Table 1: Mathematical models used for modelling of drying curves of shrimps

Model Name	Model equation
Newton	$MR=\exp(-kt)$
Page	$MR=\exp(-kt^n)$
Henderson and Pabis	$MR=a\exp(-kt)$
Logarithmic	$MR=a\exp(-kt)+c$
Two term	$MR=a\exp(-k_0t)+b\exp(-k_1t)$
Two term exponential	$MR=a\exp(-kt)+(1-a)\exp(-kat)$
Wang and Singh	$MR=1+at+bt^2$
Diffusion approach	$MR=a\exp(-kt)+(1-a)\exp?(-kbt)?$
Verma *et al.* (1985)	$MR=a\exp(-kt)+(1-a)\exp(-gt)$
Modified Henderson and Pabis	$MR=a\exp(-kt)+b\exp(-gt)+c\exp(-ht)$
Midilli model	$MR=a\exp(-kt^n)+bt$

In the models, a,b,c,g, h,n are constants; k, k---0 and k1 are the drying rate constants and t is the drying time (h).

RESULTS AND DISCUSSION

Drying characteristics of shrimps

Fig. 2 shows the changes in moisture content of shrimps with respect to time during drying. Moisture content of shrimps was decreased from 79.03±2.37to 73.45±1.26 % wb after immersion in salt solution and further reduced to 8.32±1.15(% wb) at the end of drying time of8 h. Moisture content of shrimp was gradually decreased as drying proceeded due to the evaporation of moisture from shrimp. Fig. 3 shows the drying rate with time and it is observed that drying rate was found to be high at first hour of drying and become reduced while drying proceeds. The drying rate was observed to be 0.67 kg water/kg dry matter/h during the first one hour of drying. This might be due to the fast removal of free moisture which is available in shrimp surface. Further drying rate decreased with time and the lowest drying rate value (0.29 kg water/kg dry matter/h) was observed after 8 h of drying. This reduction in drying rate may be due to moisture diffusion process from internal shrimp tissue to surface. Drying rate curve showed that drying followed falling rate drying and there

Table 2: Statistical parameters of various drying kinetics models

Model	Coefficients and constants	R^2	RMSE	χ^2
Newton	k= 0.4806	0.992	0.028	0.001
Page	k = 0.5668 n = 0.8343	0.998	0.010	1×10^{-4}
Henderson and Pabis	a = 0.9718 k = 0.4669	0.993	0.027	0.001
Logarithmic	a = 0.9513 c = 0.03106 k = 0.5175	0.992	0.025	7.8×10^{-4}
Two term	a = 0.8281 b = 0.1718 k_0 = 0.3987 k_1 = 23.27	0.999	0.007	5×10^{-5}
Two term exponential	a = 0.1902 k = 2.086	0.999	0.008	8×10^{-5}
Wang and Singh	a = -0.3196 b = 0.02584	0.940	0.083	0.008
Diffusion approach	a = 0.8285 b = 36.02 k = 0.3991	0.999	0.006	4×10^{-5}
Verma *et al.* (1985)	a = 0.8276 g = 25.31 k = 0.3986	0.999	0.006	4×10^{-5}
Modified Henderson and Pabis	a = 0.4616 b = -13.84 c = 14.37 g = 1.113 h = 1.103 k = 0.2849	0.997	0.028	0.0011
Midilli model	a = 0.9997 b = -0.0050 k = 0.5757 n = 0.756	0.999	0.004	2×10^{-5}

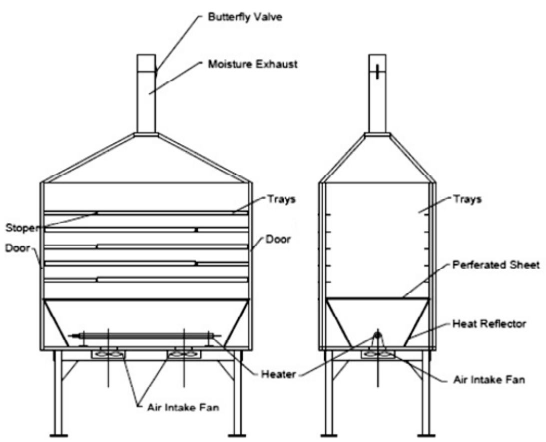

Fig. 1: Illustration of electrical dryer

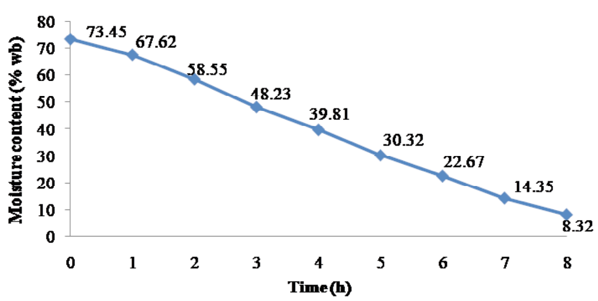

Fig. 2: Moisture content (%wb) of shrimps versus drying time in electrical dryer

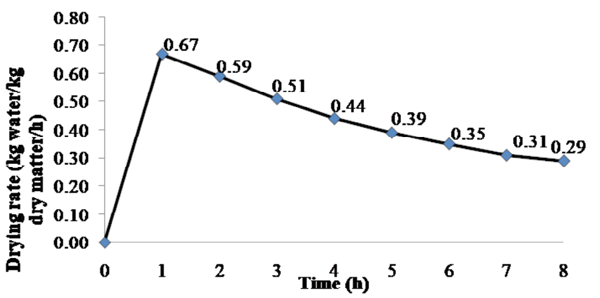

Fig. 3: Drying rate curve of shrimps dried in electrical dryer

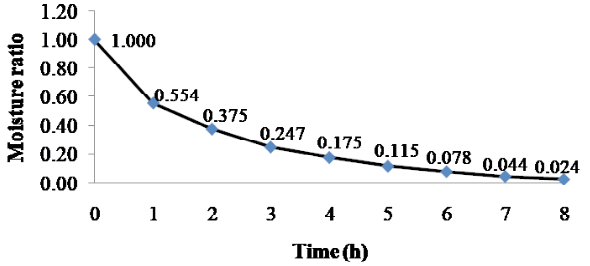

Fig. 4: Experimental values of moisture ratio with respect to time

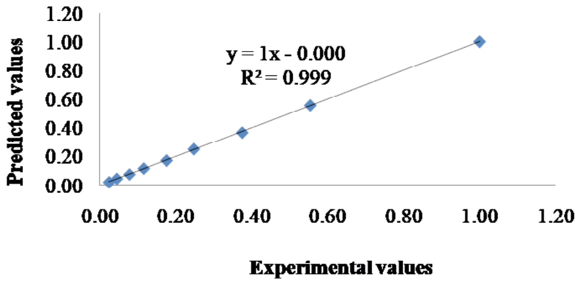

Fig. 5: Experimental and predicted moisture ratio (Midilli model) values

is no constant rate drying. This is mainly because of the dominant moisture movement by diffusion and thin layer of material drying (10 mm) which enabled easy removal of water. Shrimp drying in electrical dryer is a diffusion controlled process since the moisture movement in shrimp is restricted by diffusion. Similar results were observed in drying of by-products from pomegranate juice and broccoli (Kara and Doymaz, 2015; Karaaslan, 2016).

Change in moisture ratio with drying time is shown in Fig. 4. It is observed from the figure that moisture ratio decreased as drying time increased. Moisture ratio was reduced from the initial value of 1 to 0.554 in first hour of drying and further it reduced gradually to 0.024at the end of 8 h of drying.

Mathematical modelling of drying curves

Moisture ratio curve was fitted with various drying kinetics models. Suitability of the drying models were analysed by correlation analyses, χ^2test and RMSE values. Statistical factors obtained from the model fitting of drying curves of shrimps are shown in Table 2 and it was observed that all models had good fitness to the experimental data of shrimp drying. Drying model with higher R^2 and lower χ^2 and RMSE values was selected as the best fit model for the dying data.

R^2 values ranged from 0.940 to 0.999 (Table 2), representing a good fit to the experimental drying data. Reduced chi-square (χ^2) values are observed as less than 0.008 and RMSE values are less than 0.083. Midilli model was found to have highest R^2 (0.999), lowest χ^2 (0.00002) and RMSE (0.004) values (Table 2). Thus Midilli model had the best fitness to experimental shrimp drying data at air temperature, air velocity and humidity of 55^{0}C, 0.8 m/s and 55% RH, respectively. Therefore, drying kinetics of shrimps in electrical dryer can be described by Midilli model and could be used for prediction of drying process of shrimps. Similarly Brahim Boudinar *et al.* (2016) reported that drying kinetics of shrimps in solar dryer is explained by Midilli model.

Experimental and the predicted moisture ratio (Midilli model) values for shrimp drying in electrical dryer is shown in Fig. 5. It can be observed that Midilli model showed a straight line with R^2 = 0.9999.Thus it showed the suitability of Midilli model to predict the drying characteristics of shrimps in electrical dryer.

CONCLUSION

Shrimp drying was conducted at drying air temperature of 55°C, air velocity of 0.8 and 55% RH. Total drying time of eight hours was necessary for the reduction of moisture content of shrimps from 73.45±1.26 (%wb) to 8.32±1.15 (%wb). Drying rate curve indicated that shrimp drying occurred under falling rate and no constant rate drying. Experimental moisture ratio value with respect to time was fitted in various drying kinetics models. Results indicated that Midilli model is found to be suitable to explain the drying characteristics of shrimp in electrical dryer with higher R^2 and lowest χ^2 and RMSE values. It was observed that Midilli model was adequately described the drying characteristics of shrimp in electrical drying and also moisture content with respect to drying time can be predicted under specified operating conditions.

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