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Study the drying kinetics of open sun drying of fish

Dilip Jain *, Pankaj B. Pathare

Central Institute of Post Harvest Engineering and Technology, PAU Campus, Ludhiana 141 004, India

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Abstract

The drying behavior of prawn and chelwa fish (Indian minor carp) has been studied under open sun drying (OSD). The drying rate curves contained no constant rate period and showed a linear falling rate throughout the drying process. An asymptotic regression precisely represents the open sun drying behavior with the coefficient of determination and mean square of deviation as 0.9996 and 0.33×10^{-4} for prawn and 0.9993 and 0.58×10^{-4} for chelwa fish, respectively. Effective moisture diffusivity values were estimated from Fick's equation. The hourly effective moisture diffusivity has an exponential relation with the hourly mean moisture content of fish. The average effective moisture diffusivities were 11.11×10^{-11} and 8.708×10^{-11} $m^2 s^{-1}$ for prawn and chelwa fish drying, respectively.

Keywords: Open sun drying; Fish; Moisture diffusivity; Drying model

1. Introduction

Fish is a very important foodstuff in developing countries, due to its high protein content and nutritional value. Temperature being a very important factor accelerating the process of spoilage. The spoilage reactions connecting on the death of the fish proceed at very rapid rate. Fresh fish contains up to 80% of water. It is highly perishable material and having a short storage life (Bala & Mondol, 2001).

Drying of fish is mainly carried out by traditionally under open sun. Sun drying represents a low cost processing technique to preserve fish. Natural sun drying has been used since time immemorial for agricultural products. Open sun drying has limitation to control the drying process and parameter, weather uncertainties, high labour costs, required large drying area, insect infestation, mixing with dust and other foreign materials and so on. However, open sun drying is widely practiced in tropical and subtropical countries to preserve agricultural products, where solar radiation is convenient (Szulmayer, 1971). It is abundant, inexhaustible, and environmental friendly (Basunia & Abe, 2001).

Under the influence of natural heat of the sun, the moisture evaporates from the surface of the fish. In the cooler part of the day diffusion of moisture does not take place from the inner layers of the fish to the outer surface. The enzymes present in the cells and tissues of the fish act on the fat and proteins. With the completion on sun drying, fish meat becomes condensed, saturated with oil, becomes translucent and acquires an amber color, a typical flavor, dense consistency and pleasant taste (Gerasimov & Antonova, 1979).

Moisture diffusivity is a transport property related to solid's drying or rehydration phenomena. Its accurate prediction can lead to optimization of drying process (Zogzas, Maroulis, & Marinos-Kouris, 1994). There is significant number of researchers who consider diffusivity as effective in order to report for a representative mean value during the falling rate period and simple engineering calculations (Hawladar, Uddin, Ho, & Teng, 1991; Perry & Green, 1984).

Therefore, the study of the drying kinetics, development of mathematical models for describing drying process and

* Corresponding author. Tel.: +91 161 2808155.
E-mail address: jaindilip25@rediffmail.com (D. Jain).

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Nomenclature

a_0, a	coefficient of drying models
D_{eff}	effective moisture diffusivity, $m^2\ s^{-1}$
D_R	drying rate, kg water/kg dry matter h^{-1}
e_s	standard error
F_0	Fourier number
k	drying coefficient
M	moisture content of fish, kg water/kg dry matter
M_0	initial moisture content, kg water/kg dry matter
M_m	hourly mean moisture content, kg water/kg dry matter
M_e	equilibrium moisture content, kg water/kg dry matter
M_R	dimensionless moisture ratio
M_w	moisture content of fish on wet basis, kg water/kg fish
N	number of observations
N_c	number of coefficients in model
n	exponential coefficient of Eq. (2)
R	radius of cylinder (fish), m
r^2	coefficient of determination
t	time, s
t_h	drying time, h
ρ	density, $kg\ m^{-3}$
λ	roots of Bessel function
χ^2	mean square of the deviation

the effective moisture diffusivity of fish under open sun drying has been carried out.

2. Theoretical consideration

2.1. Modeling drying kinetics

Average moisture content for thin layer drying is presented by the following expression:

$$M_R = \frac{M - M_e}{M_0 - M_e} \tag{1}$$

The moisture ratio may be simplified to M/M_0 instead of $(M - M_e)/(M_0 - M_e)$ because of the value of dynamic equilibrium moisture content M_e is very small compare to M and M_0 (Doymaz & Pala, 2002; Doymaz, Gorel, & Akgun, 2004) and the relative humidity of drying air is continuously fluctuated during sun drying (Diamante & Munro, 1993; Midilli & Kucuk, 2003).

In order to determine the moisture content as a function of drying time, various empirical equations were attempted by several investigators (Jain & Pathare, 2004; Toğrul & Pehlivan, 2002; Yaldiz & Ertekin, 2001; Yaldiz, Ertekin, & Uzan, 2001). The empirical model of Page, Hendersom and Pabis, and asymptotic (logarithmic) regression (Eqs. (2)–(4), respectively) were fitted more appropriately to describe the thin layer drying of many fruits and vegetables. Therefore, these models were attempted to study the sun drying kinetics of fish also.

$$M_R = \exp(-kt^n) \tag{2}$$

$$M_R = a\exp(-kt) \tag{3}$$

$$M_R = a_0 + a\exp(-kt) \tag{4}$$

The acceptability of the models has been determined by the coefficient of determination r^2, which should be close to one, the reduced values of the standard errors e_s, and the mean square of the deviation χ^2 (Chapra & Canale, 1989).

2.2. Effective moisture diffusivity

Diffusivity is used to indicate the flow of moisture out of material during drying. In the falling rate period of drying, moisture is transfer mainly by molecular diffusion. Moisture diffusivity is influenced mainly by moisture content and temperature of material. Fish samples were considered as infinite cylinder. The moisture diffusivity for infinite cylinder was therefore calculated by the following expression proposed by Crank (1975):

$$M_R = \frac{M - M_e}{M_0 - M_e} = \sum_{n=1}^{\infty} \frac{4}{\lambda_n^2} \exp\left(-\frac{\lambda_n^2 D_{eff} t}{R^2}\right) \tag{5}$$

where λ_n are the roots of Bessel function (2.405, 5.520, 8.654,...) of zero order $J_0(r) = 0$. For $n > 1$, the second order and subsequent terms of the above equation become negligible (Sharma & Prasad, 2004). Thus, λ_1 is equal to 2.405 for Eq. (5).

Eq. (5) is evaluated numerically for Fourier number, $F_0 = D_{eff}t/R^2$ for diffusion and can be rewritten as

$$M_R = \frac{4}{\lambda_1^2}\exp(-\lambda_1^2 F_0) \tag{6}$$

$$F_0 = -0.173\ln M_R - 0.0637 \tag{7}$$

Thus, effective moisture diffusivity (D_{eff}) can be calculated by the following expression:

$$D_{eff} = \frac{(F_0)_{th}}{(t/R^2)} \tag{8}$$

The effective moisture diffusivity (D_{eff}) was estimated by substituting the positive values $(F_0)_{th}$ and the drying time t along with the radius of sample in Eq. (8), for each corresponding hourly mean moisture content under different drying conditions. The radius of fish changes during the drying process. Shrinkage factor during drying of fish muscles can be calculated (Balaban & Pigott, 1986) with the help of change in density of fish with moisture content as

$$\rho = 1.4 - 0.5M_w; \quad r^2 = 0.875 \tag{9}$$

3. Materials and methods

Freshwater prawn (*Macrobrachium lamarreii*); invertebrate and Indian minor carp, chelwa (*Oxygaster bacaila*); vertebrate fish were considered for study the open sun drying (OSD). The fresh fish were obtained from the local fish market of Ludhiana and washed with clean water. The initial moisture content of sample was determined by the method of drying at temperature of 130 °C described by Gerasimov and Antonova (1979) and observed as 3.621 and 2.676 kg water/kg dry matter in prawn and chelwa fish, respectively. The radius of fish was measured with vernier calliper (list count—0.01 mm) at two positions of each fish and average radius was determined from the 15 fish. The average fish radii were 3×10^{-3} and 4×10^{-3} m of prawn and chelwa fish, respectively.

Surface water was removed by soaking paper before conducting the drying experiments. A steal wire mesh tray of 0.26 m × 0.22 m was used for open sun drying of the fish. The fish were arranged in single layer in the drying tray. The 305 number of prawn comprised of 0.172 kg and 101 number of chelwa was in 0.207 kg weight. The fish tray was kept in the sun, where the disturbance of wind was minimum. Experiments were conducted in the months of April 2005 during 10–17 h under the climatic condition of Ludhiana, India (latitude 30°45′N; longitude 75°48′E). The solar radiation ranged during these hours from 460 to 820 W m^{-2}. During drying experiments, the temperature of ambient air ranged from 32.5 to 42.5 °C and relative humidity vary between 15% and 32%.

Moisture loss was recorded hourly during 10–17 h. The weighing of fish was done on an electronic balance with least count of 0.1 g. Drying was continued until the sample reached the desired moisture level.

4. Results and discussion

4.1. Sun drying of fish and prawn

Drying rate is a fundamental parameter in the production of dried. The limited information is available on the kinetics of water removal from prawn and chelwa fish. The effect of sun drying on drying rate of prawn and chelwa fish was evaluated. The drying rate of fish is a function of moisture content. The drying rates were calculated from the drying data by estimating the change in moisture content, which occurred in each consecutive time interval and was expressed as kg water/kg dry matter h^{-1}. The drying rate curves (rate versus hourly mean moisture content) are presented in Fig. 1. The prawn dried in about two sunny days while chelwa took over three sunny days. The variation in drying rates is due to the shape, size and nature of the two varieties. The drying rates were higher at the beginning of the drying process and later decreased with decreasing moisture content. As indicated in the curves of Fig. 1, there was no constant rate of drying period. The drying occurred throughout under falling rate of drying period. During falling rate of drying period, the predominant mechanism of mass transfer in the sample is that of internal mass transfer.

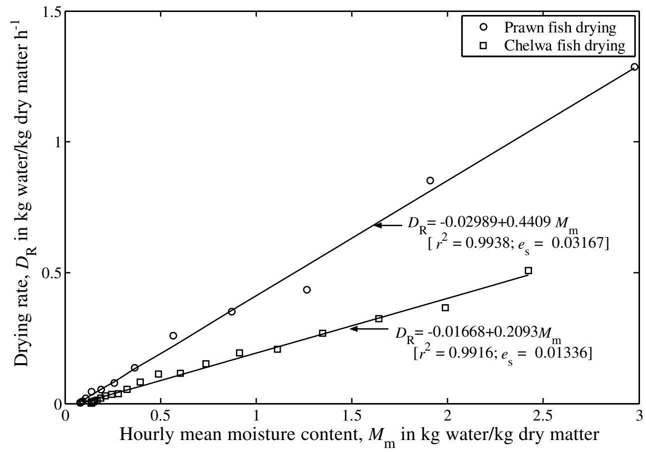

Fig. 1. Effect of moisture content on the drying rate for the open sun drying of fish.

A linear regression analysis was done to find the relationship between drying rate and hourly mean moisture content. Coefficients of determination (r^2) were in the range of 0.9938 and 0.9916 for prawn and chelwa, respectively.

$$D_R = -0.02989 + 0.4409 M_m; \quad r^2 = 0.9938, \quad e_s = 0.03167 \text{ (prawn)} \tag{10}$$

$$D_R = -0.01668 + 0.2093 M_m; \quad r^2 = 0.9916, \quad e_s = 0.01336 \text{ (chelwa)} \tag{11}$$

4.2. Model evaluation

The regression analyses were done for the empirical models of Page, Henderson and Pabis, and asymptotic (logarithmic) by relating the drying time and dimensionless moisture ratio. The acceptability of the model is based on a value for the coefficient of determination (r^2) that should be close to one, and low values for the standard error (e_s) and mean square of the deviation (χ^2). The model coefficients and parameters of error analysis are presented in Table 1. It can be observed that the asymptotic regression model has the highest value for the coefficient of determination as 0.9996 and 0.9993, lowest standard error of 0.4309×10^{-3} and 1.174×10^{-3}, and lowest value of χ^2 as 0.33×10^{-4} and 0.58×10^{-4} for prawn and chelwa fish drying, respectively. The results are also graphically shown in Fig. 2.

4.3. Calculation of effective moisture diffusivity

The effective moisture diffusivities estimated from the drying data represents an overall mass transport property of moisture in the material, which may include liquid diffusion, vapor diffusion or any other possible mass transfer

Table 1
Coefficients and error for the Page's, Henderson and Pabis, and asymptotic model for prawn and chelwa fish under open sun drying

Fish variety	Model	Parameters	Value	Coefficient of determination (r^2)	Standard error (e_s)	Mean square of deviation (χ^2)
Prawn	Page's	k (h^{-1})	0.4549	0.9989	9.9×10^{-3}	4.65×10^{-4}
		n	0.9311			
	Henderson and Pabis	a	0.9903	0.9981	1.3×10^{-3}	1.67×10^{-4}
		k (h^{-1})	0.4178			
	Asymptotic (logarithmic)	a_0	0.01738	0.9996	0.6×10^{-3}	0.33×10^{-4}
		a	0.9805			
		k (h^{-1})	0.4439			
Chelwa	Page's	k (h^{-1})	0.2135	0.9975	14.2×10^{-3}	2.02×10^{-4}
		n	0.9504			
	Henderson and Pabis	a	0.9890	0.9969	15.7×10^{-3}	2.48×10^{-4}
		k (h^{-1})	0.1927			
	Asymptotic (logarithmic)	a_0	0.0288	0.9993	7.8×10^{-3}	0.58×10^{-4}
		a	0.9630			
		k (h^{-1})	0.2126			

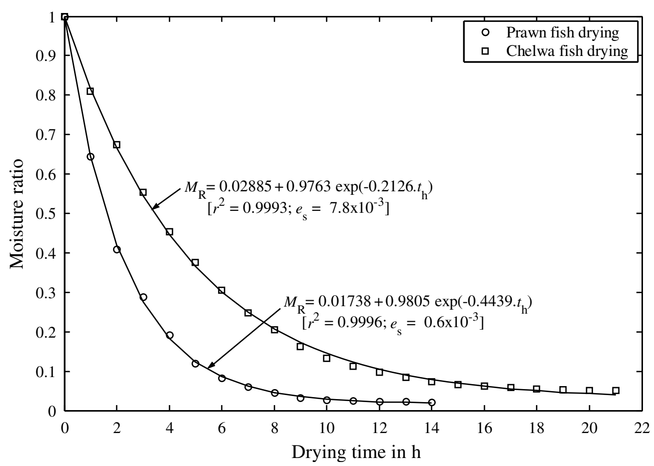

Fig. 2. Fitting of asymptotic (logarithmic) relation between drying time and moisture during the open sun drying of fish.

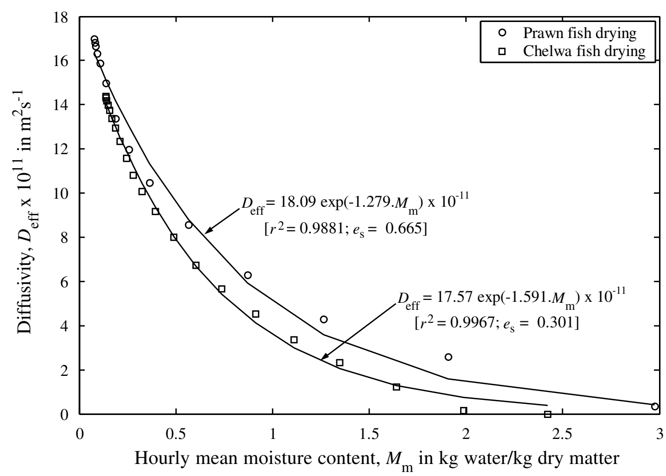

Fig. 3. Effect of mean moisture content on the diffusivity for the open sun drying of fish.

mechanism. The values of D_{eff} corresponding to positive F_0 values are plotted against moisture content and the variations are presented in Fig. 3. The effective moisture diffusivities exponentially increased with decrease in moisture content during the sun drying. The following expressions were obtained by fitting with exponential regression between M_m and D_{eff}:

$$D_{eff} = 18.09 \exp(-1.279 M_m) \times 10^{-11}; \quad r^2 = 0.9881; \quad e_s = 0.655; \quad \text{(prawn)} \tag{12}$$

$$D_{eff} = 17.57 \exp(-1.591 M_m) \times 10^{-11}; \quad r^2 = 0.9967; \quad e_s = 0.301; \quad \text{(chelwa)} \tag{13}$$

The average effective moisture diffusivity was calculated by taking arithmetic mean of the effective moisture diffusivities that were estimated at various levels of moisture content during the course of drying. The values of average effective moisture diffusivity were 11.11×10^{-11} and 8.708×10^{-11} m^2 s^{-1} for prawn and chelwa fish, respectively. These values are within the general range of 10^{-11}–10^{-9} m^2 s^{-1} for drying of fish reported by Panagiotou, Krokida, Maroulis, and Saravacos (2004).

5. Conclusion

The open sun drying of fish falls under falling rate of drying period. An asymptotic (logarithmic) regression model could adequately describe the drying of prawn and chelwa fish on the basis of statistical parameters such as coefficient of determination, standard error and mean square of the deviation value. Effective moisture diffusivities were 11.11×10^{-11} and 8.708×10^{-11} m^2 s^{-1} for prawn and chelwa fish, respectively.

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