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Heat and Mass Transfer of Greenhouse Fish Drying Under Forced Convection Mode

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Abstract: In this communication, a study of convective heat transfer coefficient during greenhouse fish drying for prawn (*Macrobrachium lamarrei*) under forced convection mode has been performed. The experiment has been performed during July 2006 for the composite climate of New Delhi. The hourly data for the rate of moisture evaporation, wind velocity, fish temperature and relative humidity inside greenhouse have been recorded for complete drying of fish under both natural and forced convection mode. These data were used for determination of the coefficients of convective heat transfer. Convective heat transfer coefficients are higher for forced convection than natural convection drying. Also the drying time required for forced convection is lesser than natural convection drying. It is mainly dependent on the rate of moisture transfer under the drying process. The curve fitting was carried out for different available model out of various observations. A quadratic curve exhibited best relation between convective heat transfer coefficient and drying time. This model gives the maximum coefficient of determination.

Key words: Greenhouse dryer, fish drying, forced convective mode, natural convection mode

INTRODUCTION

In recent years, fish farming is gaining popularity in India due to providing nutritional security to the food basket and earning foreign currency. Fish is a very important foodstuff in developing countries, due to its high protein content and nutritional value, supplying approximately 6% of global protein requirement and 16% of the total animal protein (Ayyappan and Diwan, 2003). Minor fish species consumed with bones and shell body are good source of calcium, protein, vitamin B and vitamin B12 (Zakhia, 2000).

Fish drying is practice to preserve the fish for longer duration. The spoilage reactions connecting on the death of 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 and Mondol, 2001). Some traditional techniques for improving preservation and storage are fish salting/brining, open sun drying and smoking. Open sun drying is still the most common method used for preserving food products in tropical and subtropical countries. Drying is widely used industrial preservation method in which water activity of food is decreased to minimize biochemical, chemical and microbiological deterioration (Doymaz and Pala, 2002). With the completion of 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 and Antonova, 1979). Open sun drying has some limitation, there are considerable losses and fish quality is lowered because of over drying, insufficient drying and contamination by foreign materials, insects and microorganisms as well as discoloring by UV radiation

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(Tiwari and Sarkar, 2007). In comparison to open sun drying the use of greenhouse dryer lead to reduction of the drying time up to 50% and to a significant improvement to the product quality in terms of color, texture and taste (Esper and Muhlbauer, 1998). For onion flakes the rate of moisture evaporation in case of greenhouse drying is more than that of open sun drying during the off sunshine hours due to the stored energy inside the greenhouse (Kumar and Tiwari, 2006).

The modeling of heat and mass transfer mechanism for solar drying of fish is complex. The convective heat transfer coefficient is an important parameter in drying rate simulation since the temperature difference between the air and fish varies with this coefficient (Jain, 2006). Ratti and Crapiste (1995) have evaluated the convective heat transfer coefficient from the data on crop drying under forced mode of operation. The experimental convective heat transfer coefficient for potatoes, apples and carrots ranged from 25 to 90 W m^{-2}. The convective heat transfer coefficient of jaggery under solar drying has been evaluated by Tiwari *et al*. (2004). Anwar and Tiwari (2001), as also Jain and Tiwari (2003) evaluated the convective heat transfer coefficient for some crops (green chilies, green peas, white gram, onions potatoes and cauliflowers) under solar drying and developed a mathematical model for predicting the drying parameter. The forced convection drying is better than natural convection drying because it reduces the drying time of fish.

No such work has been reported so far on greenhouse fish drying under forced convection mode. For the first time, experiment have been conducted by Tiwari *et al*. (2006) to determine the coefficient of convective heat transfer for greenhouse fish drying under natural convection mode. However no one has studied the heat and mass transfer of greenhouse fish drying under forced convection mode.

Therefore, the present studies were undertaken to determine the convective heat and mass transfer coefficient at different durations of greenhouse drying time of prawn under forced convection mode.

MATERIALS AND METHODS

Experimental Observation

For fish drying under forced mode, Indian minor carp prawn (*Macrobrachium lamarrei*); invertebrate was considered for drying in greenhouse. Dead and fresh fish was purchased from local market near IIT Delhi. The fresh fish was washed with fresh water. Surface water was removed by blotting with absorbent paper. A steel wire mesh tray was used during drying of the fish. The dimension of tray was of 0.25×0.20 m. The fish were arranged in a single layer in the drying tray. The tray with fish was kept on the measuring balance. Experiments were conducted in July 2006 between 8:00 and 17:00 h for forced drying and 10:00 to 17:00 h for natural drying under the composite climate of New Delhi, India as described in Tiwari *et al*. (2006). The solar radiation ranged during these hours between 150 and 900 W m^{-2}. Similarly Jain (2006) determined the convective heat and mass transfer coefficients for solar (open) drying of fish.

Experimental Greenhouse

The photograph of experimental greenhouse dryer at Solar Energy Park, IIT Delhi (Latitude-28°35′ N, Longitude-77° 12′ E and an altitude of 216 m above mean sea level) for fish drying under natural and forced mode is shown in Fig. 1a, b, respectively. The plastic cover of greenhouse transmits the solar radiations inside the greenhouse. The fraction of transferred solar radiation received partly by the fish, floor, exposed tray area and remaining solar radiation will heat the enclosed air inside the greenhouse. An even span roof type greenhouse with effective floor area of 120×0.78 m^2 was used for experimental purposes. The orientation of the greenhouse dryer was fixed with east-west direction. The inclination of south and north roof was 25.90°. The central height and sidewalls were raised to 0.60 and 0.40 m, respectively. For forced convection a fan of 120 mm sweep diameter with air velocity 5 m sec^{-1} was provided on the sidewall of the greenhouse during the experiments. There were provisions of two vents each of 0.2×0.1 m^2 on the south and north roof for natural ventilation purposes during over heating inside the greenhouse, if any.

Fig. 1a, b: Experimental set-up for prawn drying inside greenhouse under forced convection mode

Instrumentation

For measurement of temperature, a non-contact thermometer (Raytek-MT4) having least count of 0•1°C with accuracy of ±2% was used. The range of thermometer was -18 to 260°C. A digital hygro-thermometer (model: Lutron HT-3003)with least count of 0.1% was used to measure the relative humidity inside greenhouse. A digital balance of 1 kg weighing capacity was used to weigh the sample during the drying with least count of 0.1 g. The difference in weight gave the moisture evaporated during drying. The solar radiation was measured with a solarimeter, in W cm^{-2} having a least count of 2 m W cm^{-2} with + 2% accuracy. The air velocity across the greenhouse section during the forced convection mode was measured with an electronic digital anemometer (model : Lutron AM-4201). It had a least count of 0.1 m sec^{-1} with ±2% accuracy on the full scale range of 0.2-40.0 m sec^{-1}. Ambient air temperature (T_a) and just above the surface temperature of fish inside greenhouse temperature (T_g) were measured by calibrated alcohol - filled, glass - bulb thermometers (least count was 1°C).

Computation Methodology

Convective Heat Transfer Coefficient

The Nusselt number (Nu) is a function of Reynolds (Re) and Prandtl (Pr) numbers for forced convection heat transfer.

$$Nu = \frac{h_c X}{K_V} = C(Re\,Pr)^n \quad (1)$$

Now, the forced convective heat transfer coefficient is determined by using the following expression obtained from Eq. 1:

$$h_c = \frac{K_V}{X} C(RePr)^n \quad (2)$$

The rate of moisture evaporate is given (Malik *et al*., 1982) by:

$$Q_e = 0.016 h_c \left[P(T_f) - \gamma P(T_g) \right] \quad (3)$$

After substituting expression for h_c from Eq. 2 in 3 we get:

$$Q_e = 0.016 \frac{K_v}{X} C \left(\text{Re Pr}\right)^n \left[P(T_f) - \gamma\, P(Tg)\right] \quad (4)$$

From the above equation we can get the rate of mass evaporated:

$$m_{ev} = \frac{Q_e}{\lambda} A_t t = 0.016 \frac{K_v}{X} C(\text{RePr})^n [P(T_f) - \gamma P(T_g)] A_t t \quad (5)$$

After algebraic simplification:

$$\frac{m_{ev}}{Z} = C\,(\text{Re, Pr})^n \quad (6)$$

where:

$$Z = 0.016 \frac{K_v}{X} [P(T_f) - \gamma P(T_g)] A_t t$$

After taking the logarithm of both sides of Eq. 6, we get:

$$\ln\left[\frac{m_{ev}}{Z}\right] = n \ln(\text{Re, Pr}) + \ln C \quad (7)$$

Equation 7 is of a straight-line equation and is rewritten as:

$$Y = b_1 X + b_0$$

where:

$b_1 = b_o$ are the independent and dependent variables. $Y = \ln\left[\frac{m_{ev}}{Z}\right]$, $b1 = n$

$X = \ln(\text{Re, Pr})$

$b_o = \ln C$ can be rewritten as $C = e^{bo}$ (8)

Once the values of the C and n are known, the convective heat transfer coefficient is computed by Eq. 2 using measured values of the ambient air, inside greenhouse air, surface temperature of fish and relative humidity in greenhouse condition during a given time period (Table 2).

Computation Technique

The average surface temperature of fish $\overline{T}_f$ and inside greenhouse temperature above the fish surface $\overline{T}_i$ were calculated at hourly intervals for corresponding moisture evaporated. The physical properties of humid air were evaluated for the mean temperatures of $\overline{T}_f$ and $\overline{T}_g$ using equations given in appendix. These physical properties were utilized for calculating the values for the Reynolds (Re) and Prandtl (Pr) numbers. The values of C and n in Eq. 2 were obtained by linear regression analysis expressed in Eq. 8 at the increment of every hour of observation and thus the mean values of h_c were computed at the corresponding hour of drying. The convective heat transfer coefficient in case of natural drying was computed following the method given in Tiwari *et al*. (2006). The computer program was prepared in the Excel.

Table 1: Observation on greenhouse fish drying under natural convection (initial weight, 163 g; number of fish 250; month-July, 2006)

Day	Drying time (h)	I (t) W m^{-2} °C	T_a °C	Greenhouse drying T_f	T_g	γ (%)	m_{ev} (g)	C	n	hc
1st	0	620	36	38	51	32.80	-	1.47	0.26	
	1	540	37	46	53	31.20	49.4	1.47	0.26	9.20
	2	300	38	48	54	35.50	33.9	1.47	0.26	8.10
	3	560	39	49	54	33.10	19.6	1.47	0.26	7.17
	4	460	39	49	54	32.60	13.6	1.47	0.26	6.80
	5	400	38	49	52	31.10	8.3	1.47	0.26	5.55
	6	280	38	49	50	30.90	7.4	1.47	0.26	4.47
	7	160	36	41	44	28.00	3.6	1.47	0.26	3.46
2nd	8	420	32	43	40	39.20	2.1	1.47	0.26	3.23
	9	320	34	47	44	31.90	1.2	1.00	0.22	2.87
	10	200	33	49	43	34.00	0.5	1.00	0.22	2.29
	11	400	34	50	45	23.00	0.1	1.00	0.22	2.10
	12	600	35	51	47	24.60	0.1	1.00	0.22	1.23

Table 2: Observation on greenhouse fish drying under forced convection (initial weight, 163 g; number of fish 250; month-July, 2006)

Day	Drying time (h)	I (t) W m^{-2} °C	T_a °C	Greenhouse drying T_f	T_g	γ (%)	m_{ev} (g)	C	n	hc
1st	0	360	30	35	36	32.80	-	1.28	0.26	
	1	500	31	46	38	31.20	38.5	1.28	0.26	19.0
	2	620	32	48	43	35.50	49.1	1.28	0.26	21.0
	3	810	33	49	48	33.10	51.6	1.28	0.26	19.2
	4	900	34	49	51	32.60	42.6	1.28	0.26	18.4
	5	820	35	49	55	31.10	31.2	1.28	0.26	15.4
	6	740	33	49	53	30.90	20.1	1.28	0.26	11.3
	7	600	33	41	51	28.00	16.4	1.28	0.26	08.3
	8	420	32	43	47	39.20	0.1	1.28	0.26	01.7
	9	300	30	47	42	31.90	0	1.28	0.26	01.5

RESULTS AND DISCUSSION

The input parameter required for the computation of convective heat transfer coefficients for prawn (invertebrates) during greenhouse drying for both the case is given in Table 1 and 2, respectively. It took 12 h (two sunny days) and 9 h (one day) to dry the fish for natural and forced convection mode of drying, respectively. The moisture evaporation rate was higher in the initial few hours of drying. Changes in coefficients C and n are observed as the number of observations and drying time increase. The values of C and n are 1.47, 1.00 and 0.26, 0.22 for 1st and 2nd days observations during natural drying and 1.28 and 0.26 during forced convection drying, respectively.

The convective heat transfer coefficient h_c for prawn drying ranged from 9.2-1.23 W m^{-2} °C in case of natural convection and 21-1.5 W m^{-2} °C in case of forced convection drying. The convective heat transfer coefficient declined with a decrease in moisture content of prawn as expected. Experimental convective heat transfer coefficients during forced convection drying have been fitted by various mathematical relations as a function of drying time in hours viz., Linear, $Y = a+b\times T$, Log-Linear, $Y = a\times T^b$, Exponential, $Y = a\times e^{b\times T}$ and Quadratic, $Y = a+ b\times T+c\times T^2$. A Quadratic curve exhibited best relation between convective heat transfer coefficient and drying time as it gave the maximum coefficient of determination ($R^2 = 96.53\%$) .

The variation of convective heat transfer coefficient with respect to drying for both the condition is shown in Fig. 2. From the Fig. 2 it is observed that the heat transfer coefficient is almost double in the case of forced convection drying then natural convection drying and also it drying time for forced convection is almost reduced to half.

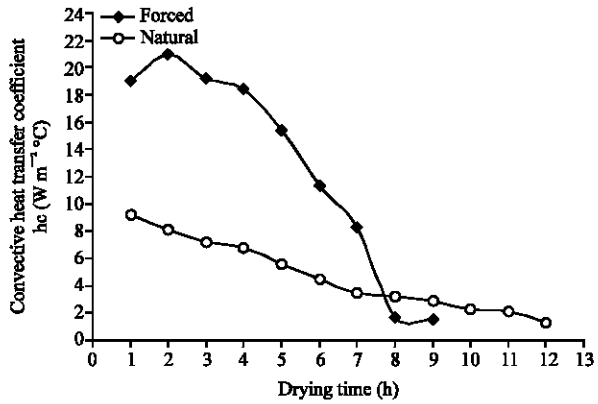

Fig. 2: Variation of convective heat transfer coefficient with drying time for fish under forced and natural convection in greenhouse (July, 2006)

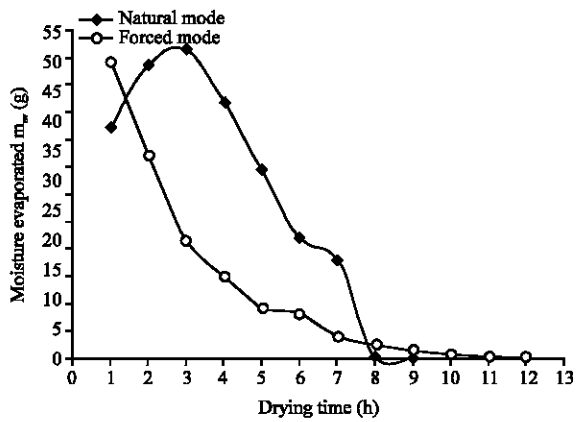

Fig. 3: Moisture evaporated during the drying of fish under natural and forced convection in greenhouse (July, 2006)

The amount of moisture evaporated during the drying of fish under natural and forced convection mode is shown in Fig. 3. It is observed that amount of moisture removed in the case of forced convection drying is higher and faster then the natural convection drying.

CONCLUSION

The convective heat transfer coefficients of minor fish species like prawn (invertebrates) have been determined under greenhouse drying for both natural and forced convection condition at different drying times. Convective heat transfer coefficient was a function of moisture removal, physical properties of moist air, operating temperature and surface area. The heat transfer coefficient can be increased by providing forced convection drying. Moisture removed in the case of forced convection drying is higher and faster then the natural convection drying.

Nomenclature

A_t = Area of fish (tray) (m^2)
C = Constant

C_v = Specific heat of humid air (J kg^{-1} °C)
C_f = Specific heat of fish (J kg^{-1} °C)
c = Coefficient
Re = Reynolds No. (= ρ_v v d μ_v)
h_c = Convective heat transfer coefficient of fish (W m^{-2} °C)
K_v = Thermal conductivity of humid air (W m^{-1} °C)
X = Characteristic dimension (m)
m_{ev} = Moisture evaporated (kg)
Nu = Nusselt No. (= h_cL/K_v)
n = Coefficient
Pr = Prandtl number (= μ_v C_v/K_v)
P(T) = Partial vapor pressure at temperature T (N m^{-2})
Q_e = Rate of heat utilized to evaporate moisture (J m^{-2} s)
R^2 = Coefficient of determination
T_f = Surface temperature of fish (°C)
T_e = Temperature of humid air above the fish surface (°C)
T_i = Average of fish and humid air temperature (°C)
t = Time (sec)
γ = Relative humidity (%)
λ = Latent heat of vaporization (J kg^{-1} °C)
μ_v = Dynamic viscosity of humid air (kg m sec^{-1})
ρ_v = Density of humid air (kg m^{-3})

Appendix

The expressions used for calculating values of various physical properties of humid air, i.e., specific heat (C_v) in J kg^{-1} °C, thermal conductivity (K_v) in W m^{-2} °C, density (ρ) in kg m^{-3}, dynamic viscosity (μ_v) in kg m^{-1} and the partial vapor pressure (P) in N m^{-2} are given below.

$C_v = 999.2+0.1434\,T_i+1.101\times10^{-4}\,T_i^2- 6.7581\times10^{-8}\,T_i^3$ (Kyokai and Kogaku, 1978)

$K_v = 0.0244+0.6773\times10^{-4}$ (Kyokai and Kogaku, 1978)

$$\rho_V = \frac{353.44}{T_i + 273.15}$$ (Toyama *et al*., 1987)

$\mu_v = 1.718\times10^{-5}+4.620\times10^{-8}$ (Kyokai and Kogaku, 1978)

$$P(T) = \exp\left(25.317 - \frac{5144}{T_i + 273}\right)$$ (Fernandez and Chargoy, 1990)

$$T_i = \frac{T_f + T_e}{2}$$

REFERENCES

Anwar, S.I. and G.N. Tiwari, 2001. Evaluation of convective heat transfer coefficient in crop drying under open sun drying. Energy Conver. Manage., 42: 627-637.

Ayyappan, S. and A.D. Diwan, 2003. Fish for food security-an opportunity. Indian Farming, 53: 47-51.

Bala, B.K. and M.R.A. Mondol, 2001. Experimental investigation on solar drying of fish using solar tunnel dryer. Drying Technol., 19: 427-436.

Doymaz, I. and M. Pala, 2002. Hot air drying characteristics of red paper. J. Food Eng., 55: 331-335.

Esper, A. and W. Muhlbauer, 1998. Solar drying- An effective means of food preservation. Renewable Energy, 15: 95-100.

Fernandez, J. and N. Chargoy, 1990. Multistage indirectly heated solar still. Solar Energy, 44: 215.

Gerasimov, G.V. and M.T. Antonova, 1979. Techno-Chemical Control in the Fish Processing Industry. Amerind Publication Co. Pvt. Ltd., New Delhi.

Jain, D. and G.N. Tiwari, 2003. Thermal aspects of open sun drying of various crops. Energy, 28: 37-54.

Jain, D., 2006. Determination of convective heat and mass transfer coefficient for solar drying of fish. Biosyst. Eng., 94: 429-435.

Kumar, A. and G.N. Tiwari, 2006. Effect of mass on convective mass transfer coefficient during open sun and greenhouse drying of onion flakes. J. Food Eng., 79: 1337-1350.

Kyokai, K. and Kogaku, 1978. Kagaku Kogaku Binran. Maruzen:Tokyo.

Malik, M.A.S., G.N. Tiwari, A. Kumar and M.S. Sodha, 1982. Solar Distillation. Pergamon Press, Oxford.

Ratti, C. and G.H. Crapiste, 1995. Determination of heat transfer during drying of foodstuffs. J. Food Process. Eng., 18: 41-53.

Tiwari, G.N., S. Kumar and O. Prakash, 2004. Evaluation of convective mass transfer coefficient during drying of jaggery. J. Food Eng., 63: 219-227.

Tiwari, G.N., T. Das and B. Sarkar, 2006. Experimental study of greenhouse prawn drying under natural convection. Agricultural Engineering International: The CIGR Ejournal. Manuscript FP06016. Vol. VIII December.

Tiwari, G.N. and B. Sarkar, 2007. Greenhouse Drying and other Applications. Fundamentals of Aquaculture Greenhouse. Anamaya Publishers, Lado Sarai, New Delhi, pp: 93.

Toyama, S., T. Aragaki, H.M. Salah, K. Murase and M. Sando, 1987. Simulation of multi-effect solar still and the static characteristics. J. Chem. Eng., 20: 473.

Zakhia, N., 2000. Adoption of a Quality Assurance Methodology to Traditional Fish Drying in Mali. CIRAD-AMIS, France.