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Research Note

Drying Characteristics of Indian Cheese at Low Pressure Superheated Steam Drying

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ABSTRACT

Indian cheese is an important dairy product and is used to prepare different culinary dishes. It is highly perishable in nature at ambient conditions and its shelf life is very low. The product develops a sour smell. bitter taste and being sparsely covered with moulds when expressed to high temperature. This study was undertaken to investigate the drying characteristics of *Indian cheese*, at low pressure superheated steam drying (LPSSD). The effect of steam temperature (62, 72 and 82°C) and pressure (10, 14 and 18 kpa) on drying rates was determined. Page's model was selected as a better predictive model as compared to generalized exponential and logarithmic models.

Superheated steam drying is a viable new hybrid drying technology with immense potential and is extensively used in food industries (Mujumdar, 2004b). The products dried with low pressure superheated steam has higher porosity hence better rehydration, absence of oxidative reactions, high heat transfer coefficients and higher drying rates. The process is eco friendly since it is in a closed system and can be used in combination with other product treatment like pasteurization or sterilization (Devahastin *et al.,* 2004; Deventer *et al.,* 2001). Most foods or other temperature sensitive products melt, undergo glass transition and/or damaged at the superheated steam temperature corresponding to the atmospheric or higher pressure, the possible way to alleviate the above mentioned problems is to operate the dryer at reduced pressure. LPSSD has been applied to drying of shrimp, banana, apples, potatoes, cassavas, carrots (Elustondo *et al.,* 2001; Mujumdar 2004a,b).

The mechanism of drying depends on the nature of solid and on the methods of contacting the solids and the heating medium. The overall diffusivity during drying decreases with the moisture content reduction. The diffusivity depends on temperature in the entire drying range, but at the beginning of drying with steam, the diffusivity is also influenced by moisture content. Effective diffusion coefficients increase with increasing drying temperature, and higher in hot air drying than those in superheated steam drying. The effective diffusivity increases with increase in drying air temperature. The effect of temperature on the diffusivity was greater in superheated steam dehydration than that in hot air dehydration (Jamradloedluk *et al.,* 2003; Karabulut *et al.,* 2007; Markowski *et al.,* 2003; Tang *et al.,* 2000). Drying with hot air had higher moisture diffusion than one dried with superheated steam (Prachayawarakorn *et al.,* 2006).

The objective of the present study was to investigate the drying characteristics of *Indian cheese*, selection of predictive model from the available analytical model and estimating the diffusion coefficient of *Indian cheese*.

MATERIALS AND METHODS

Indian cheese with the brand name 'Anchal', prepared from standardized cow milk was procured and kept at 4°C in a refrigerator until use. The initial moisture content of *Indian cheese* was about 100% (d.b). It was diced into 1.5 cm^3 with stainless steel knife. Prior to drying, cubes were pre-treated with sodium chloride and potassium sorbate. A fixed volume of water (0.5 l) containing 2.5% sodium chloride and 0.5% potassium sorbate was heated to 50°C in water bath. By this treatment, *Indian cheese* cubes could be successfully dried without loss of fat and browning (Singh *et al.,* 2004). After pre-treatment, approximately 50 g of samples were dried. The samples were dried until the desired final moisture content of about 1% (d.b.) was obtained. The equilibrium moisture content of the samples was also determined by drying the samples until no changes in their weight were observed. The experiment was performed at 10, 14 and 18 kPa absolute pressure and 62, 72 and 82°C steam temperature. MATLAB-7 software was used for moisture diffusivity analysis of *Indian cheese*. The experiment was performed in triplicate.

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Experimental Setup

A schematic diagram of the developed experimental setup of low pressure superheated steam dryer is shown in Fig. 1. Setup components were steam generator, drying chamber, vacuum pump and data acquisition system with computer. The drying chamber consisted of a box insulated properly with rock wool. Two 1.5 kW electric heaters were provided on opposite side walls of the drying chamber. The temperature of drying chamber was controlled by a temperature controller. The drying chamber was connected by a pipe from bottom to a chamber in which digital balance was kept. An autoclave was used as a steam generator. A steam trap was provided to reduce accumulation of steam condensate in the reservoir. Steam was transported to the drying chamber through a pipe insulated with glass wool. A 1kW heating tape was mounted on the steam pipeline to increase steam temperature to the desired level of superheating. The sample holder was made using thin stainless steel sheet. This was connected to a balance by a thin rod passing through a G.I. pipe. One side of the rod was attached to the sample holder and other side was rested on the analytical digital balance. The balance was placed in a smaller chamber. The balance had a weighing capacity of 320 g with a least count of 0.001g. The continuous data recorded by the balance was transferred through a serial cable to a computer by software. Thermocouples were installed to continuously measure the temperature of superheated steam at the inlet of drying chamber, drying chamber and product chamber. These thermocouples were attached to the data logger. Thermocouple signals were multiplexed and transferred to the computer through the Terminal Software. A vacuum pump was used to create the desired vacuum in the drying chamber, and then the chamber was sealed.

Steam was generated till it reached to a constant gauge pressure of 150 kpa. The vacuum pump was then switched on to evacuate the drying chamber to the desired operating pressure, and then the steam inlet valve opened slowly to flash the steam into the drying chamber. Because of the low pressure environment in the chamber, steam became superheated. Although the ratio of the steam pressure in the steam reservoir to that in the drying chamber was rather high, the effect of adiabatic expansion of steam in the drying chamber on steam temperature was rather small as the electric heater installed in the drying chamber helped in stabilization of the steam temperature. At the end of drying, vacuum break-up valve was opened to allow air in to the drying chamber before opening the chamber door and loading off the sample.

Selection of Thin Layer Model

Mathematical models are required to predict moisture content and/or drying rate for the design of a dryer or select drying conditions. The moisture ratio curves explain

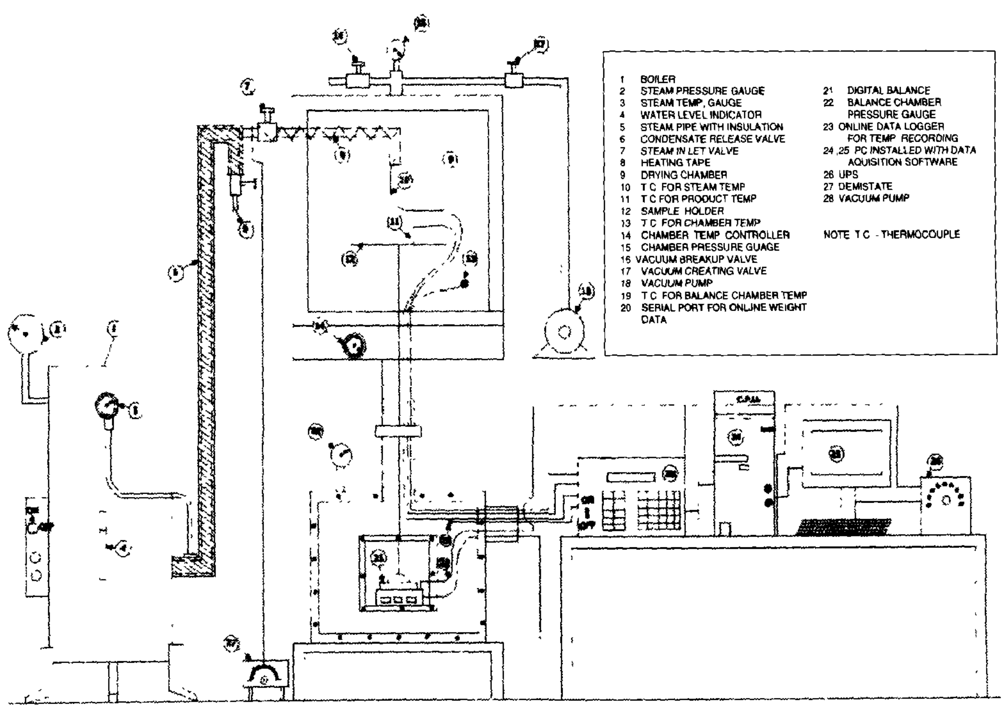

Fig. 1: Schematic diagram of low pressure superheated steam dryer and associated units

drying behaviour better than that of moisture content curve. Data were fitted into Page's generalized exponential and logarithmic model in order to select the best predictive model for low pressure superheated steam and vacuum drying of *Indian cheese* cubes. The models are given below:

(a) Page's model

$$MR = \frac{M - M_e}{M_o - M_e} = \exp(-Kt^N) \quad ...(1)$$

Where, t = Drying time, min; K, N = Constants of Page's equation, MR = Moisture ratio, M = Moisture content at time t (min) during drying (%db), M_0 = Moisture content at time zero during drying (%db), M_e = Equilibrium moisture content.

(b) Generalized exponential model

$$MR = \frac{M - M_e}{M_o - M_e} = A, \exp(-Kt) \quad ...(2)$$

(c) Logarithmic model

$$MR = \frac{M - M_e}{M_o - M_e} = a + b, x, \ln(t) \quad ...(3)$$

Where, A, a, b are drying constants.

Fick's second law of diffusion can be used to describe the effective diffusivity of *Indian cheese*. Analytical solution of Fick's diffusion equation for an infinite slab, assuming uni-dimensional moisture movement; constant volume, temperature and diffusivity coefficients, and negligible external resistance is given by equation 4 (Crank, 1975);

$$\frac{M - M_e}{M_o - M_e} = \sum_{n=1}^{n=\infty} \frac{8}{(2n-1)\Pi^2} \exp\left(\frac{-D_{eff}(2n-1)^2\Pi^2 t}{(4L)^2}\right) \quad ...(4)$$

Where,

L = Half thickness of slab,

n = Positive integer. and

D_{eff} = Effective diffusivity, m²/s.

A programme was developed in MATLAB-7 for linearization of equation and calculation of effective diffusivity.

RESULTS AND DISCUSSION

Drying times were determined at different moisture contents of 7, 5 and 2% (db) and are reported in Table 1. It was observed that as moisture content decreased, drying time increased. Moreover, the drying time increased with increase in pressure due to less temperature gradient at higher pressure.

Table 1. Drying time (min) of low pressure superheated steam drying of Indian cheese

Pressure (kPa)	Drying temperature (°C)	Moisture content (% db) 7	5	2
10	62	280	300	348
	72	240	275	343
	82	230	260	318
14	62	245	285	390
	72	235	280	370
	82	230	255	313
18	62	275	305	403
	72	265	290	380
	82	255	280	350

Empirical Modelling

Page's equation, generalized exponential equation and logarithmic equations were fitted to the experimental data in their linearized forms using regression technique as well as 'MATLAB-7' software to determine the constants of the models. In order to select the model which had better prediction, coefficient of determination (R^2) and standard deviation (SD) were considered. The results of regression analysis with minimum and maximum R^2 and SD over the entire experimental range are given in Table 2.

Table 2. Coefficient of determination and standard deviation of fitted equations

Model	R^2 Minimum	R^2 Maximum	SD Minimum	SD Maximum
Page's	0.9772	0.9972	0.0010	0.0043
Generalized	0.8455	0.9929	0.0043	0.0284
Logarithmic	0.9082	0.9776	0.0100	0.3052

Page's model had higher R^2 (0.9972) and lower standard deviation (0.0010) in comparison to generalized exponential and logarithmic models. Therefore, Page's model was chosen for detailed analysis.

The average value of parameter K and N varied from 0.0021 to 0.0044 and 1.1987 to 1.3032, respectively in superheated steam drying. The predicted moisture ratio by Page's model is shown in Fig. 2. For simulation. it is generally not convenient to use individual value of Page's equation parameters K and N at selected experimental conditions as they are not suitable under changed

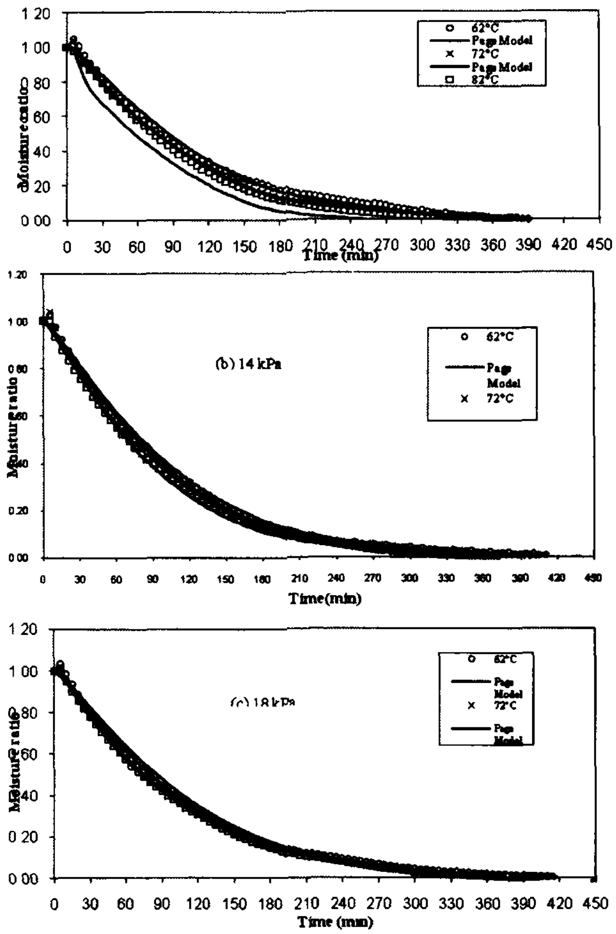

Fig. 2: Relationship between moisture ratio and drying time of Indian cheese

conditions. Therefore, a model was developed (in MATLAB-7 software) by relating the Page's equation parameters to temperature and pressure. The K and N values were thus substituted by K' and N' which depend on temperature and pressure. A second degree polynomial (eq. 5) was used to determine the values of K' and N'. The values of the constants are given in table 3.

Table 3. Coefficients for constants K' and N'

Coefficients	K'	N'
a_1	-3.8577e-05	1.2781e-03
a_2	3.5769e-06	-1.1197e-04
a_3	-7.6923e-08	2.3471e-06
b_1	5.5051e-03	-1.9599e-01
b_2	-5.0608e-04	1.7025e-02
b_3	1.0894e-05	-3.5689e-04
c_1	-2.0128e-01	9.2213e+00
c_2	1.8551e-02	-6.8478e-01
c_3	-3.9822e-04	1.4259e-02

$$K' \text{ or } N' = A_1T^2 + B_1T + C_1 \quad \ldots(5)$$

$$A_1 = a_1 + a_2P + a_3P^2;\ B_1 = b_1 + b_2P + b_3P^2;\ C_1 = c_1 + c_2P + c_3P^2$$

Where,

P = Pressure, kPa, T = Temperature, °C, and

A_1, B_1, C_1, a_1, a_2, a_3, b_1, b_2, b_3, c_1, c_2, c_3 = Constants.

Diffusion Analysis

The overall diffusivity includes the diffusion of water inside the solids in the form of liquid and vapour or vapour only. The result (Fig.3) showed that the effective diffusivity increased as the temperature increased. It also varied with the moisture content. Karabulut et al. (2007) also observed that the effective diffusivity of dried kurkut increased with increase in drying temperature. The range of diffusivity ranged between 1.52×10^{-8} and 2.11×10^{-8}

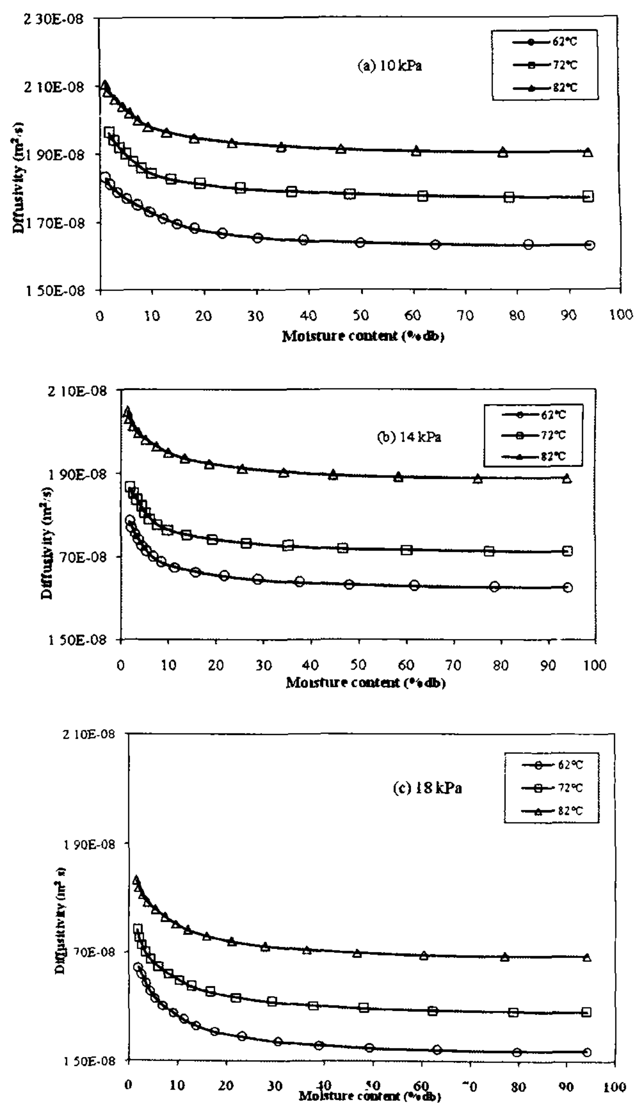

Fig. 3: Variation of effective diffusivity with moisture content

m^2/s for *Indian cheese* dried in superheated steam. The Fig. 3 showed that effective diffusivity (D_{eff}) decreased with increase in moisture content. It can also be seen that the decrease in D_{eff} was more up to 20% moisture content (db), and then remained almost constant. It was also observed that D_{eff} decreased with increase in pressure. The effective diffusivity coefficient is dependent on temperature and can be described by the Arrhenious equation. Activation energy for diffusion was estimated by the following Arrhenious equation:

$$D_{eff} = D_o \cdot \exp\left(-\frac{E_a}{RT}\right) \qquad \ldots(6)$$

Where,

D_0= Diffusion coefficient in Arrhenious equation, m^2/s,

E_a = Activation energy, J/mol,

T = Absolute temperature, ^0K, and

R = Universal gas constant, J/mol. °K.

Table 4. Activation energy (J/mol) of Indian cheese at different moisture content

Pressure (kPa)	Moisture content (%,db)								
	80	60	25	12	9	7	5	3	2
10	7696	7670	7465	6851	6604	6629	6777	6844	6885
14	7375	7369	7338	7364	7374	7326	7064	6607	6328
18	5363	5343	5247	5052	4961	4888	4738	4324	4169

The values of activation energy are given in table 4. The minimum activation energy was 4.17 and maximum was 7.70 kJ/mol over the entire temperature, pressure and moisture content ranges. The activation energy of *Indian cheese* is lower than the values reported 15-40 kJ/mol for various foods (Rizvi, 1986) and 19.88 kJ/mol for kurkut (Karabulut *et al.,* 2007).

CONCLUSIONS

Indian cheese dried at 10, 14 and 18 kPa absolute pressure and 62, 72 and 82°C steam temperature followed Page model as the best predictive model. Effective diffusivity (D_{eff}) decreased with increase in moisture content and pressure. It remained constant below 20% moisture content (db). Programme developed can be utilized at any temperature and pressure combination to calculate the diffusivity of dried products.

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