Drying Kinetics of Fluidised Bed Drying of Garlic Slices

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Garlic (Allium sativum Linn), a bulbous perennial plant of the lilly family, is consumed due its flavour, aroma and medicinal value. Dehydrated garlic is used as an important ingredient in many food formulations including tomato sauce, instant soups, mayonnaise, salads, snacks, chutneys, pickles etc. and pharmaceutical preparations. Optimisation of the drying parameters is done to achieve best quality of dried products whereas the study of drying kinetics helps in design of the drying equipment. The fluidised bed drying characteristics of garlic slices were studied as a function of the drying parameters, air temperature, slice thickness, air velocity and pre treatment by sodium meta-bisulphite. The experimental data was fitted to the mathematical models available in the literature. The slice thickness and temperature of the drying air were observed to be significant factors affecting drying. The influence of air velocity and concentration of sodium meta-bisulphite (within the range studied) was statistically insignificant. The two compartment exponential model was observed to match with the fluidised bed drying characteristics. The r^2 values were above 0.999 and the mean relative deviation modulus (P) was in the range 0.99 % to 8.24%.

Keywords **:** Garlic; Drying kinetics; Fluidised bed drying

INTRODUCTION

Garlic (*Allium sativum Linn*), a bulbous perennial plant of the lilly family, is cultivated worldwide on account of its culinary, medicinal and therapeutic properties. Fresh peeled garlic cloves contain moisture in the range of 160%(db) to 235 % (db). It is dried to safe moisture content of 6 % (db), mainly to produce slices, cubes, chunks and powder. Several studies have been carried out to investigate the effect of drying air temperature, slice thickness relative humidity, flow rate etc on drying rate of garlic[1-3]. In most of these studies, the experiments were carried out in thin layers. Combined microwave hot air drying has resulted in reduction in drying time[4], however, cost factors still prohibit its application on a commercial scale. Sulphitation prior to drying is usually carried out to control non enzymatic browning in order to improve acceptability of the products. Soaking of garlic slices in 0.5 % sodium meta-bisulphite solution for 20 min prior to drying at 55°C to 85°C, reduced pyruvate loss during heating, inhibited browning and reduced microbial counts compared with the unsulphited control[5]. Theoretical, semi-empirical and purely empirical mathematical models, characterising drying rates of biological products are available in the literature like the Lewis model, Page model, exponential (or logarithmic) model and two compartment diffusion model. The analysis of drying rate based on theoretical models involves complex computations. In view of this, empirical models have gained considerable importance.

Lewis suggested an equation analogous to Newton's law of cooling, to describe the drying rate. It is based on the diffusion theory, but assumes that the internal resistance to moisture movement and thus the moisture gradients within the material are negligible[6, 7].

The exponential (or logarithmic) law or model, is based on the assumption that the resistance to diffusion occurs mainly in a thin outer layer of the body and has been widely used by researchers in describing the thin layer drying characteristics of agricultural products[8, 9].

The Page model is an empirical modification of the exponential model to correct for its shortcomings and has been used by several authors. In this model the term containing time in the exponential model is raised to a numerical exponent, which has an effect of moderating the time and gives better results for the prediction of moisture loss from composite materials[10].

The two compartment diffusion model is a part of an infinite series of negative exponentials derived from a general solution to the diffusion equation. This solution applies regardless of particle geometry and boundary conditions, but assumes that diffusivity is constant (*ie*, requires constant product temperature during drying). It has proved to be the most widely popular[11- 13].

The objectives of the present study were to determine experimentally, the fluidised bed drying characteristics of garlic slices as a function of the drying parameters and fit the experimental data to mathematical models available in the literature.

MATERIALS AND METHODS

The cloves of fresh garlic bulbs of G282 variety used in the investigation were separated, peeled by hand and sliced across the length to the required thickness by equally spaced stainless steel blades. The slices were obtained from the middle of uniformly sized cloves. The peeled garlic cloves had initial moisture content of 225 % (db).

A laboratory fluidised bed hot air drying set up was fabricated for the drying studies. The set up consisted of three basic parts, a system for the provision of air, a section for heating the air and a drying chamber. A centrifugal blower of 50 m^3/min capacity was used to force the air through the product to be dried. A 0.75 kW, 3-phase electric motor, controlled by a simple general purpose ac drive was used to drive the blower and control the air flow rate. The air was heated while flowing through a 6 kW electric resistance heater. An auto tune PID controller along with Pt100 temperature sensor was used to control the temperature of the drying air with an accuracy of 0.1°C. The stainless steel drying chamber had a perforated bottom, (with 3 mm diameter openings, open area greater than 50%). The schematic of the drying

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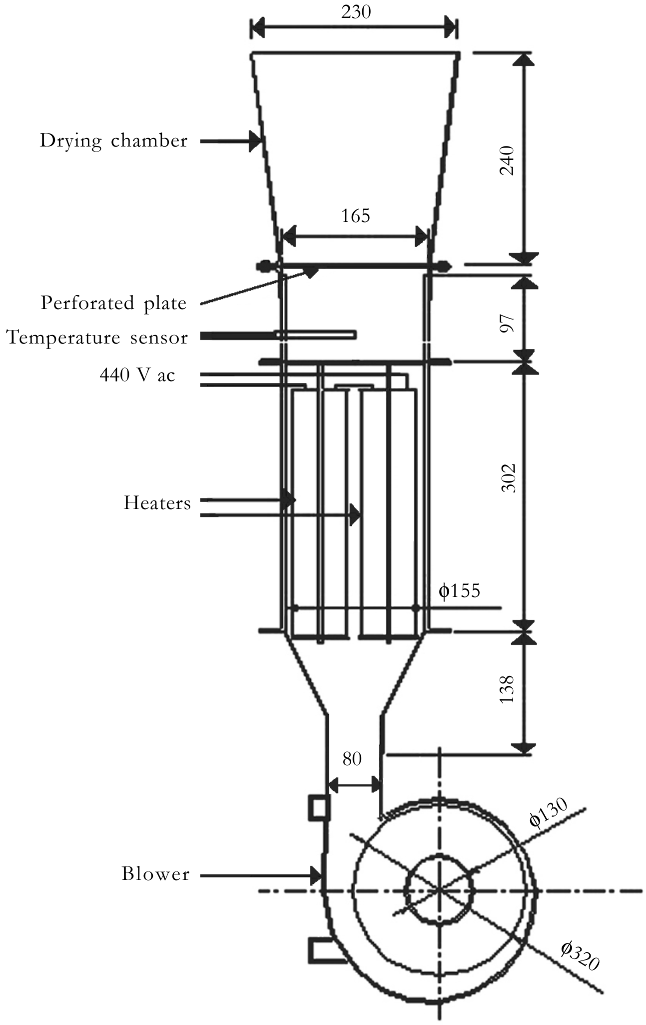
set-up is shown in Figure 1.The drying chamber was easily removable and the weighing of the samples along-with the drying chamber were carried out on an electronic balance (capacity 5 kg , precision ±0.5 g). The weights of the samples were taken at regular intervals. Initially, the weights were taken at smaller intervals (1 min to 5 min), and as the drying progressed, the weights were taken at longer intervals of time (10 min to 30 min), till the rate of reduction in weight approached a level of 0.05 g/min.

The experiments on drying were conducted as per the Box and Behnken design, for three levels and four factors[14]. The factors chosen were air temperature, slice thickness, air velocity and the concentration of meta-bisulphite pre treatment. A total of 27 treatment combinations, as described in Table 1 were conducted.

The moisture ratio (MR) in each case was calculated. The equilibrium moisture contents were determined by the static method using saturated salt solutions. Exponential model, Page model and two compartment exponential model were fitted to all the 27 runs, individually. The mean square error (MSE), r^2, mean relative deviation modulus (P) and the model coefficients for each run were calculated using the non linear regression technique of SPSS Version 9.0 for comparison of the models[15-17].



All dimensional in mm

Figure 1 Schematic of the drying set-up

Table 1 Experimental design with actual levels of the process variables

Treatment number	Air temperature, °C	Slice thickness, mm	Air velocity, m/s	Concentration of sodium meta-bisulphite, %KMS
1	55	3.0	7.5	0.2
2	65	3.0	7.5	0.2
3	55	6.0	7.5	0.2
4	65	6.0	7.5	0.2
5	60	4.5	6.0	0.1
6	60	4.5	9.0	0.1
7	60	4.5	6.0	0.3
8	60	4.5	9.0	0.3
9	60	4.5	7.5	0.2
10	55	4.5	7.5	0.1
11	65	4.5	7.5	0.1
12	55	4.5	7.5	0.3
13	65	4.5	7.5	0.3
14	60	3.0	6.0	0.2
15	60	6.0	6.0	0.2
16	60	3.0	9.0	0.2
17	60	6.0	9.0	0.2
18	60	4.5	7.5	0.2
19	60	3.0	7.5	0.1
20	60	6.0	7.5	0.1
21	60	3.0	7.5	0.3
22	60	6.0	7.5	0.3
23	55	4.5	6.0	0.2
24	65	4.5	6.0	0.2
25	55	4.5	9.0	0.2
26	65	4.5	9.0	0.2
27	60	4.5	7.5	0.2

RESULTS AND DISCUSSION

Influence of Process Variables

The effects of the process variables, such as, drying air temperature, slice thickness, air velocity and concentration of sodium meta-bisulphite on drying characteristics were analysed using analysis of variance (ANOVA). It clearly showed that temperature and slice thickness were significant factors in drying. The influence of air velocity and concentration of sodium meta-bisulphite (within the range studied) were statistically insignificant. Figure 2 shows the effectiveness of increasing the drying air temperature in accelerating the dehydration of 3 mm slices (treatment numbers 2, 1 and 19). The drying rate of 3 mm thick slices was observed to be 5.10 kg of H_2O/kg dry matter-h, at 65°C and 2.60 kg of H_2O/kg dry matter-h, at 55°C temperature in the beginning. As the drying progressed, the drying rates reduced to 1.41 kg of H_2O/kg dry matter-h, at 65°C and 0.65 kg of H_2O/kg dry matter-h, at 55°C, temperature. The drying rates were observed to increase with increase in drying air temperature in all the cases. Similar effect of drying air temperature was observed on the drying rates of 4.5 mm and 6 mm thick slices. The garlic slices dried faster at higher drying air temperatures. The experimental results were consistent with literature in which drying air temperature is considered as the single most important factor affecting drying rate.

The effect of slice thickness on moisture ratio (MR) at 55°C temperature is presented in Figure 3 (treatment numbers 19, 9 and 20). Similar trends were observed at 60°C and 65°C temperature. The thinly sliced garlic samples dried faster compared to thick slices at all the three selected temperatures due to the reduced distance the moisture travels, and the increased surface area exposed for a given volume of the product. The drying rates were observed to decrease with increase in slice thickness in all the cases.

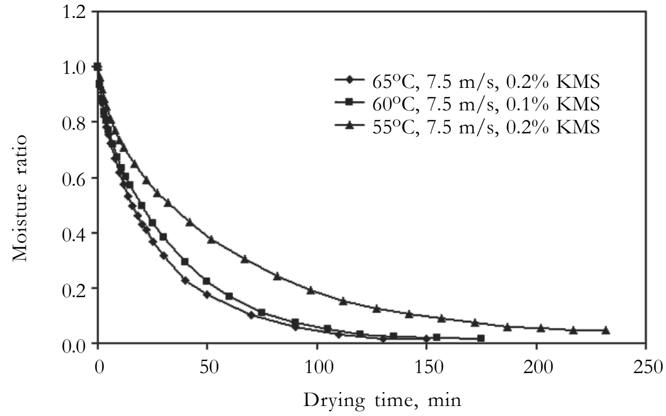


Figure 2 Effect of temperature on moisture ratio of 3 mm thick garlic slices

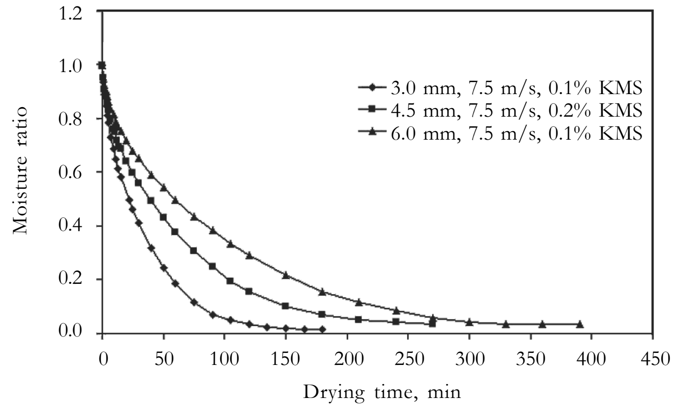


Figure 2 Effect of slice thickness on moisture ratio at 55°C temperature

Modelling of the Drying Characteristics

Exponential model, Page model and two compartment exponential model were fitted to all the 27 runs, individually. The model coefficients for each run for exponential model, Page model and two compartment exponential model, were calculated using the non linear regression technique of SPSS Version 9.0. The calculated values of the drying constants J, k and n of the exponential model and Page model and the linear parameters A_0, A_1 and the non linear parameters k_0, k_1 of the two compartment exponential model are presented in Table 2. The values of r^2, mean square error (MSE) and the per cent *P* are presented in Table 3 for each treatment run. Acceptable values of r^2, (> 0.96) were obtained for all the three models. However, the Page model and the two compartment exponential equation were giving consistently higher values than the lumped exponential model. An examination of the MSEs showed that the two compartment model gave superior fit to the data compared to the Page and the lumped exponential model due to its lower values. The per cent *P* indicates the deviation of the observed data from the predicted line. The *P* values were observed to be in the range of 0.99 % to 8.24%, 3.83 % to 15.53% and 12.75 % to 25.35 % in case of two compartment model, Page model and exponential model, respectively. Mean relative deviation modulus, for the two compartment exponential model was found to be the least, however these were maximum for the lumped exponential model. On comparison it was observed that the two compartment exponential model fitted best in the experimental data.

Table 2 Constants obtained for exponential, Page and two compartment exponential model for each experimental run

Treatment number	Exponential model	Page model		Two compartment exponential model			
	'J'	'k'	'n'	'A_0'	'k_0'	'A_1'	'k_1'
1	0.020129	0.051020	0.757311	0.198029	0.158878	0.799721	0.014339
2	0.042866	0.078145	0.793464	0.189345	0.223157	0.802586	0.030679
3	0.005629	0.021009	0.743866	0.136481	0.141452	0.854777	0.004363
4	0.014794	0.042329	0.748310	0.147740	0.404362	0.852714	0.011561
5	0.020171	0.046747	0.774878	0.130054	0.307645	0.867164	0.015686
6	0.021176	0.049421	0.770558	0.149680	0.252525	0.849563	0.016005
7	0.020176	0.046209	0.779552	0.130320	0.321158	0.866630	0.015772
8	0.018614	0.049135	0.745125	0.157469	0.250923	0.840560	0.013565
9	0.015217	0.046705	0.720830	0.177111	0.153292	0.809276	0.010444
10	0.009435	0.030218	0.746156	0.144986	0.154567	0.847673	0.007153
11	0.020902	0.059154	0.725198	0.182819	0.293888	0.816096	0.014956
12	0.010955	0.035216	0.736438	0.154768	0.176666	0.836419	0.008144
13	0.017892	0.056368	0.715527	0.250185	0.098832	0.728535	0.011750
14	0.030550	0.066037	0.764569	0.163291	0.305128	0.835967	0.022345
15	0.011662	0.034104	0.753971	0.134139	0.228712	0.863117	0.009106
16	0.032664	0.060839	0.810037	0.137167	0.363870	0.863827	0.025635
17	0.011972	0.034082	0.758750	0.131852	0.252443	0.864042	0.009288
18	0.019008	0.047548	0.759538	0.150899	0.238496	0.845679	0.014228
19	0.035189	0.066531	0.799326	0.148248	0.336781	0.851212	0.026928
20	0.011613	0.032710	0.762013	0.130396	0.263988	0.870004	0.009117
21	0.036799	0.069540	0.795127	0.155771	0.314904	0.844909	0.027898
22	0.011619	0.034075	0.753993	0.136159	0.221302	0.860656	0.009031
23	0.011026	0.034484	0.743096	0.171775	0.093675	0.810314	0.007927
24	0.015008	0.036384	0.787181	0.125567	0.319546	0.871992	0.012357
25	0.011818	0.041204	0.710907	0.176027	0.137666	0.810834	0.008230
26	0.020091	0.054543	0.740606	0.171649	0.235399	0.822141	0.014907
27	0.019466	0.044634	0.784294	0.141132	0.261683	0.859221	0.015150

Table 3 Curve fitting criteria for comparing the exponential, Page and two compartment exponential model for the drying of garlic slices

Treatment number	Exponential model			Page model			Two compartment model		
	r^2	MSE	P, %	r^2	MSE	P, %	r^2	MSE	P, %
1	0.977	2.59×10^{-3}	24.77	0.999	8.46×10^{-5}	3.83	0.999	4.10×10^{-5}	4.57
2	0.985	1.43×10^{-3}	18.02	0.999	2.20×10^{-5}	4.67	0.999	3.50×10^{-5}	3.49
3	0.964	3.52×10^{-3}	16.12	0.993	7.11×10^{-4}	15.18	0.998	1.27×10^{-4}	7.29
4	0.964	3.17×10^{-3}	22.13	0.993	6.54×10^{-4}	12.58	0.999	4.26×10^{-5}	4.28
5	0.976	2.38×10^{-3}	14.09	0.997	2.67×10^{-4}	6.69	0.999	2.60×10^{-5}	2.65
6	0.977	2.42×10^{-3}	17.85	0.998	2.17×10^{-4}	5.48	0.999	4.40×10^{-5}	4.39
7	0.976	2.35×10^{-3}	12.75	0.997	2.93×10^{-4}	7.14	0.999	2.12×10^{-5}	1.29
8	0.968	3.20×10^{-3}	20.24	0.997	2.94×10^{-4}	8.08	0.999	2.75×10^{-5}	3.59
9	0.967	3.53×10^{-3}	25.35	0.998	$1.36x\times10^{-4}$	5.50	0.999	6.82×10^{-5}	5.38
10	0.970	3.14×10^{-3}	16.60	0.996	4.04×10^{-4}	8.96	0.999	2.61×10^{-5}	1.52
11	0.965	3.45×10^{-3}	33.36	0.997	2.87×10^{-4}	8.48	0.999	5.81×10^{-5}	8.24
12	0.969	3.21×10^{-3}	20.27	0.997	3.38×10^{-4}	8.95	0.999	2.00×10^{-5}	1.69
13	0.967	3.37×10^{-3}	24.84	0.999	5.60×10^{-5}	2.69	0.999	1.15×10^{-4}	5.12
14	0.976	2.44×10^{-3}	16.54	0.998	1.59×10^{-4}	5.09	0.999	3.71×10^{-5}	4.07
15	0.969	3.01×10^{-3}	16.32	0.995	4.65×10^{-4}	9.98	0.999	3.30×10^{-5}	2.88
16	0.986	1.59×10^{-3}	19.74	0.998	2.41×10^{-4}	13.32	0.999	3.90×10^{-5}	5.87
17	0.974	2.89×10^{-3}	19.73	0.996	5.13×10^{-4}	15.53	0.999	3.68×10^{-5}	4.82
18	0.973	2.78×10^{-3}	15.97	0.997	2.51×10^{-4}	8.21	0.999	1.62×10^{-5}	1.85
19	0.985	1.67×10^{-3}	20.52	0.998	1.32×10^{-4}	8.15	0.999	8.13×10^{-6}	3.93
20	0.972	2.91×10^{-3}	14.09	0.995	5.80×10^{-4}	11.76	0.999	4.66×10^{-5}	3.22
21	0.985	1.67×10^{-3}	20.59	0.998	1.18×10^{-4}	6.36	0.999	5.81×10^{-5}	8.20
22	0.971	2.97×10^{-3}	16.50	0.996	4.33×10^{-4}	9.58	0.999	3.00×10^{-5}	2.67
23	0.974	3.00×10^{-3}	17.46	0.998	1.28×10^{-4}	5.04	0.999	3.86×10^{-5}	0.99
24	0.984	1.69×10^{-3}	16.79	0.996	3.97×10^{-4}	7.35	0.999	1.15×10^{-4}	8.04
25	0.963	3.90×10^{-3}	25.19	0.998	1.99×10^{-4}	6.09	0.999	7.03×10^{-5}	5.06
26	0.968	3.03×10^{-3}	23.63	0.997	2.59×10^{-4}	11.39	0.999	1.50×10^{-5}	1.65
27	0.981	2.22×10^{-3}	20.89	0.997	2.94×10^{-4}	9.91	0.999	7.39×10^{-5}	7.46

CONCLUSIONS

The slice thickness and temperature of the drying air were observed to be significant factors affecting drying. The influence of air velocity and concentration of sodium meta-bisulphite (within the range studied) was statistically insignificant. The fluidised bed drying characteristics of all the treatment combinations, was satisfactorily described by a two compartment exponential model. The r^2 values were above 0.999 and the P was in the range 0.99% to 8.24% for all the treatment combinations. The two compartment exponential model was observed to be superior as compared to the Page model and the exponential model. An optimum drying temperature of 60°C for drying 3 mm garlic slices, pre treated with 0.1% sodium meta-bisulphite solution at an air velocity of 9 m/s is recommended.

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