Diffusion Models for Gorgon Nut Roasting

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This paper deals with an experimental study on a single layer roasting of gorgon nuts in open cast iron pan at 200°C to 400°C surface temperature and compares the performance of some selected empirical diffusion models in describing the experimental data. It has been observed that second order polynomial and generalized exponential models performed satisfactorily, whereas the latter one is found to be the best among all the tested models.

Keywords : Gorgon nut, Diffusion, Roasting, Popping.

INTRODUCTION

Roasting is an important final operation of gorgon nut (*Euryale ferox*) processing. The conditioned gorgon nut is roasted with continuous stirring in open cast iron pan and the hot roasted nut is popped by instantaneous hitting by the mallet[1]. The popped gorgon nut is commonly known as makhana in India. The quality and the expansion ratio of makhana depend on roasting parameters and moisture content of the nut[2]. Optimum roasting time is very much dependent on rate of moisture diffusion from the nut and roasting pan surface temperature which are still unknown.

Theoretically, a single layer roasting of a grain particle can be described by moisture diffusion in a single grain kernel assuming that the whole grain be always in contact with the pan surface for a high degree of stirring. Some diffusion models are presented by Crank[3] and have successfully been applied by many investigators to the drying of grains. Due to differences in drying and roasting operation and the complexities of the diffusion based models, this too cannot be done easily. The selection of the best empirical models, therefore is an easy way out for the practical purposes.

MATERIALS AND METHODS

Gorgon nuts were procured from a local merchant of Madhubani, Bihar for this investigation. Experiments were conducted on medium size gorgon nuts (diameters 8 mm to 10 mm) to generate data for comparing the performance of selected models. Samples were roasted in open cast iron pan with continuous gentle stirring using a heat source of 1.5 kW electric heater. Temperature of the pan surface was measured by an iron-constantan (J-type) thermocouple attached to the millivoltmeter having the least count of ± 0.01 mV; and the temperature of corresponding millivolt was noted using the standard calibration chart of the thermocouple. Input voltage of the heater was regulated for maintaining a particular temperature of the pan surface by an auto-transformer connected to the power source. The raw nuts (moisture content 60% db) were conditioned by drying and roasting[2,4] to get two different initial moisture contents, *ie*, 34% and 26% of the samples, respectively for the purpose. A small sample was put into the pan in single layer when a pre-set temperature of the pan surface was reached and the stop watch was started. The sample was agitated so gently by a manual agitator that the layer of the nut was not disturbed. It merely could give slow motion to nuts for changing the surface without toppling to each other. The representative samples at 0.5, 1, 2, 3, 4 and 5 min intervals were taken out and kept quickly in pre-weighed moisture box for moisture content determination.

The study was conducted at three pan temperatures, *ie*, 200°C, 300°C and 400°C and three initial moisture content of sample (60%, 34% and 26% db). The roasting temperatures and initial moisture contents of the samples were selected based on the ranges followed in processing of gorgon nut[4]. The moisture content of nut was determined by vacuum oven method[5]. The experiments were replicated thrice to minimize the experimental error.

Analysis of the Data and Selection of Models

The experimental data in terms of moisture content was converted to moisture ratio (MR) assuming the equilibrium moisture content of nut at high temperature conduction roasting is zero[6]. The roasting behaviour at different temperatures and initial moisture content of nuts is presented in Fig 1.

Model Selection

Diffusion models for drying of few grains are known whereas for their roasting, very little are reported in literature. In case

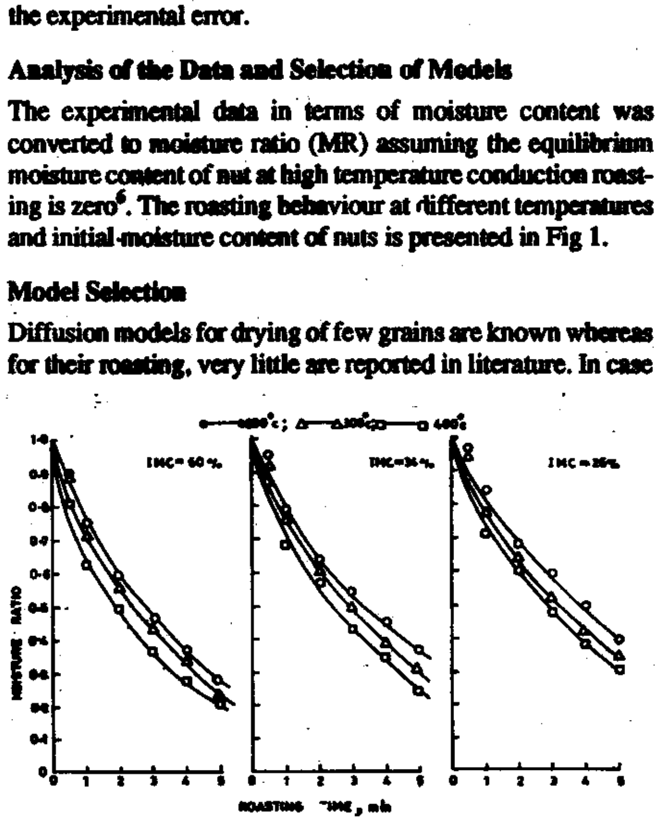

Fig 1 Single layer roasting behaviour of gorgon nut

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This paper (modified) was received on October 7, 1996 and was presented and discussed at the Annual Paper Meeting held at Patna on November 29, 1997.

Fig. 1 Simple ... behavior of gorgon nut

of gorgon nut, no trends of moisture diffusion either during drying or roasting are known. It was, therefore, thought to select and test few standard forms of equations usually used in engineering problems. The following models were, thus, selected for comparison which may be the basis for further investigation in future:

$$MR = A\theta^2 + B\theta + C \quad (1)$$

$$MR = A\theta + B \quad (2)$$

$$MR = A\theta^B \quad (3)$$

$$MR = A e^{B\theta} \quad (4)$$

$$MR = A \ln(\theta) + B \quad (5)$$

where, MR and θ are moisture ratio and roasting time in min respectively and A, B and C are empirical constants of the models.

Equations (1) to (5) are designated as M_1, M_2, M_3, M_4 and M_5 respectively, for the sake of convenience. It may be noted that M_1 is generalized form of Wang and Singh[6] model, whereas M_2, M_3, M_4 and M_5 are generalized linear, power, exponential and logarithmic models, respectively.

Evaluation of the Model Constants

Among the selected models, M_2 and M_5 are already in linear form, whereas, M_1, M_3 and M_4 can be linearized, respectively, as follows.

$$(MR - C)/\theta = A\theta + B \quad (6)$$

$$\ln MR = \ln A + B \ln\theta \quad (7)$$

$$\ln MR = \ln A + B\theta \quad (8)$$

For evaluation of model constants, a computer program was developed based on technique of least square regression. Experimental data were analyzed by the developed program on a personal computer (PC-386) and constants and correlation coefficients of models were evaluated.

Comparison of Models

Experimental and predicted roasting behaviours at 300°C temperature and initial moisture content of 25.9% (db) are shown in Fig 2. The figure shows that M_3 do not follow the experimental roasting curve at any stage. The model M_2 gives straight line, whereas experimental data produces curvilinear nature. The logarithmic model M_5 also does not perform very well. Quadratic and exponential models M_1 and M_4 respectively describe the data adequately at each stage (Fig 2), but M_4 appears to be more accurate in predictions.

The correlation coefficients of the models are presented in Table 1. This shows that the correlation coefficient of model M_4 is highest for all the initial moisture contents and pan temperatures. In most of the cases correlation coefficients of models decrease with temperature which indicates that accuracy of models decreases with increase in roasting temperature. Coefficient A of exponential model is almost unity (Table 2) which may be due to spherical shape of gorgon nut[1]. The constant B increases with roasting temperature and initial

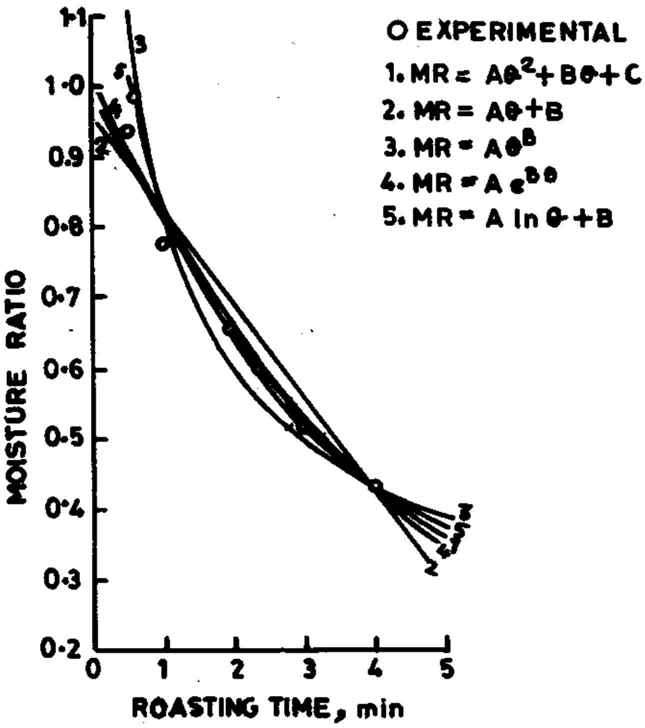

Fig 2 Comparison of models (T = 300°C, IMC = 25.9%)

Table 1 Correlation coefficients of different roasting models

Initial Moisture, %, db	Roasting Pan Temp °C	Correlation Coefficients for Models M_1	M_2	M_3	M_4	M_5
	200	0.9984	0.9835	0.9397	0.9992	0.9363
60.1	300	0.9961	0.9792	0.9325	0.9974	0.9276
	400	0.9931	0.9616	0.9274	0.9971	0.8956
	200	0.9944	0.9800	0.9523	0.9960	0.9513
33.7	300	0.9924	0.9756	0.9396	0.9956	0.9328
	400	0.9939	0.9677	0.9381	0.9953	0.9188
	200	0.9959	0.9899	0.9495	0.9971	0.9587
25.9	300	0.9962	0.9802	0.9515	0.9971	0.9482
	400	0.9924	0.9698	0.9469	0.9943	0.9365

Table 2 Constants of exponential models for roasting of gorgon nuts

Initial Moisture, %, db	Roasting Pan Temperature, °C	Constants A	B, min⁻¹
	200	0.998	−0.249
60.1	300	0.992	−0.276
	400	0.939	−0.303
	200	1.001	−0.199
33.7	300	0.984	−0.232
	400	0.960	−0.258
	200	1.027	−0.189
25.9	300	0.999	−0.214
	400	0.978	−0.233

moisture content of gorgon nut (Table 2) because of the fact that the rate of moisture transfer is faster at higher temperature and moisture content as compared to those at lower ones. The assumption for formulation of models that the equilibrium moisture content of gorgon nut in roasting pan at high temperature is zero can be visualized very easily. Because, after few minutes of roasting the nut may start burning and may turn to ashes. Good fit of the model (M_4) having correlation coefficient always more than 0.99 also shows that the assumption will not affect the performance of the model.

CONCLUSION

Generalized form of Wang and Singh[6] model performed well, however, the exponential model may represent the roasting behaviours of gorgon nut best among the tested ones.

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ACKNOWLEDGEMENT

The Institution of Engineers (India) acknowledges the valuable guidance provided by the following experts which immensely helped in maintaining the technical standard of the Journal.

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