ISSN: 2278 – 1323
International Journal of Advanced Research in Computer Engineering & Technology
Volume 1, Issue 4, June 2012

# Mathematical Modeling of Hot Air Drying of Spinach Leaves in Universal Hot Air Oven

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*Abstract-* **The objective of this study was to develop a model for drying characteristic curve of Spinach in Universal Hot Air Oven .Drying experiment were conducted using a constant air velocity2.2m/s and three drying air temperature of 55, 65, and75 °C with two pretreatment conditions and load densities that are given respectively condition (Blanched and Unblanched) load density (3kg/m$^2$, 3.5 kg/m$^2$).The drying rate increased with increased in temperature and decrease with increase in time. Pretreatment and load densities had an insignificant role on drying rate. The experimental drying data of spinach applied to four moisture ratio models, namely, page l, modified page, generalized exponential, and two term models. Nonlinear regression analysis performed to relate the parameters of the model with the drying conditions. The performance of these models evaluated by comparing the coefficient of determination, $R^2$, and reduced chi-square, $\chi^2$, between the observed and predicted moisture ratio. Among all these model page model was found to be best describe the drying behavior of spinach leaves .the standard error of estimation was least(0.004-0.031) as well as coefficient of determination ($R^2$)was highest (0.991-1) in page model as compared to other models.**

**Keywords: Thin layer drying, (SEE) Standard Error Estimation, (RSS) Residual Sum of Square, ($M_e$) Equilibrium Moisture Content, (MR) Moisture Ratio,($R_a$)adjustable coefficient of determination.**

## I. INTRODUCTION

Spinach (Spinacia oleracea) is a flowering plant in the family of Amaranthaceae and locally known as Palak. It is native to central and Southwestern Asia. In India it is cultivated in almost all the state. It is a rich source of iron ,magnesium and potassium and extraordinary high in vitamins C,A,E,B6,and thiamine(Wikipedia Encyclopedia 2011 Drying processes not only Inhibit microbial growth but also several biological and chemical degradation reactions; nevertheless, they also affect sensorial and nutritional characteristics promoting the collapse of vegetable tissues and the degradation of vitamins and antioxidants(Ibarz and Barbosa-Canovas,2003).Moreover, in the last 30 years the need of new technologies allowed to develop several dehydration methods Such as hot air dehydration, osmotic dehydration, microwave dehydration, infrared (IR) dehydration, ultrasonic dewatering, hybrid technologies, etc. The introduction of these technologies in food industries has increased the quality of dried vegetables leading to an exponential increase of the market of these products. For instance, a report published from Research and Markets showed that the total West European dehydrated food market was worth Euros 11.5 billion in 2009. Strictly speaking, during drying processes, the key factor of all traditional and innovative techniques is the mass transfer from vegetable tissues to its surrounding and vice versa. In general, water is the component that moves from vegetable tissues toward the surrounding air but this transfer may occurs through several mechanisms such as capillary flow, diffusion of water due to concentration differences, surface diffusion, vapor diffusion in the pores due to pressure gradient, water vaporization-condensation (Ibarz and Barbosa-Canovas, 2003), etc.; moreover, some of these mechanisms may affect each other, making the drying a very complex phenomenon. In general process of drying requires latent heat of vaporization to evaporate moisture, fundamental research with aid of mathematical modeling and numerical simulation provides an extremely powerful and cognitive tool for investigating the complicated physics that evolve during the drying of wet porous materials (Turner and Majumdar1997).

Drying mechanism is a complicated one and still it could not be understand by any mathematical model or physical law therefore for better understanding of drying in falling rate period an experiment was performed for better understanding of drying of spinach for highly perishable product like spinach moderate to low temperature drying is more suitable to achieve quality dehydrated product(Kanawade and Narain1993).The removal of moisture prevents the growth of micro organism and minimizes many of the moisture induced deteriorative reaction. (Mazumdar, 1995).

Blanching of vegetable is carried out before drying to inactivate natural enzymes in order to improve colour, texture and ultimately the overall acceptability of product (Ahmed et al., 2001) for green vegetable, pretreatment prior to drying can aid the chlorophyll retention during drying .several studies have been carried out to investigate the effect of pretreatment and hot air temperature on quality of processed vegetables (Kaur et al., 2006).

In recent work drying equation has developed for paddy by using hot air, carbon dioxide and nitrogen gases as a drying medium(Siri Doungporn et al.2011).And(Gulsah cakmak & cengiz Yildiz ,2011) Experimentally evaluating the drying kinetics of seeded grapes. They performed experiments with different air velocities and evaluate moisture ratio value at different conditions. The obtained moisture ratio value values have been applied to six different moisture ratio models in the literature .The model having highest correlation coefficient (R) and lowest chi-square ($\chi^2$) value has been determined as the most relevant one .In existing literature drying behavior of spinach leaves has not been described. Therefore present study was conducted with the following specific objectives.

(1) To study the drying characteristic of spinach at various temperature.

(2) To study the effect of pretreatment on drying characteristics of spinach leaves.

(3) To select a best model to describe the behavior of spinach and develop a drying equation.

## II. EXPERIMENTAL METHOD

### A. Materials

Fresh spinach leaves were procured from local market everyday prior to the experiment. They were washed with tap water the moisture on the wet sample surface was removed with filter paper .The average value of moisture content 93.41% (w.b.) which shows that spinach leaves can be grouped under highly perishable vegetables. Spinach leaves were pre treated by blanching with distilled water. Treated sample were placed over filter paper (Wattman filter paper .size 41 A) for 1 minute to absorb excess water.

### B. Experimental method

Drying experiments were carried out in cabinet dryer (universal hot air oven, tradevel scientific industries, least count $1^0$C) and installed in Department of Post Harvest Process and Food Engineering, College of Agriculture Engineering (JNKVV, JABALPUR). Sample were weighed in digital balance (METTLER, least count 0.001g )according to the loading density of 3.0kg/m$^2$ and 3.5kg/m$^2$ and placed in a stainless steel mesh tray of size 0.0123m$^2$ and 0.0168 m$^2$giving equivalent sample weight of 70g and 80g corresponding to different loading densities. Method recommended by Ranganna (1986) was used for determination of moisture content and for all experiments the initial moisture content was taken to be 1418.37 %( d.b.).The sample of both blanched and Unblanched were subjected to uniform air velocity 2.2 m/s at specified three level of temperature (55.65,and 75 $^0$C) and two level of loading density (3.0 and 3.5 kg/m$^2$) .The sample were dried for a minimum of eight hours of drying. Weights of the samples were recorded after every hour during drying process. The dried samples were cooled under laboratory conditions after each drying experiments, and were kept in air tight jars. The experiments were triplicate and average of the moisture ratio at each value was used for drawing the drying curves.

## III. RESULTS AND DISCUSSIONS

It was attempted to describe the drying process of spinach leaves by fitting the experimental data on selected drying model for mathematical modeling of it. The suitability of drying models was evaluated on the basis of regression coefficient value ($R^2$), standard error of estimation (SEE). The best model describing the drying characteristic of sample was chosen as the one with the highest coefficient of determination and the least reduced chi-square error (Ozdemir and Devres 1999; Ait Mohamed et al. 2005). The reduced chi-square value can be calculated as follows:

$$\chi^2 = \frac{\sum_{i=1}^{N}(MR_{exp,i} - MR_{pre,i})^2}{N - Z} \qquad (1)$$

Where $MR_{exp,i}$ and $MR_{pre,i}$ are experimental and predicted dimensionless moisture ratio, respectively N is the number of observations and z is number of constants. And the value of MR moisture ratio is calculated by the help of equilibrium moisture content which is calculated by the method developed by Henderson and Perry (1976)

$$MR = \frac{M - M_e}{M_o - M_e} \qquad (2)$$

Where, $M_o$ and M are the moisture content (% db) at time (θ) equal to zero and at any time (θ). To simulate the experimental drying curves some mathematical models were used which is mentioned in table.1for exponential model equation.

*Table 1 for exponential model equations*

| S.No. | Model Name | Model Equation | References |
|---|---|---|---|
| 1 | Page (1949) | $MR = \exp(-kt^n)$ | Page |
| 2 | Henderson and pabis (1969) | $MR = a.\exp(-kt)$ | Henderson and Pabis |
| 3 | Newton (1971) | $MR = \exp(-kt)$ | O' Callaghan et al. |
| 4 | Modified Page(1973) | $MR = \exp[-(kt)^n]$ | Overhults et al. |
| 5 | Two Term (1980) | $MR = a.\exp(-k_o t) + b.\exp(-k_1 t)$ | Sharaf-Eldeen et al. |
| 6 | Midilli (2002) | $MR = a.\exp(-kt^n) + bt$ | Midilli et al. |

All these equations used the moisture ratio (MR) as dependent variable, which related the gradient of the sample moisture content in real time with the initial moisture content and equilibrium moisture content. The experimental drying data were graphically analyzed. Variations of moisture content with time, variation in drying rate with drying time and variation in moisture ratio with drying time in terms of reduction in moisture content were drawn. The experimental data for drying of spinach leaves was statistically and graphically analyzed with the help of Data FIT 8.2 and spread sheet (EXCEL) software packages on personal computer

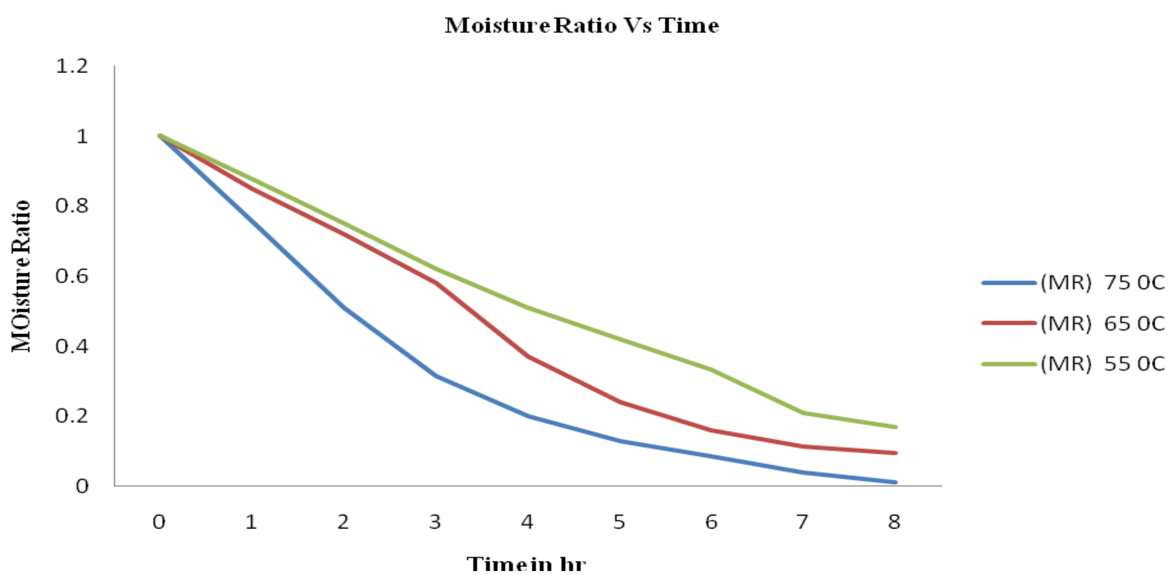


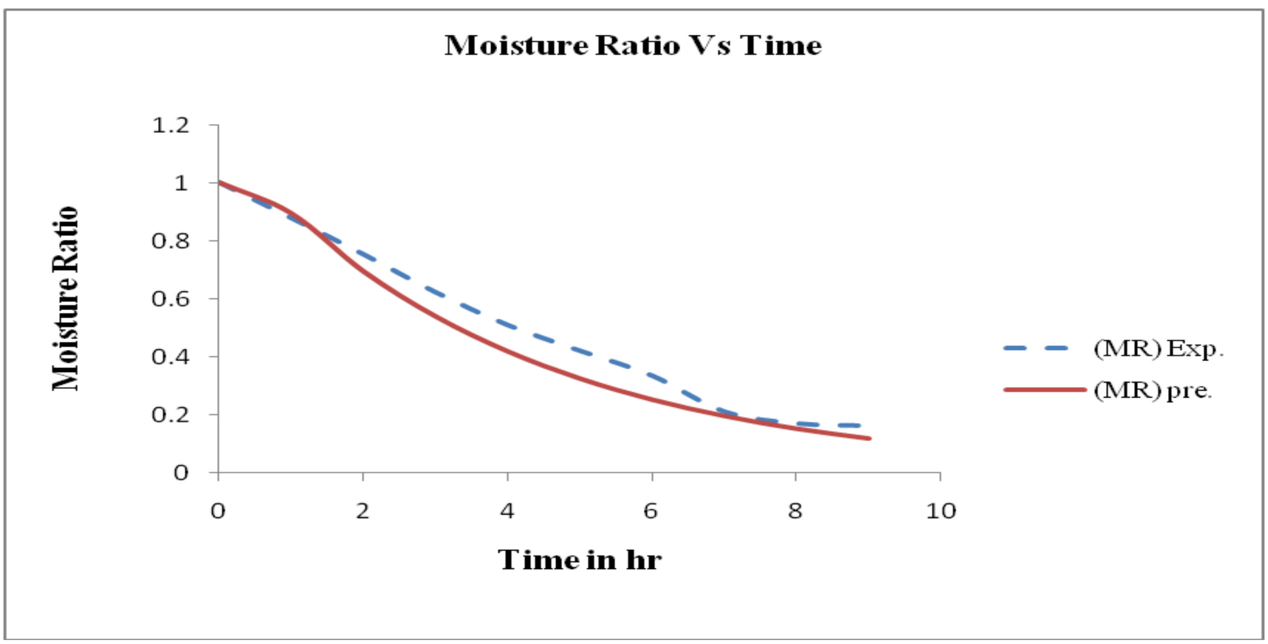

*Fig.1 curve for moisture ratio of spinach at different temperature at 55 °C, 65°C, 75°C*

On the basis of experimental results and data analysis the following conclusion were drawn.
From( figure-1) total drying time considerably reduces with the increase in drying air temperature from 55$^0$C to 75 $^0$C and the spinach does not dry at a constant rate the whole drying took place in falling rate period only. Drying rate increased with increased with temperature and decreased with decreased with temperature. And the load densities had a small and insignificant role on the drying rate especially at higher temperatures also the pretreatment had an insignificant role on the drying rate.
The page model was found to best describe the drying behavior of spinach leaves .The standard error of estimation was least (0.004-0.031) as well as the coefficient of determination ($R^2$) was highest (0.991-1) in page model as compared to other models. And statistical parameter for drying model was given in the table given below.

*Table 2 Comparison of different exponential models*

| *Temperature, Loading density* | *Rank* | *Model* | *Standard Error* | *RSS* | *$R^2$* | *$Ra^2$* |
|---|---|---|---|---|---|---|
| 65$^o$C, 3 kg/m$^2$treated | 1 | Page model | 0.027094444 | 0.005138762 | 0.994569804 | 0.993794062 |
| 75$^o$C,3.5kg/m$^2$untreated | 1 | Modified Page | 0.004593624 | 0.00014771 | 0.999848136 | 0.999826441 |
| 75$^o$C,3.5 kg/m$^2$untreated | 2 | Page model | 0.004593624 | 0.00014771 | 0.999848136 | 0.999826441 |
| 75$^o$C,3.5 kg/m$^2$untreated | 5 | Generalized exponential model | 0.031383051 | 0.006894271 | 0.992911836 | 0.991899241 |
| 753.5 kg/m$^2$untreated | 6 | Two term model | 0.037132926 | 0.006894271 | 0.992911836 | 0.988658938 |

*Figure 2 comparisons between experimental and predicted values of MR*



## IV. CONCLUSION

Drying characteristic of spinach leaves at different temperature were studied in this work .The drying curve showed a clear exponential tendency and the formula used to simulate the experimental reading is

$$MR = 1.15125\ e^{(-0.2535t)} \qquad (3)$$

## REFERENCES

[1] *WIKIPEDIA ENCYCLOPEDIA. 20011. Spinach. Available from http:// en.wikipedia.org /wiki/Spinach (accessed June 2, 20011).*

[2] *IBARZ,A; BARBOSA CANOVAS,G.V.Unit Operations in Food Engineering. Boca Raton:CRC Press LLC. 2003.*

[3] *Mazumdzar , A.S. 1995. Handbook of industrial drying. New York: Marcel dekker.*

[4] *Kanwade ,V.L.and Narain M. 1993. Fluidized bed drying of peas. Journal of Food Science and Technology. 30(2),118-120.*

[5] *Ahmed, J.;Shi.S. and Singh,G.2001.Drying characteristics and product quality of coriander leaves. Journal of Food Bioproduct Processing,79,103-106.*

[6] *Kaur , P.; Kumar, A.; Arora, S. and Ghumann B. S. 2006. Quality of dried coriander leaves as Affected by pretreatment and method of drying. European Food Research and Technology.223, 189-194.*

[7] *Siri Doungporn ; Nattapol Poomsa-ad;Lamul Wiset 2011.drying equationof thai hom paddy by using hot air carbon dioxide and nitrogen gases as drying media.Journal of food and bioproduct processing,Elsevier*

[8] *Gulsah C.;Cengiz Yild 2011; The drying kinetics of seeded grape in solar dryer ;Journal of Elsevier, Food and Bioproduct processing.*

[9] *Ait Mohamed, l., Kouhila, M., Jamali, A., S., Kechaou,N. and Mahrouz, M. 2005. Single layer solar drying behaviour of citrus aurantium leaves under forced convection. Energy convers. and manage. 46, 1473–1483.*

[10] *Akpinar, E.K. 2006. Mathematical modelling of thin layer drying process under open sun of some aromatic plants. J. Food Eng. 77, 864–870.*

[11] *AL-Khuseibi, M.k., Sablani,S.S. and Perera, c.o. 2005. Comparison of water blanching and high hydrostatic pressure effects on dryingkinetics and quality of potato. Drying Technol. 23, 2449–2461.*

[12] *Bajgai, T.R. and Hashinaga, F. 2001. Drying spinach with a high electric field. Drying Technol. 19, 2331–2341*

[13] *Baysal, T., Icier, F., Ersus, S. and Yildiz, H. 2003. Effects of microwave and infrared drying on the quality of carrot and garlic. Eur. Food Res. Technol. 218, 68–73.*

[14] *Bruce, D.M. 1985. Exposed-layer barley drying, three models fitted to new data up to 150°C. J. Agric. Eng. Res. 32, 337–347.*

[15] *Bruin, S. and Luyben, K., 1980, in Mujumdar, A.S. (ed)(McGraw-Hill Co, US), pp.155–215.(McGraw-Hill Co, US).*

[16] *C ¸ akmak, G. and Yıldız, C., 2009, Design of a new solar dryer system with swirling flow for drying seeded grape. Int.Commun. Heat Mass Transfer, 36:984–990.*

[17] *Diamante, L.M. and Munro, P.A. 1993. Mathematical modeling of the thin layer solar drying of sweet potato slices. Solar Energy 51, 271–276.*

[18] *Doymaz, I., 2006, Drying kinetics of black grapes treated with different solutions. J. Food Eng.,76: 212–217.*

[19] *Henderson, S.M. and Pabis, S., 1969, Grain drying theory. I.Temperature effect on drying coefficient. J. Agric. Eng. Res., 6:169–174.*

[20] *Karathanos, V.T. and Belessiotis, V.G., 1999, Application of a thin-layer equation to drying data of fresh and semi-driedfruits. J. Agric. Eng. Res.,74:355–361.*

[21] *Mulet, A., Berna, A., Borras, M. and Pinaga, F., 1987, Effect of air flow rate on carrot drying. Dry. Technol., 5: 245–258*

[22] *Planinic, M., Velic, D., Tomas, S., Bilic, M. and Bucic, A., 2005,Modelling of drying and rehydration of carrots using Peleg'smodel. Eur. Food Res. Technol., 221: 446–451.*