THIN LAYER MATHEMATICAL MODELLING OF BANANA SLICE USING MATLAB

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Abstract: *Drying of bananas is not a new thing but to reduce the loss of the product drying is needed. The drying characteristics of bananas were experimentally determined. The experiment was carried out with the ambient temperature range of 25 to 32^0 C and the hot air temperature range was from 30 to 620C. The air velocity was kept constant at 3.5 m/s. To describe the convective drying process some mathematical models were used. The experimental results were fitted to 10 thin layer drying models by using MATLAB and MS EXCEL. The curve fitting found that's the Lewis, Page, Modified Page, Modified Henderson, Middili kuck, Approximation Diffusion, Logarithmic, and Verma models gave the better curve fitting than another model. A total of 12 different models were examined and 8 shows the better curve fitting. The R square, RMSE, and Chi-square also help to understand the curve fitting in more detail.*

Keywords: mathematical modeling, thin layer modeling, drying rate, drying of banana, MATLAB

1. INTRODUCTION

Preservation of food is needed, to preserve food items drying is the most valuable solution. Bananas are the most valued crop plant in the tropics and subtropics [1]. It was found that 1/3 of world food production is wasted from the primary supply chain [2]. Drying needs a high amount of energy i.e. between 10 to 15 % of overall energy [3]. Previously sun drying and now fossil fuel dryers are the major source of drying. But for a few decades' researchers are experimenting to replace this old sun drying and fossil dryer with the solar drying system. Solar drying can be used in a hybrid way to get the more prominent result [4]. Solar energy has the great potential to full fill the needs of energy for today and tomorrow's future world.

Wastage of harvested product is Around 28% [5]. Drying vegetables and food items with different methods increase the life of the product and even helps in retaining its vitamin and mineral properties[6]. It is really helpful to know the drying kinematics of the specific crops, it helps in the design and control of drying systems [7]. The mathematical model defines by many researchers describes the behavior of food while drying. Few are based on interaction theory i.e. between water and food, other models deal with the empirical values. To find the most appropriate model degree fit is the criterion of judgment [8].

The main objective of this paper is to study the thin layer drying characteristics of bananas by using solar drying methods. To closely fit the experimental data obtained to mathematical model describe for thin-layer drying kinematics.

Nomenclature

M_o – initial moisture content
M_t – moisture content at time t
M_e – equilibrium moisture content
MR – Moisture ratio (experiment value)
n- Number of constant
R^2 - correlation coefficient
χ^2 - Chi-Square
RMSE - Root mean square error
MRexp,i – Experimental moisture ratio of ith observations

MRpre,i – Predicted moisture ratio of ith observations
Z – number of drying constant
N – number of observations

2. Material and Methods

2.1. Raw Material and instruments

Ripe banana was purchase from the local market of Akola city and used immediately after purchase. The initial moisture content for bananas was 74% (w.b).

The materials listed below were used for the construction of the household solar dryer:

1. MS square pipe - square pipe of size 0.5 inch for preparing the entire structure, it is light in weight, easily available, durable, and have more strength than another material even cost is effective.
2. Glass – to cover the collector as it allows the rays to go inside and heat the sheet and it resists the heat to go outside.
3. An Aluminium sheet of 1mm thickness use to increase the temperature of the air passing through the air chamber painted black with tar for absorption of solar radiation.
4. UV Protected transparent Polythene sheet is used to cover the tray's chamber as shown in fig. 1.
5. Fan – Two fan of size 3 inch is used for giving the thermosiphon effect in the dryer.
6. Battery – 12-volt battery is used for the power supply to the fan.
7. Regulator circuit – A regulator with the circuit is used for regulating the speed of air
8. Paint – black paint is used for the whole dryer.
9. Angle – half-inch angle is used for making the tray.
10. Net – is in a tray for air circulating.
11. Banana - The banana was obtained from the local market; the initial moisture content was 74% wet basis (wb).
12. Slicer – for cutting the banana in 3mm size.
13. Anemometer – to measure the airflow rate and temperature of the air anemometer is used (Cpixen MM-2150 digital anemometer wind speed – 0-30 m/s, temperature 0- 500C)
14. Weighting machine – Weighting machine (0-10 kg) is used to measure the banana slice.
15. Thermo gun – The temperature of the tray is measured by the thermo gun.

2.2. Experimental Procedure

The solar dryer was prepared as per the need. The need is to manufacture a solar dryer occupying less carpet area. The area occupies is less than $0.5m^2$. The dryer was equipped with a fan for the forced convection effect.

The banana slices were cut with the help of a slicer and the thin size banana slices were prepared. the whole dryer was covered with the UV-protected polythene sheet as shown in fig.1. The parameters like air velocity were recorded as 3.5m/s. The banana was properly peeled and weighed. The slices were thin with 1 to 2 mm thickness. The experiment was carried out and the temperature reading with the reduction in weight was recorded. The weight of the banana sample was recorded after 60 minutes of time interval through the drying period until and unless three constant readings were recorded.

Fig 1. Solar dryer for household

2.3. Mathematical modeling

To study the unique drying characteristics of any particular food material thin-layer drying models are used. Thin-layer drying means studying the moisture content of a bio-material that is exposed to a stream of hot air. Several mathematical models have been developed to stimulate moisture movement and mass transfer through the drying of food items.

The moisture content of banana slices was fitted with the following models shown in table 1. The moisture content can be calculated as

$$(MR) = \frac{M_t - M_e}{M_o - M_e} = \frac{M_t}{M_o} \quad (1)$$

As I is equilibrium Moisture content which is negligible and can be neglected.

Table 1. Thin-Layer drying mathematical models tested for banana slices [1-17].

S.N.	Model name	Model Equation
1.	**Lewis or Newton model**	$MR = \exp(-Kt)$
2.	**Page Model**	$MR = \exp(-Kt^n)$
3.	**Modified Page Model**	$MR = \exp(-Kt)^n$
4.	**Henderson and Pabis Model**	$MR = a\exp(-Kt)$
5.	**Logarithmic Model**	$MR = a\ exp\ (-Kt)\ + c$
6.	**Modulili kuck**	$MR = aexp\ ((-kt^n) + bt$
7.	**Approximation of diffucsion**	$MR = aexp\ (-Kt)\ +\ (1-a)exp(kbt)$
8.	**Modified hinderson and pabis**	$MR = aexp\ (-Kt)\ +\ bexp(-gt) + cexp(-ht)$
9.	**Verma**	$MR = aexp(-Kt) + (1-a)exp(-gt)$

It is difficult to find the best model for this a regression technique is used. The model shown above can be refined to find the best model employing correlation coefficient R^2, Chi-

Square χ^2 and Root means square error (RMSE). The best model is considered by the highest value of R^2 and the lowest value of RMSE and Chi-Square [15-17].

$$R^2 = 1 - \frac{\sum_{i=1}^{N}[MR_{exp,i} - MR_{pre,i}]}{\sum_{k=1}^{N}[MR_{pre,i} - \frac{\sum_{k=1}^{N} MR_{pre,i}}{N}]} \tag{2}$$

$$\text{RMSE} = \sqrt{\frac{\sum_{i=1}^{N}[MR_{pre,i} - MR_{exp,i}]}{N}} \tag{3}$$

$$\chi^2 = \frac{\sum_{i=1}^{N}[MR_{exp,i} - MR_{pre,i}]}{N-n} \tag{4}$$

3. Result and Discussion

The drying curves were stimulated for nine different models and the curved was plotted for predicted and experimental data shown in figures below i.e. from fig 2 to fig.9.

Drying curves

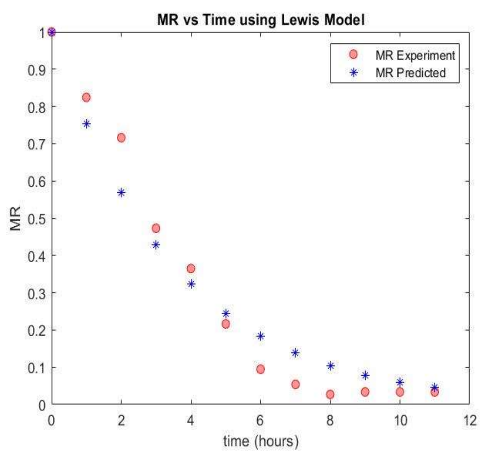

Fig 2. MR Exp & MR pre-Vs Time using Lewis Model

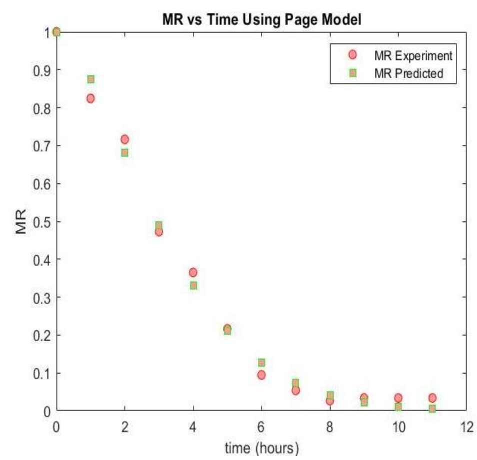

Fig 3. MR Exp & MR pre-Vs Time using Page Model

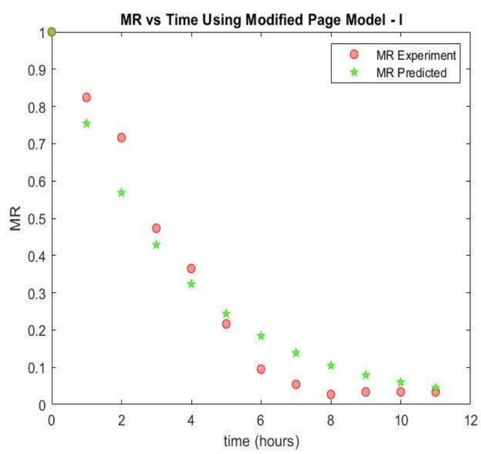

Fig 4. MR Exp & MR pre-Vs Time using Modified Page Model

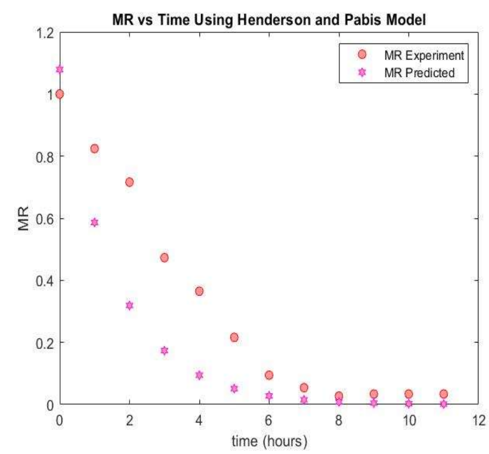

Fig 5. MR Exp & MR pre-Vs Time using Henderson and Pabis Model

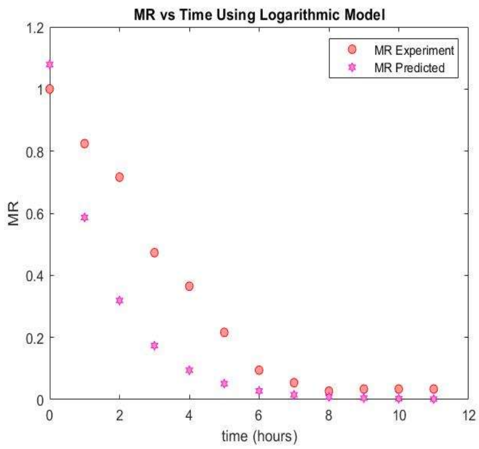

Fig 6. MR Exp & MR pre-Vs Time using Logarithmic Model

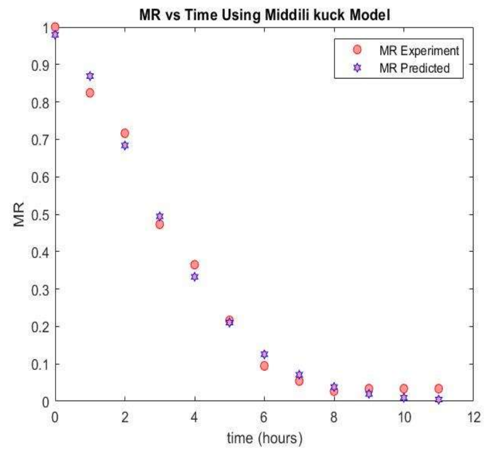

Fig 7. MR Exp & MR pre-Vs Time using Middilli kuck Model

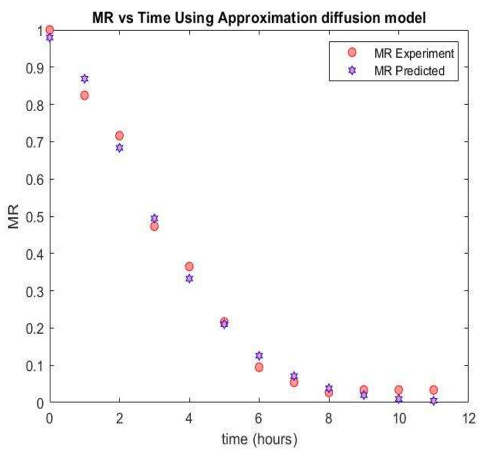

Fig 8. MR Exp & MR pre-Vs Time using Approximation and Diffusion Model

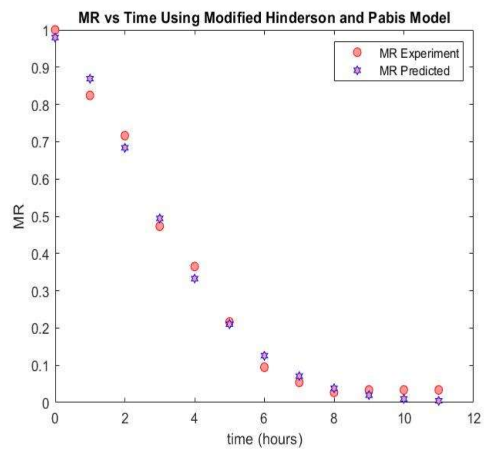

Fig 9. MR Exp & MR pre-Vs Time using Modified Hinderson and Pabis Model

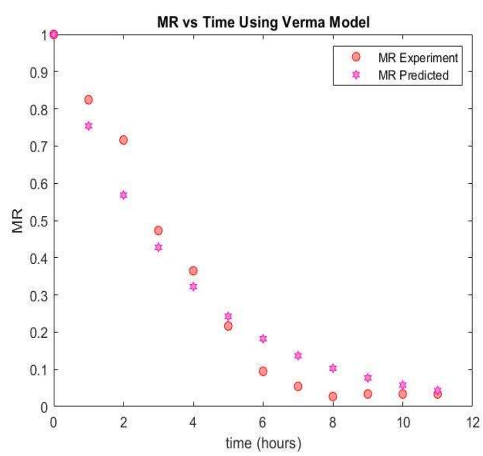

Fig 10. MR Exp & MR pre Vs Time using Verma Model

Fig 2 to fig 10. Gives the comparison of the experimental and predicted values of moisture ratios using nine different models. The regression analysis for the banana slices is presented in table 2.

Table 2. Regression value of Mathematical model

Mathematical Model	**RMSE**	**Chi-square**	**R^2**
Lewis model	0.0677615	0.005509945	0.973630355
Page Model	**0.026579085**	**0.000847737**	**0.981685454**
Modified Page Model	0.0677615	0.005509945	0.973630355
Henderson and Pabis Model	0.0677615	0.005509945	0.969763604
Logarithmic Model	0.061676138	0.004564735	0.969762863
Modulili kuck	0.756573236	0.686883674	0.994258907
Approximation of diffusion	**0.025822815**	**0.001000227**	**0.973630355**
Modified hinderson and pabis	0.0677615	0.006122161	0.969763484
Verma	0.061676138	0.007607892	0.974575751

The simulation curves and statistical parameters indicate that the page model and Approximation diffusion model show a better fit for the drying of the banana slice. As this model gives the higher values of R^2 and lower values of Chi-Square, root means square error. The whole work was done using MATLAB software.

4. Conclusion

From the mathematical equation, after studying the nine equations it is found that the page model and Approximation of diffusion better fit the curves. As the values of R^2 are higher and values of Chi-Square, root means square error is lower. The result shows that page model and approximation diffusion model could be used to predict the moisture content of the product during the drying process with a high ability for thin-layer drying.

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