ΕΤΑΙΡΕΙΑ ΓΕΩΡΓΙΚΩΝ ΜΗΧΑΝΙΚΩΝ ΕΛΛΑΔΟΣ

«Η συμβολή της Γεωργικής Μηχανικής στην Ανάπτυξη της Ελληνικής Γεωργίας»

ΕΓΜΕ HelAgEng

2017

28-29 Σεπτεμβρίου 2017
Συνεδριακό Κέντρο
Γεωπονικό Πανεπιστήμιο Αθηνών

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Mathematical modelling of single layer air–drying of mushroom (Agaricus bisporus)

Abstract

In this research, seven well–known mathematical thin–layer drying models were fitted to mushroom (*Agaricus bisporus*) drying experimental data, implementing non–linear regression analysis techniques. The experiments were conducted in two laboratory scale dryers. A range of temperatures 50–65 ^oC and air velocities 1.0–5.0 m/s were tested. The statistical analysis concluded that the best model in terms of fitting performance was the *logarithmic*. Correlations expressing *logarithmic* model parameter dependence with the drying–air coefficients and geometric characteristics are also reported.

Objective

To develop a mathematical model describing the single–layer mushroom drying, testing seven thin–layer drying models and finally integrate statistically in the chosen one, the drying–air coefficients (temperature, air velocity, absolute humidity) as well as the geometrical characteristics of the drying material.

Mathematical modelling of the drying curves

The basic equation commonly used to describe the thin layer drying process, is similar to Newton's law of cooling, incorporating a single drying constant (k, h^{-1}) for the combined effect of the various transport phenomena existing. It was first suggested by Lewis (1921) and has the general form:

$$\frac{dM}{dt} = -k\left(M - M_{eq}\right) \qquad (1)$$

where: *M*, M_{eq} are the water content and equilibrium water content respectively [kg_w/kg_{dm}], *k* is the drying constant [h^{-1}] and *t* the elapsed drying time [h].

Table 1. Thin–layer drying models content based on *Fick's* second law

Model name	Model Expression	Reference
Newton	MR=exp(-kt)	Brooker, Bakker–Arkema & Hall, 1992
Page	MR=exp(-kt^n)	Zhang & Litchfield, 1991
Henderson & Pabis	MR=a exp(-kt)	Yaldiz & Ertekin, 2001
Logarithmic	MR=a exp(-kt)+c	
Two term exponential	MR=a exp(-k_o t)+b exp(-k_1 t)	Henderson, 1974
Wang & Singh	MR=1+a t+b t^2	Wang & Singh ,1978
Mod. Henderson & Pabis	MR=a exp(-kt)+b exp(-gt)+c exp(-ht)	Karathanos, 1999

In these models it is assumed that the material la… so high, that the conditions of the drying air (hum… throughout the material.

Materials and Methods

Experimental facility

The drying of mushrooms was carried out in two experimental drying cabinets. The drying–air, was electrically heated. The drying conditions (temperature, velocity and humidity of drying air) were manually controllable.

Sample preparation and drying conditions

Fresh mushrooms of initial water content 11.60±0.25 kg_w/kg_{dm} were used. The fresh mushrooms were placed inside the drying cabinets whole and untreated, with the pileus facing towards the airflow. Four air temperatures (50, 55, 60, 65 ^oC) and seven air velocities (1.0, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0 m/s) were tested. Drying was terminated when the water content <18% w.b. The absolute humidity of drying–air in the drying cabinets, was 10.87±0.94 g_w/kg_{da}. Individual mushroom weight was measured in fixed time intervals and recorded. The water content was determined at 105 ^oC until steady weight was achieved (AOAC, 1997).

The water equilibrium equation

The following sorption isotherm model [*Chung-Pfost*] was used:

$$M_{eq} = -\frac{1}{B}\ln\left[-\frac{\ln(a_w)}{A}\right] \qquad (2)$$

The specific model was chosen by Shivhare *et al.* (2004) among other 11 known sorption isotherm models. The model is valid for a range of temperatures (30–70) ^oC. and relative humidities (20–80)%. The values of A and B parameters of the model are given by Shivhare et al. (2004) for the different tested temperature and relative humidity values.

Analysis of the drying data and application of the models

The drying data (drying curves) were analyzed applying non–linear regression statistical methods and the different models (Table 1) were fitted adopting the *Levenberg–Marquardt* method to solve nonlinear regressions.

Estimation of the mean mushroom surface and the effective diameter

To correlate mushroom initial mean surface area with its mass, 5 mass classes were used (5-10g, 10-15g, 15-20g, 20-25g and 25-30g) of 7 mushrooms each. The geometric features were measured. The *characteristic mushroom* was selected and its surface was carefully measured using aluminium foil straps avoiding overlapping. Then using image processing software the area of the foil straps was estimated in m^2. From the regression analysis of the measured surface S (m^2) against mushroom weights (g) Eqn 3 was derived, having R^2=91.21 %.

$$\bar{S} = 0.0002 \cdot m + 0.0011 \qquad (3)$$

Results and Discussion

Figure 1 presents the experimental data obtained for drying–air at 50–65 ^oC and minimum and maximum velocity 1.0 m/s and 5.0 m/s respectively. In these figures the best fitting is also included as solid line.

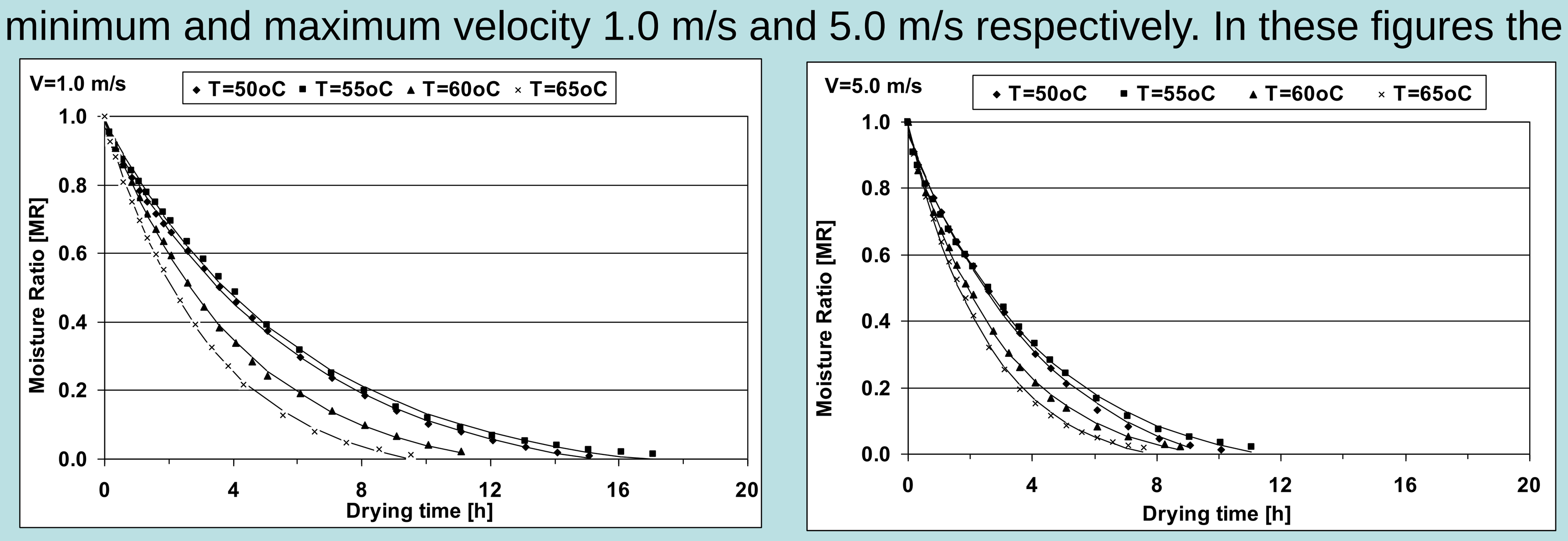

Figure 1. Experimental (symbols) and simulated (lines) curves using the logarithmic model for different air temperatures and air velocities 1.0 m/s (left) and 5.0 m/s (right).

As can be seen the effect of increasing air temperature on drying rate, when air velocity is kept constant, is evident. Drying–air velocity had no effect on drying rate at high air velocities. As can be seen from Fig. 2, at the highest air–drying temperature (65 ^oC) all the MR are close. The best scored R^2 combination was chosen, Eqs 4–6.

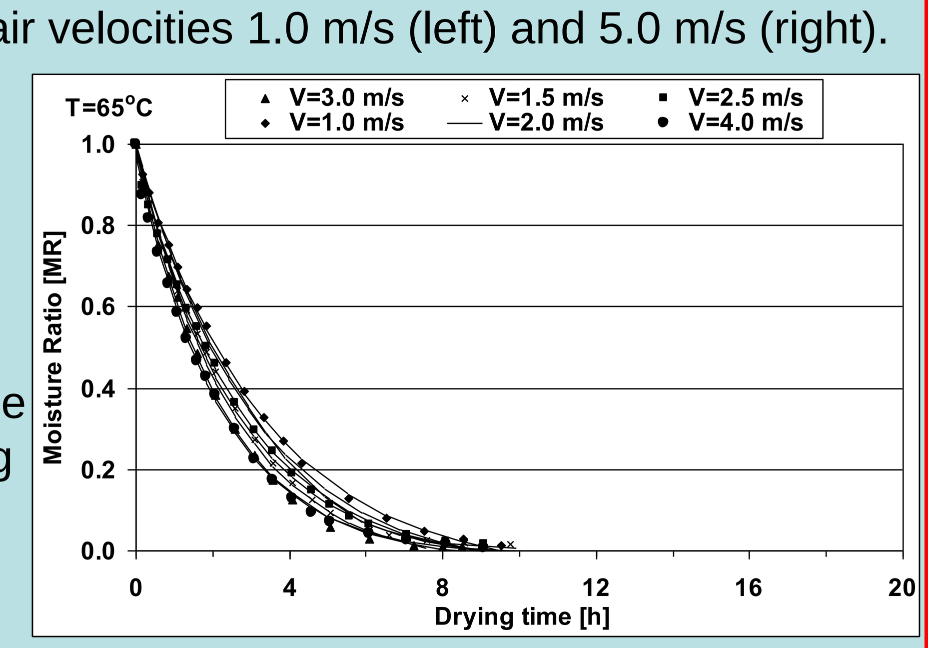

Figure 2. Experimental (symbols) & simulated (lines) curves using the *logarithmic* model for different V_{air} & one air–drying temperature 65 ^oC.

$$a = 1.27243 - 0.00233186 \cdot T - 17.5024 \cdot \bar{S} \qquad (4)$$

$$k = -0.493161 + 0.0128182 \cdot T + 0.0134525 \cdot V \qquad (5)$$

$$c = -0.32102 + 0.00295994 \cdot T + 16.4872 \cdot \bar{S} \qquad (6)$$

The resulted thin–layer drying model had R^2=97.92 % and SEE=0.047 and plotting the computed MR values vs. experimental ones, Fig. 3 is obtained.

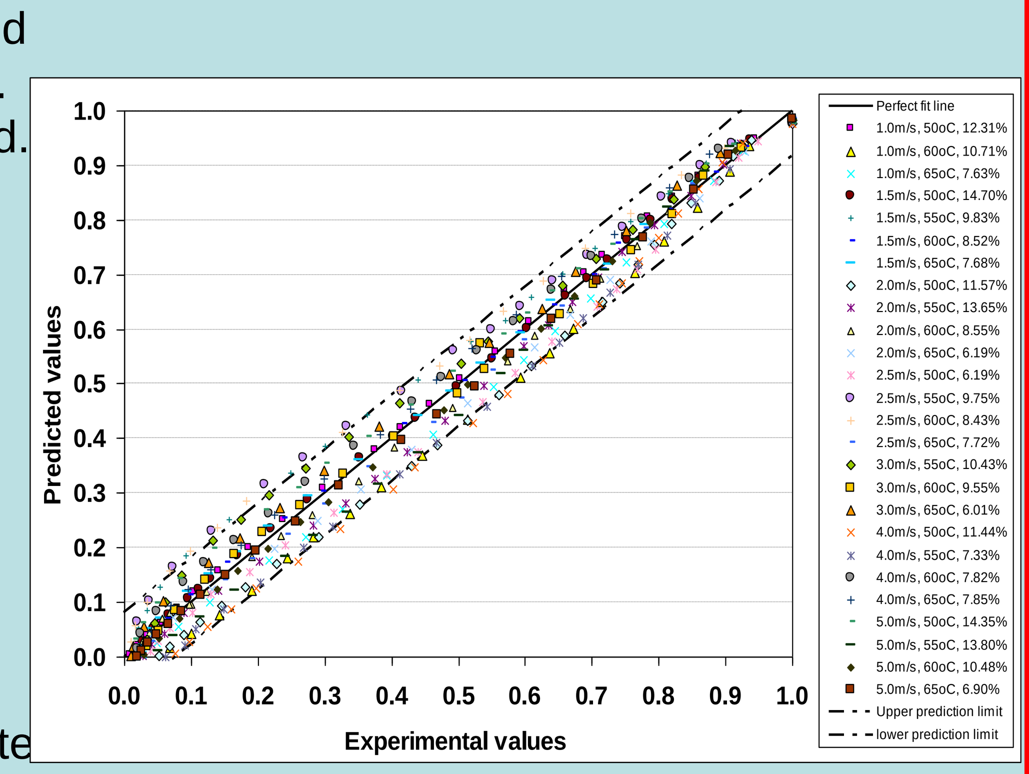

Figure 3. Experimental MR values vs. predicted ones from the derived model

Conclusions

In the present study, seven widely used thin-layer drying models were fitted to experimental data obtained from air drying of mushrooms in air temperature range 50–65 ^oC and velocities, 1.0 m/s up to 5.0 m/s. The analysis based on non–linear regression methods, investigated model capability to efficiently simulate convective drying of mushrooms for the entire experimental range of temperature and velocity values. Regression coefficients for all models were calculated and finally the logarithmic model exhibited the best performance in fitting the experimental data. Relations between the model parameters and the drying conditions as well as mushroom initial mean surface for the calculation of the moisture ratio in relation to drying time were determined and reported.

Acknowledgements

References [As they are presented in the full paper.]

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