Proceedings of the 17th World Congress
The International Federation of Automatic Control
Seoul, Korea, July 6-11, 2008

Fuzzy logic application to drying kinetics modelling

Henry A. Váquiro *. José Bon **. José L. Diez ***

**Faculty of Agronomic Engineering, University of Tolima, Ibagué, Colombia (e-mail: hvaquiro@ tal.upv.es).*
*** Department of Food Technology, Polytechnic University of Valencia, Spain (e-mail: jbon@tal.upv.es)*
**** Department of Systems Engineering and Control, Polytechnic University of Valencia,*
Camino de Vera 14, 46022 Valencia, , Spain, (Tel: +34-963877007 ext. 75794; e-mail: jldiez@isa.upv.es)

Abstract:

A Fick's model that includes a Takagi-Sugeno fuzzy model to estimate the effective diffusivity was analyzed. The modelling of drying kinetics on mango trough this diffusional-fuzzy model was compared with the theoretical Fick's model and the empirical Peleg and Weibull models. The identification and validation was performed from experimental drying curves of ripe mango slices (Mangifera indica L. cv. Tommy Atkins) at constant air velocity (4 m/s) and different drying temperatures (40, 50, 60 and 70 ºC). The fuzzy sets for the antecedent of Takagi-Sugeno system were identified by the Gustafson-Kessel clustering algorithm and approximated by membership functions of piecewise exponential form. On identification and validation, the diffusional-fuzzy model showed best results than the Fick's model, whereas it showed little difference with the Weibull and Peleg models. The diffusional-fuzzy model keeps the interpretability of Fick's model, improves the process simulation and avoids phenomenon and property considerations which require additional experimental and modelling work.

1. INTRODUCTION

Over the last years, dehydration food processes have advanced through merging of new technologies that make possible a more deep and complete study of processes. On this way, the modelling techniques have been applied for process design, control and optimization, as well as the study and research of involved phenomena (Mujumdar, 2006a).

These efforts has been realized on hot-air drying, one of the most ancient, common and diverse processes of conservation. Also, it is one of the industrial activities that demand more energy resources (Mujumdar, 2006b), in consequence, it causes considerable environmental effects, at the same time that affects significant parameters of commercial acceptance as organoleptic and nutritional quality of products (Jayaraman & Das Gupta, 2006, Raghavan & Orsat, 2006).

In order to advance on drying technologies, R&D approach leads to techniques that offer quality products and reduce the environmental impact by means of industrial energy efficiency. This approach includes, in relevant way, the establishment of mathematical models to study, develop or improve new or existing process and equipments (Mujumdar, 2006a).

The fuzzy modelling uses artificial intelligence techniques to model non-linear systems by sub-models integration. It is an alternative methodology on some complex processes that do not enable an effective application of traditional modelling techniques and require approximated and fast solutions (Diez, 2003, Labadini & Baker, 2006, Ross, 2004).

The mango (*Mangifera indica* L.) performs an important economic role for several nations world-wide. According to levels of production and importation, mango is ranked as the third tropical fruit and occupies the fifth place on all fruits on the world (FAO, 2005). Its dehydration is an alternative in order to utilize production surplus and increase the diversification and offer of added-value products (De La Cruz Medina & García, 2003).

The heterogeneity on solid-soluble and fiber content within a mango fruit could influence on the mechanisms that govern the drying process and difficult the representation by the diffusion model when the material properties are considered constant.

In this study the modelling of drying kinetics on mango trough a Fick's model that includes a Takagi-Sugeno fuzzy model to estimate the effective diffusivity was analyzed. Thus, an alternative model to improve the process simulation was obtained. The resulting estimations were compared with the theoretical Fick's model and the empirical Peleg and Weibull models.

2. PRELIMIMARIES

In the case of foods and other biological materials, the convective drying normally describes the water removal process from a solid material by exposition to a hot-air flux. It is an operation realized to minimize the chemical and enzymatic reactions or prevent the microbial growing and degradation by reducing to a given level the moisture content. This technology occupies an important place on the foodstuff transformation and post-harvest treatments. Also, it entails the diminishing of volume and weight of products that, as fruits and vegetables, minimize packaging, storage and transport costs (Jayaraman & Das Gupta, 2006, Raghavan & Orsat, 2006).

The food responses during the drying depend on product and hot-air properties of mass and heat transfer. The knowledge of the temperature and moisture distribution and its evolution through time is essential to process and equipment design, quality control and selection of suitable storage conditions and handling practices (Özilgen & Özdemir, 2001).

On the drying process, the variables of interest can be estimated by mathematical models that represent the mass and heat transport phenomena within the product**.** In this sense, the diffusion model based on the Fick's second law is one of the most used and cited for agro-food applications. This theoretical model relates the experimental results to physic laws (García-Pascual *et al.,* 2006).

The variation of moisture content across an infinite slab of material as function of time using the Fick's second law, considering that moisture transport from interior to surface is mostly performed by liquid diffusion and the material is homogeneous and isotropous, can be expressed as (Crank, 1975, García-Pascual *et al.,* 2006):

$$\frac{\partial M(r,t)}{\partial t} = \frac{\partial}{\partial r}\left(D_e \frac{\partial M}{\partial r} \right). \quad (1)$$

$M(r,t)$ is the local moisture content at time t (kg water / kg dried solid), t is the time (s), D_e is the effective diffusivity (m^2/s) and r is the distance at slab centre in thickness direction (m).

The formulation of the mass transport process on the slab proceeds defining its initial and boundary conditions. The initial moisture content in the slab is uniform (2). The condition of system symmetry for the geometry is assumed (3). The moisture content at surface corresponds to equilibrium moisture content with hot air (4) when the effect to external resistance mass transfer is negligible (Simal *et al.,* 2003).

$$M(r,0) = M_0 . \quad (2)$$

$$\frac{\partial M(0,t)}{\partial t} = 0 \leftrightarrow t = 0 . \quad (3)$$

$$M(L,t) = M_e . \quad (4)$$

$M(L,t)$ is the moisture content in the surface at time t (kg_w/kg_{ds}), M_e is the equilibrium moisture content (kg_w/kg_{ds}), L is the slab half-thickness (m).

In the empirical models the proposed by Peleg, to describe the sorption curves, also has been used on the dehydration and rehydration modelling on diverse foodstuffs (Ruíz-Díaz *et al.,* 2003, Simal *et al.,* 2003, García-Pascual *et al.,* 2006). The Peleg model applied to dehydration as shown in (5), where $\overline{M}$ is the average moisture content (kg_w/kg_{ds}), M_0 is the initial moisture content and, k_{P1} and k_{P2} are the model parameters.

$$\overline{M} = M_0 - \frac{t}{k_{P1} + k_{P2} t} . \quad (5)$$

Other important empirical model is the probabilistic Weibull model, which describe the degradation kinetic of foodstuff submitted to stress conditions by a given time. This has been employed to describe the drying on diverse products in the form of Page's model (García-Pascual *et al.,* 2006):

$$\overline{M} = M_e + (M_0 - M_e)\, exp\left(-\left(\frac{t}{k_{w2}} \right)^{k_{w1}} \right). \quad (6)$$

Here, k_{w1} and k_{w2} were the shape and scale parameters respectively.

3. METODOLOGY

From experimental information, three kinds of models were used to describe the drying kinetic: the theoretical Fick's model, the empirical models of Peleg and Weibull, and the Fick's model that integer the fuzzy model to calculate the effective diffusivity.

Matlab® was used as computational platform to program the algorithms of fuzzy-model identification, theoretical and empirical model identification, and numerical solving of partial differential equations of Fickian models.

3.1 Experimental information

Physical and chemical product properties are significant on movement moisture mechanisms that govern the mango drying process. The mango fruit commonly has fibrous pulp, with high content of soluble solids and water. Its heterogeneous ripening process is more pronounced at the exterior and the sunlight incidence zones. This characteristics influence on the existence of zones with different solid-soluble and fiber content, fiber orientation and consistency within a mango fruit. Likewise, on drying process they cause a product response of difficult representation by conventional theoretical models. Particularly, in the models based on the diffusion theory, the influence of those characteristics on the shrinking and internal resistance to transport phenomena should be assumed, raising in a substantial manner the complexity without to improve the solving accuracy.

The identification and validation of the considered models was performed from experimental data for drying curves of ripe mango slices (*Mangifera indica* L. cv. Tommy Atkins, ºBrix = 13.01 ± 0.93, acidity = 0.516 ± 0.078 % malic acid, thickness = 5 mm), dried by hot air at constant conditions during the process. The experiments was realized four times at 40, 50, 60 and 70 ºC and 4 m/s hot air conditions until a average moisture content around of 0.25 kg_w/kg_{ds} (Fig. 1). Three of the temperature series were used to fuzzy sets and model parameters identification, while the last one was used to model validations.

Through the discrete differentiation of average moisture content as function of time the drying rate was calculated. The drying rate and the average moisture content (Fig. 2) were selected as input variables to identify the fuzzy sets in the Takagi-Sugeno model, since the diffusion usually depends on moisture content and symbolizes the transport coefficient in the diffusional mass transfer phenomena that govern the drying mechanisms (Saravacos, 2005).

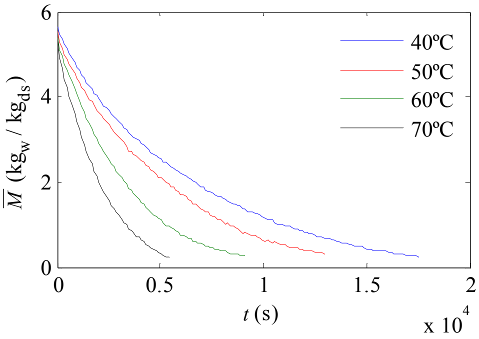

Fig. 1. Drying curves: average moisture content vs. time. Experimental data for one temperature series.

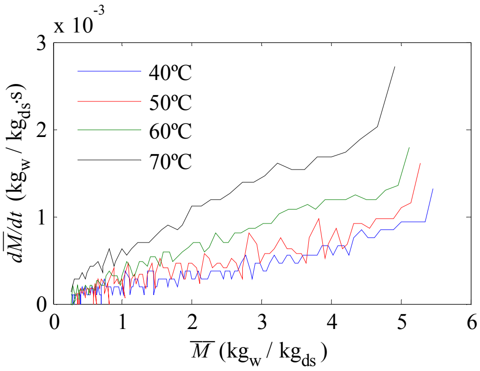

Fig. 2. Drying curves: drying rate vs. average moisture content. Experimental data for one temperature series.

3.2 Diffusional-fuzzy model formulation

In this work the diffusional-fuzzy model concerns to Fick's model that integer a Takagi-Sugeno model for estimating the effective diffusivity.

The Takagi-Sugeno model is a base-rules fuzzy system that combines three fuzzy sets in the antecedent and associates each of them with effective diffusivity coefficients in the consequent. It is used to estimate the effective diffusivity as function of its membership to high, medium and low moisture ranges.

The identification of fuzzy sets was carried out by clustering through application of the *Gustafson-Kessel* algorithm on the normalized input variables (average moisture content and drying rate) (Fig. 3). Thus**, a**ntecedent fuzzy sets were established from the fuzzy partition projected on average moisture content.

The *Zscore* normalization (7) was applied on input variables before clustering because distance norm can be sensitive to variations in the numerical ranges of the different data (Chen *et al.,* 2001). This normalization translates and scales the experimental data so that all the values have zero mean and unit variance.

$$z_j^* = \frac{z_j - \bar{z}}{\sigma}. \qquad (7)$$

Here, z_j^* is the normalized datum of z_j, $\bar{z}$ and σ are the mean and the standard deviation of data respectively. The asterisk denotes the normalized data.

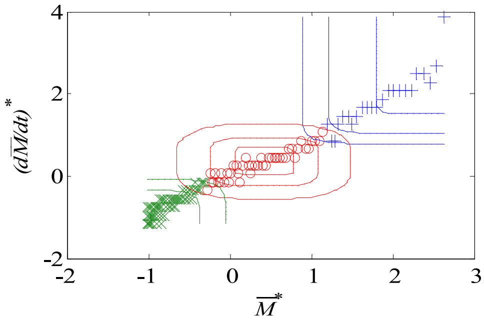

Fig. 3. Fuzzy clustering of normalized drying rate and average moisture content by Gustafson-Kessel algorithm. Data at 40ºC.

The rule-base for the Takagi-Sugeno model were established as (8), where A is the fuzzy partition projected on $\overline{M}$, A_i is the antecedent fuzzy set for each class i (i = 1, 2, 3), D_i is the effective diffusivity coefficient (m^2/s) in the consequent associated to each antecedent fuzzy set.

$$\begin{aligned} &R_1 : If\ \overline{M}\ is\ A_1\ then\ D_1.\\ &R_2 : If\ \overline{M}\ is\ A_2\ then\ D_2.\\ &R_3 : If\ \overline{M}\ is\ A_3\ then\ D_3.\end{aligned} \qquad (8)$$

The fuzzy partitions were approximated by membership functions of piecewise exponential form (Fig. 4) to represent mathematically each antecedent fuzzy set.

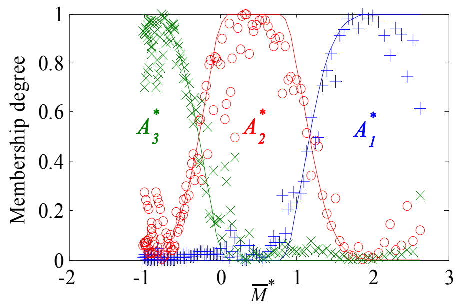

Fig. 4. Projection of fuzzy partition A^* over normalized moisture content $\overline{M}^*$ and approximation of membership functions. Data at 40ºC.

The denormalized membership functions are shown in (9), (10) and (11).

$$A_1(\overline{M},\alpha_1,\alpha_1,\beta) = \begin{cases} 1 - A_2 - A_3 \ \ if\ \overline{M} < \alpha_1. \\ 1 - A_2 \ \ if\ \overline{M} > \alpha_1. \end{cases} \qquad (9)$$

$$A_2(\overline{M},\alpha_1,\alpha_2,\beta)=\begin{cases} e^{-\left(\frac{\overline{M}-\alpha_1}{\beta}\right)^2} & \text{if } \overline{M}<\alpha_1. \\ e^{-\left(\frac{\overline{M}-\alpha_2}{\beta}\right)^2} & \text{if } \overline{M}>\alpha_2. \\ 1 & \text{if } \alpha_1<\overline{M}<\alpha_2. \end{cases} \tag{10}$$

$$A_3(\overline{M},\alpha_1,\alpha_2,\beta)=\begin{cases} 1-A_2 \text{ if } \overline{M}<\alpha_2. \\ 1-A_1-A_2 \text{ if } \overline{M}>\alpha_2. \end{cases} \tag{11}$$

Posterior to definition of the denormalized membership functions, the global structure of the consequent for the effective diffusivity estimation (12) was established as a function of the effective diffusivity coefficients (D_1, D_2 and D_3) for each range of moisture content:

$$D_f(M,\alpha_1,\alpha_2,\beta)=A_1D_1+A_2D_2+A_3D_3. \tag{12}$$

The diffusional-fuzzy model (13) is established by including the effective diffusivity Takagi-Sugeno model (12) in the classic Fick's model:

$$\frac{\partial M(r,t)}{\partial t}=\frac{\partial}{\partial r}\left(D_f\frac{\partial M}{\partial r}\right). \tag{13}$$

The average moisture content was calculated by integration of the moisture content profile (local values) in thickness direction using the equation (14).

$$\overline{M}(0,t)=\frac{1}{L}\int_0^L M(r,t)dr. \tag{14}$$

3.3 Solving and parameter identification

Fick (1) and diffusional-fuzzy (13) models were solved numerically considering the initial and boundary conditions (2), (3) and (4). Although the analytical solution of the classic Fick's model is possible, the numerical solution was considered to use a same algorithm for the identification and simulation of the models based on Fick's theory (classic and fuzzy). Then, the numeric solution of the partial differential equation was accomplished by the *pdepe* Matlab function, tool that solves systems of elliptic and parabolic partial differential equations in one spatial dimension and time.

Optimization problems to find the parameters for Fick, Peleg, Weibull and diffusional-fuzzy models were formulated to identify the optimal parameters that minimize the root mean square deviation between experimental and estimated data (15). As parameters of Fick and diffusional-fuzzy models a constant effective diffusivity (D_e) and three effective diffusivity coefficients (D_1, D_2 and D_3) were considered, respectively.

$$RMSD=\sqrt{\frac{1}{N}\sum_{j=1}^{N}\left(\overline{M}_j-\overline{M}_j^s\right)^2}. \tag{15}$$

Thus each mathematical model was solved in an optimization algorithm that uses the *fminsearch* Matlab function (multivariate unconstrained non-linear optimization based on the Simplex method).

3.4 Statistical analysis of parameters

As regards Fick, Peleg, Weibull and diffusional-fuzzy models, the explained variance (16, 17 and 18) was used to assess and compare how close the fit of models were. Note that the explained variance consider the number of model parameters, that vary in each case, to achieve an adequately comparison among them.

$$VAR=\left(1-S_{yx}^2/S_y^2\right). \tag{16}$$

$$S_y^2=\frac{1}{N-1}\sum_{j=1}^{N}\left[\overline{M}_j-\overline{M}_{mean}\right]^2 \tag{17}$$

$$S_{yx}^2=\frac{1}{N-p-1}\sum_{j=1}^{N}\left[\overline{M}_j-\overline{M}_{mean}^s\right]^2 \tag{18}$$

N is the number of data, s superscript denotes the estimated data by the model, VAR represents the relative variance explained by the model S_{yx}^2 with respect to total variance S_y^2, *mean* subscript denote the data average, and p is the number of parameters.

3. RESULTS AND CONCLUSIONS

The parameters of membership functions for the antecedent of Takagi-Sugeno model were defined from averages values (Table 1) since the parameters exhibit similar values to different drying temperatures (fig. 5).

Table 1. Parameters of denormalized membership functions.

Sample	Drying temp. (ºC)	α_1	α_2	β
1	40	2.090	3.174	0.296
2	40	2.054	3.102	0.252
3	40	1.963	2.979	0.304
4	50	2.167	3.091	0.398
5	50	2.131	2.881	0.384
6	50	2.254	2.743	0.422
7	60	1.980	2.961	0.282
8	60	2.253	3.106	0.432
9	60	2.229	2.989	0.256
10	70	1.971	2.988	0.318
11	70	2.298	3.199	0.388
12	70	2.191	3.182	0.378
Mean		2.153	3.038	0.342

The identification and validation of the models for each drying temperature was done. The parameters identified are shown in Table 2, the models' validation in Fig. 6 and the root mean square deviations and the explained variances in Table 3. The effective diffusivity calculated by Takagi-Sugeno fuzzy model is represented in Fig 7.

The effective diffusivity coefficients identified for the Takagi-Sugeno model were inversely proportional to moisture content of the sample: 8.99e-11, 3.84e-10 and 5.19e-10 m^2/s at 40ºC; 9.31e-11, 4.57e-10 and 7.15e-10 m^2/s

at 50ºC; 1.60e-10, 6.73e-10 and 1.03e-9 m^2/s at 60ºC; 1.17e-10, 1.08e-9 and 1.65e-9 m^2/s at 70ºC; for moisture ranges of high (3.3 to 6 kg_w/kg_{ds}), medium (1.8 to 3.3 kg_w/kg_{ds}) and low (0 to 1.8 kg_w/kg_{ds}) respectively (Table 2).

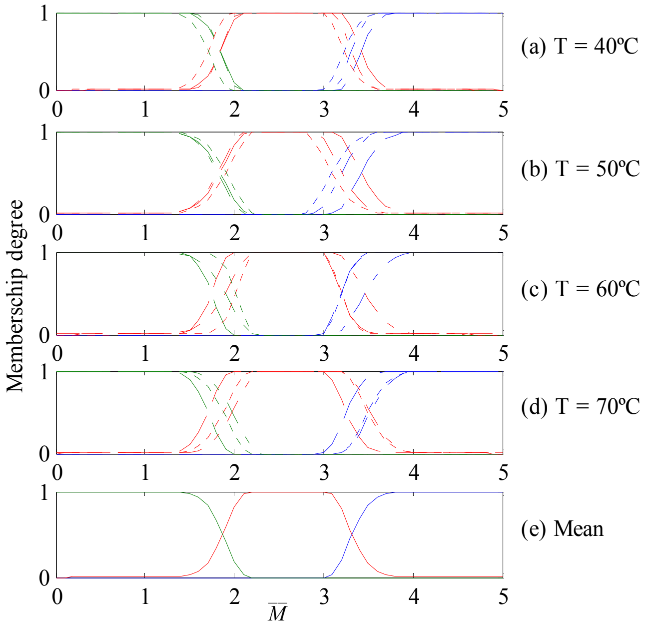

Fig. 5. Denormalized membership functions.

Table 2. Model parameters: Averages of three identified values for each temperature.

Model parameters	Drying temperature (ºC)			
	40	50	60	70
Fick D_e	3.56E-10	4.28E-10	6.35E-10	9.68E-10
Peleg				
k_{p1}	827.0	806.9	455.3	372.7
k_{p2}	0.119	0.120	0.104	0.118
Weibull				
k_{w1}	1.011	1.063	1.046	1.080
k_{w2}	5758	4787	3244	2112
Diffusional-fuzzy				
D_1	8.99E-11	9.31E-11	1.60E-10	1.17E-10
D_2	3.84E-10	4.57E-10	6.73E-10	1.08E-10
D_3	5.19E-10	7.15E-10	1.03E-9	1.65E-9

On identification and validation, the diffusional-fuzzy model showed best results than the traditional Fick's model, whereas it showed little difference with the empirical Weibull and Peleg models, such as is indicated by root mean square deviations and explained variances in Table 3.

In contradistinction to empirical models that lack of meaning as regards heat and mass transfer phenomena, the diffusional-fuzzy model keeps the interpretability of Fick's model and presents an alternative to effective diffusivity estimation that improves the process simulation. Likewise, it enables to estimate the moisture profiles inside the solid and estimates its evolution through time (Fig. 8), interesting advantages on study, design and optimization of some drying process.

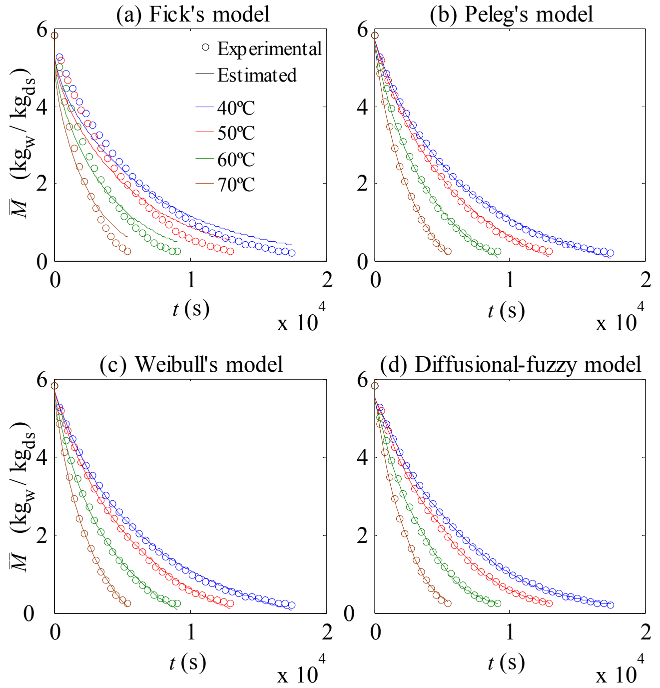

Fig. 6. Model validation: Experimental and estimated data using Fick (a), Peleg (b), Weibull (c) and diffusional-fuzzy (d) models for each drying temperature.

Table 3. Root mean square deviations and explained variances of the considered models. (*) On the identification, *RMSD* and *VAR* correspond to averages of three values for each drying temperature.

Model	*T*(ºC)	Identification*		Validation	
		RMSD	*VAR*	*RMSD*	*VAR*
Fick	40	0.0440	0.9712	0.0457	0.9689
	50	0.0534	0.9594	0.0441	0.9609
	60	0.0502	0.9640	0.0550	0.9568
	70	0.0563	0.9558	0.0465	0.9677
Peleg	40	0.0538	0.9988	0.0437	0.9979
	50	0.0511	0.9988	0.0492	0.9981
	60	0.0543	0.9990	0.0435	0.9978
	70	0.0392	0.9993	0.0463	0.9982
Weibull	40	0.0588	0.9986	0.0609	0.9971
	50	0.0793	0.9971	0.0903	0.9962
	60	0.0907	0.9972	0.0774	0.9969
	70	0.0795	0.9970	0.0723	0.9964
Diffusional-fuzzy	40	0.0046	0.9997	0.0071	0.9983
	50	0.0055	0.9996	0.0062	0.9985
	60	0.0051	0.9996	0.0067	0.9982
	70	0.0095	0.9987	0.0057	0.9986

The resulting Takagi-Sugeno fuzzy model enables to interpret the effective diffusivity as function of moisture content ranges. In addition, diffusional-fuzzy model preserves the mathematic structure and the assumptions of principal govern equation, thus phenomenon and property considerations that require additional experimental and modelling work are avoided. However, the existence of membership functions and effective diffusivity coefficients increase the number of parameters.

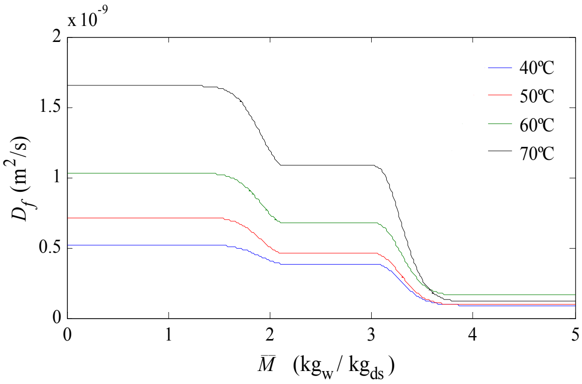

Fig. 7. Effective diffusivity estimated by Takagi-Sugeno fuzzy model.

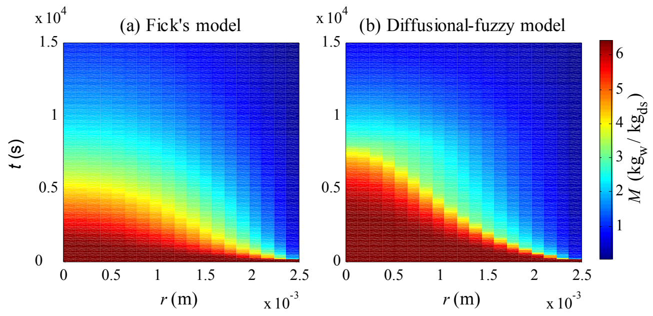

Fig. 8. Estimated moisture profiles by Fick and diffusional-fuzzy models. Data at 40ºC.

From obtained results, it is deduced that fuzzy logic integration to effective diffusivity within the Fick's model improves the simulation of drying process on *Mangifera indica* L.

4. ACKNOWLEDGMENTS

The authors would like to acknowledge the financial support of MCyT project (ref: AGL2006-14146-C02-01).

H.A. Váquiro received a grant from the University of Tolima and COLCIENCIAS (Colombian governmental institute for science and technology development).

5. REFERENCES

Abonyi, J., R. Babuska, L. Nagy and F. Szeifert (2000). Local and global identification for fuzzy model based control. *Proceedings of the Intelligent Systems in Control and Measurement Symposium INTCOM 2000*, 111- 116.

Chen, C.L., H.X. Li and H.P. Huang (2001). Data preprocessing. In. *Fuzzy neural intelligent systems: mathematical foundation and the applications in engineering*. CRC Press, Boca Raton, Florida.

Crank, J. (1975). *The mathematics of diffusion*, 2nd Edn. Oxford University Press, Oxford.

Diez, J.L. (2003). *Técnicas de agrupamiento para identificación y control por modelos locales*. PhD Thesis. Polytechnic University of Valencia, Spain.

FAO (2005). Trade: crops & livestock primary & processed. In: *FAOSTAT*. FAO Statistics Division. Online resource, last checked: 7.Jan.2008. http://faostat.fao.org

De La Cruz Medina, J. and H.S. García (2003). *Mango: post-harvest operations*, In: Compendium on post-harvest operations, chapter XX, AGSI/FAO, Online resource, last checked: 7.Jan.2008. http://www.fao.org/inpho

García-Pascual, P., N. Sanjuán, R. Melis and A. Mulet (2006). *Morchella esculenta* (morel) rehydration process modelling. *J. Food Eng*., Vol.72, 346-353.

Jayaraman, K.S. and D.K. Das Gupta (2006). Drying of fruits and vegetables. In: *Handbook of Industrial Drying*, 3rd Edn (Mujumdar, A.S.(Ed)). CRC Press, Boca Raton, Florida.

Labadini, H.M.S. and C.G.J. Baker (2006). Fuzzy modelling an alternative approach to the simulation of dryers. *Proceedings of the 15th International Drying Symposium IDS 2006*, Vol.A, 258-264.

Martín, B. and A. Sanz (2001). *Redes neuronales y sistemas borrosos*, 2nd Edn. Ra-Ma, Madrid, Spain.

Mujumdar, A.S. (2006a). Innovation and globalization in drying R&D. *Proceedings of the 15th International Drying Symposium IDS 2006*, Vol.A, 3-17.

Mujumdar, A.S. (2006b). Principles, classification and selection of dryers. In: *Handbook of Industrial Drying*, 3rd Edn (Mujumdar, A.S.(Ed)). CRC Press, Boca Raton, Florida.

Nelles, O., A. Fink, R. Babuska and M. Setnes (2000). Comparison of two construction algorithms for Takagi-Sugeno fuzzy models. *Int. J. Math. Comput. Sci.*, Vol.10, 835-855.

Özilgen, M., M. Özdemir (2001) A Review on Grain and Nut Deterioration and Design of the Dryers for Safe Storage with Special Reference to Turkish Hazelnuts. *Crit. Rev Food Sci.,* Vol. 41, 95-132.

Raghavan, G.S.V. and V. Orsat (2006). Recents advances in drying of bio-materials for superior quality bio-products. *Proceedings of the 15th International Drying Symposium IDS 2006*, Vol.A, 44-53.

Reznik, L. (1997). *Fuzzy controllers*. Newnes, Boston.

Ross, T.J. (2004). *Fuzzy logic with engineering applications*, 2nd Edn. John Wiley and Sons Ltd., London.

Ruíz-Díaz, G., J. Martínez-Monzó, P. Fito and A. Chiralt (2003). Modelling of dehydration-rehydration of orange slices in combined microwaveyair drying. *Innovative Food Sci. Emerging Tech*., Vol.4, 203-209.

Saravacos, G.D. (2005). Mass transfer properties of foods. In: *Engineering properties of foods*, 3rd Edn (Rao, M.A., Rizvi, S.S.H, Datta, A.K. (Eds)). CRC Press, Boca Raton, Florida.

Simal, S., A. Femenia, P. García-Pascual and C. Roselló (2003). Simulation of the drying curves of a meat-based product: effect of the external resistance to mass transfer. *J. Food Eng*., Vol.58, 193-199.