MOISTURE RATIO PREDICTION IN DRYING PROCESS OF AGRICULTURAL PRODUCTS: A NEW CORRELATION MODEL

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ABSTRACT. *In this study, a new prediction model for fluidized bed drying is proposed. This correlation model has been developed by using Rayleigh dimensional analysis method. To obtain experimental results, a fluidized bed drying set-up was constructed and used in batch conditions. The prediction performance of the proposed model has been tested by using some agricultural products such as corn, bean, and chickpea. A good agreement is observed between the experimental and the model results. Correlation coefficient (R^2) and root mean square error (RMSE) values were obtained as acceptable. In addition, another fluidized bed drying data were collected from the literature and used for showing the prediction performance of the model. Comparative evaluation results show that the proposed model can be used in prediction of moisture ratio (MR) for agricultural products. The absence of a general model for MR prediction in literature makes the proposed model valuable.*

Keywords. *Fluidized bed drying, Prediction model, Agricultural products.*

Drying is the removal of moisture or liquid from a wet solid. Drying is also a process of simultaneous heat and mass transfer. Heat is required for volatilization and it is applied to the particles of materials to remove moisture steam from materials. Heat is transported by convection from the surroundings to the particle surfaces and from there, by conduction, further into the particle. Moisture is transported in the opposite direction as a liquid or steam; on the surface it volatilizes and passes on by convection to surroundings (Syahrul et al., 2003). In agricultural industries, drying process is important for grains. Various drying methods have been used in industries, for example, the use of cabin, infinite band tunnel, rotary cylindrical, fluidized bed, and spray drying, etc. Depending on the particle size and the nature of feed, the preferred method is changed as spray drying, flash drying, or fluidized bed drying. Fluidized beds are generally operated with wet solid feeds. Industrial fluidized bed dryers are the most popular family of dryers for drying agricultural and chemical products in dispersion or multi-dispersion state (Topuz et al., 2004).

Fluidized bed drying among the others has some advantages. These advantages can be summarized as: (a) the good contact between particles and drying gas supplies, (b) high heat and mass transfer rates, (c) uniform temperature and bulk moisture content of particles, (d) a temperature control and an operation up to the highest temperature of the operation, (e) less drying time due to high rates of heat and mass transfer, (f) ease in the operation and the maintenance of the dryer, (g) adaptability to automation, (h) combining several processes such as mixing, classification, drying, and cooling (Izadifar and Mowla, 2003; Topuz et al., 2004).

In the literature, there are several studies on fluidized bed drying of agricultural and other granular materials. They include Ozbey and Soylemez (2005), wheat grains; Goksu et al. (2005), macaroni beads; Senadeera et al. (2003), green beans, potatoes, and peas; Syahrul et al. (2003), wheat and corn; Izadifar and Mowla (2003), paddy rice; Prakash et al. (2004), blanched carrots; Walde et al. (2006), mushroom; Chen et al. (2001), coal; Temple and van Boxtel (1999), black tea; Kashaninejad et al. (2005), pistachio nuts; Soponronnarit et al. (2001), soybeans; Shi et al. (2000), wet sand, glass beads and sliced foods; Mizota et al. (2004), anhydrous lactulose; Topuz et al. (2004), hazelnuts; Tasirin et al. (2007), bird's chilies; Srinivasakannan and Balasubramanian (2008), ragi; Madhiyanon (2009), chopped coconut; Tatemoto et al. (2007), silica gel beads; Srinivasakannan and Balasubramanian (2009), green pepper. Additionally, the mathematical modeling and the thermal analysis of the drying process have been studied in many works in the literature. Some of these works are: Garnavi et al. (2006) have proposed a numerical simulation method based on a two-phase theory of the fluidization. Izadifar and Mowla (2003) have developed a mathematical model to simulate the drying of moist paddy in a cross flow continuous fluidized bed dryer. Cil and Topuz (in press) have investigated effects of the fluidizing air temperature and velocity on the drying performance of the agricultural products by carrying out a series of tests. Batch drying experiments has been conducted by applying three different air temperature and two different air velocities. Results revealed that the drying air temperature has the greatest effect on the drying kinetics of particles whereas air velocity has a small effect. Debaste et al. (2008) have developed a new mathematical model which uses Fick's Law model molecular diffusion of vapor inside the tortuous porous medium. Souraki et al. (2009) have investigated the drying behavior of cylindirical samples of carrots in a microwave-assisted fluidized bed of inert particles. In their work, a numerical solution was developed

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for the proposed model using an implicit finite difference method in one dimensional system. In addition to aforementioned works, the following mathematical models have been used for the drying process: the Henderson and Pabis, the Lewis, the Page, the Thompson, the Wang and Shing Models are used for thin layer drying process; two-phase and three-phase models are used for fluidized bed drying process (Ozdemir and Devres, 1999; Topuz et al., 2004). Lastly, Fudholi et al. (2010) have written a review article about solar dryers for agricultural and marine products. Vadivambal and Jayas (2007) have investigated in their review article, the changes in quality of microwave-treated agricultural products.

In this study, a new prediction model for fluidized bed drying is suggested. This model is developed by using Rayleigh method which uses dimensional analysis to provide an aid in efficient handling, interpretation, and correlation of experimental data.

CORRELATION MODEL

In order to obtain a generalized prediction model of MR, Rayleigh method was used. Rayleigh method uses the dimensional analysis to obtain the mathematical model of the relationship among the variables which affect the process.

Dimensional analysis provides a strategy for choosing relevant data and how it should be presented. This is a useful technique in all experimentally based areas of engineering. If it is possible to identify the factors involved in a physical situation, dimensional analysis can form a relationship between them. Dimensions are properties which can be measured. Units are the standard elements to use quantify these dimensions. In dimensional analysis, it should be only concerned with the nature of the dimension i.e. its quality not its quantity. The result of performing the Rayleigh dimensional analysis method on a physical problem is a single equation. This equation relates all of the physical factors involved to one another. This is probably best seen in an example. In order to find the force on a propeller blade it must be first decided what might influence this force. It would be reasonable to assume that the force, F, depends on the following physical properties: diameter, d; forward velocity of the propeller (velocity of the plane), u; fluid density, ρ; revolutions per second, N; fluid viscosity, μ. Before doing any analysis, this equation can be written:

$$F = \phi\ (d, u, \rho, N, \mu) \tag{1}$$

where ϕ is an unknown function. These can be expanded into an infinite series which can itself be reduced to:

$$F = K\ d^m\ u^p\ \rho^q\ N^r\ \mu^s \tag{2}$$

where K is some constant and m, p, q, r, s are unknown constant powers. From dimensional analysis, these powers can be obtained. The value of K or the function ϕ must be determined from experiment. The knowledge of the dimensionless groups often helps in deciding what experimental measurements should be taken (Sleigh and Noakes, 2008).

In this work, fluidized bed drying setup was used for drying experiments. Fluidized bed technology can be summarized as follows: This is an expanded condition in which the solids particles are supported by drag forces caused by the gas phase passing through the interstices among the particles at some critical velocity. It is an unstable condition in that the superficial gas velocity upward is less than the terminal settling velocity of the solid particles; the gas velocity is not sufficient to entrain and continuously convey all the solids. At the same time, there exist, within the stream of the gas, eddies traveling at high enough velocities to lift the particles temporarily. Particle motion is continually upward and falling back. Specifically, the solid phase and gas phase are intermixed and together behave like a boiling fluid. Fluidized bed dryers have found widespread applications for drying of particulate or granular solids in the chemical, food, ceramic, pharmaceutical, agriculture, polymer and waste management industries.

Rayleigh dimensional analysis method can be used for MR prediction of fluidized bed drying process. The variables which affect the process are arranged as follows:

$$MR = f(\rho, c_p, k, d, D, V, T_a, T_{evap.}, t) \quad \text{then}$$

$$MR = A\,\rho^a\ c_p^b\ k^c\ d^e\ D^f\ V^g\ T_a^h\ T_{evap.}^i\ t^j \tag{3}$$

where ρ, c_p, k, d, D, V, T_a, $T_{evap.}$, t are variables for fluidized bed drying process, A is a constant, and a, b, c, e, f, g, h, i, j are exponents. By using Rayleigh dimensional analysis method, a mathematical prediction model was obtained. The obtained model is given in equation 4:

$$MR = A\left(\frac{k}{\rho\, c_p D}\right)^a \left(\frac{V\,t}{d}\right)^b \left(\frac{T_a}{T_{evap.}}\right)^c \tag{4}$$

Since the drying curve is decreasing exponentially, equation 4 is changed as in equation 5.

$$MR = A\left(\frac{k}{\rho\, c_p D}\right)^a \left(\frac{b\,V}{d}\exp(-ct)\right)\left(\frac{T_a}{T_{evap.}}\right)^e \tag{5}$$

This change is made to add the exponentially decreasing effect to the model. This change does not violate the objective of equation 4.

EXPERIMENTAL APPLICATION

An experiment was made to observe the MR of the agricultural products such as corn, bean, and chickpea. In the store condition, the initial moisture content of corn, bean, and chickpea are in the level of 10.91%, 10.74%, and 9.81% on a dry basis, respectively. Before the experiments, all of materials were re-humidified by holding in water along 4 h for corn, 2 h for bean, 3.5 h for chickpea, in order to provide same MR for all particles of each product. Then, moisture contents of the corn, bean, and chickpea were obtained 23.75%, 14.9%, 52.7% on a dry basis, respectively. Other properties of the particles can be found in table 1.

For the experiments, a laboratory-scaled fluidized bed drying system was constructed and used as shown in figure 1. The experimental setup consists of a fluidization column, perforated plate, pre-heater and last heater, frequency

Table 1. Physical properties of the samples (literature).

Sample	Property	Value	Unit
Corn	d	6.45	mm
	c	1535	J/kg K
	ρ	1260	kg/m^3
	k	0.143	W/m°C
Bean	d	9	mm
	c	1300	J/kg K
	ρ	1230	kg/m^3
	k	0.132	W/m°C
Chickpea	d	7	mm
	c	1980	J/kg K
	ρ	1380	kg/m^3
	k	0.24	W/m°C

inverter, five thermocouples, two temperature and humidity measurement sticks, pitot tube, three pressure measurement sticks, electricity panel, isolation materials and fittings. The bed column was made up of iron with 200-mm inner diameter, 1000-mm height, and 2-mm wall thickness. To obtain uniform distribution of the fluidizing air, a perforated plate (2-mm thickness and with 4-mm holes) was used. Pre-heater and last heater (consist of 11 strip electric elements) were used for heating the bed air and their capacity was 5 and 6 kW, respectively. The bed air was provided by centrifugal blower and a frequency inverter was used for changing the revolution. The temperature distribution through the bed was measured by type K thermocouple (0.1 °C resolution) at different heights (8, 14, 20, 26, 32 cm) above the distributor plate. The pressure differences between the two sides of distributor plate, and the height of distributor plate and the height of fluidized bed, were measured by using an electronic pressure cell (Testo 506, 1-Pa resolution). Inlet and outlet humidity of the bed air were measured by using a humidity measurement stick (Testo hygrotest 600pht is based on two wire technology which are used to convert non-electrical parameters, e.g. temperature, pressure, relative humidity etc. to an electrical standard signal of 4 to 20 mA). All of thermocouples and humidity sticks were connected to a PC through a data acquisition system. By using the data acquisition system, the temperature and the humidity data were collected and stored on the PC in a 5-s period. To measure and determine the air velocity, a pitot tube and an electronic pressure cell were used. The moisture content of the particles was observed by using of a Precisa XM60 moisture analyzer utilizing infrared drying (In this process, moisture is removed from the sample by heating. The difference between the initial weight and the final weight yields the moisture content of a sample). Before launching experiments, the pitot tube was calibrated and minimum fluidizing velocities (The basis of the theory for prediction of minimum fluidization velocity is that the pressure drop across the bed must be equal to the effective weight per unit area of the particles at the point of incipient fluidization) for corn, bean, and chickpea were observed at 4.6, 3.68, and 4.59 m/s, respectively.

All experiments were conducted under batch fluidization. First, the blower and heater were turned on and waited until reaching the required temperature for the system. When the required experiment temperature was reached, the blower was turned off instantly and particles (700 g) were placed in the fluidized bed and then the air blower was turned on again. In order not to cause temperature change, this part of the

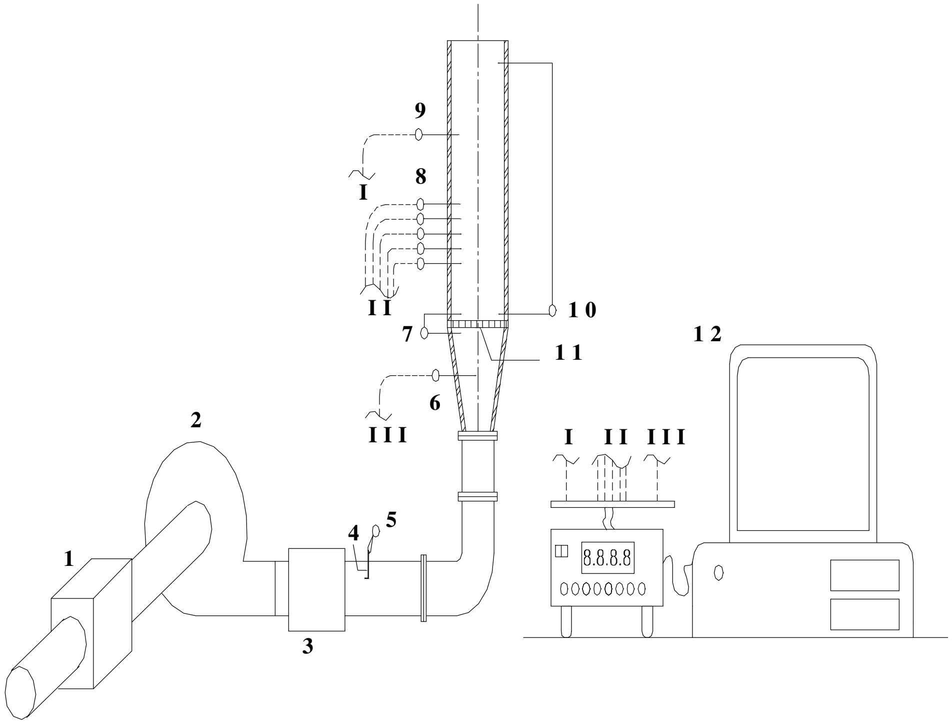


Figure 1. Schematic diagram of experimental setup. [1: Pre-heater (for heating of inlet air), 2: Fan, 3: Last heater (for heating of inlet air), 4: Pitot tube, 5-7-10: Pressure cell (for measurement pressure drop. 5: to observe inlet air velocity with pitot tube, 7-10: to measure distributor plate and fluidized bed pressure drop, respectively), 6-9: Humidity stick (for measurement of inlet and outlet air humidity), 8: Thermometers (for measurement of fluidized bed air temperature at 8, 14, 20, 26, 32 cm of bed), 11: Perforated plate, 12: Data acquisition system and PC].

experiment was carried out in a very short time. As fluidization continued, solid samples (approximately 10 - 15 g) were removed from the column at different times and were analyzed for their moisture content. In order to detect of effectiveness of the temperature and velocity, three different temperatures and two different velocity of drying air were applied. Detailed information about experimental conditions (air temperature and velocity used in the experiment) can be seen in table 2.

In order to estimate the parameters of the fitted prediction model for MR, the experimental results were recorded for each particle under specified conditions. The parameter estimation process of fitted model was explained in the next section.

ESTIMATING THE PARAMETERS OF FITTED MODEL

For parameter estimation of the model which is given in equation 5, a mixed data set for the corn, bean, and chickpea was used. IGARSET optimization algorithm was used to estimate the model parameters. IGARSET is a heuristic optimization algorithm which was developed by Hamzaçebi (2008) for function optimizations which is hard to be solved by deterministic techniques.

If a simple genetic algorithm (SGA) is well designed, the best of the population may converge to an optimal solution to the specified problem. However, because of its stochastic behavior, a SGA may suffer from slow covergence. Besides, the accuracy of found best solution may vary with the problem under consideration. Because of these disadvantages, several studies are dialed with improving the performance of SGA, such as binary encoded genetic algorithm.

In the Hamzacebi (2008), a two-phased algorithm is suggested in order to find optimum solution of continuous functions. The first phase is global search phase by GA and the second phase is the local search around the found best solution by GA. The local search phase is a dynamic random search method. IGARSET uses SGA in order to find optimum or near the optimum solution of function. After SGA search (this process is global search phase of algorithm) the local search phase starts. The obtained results in the global search phase are used as initial points of local search.

In the local search phase, the search process is carried around the found solution in global search phase. The algorithm produces dx vector from (-α α) range to adjust moving step sizes for each variable. The values of α is made smaller after an obvious search number by setting the new value half of previous value. This process continues until stop criterion is met. The aim of this phase is to investigate the existence of a better solution, with small search steps.

Table 2. Model performance criterion for each particle.

Particles	Experimental Conditions	R^2	RMSE
Corn	Ta=70.1 C, V=5 m/s	0.957	0.106
	Ta=36.2 C, V=5 m/s	0.904	0.215
	Ta=47.1 C, V=5 m/s	0.942	0.156
	Ta=47.1 C, V=6.2 m/s	0.988	0.068
Bean	Ta=70.1 C, V=5 m/s	0.984	0.075
	Ta=47.1 C, V=6.2 m/s	0.982	0.092
	Ta=47.1 C, V=5 m/s	0.941	0.169
	Ta=35.6 C, V=5 m/s	0.921	0.205
Chickpea	Ta=60.1 C, V=5.4 m/s	0.993	0.050
	Ta=47.1 C, V=5.4 m/s	0.964	0.128
	Ta=36.1 C, V=5.4 m/s	0.952	0.151
	Ta=60.1 C, V=6.3 m/s	0.969	0.104

Further information about IGARSET can be found in the reference (Hamzacebi, 2008). Therefore, IGARSET algorithm can be used to estimate the parameters of equation 5.

After the parameter estimation, the obtained model was tested with a different mixed data set called the test set. Also the model was tested separately with the data that belongs to the corn, bean, and chickpea, respectively. The estimated model is given by:

$$MR = 0.044262 \left(\frac{k}{\rho\, c_p\, D} \right)^{0.032946} \frac{0.026486\ V}{d}$$

$$\exp(-0.000204\ t) \left(\frac{T_a}{T_{evap.}} \right)^{0.050898} \tag{6}$$

RESULTS AND DISCUSSIONS

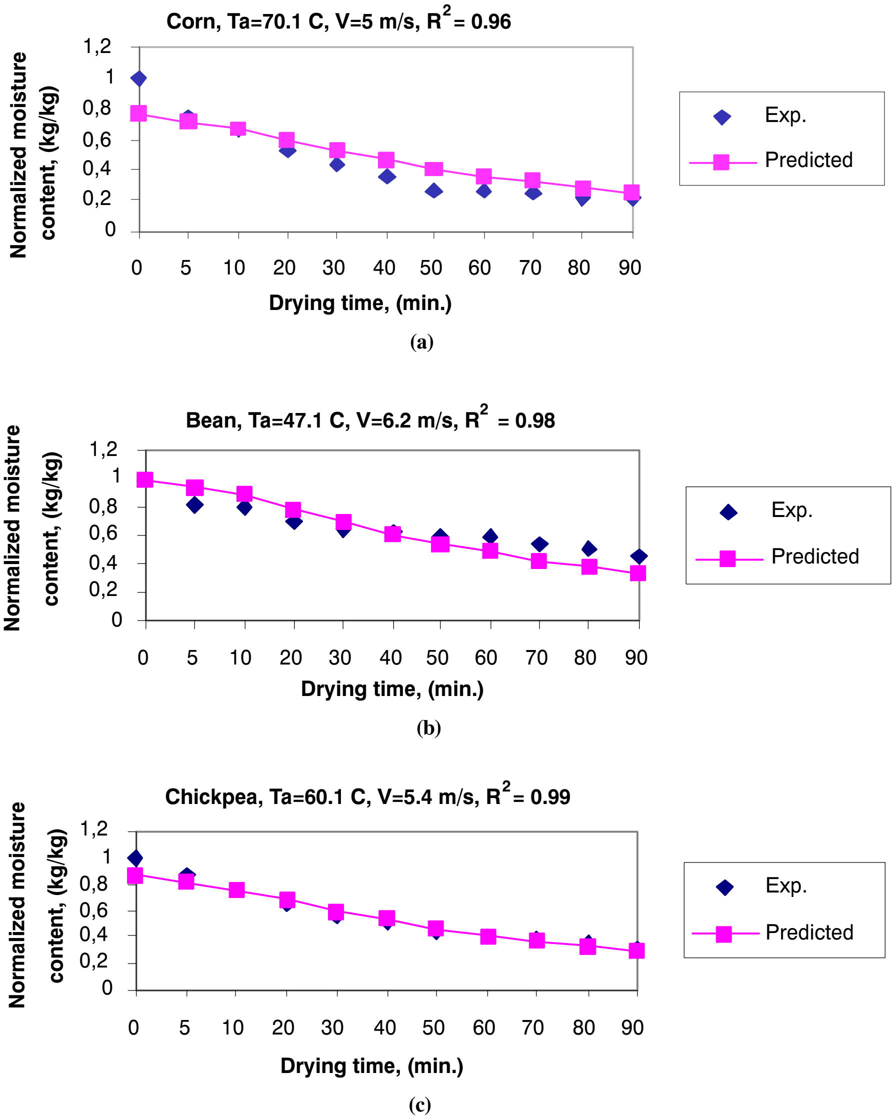
By using equation 6, the predicted values of the MR for all particles were obtained. The model performance is shown in figure 2 for the modeling phase and in figure 3 for the testing phase. The values of R^2 for the prediction model in the modeling set and in the test set are greater than 0.95. These results show that the model is satisfactory successful in prediction of the MR. In addition to the modeling and the test phases, the MR was predicted by using the model for each particle under all experimental conditions to observe the model performance. Besides correlation coefficient, root mean square errors (RMSE) were used as performance criterion. Table 2 shows the R^2 and RMSE values of the model for each particle.

In order to prove the prediction performance of the proposed correlation model, fluidized bed drying of green pepper data were collected from the literature. Srinivasakannan and Balasubramanian (2009) have investigated the drying kinetics of green pepper in a fluidized bed dryer. Comparing the experimental and model results can be seen in figure 4. The correlation coefficient and RMSE values were obtained as 0.99; 0.054, respectively.

It can be deduced from table 2 and figure 4 that the proposed model works successfully in prediction of MR of agricultural products. Hence, the model can be generalized for most of agricultural products. However the other models in the literature are particle specific and contain author's adjusted parameters, therefore not prone to generalization.

CONCLUSIONS

In the literature, several mathematical models for fluidized bed drying have been developed. But most of them depend on the characteristics of particles. In this study, a new



(a)

(b)

(c)

Figure 2. Drying curves and model performance in modeling phase for corn, bean and chickpea. (a) Drying curve for corn (T_a = 70.1°C, V = 5 m/s), (b) Drying curve for bean (T_a = 47.1°C, V = 6.2 m/s), (c) Drying curve for chickpea (T_a = 60.1°C, V = 5.4 m/s).

correlation model which does not depend on the characteristics of particles is developed. Comparison of the experimental and the proposed model results shows that there is a good agreement between them. The new model was tested with another agricultural products data collected from the literature. Correlation coefficient and RMSE values were obtained as acceptable. The prediction of MR of grain provides significant information for drying process. By using the proposed model, the MR of particle in fluidized bed drying process can be predicted without experimental study. Authors are recommended that this model can be improved by using other grains in experimental studies by researchers.

REFERENCES

Chen, Z., Agarwal P. K. and Agnew J. B. 2001. Steam drying of coal: Part 2. Modeling the operation of a fluidized bed drying unit. *Fuel* 80(2): 209-223.

Cil, B., and Topuz A. (In press). Fluidized bed drying of corn, bean and chickpea. *J. Food Process Eng.* DOI: 10.1111/j.1745-4530.2008.00327.x.

Debaste, F., Halloin V., Bossart L. and Haut B. 2008. A new modeling approach for the prediction of yeast drying rates in fluidized beds. *J. Food Eng.* 84(2): 335-347.

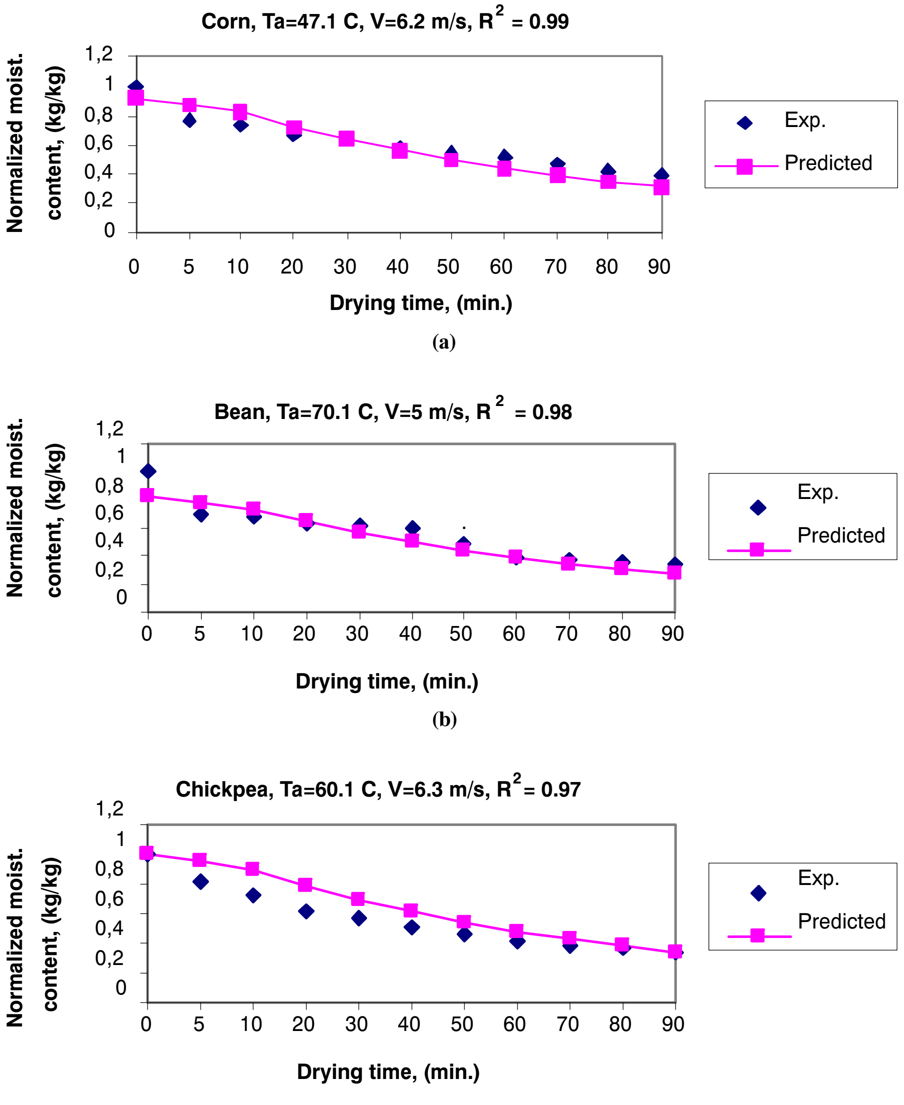
Fudholi, A., Sopian K., Ruslan M. H., Alghoul M. A. and Sulaiman M. Y. 2010. Review of solar dryers for agricultural and marine products. *Renewable and Sustainable Energy Reviews* 14(1): 1-30.

Garnavi, L., Kasiri N. and Hashemabadi S. H. 2006. Mathematical modeling of a continuous fluidized bed dryer. *Intl. Communication in Heat and Mass Transfer* 33(5): 666-675.

Göksu, E. I., Sumnu G. and Esin A. 2005.Effect of microwave on fluidized bed drying of macaroni beads. *J. Food Eng.* 66(4): 463-468.

Hamzaçebi, C. 2008. Improving genetic algorithms' performance by local search for continuous function optimization. *Applied Mathematics and Computation* 196(1): 309-317.

Izadifar, M. and Mowla D. 2003. Simulation of a cross-flow continuous fluidized bed dryer. *J. Food Eng.* 58(4): 325-329.



(a)

(b)

(c)

Figure 3. Drying curves and model performance in test phase for corn, bean and chickpea. (a) Drying curve for corn (T_a = 47.1°C, V = 6.2 m/s), (b) Drying curve for bean (T_a = 70.1°C, V = 5 m/s), (c) Drying curve for chickpea (T_a = 60.1°C, V = 6.3 m/s).

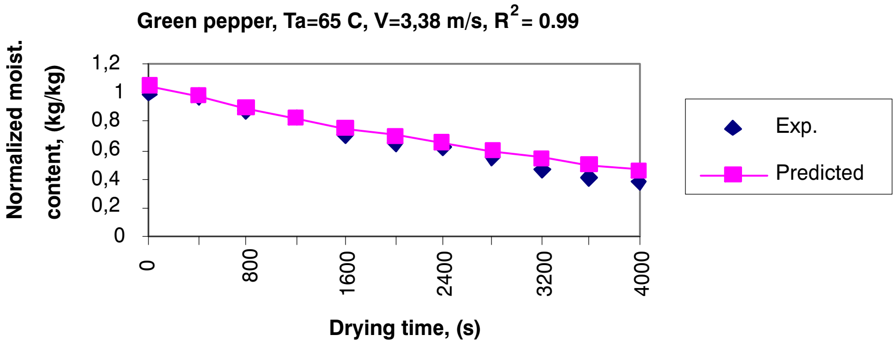


Figure 4. Comparison of experimental and correlation model results for green pepper (T_a = 65°C, V = 3.38 m/s, Ref. Srinivasakannan and Balasubramanian, 2009)

Kashaninejad, M., Mortazavi A., Safekordi A. and Tabil L. G. 2005. Thin layer drying characteristics and modeling of pistachio nuts. *J. Food Eng.* 78(1): 98-108.

Madhiyanon, T., Phila A. and Soponronnarit S. 2009. Models of fluidized bed drying for thin layer chopped coconut. *Applied Thermal Eng.* 29(14-15): 2849-2854.

Mizota, T., Seki N. and Kokubo S. 2004. Transformation of lactulose trihydrate into anhydrous lactulose by fluidized bed drying and its characterization. *Carbohydrate Res.* 339(6): 1069-1075.

Özbey, M. and Söylemez M. S. 2005. Effect of swirling flow on fluidized bed drying of wheat grains. *Energy Conversion and Mgmt.* 46(9-10): 1495-1512.

Özdemir, M. and Devres Y. O. 1999. The thin layer drying characteristics of hazelnuts during roasting. *J. Food Eng.* 42(4): 225-233.

Prakash, S., Jha S. K. and Datta N. 2004. Performance evaluation of blanched carrots dried by three different driers. *J. Food Eng.* 62(3): 305-313.

Senadeera, W., Bhandari B. R., Young G. and Wijesinghe B. 2003. Influence of shapes of selected vegetable materials on drying kinetics during fluidized bed drying. *J. Food Eng.* 58(3): 277-283.

Shi, M. H., Wang H. and Hao Y. L. 2000. Experimental investigation of the heat and mass transfer in centrifugal fluidized bed dryer. *Chem. Eng. J.* 78(2-3): 107-113.

Sleigh, A. and Noakes C. 2008. Notes for the level 1 lecture course in fluid mechanics. School of Civil Engineering. University of Leeds. Available at www.efm.leeds.ac.uk/CIVE/FluidsLevel1.

Soponronnarit, S., Swasdisevi T., Wetchacama S. and Wutiwiwatchai W. 2001. Fluidized bed drying of soybeans. *J. Stored Product Res.* 37(2): 133-151.

Souraki, B. A., Andres A. and Mowla D. 2009. Mathematical modeling of microwave-assisted inert medium fluidized bed drying of cylindirical carrot samples. *Chem. Eng. and Processing: Process Intensification* 48(1): 296-305.

Srinivasakannan, C. and Balasubramanian N. 2008. An analysis on modeling of fluidized bed drying of granular material. *Advanced Powder Tech.* 19(1): 73-82.

Srinivasakannan, C. and Balasubramanian N. 2009. Estimation of diffusion parameters in fluidized bed drying. *Advanced Powder Tech.* 20(4): 390-394.

Syahrul, S., Dincer I. and Hamdullahpur F. 2003. Thermodynamic modeling of fluidized bed drying of moist particles. *Intl. J. Thermal Sci.* 42(7): 691-701.

Tasirin, S. M., Kamarudin S. K., Jaafar K. and Lee K. F.. 2007. The drying kinetics of Bird's Chillies in a fludized bed dryer. *J. Food Eng.* 79(2): 695-705.

Tatemoto, Y., Tsunekawa M., Yano S., Takeshita T. and Noda K. 2007. Drying characteristics of porous material immersed in a bed of hygroscopic porous particles fluidized under reduced pressure. *Chem. Eng. Sci.* 62(8): 2187-2197.

Temple, S. J. and van Boxtel A. J. B. 1999. Modeling of fluidized bed drying of black tea. *J. Agric. Eng. Res.* 74(2): 203-212.

Topuz, A., Gur M. and Gul M. Z. 2004. An experimental and numerical study of fluidized bed drying of hazelnuts. *Applied Thermal Eng.* 24(10): 1535-1547.

Vadivambal, R. and Jayas D. S. 2007. Changes in quality of microwave-treated agricultural products: A review. *Biosystems Eng.* 98(1): 1-16.

Walde, S. G., Velu V., Jyothirmayi T. and Math R. G. 2006. Effects of pretreatments and drying methods on dehydration of mushroom. *J. Food Eng.* 74(1): 108-115.

NOMENCLATURE

A	constant
a,b,c,e,f,g,h,i,j	exponent
c	specific heat, J/kg °C
D	diffusivity, m^2/s
d	particle diameter, m
k	thermal conductivity, W/m °C
MR	moisture ratio, –
R^2	correlation coefficient
T	temperature, °C
t	time, s
V	superficial gas velocity, m/s

Greek Symbols

ρ	density, kg/m^3

Subscripts

a	bed air
p	particle
evap.	evaporation