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Study on Sorghum Grains Drying in a Fluidized Bed Dryer

Nandipati Ravi [1*], S.Srinu Naik[2] , Indira Dharavath[3]

[1,3,*]Research Scholars, Department of Chemical Engineering, OUCT, Osmania University, India.
[2]Professor, Department of Chemical Engineering, OUCT, Osmania University, India.
*Corresponding mail: nandipatirv@gmail.com

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ABSTRACT

Cereal grain and food drying are done as an aid to warrant minimization of grain damage, on one side and economic feasibility on another side. Proper drying procedures can eliminate the potential of spoilage during subsequent storage and improve the quality of grain. Appropriate dryer should be designed for reducing the damage to grain and for economically feasibility. The drying method and conditions effectively determine type and characteristics of the final product. The drying performance of fluidized bed dryer on sorghum grain are studied. An investigation is undertaken to study the effects of temperature, time, moisture content and gas velocity on the drying performance in the present study has been carried out to assess the drying kinetics of sorghum seeds under the operating parameters such as temperature, flow rate of the drying medium, and solids holdup. The drying rate was found to increase significantly with increase in temperature and marginally with flow rate of the heating medium and to decrease with increase in solids holdup. The drying rate was compared with various simple exponential time decay models and the model parameters were evaluated. The Page model was found to match the experimental data very closely. The experimental data were also modelled using Fick's diffusion equation, and the effective diffusivity coefficients were estimated.

Keywords: Sorghum, Drying Kinetics, Fluidized Bed, Drying Rate, Moisture Ratio

1. INTRODUCTION

Drying is one of the oldest and most widely used methods of food preservation. It is the most important method for industrial processing since moisture content is an extremely relevant parameter affecting the crucial properties of final products. It is an important unit operation in the food processing industry. The basic objective in drying agricultural products isthe removal of water in the solid up to a certain level at which microbial spoilage, deterioration and chemical reactions are greatly minimized. When a wet solid is subjected to thermal drying, two processes occur simultaneously, transfer of energy (most as heat) from the surrounding environment to evaporate the surface moisture and transfer of internal moisture to the surface of the solid and its subsequent evaporation due to the first process. Drying is one of the crucial steps in food processing and preservation. Drying is the process of moisture removal from the product, or grain. It provides optimum moisture content to the grain for processing, such as rice milling and wheat milling processes, as well as it makes grain moisture content at stage where moisture is unavailable for mould growth. In preserving grain without deterioration, drying is the cheapest among other methods that is chemical application and controlled atmosphere storage.

Sorghum (Sorghum Bicolor), a grain, forages or sugar crop, is among the most efficient crops in conversion of solar energy and use of water. Sorghum is known as a high-energy, drought tolerant crop. Because of its wide uses and adaptation" sorghum is one of the really indispensable crops" required for the survival of humankind. Globally, over half of all sorghumis used for human consumption. It is a major crop for many poor farmers, especially in Africa, Central America, and South Asia. Sorghum grain ranks fifth in cereals global production. Grain sorghum is used for flours, porridges and side dishes, malted and distilled beverages, and specialty foods such as popped grain. Sorghum is a genus with many species and subspecies, and there are several types of sorghum, including grain sorghums, grass sorghums (for pasture and hay), sweet sorghums (for syrups), and Broomcorn. India, 75% of sorghum area and 85% production is concentrated in Maharashtra, Karnataka, and Andhra Pradesh.

Grain sorghum requires less water than corn, so is likely to be grown as a replacement to corn and produce better yields than corn in hotter and drier areas, such as the Southern US, Africa, Central America and South Asia. Sorghum is also considered to be a significant crop for animal feeds, and in the US this is the major use of the grain. Finely ground grains or high-tannin grains are less palatable to cattle. Due to its hard and waxy covering, the grains need to be processed by cracking, rolling, or grinding. When processed the nutritional value of sorghum is comparable (but not equal) to maize (corn), so it requires supplementation of vitamin A. Grain sorghum is also used for silage.

Sorghum fibers are used in wallboard, fences, biodegradable packaging materials, and solvents. Dried stalks are used for cooking fuel, and dye can be extracted from the plant to color leather. A more recent use of sorghum is, it plays an important role in the production of ethanol and other bio-industrial products such as bioplastics, especially in dry areas where other crops are not as easily grown. By-products from ethanol production, such as sorghum- DDGS (distillers dried grains with solubles), are also finding a place in the market.

Various fermented and unfermented beverages are made from sorghum. It can be steamed or popped and is consumed as a fresh vegetable in some areas of the world. Syrup is made from sweet sorghum.Sorghum is also used for building material, fencing, floral arrangements, pet food and brooms.

A fluidized bed is formed by a quantity of a solid particulate substance (usually present in a holding vessel) which is placed under appropriate conditions to cause the solid/fluid mixture to behave as fluid. This is usually achieved by the introduction of pressurized fluid through the particulate medium. This results in the medium then having many properties and characteristics of normal fluids, such as the ability to free-flow under gravity, or to be pumped using fluid type technologies. The resulting phenomenon is called fluidization. Fluidized beds are used for several purposes, such as fluidized bed reactors (types of chemical reactors), fluid catalytic cracking, fluidized bed combustion, heat or mass transfer or interface modification, such as applying a coating onto solid items.

Fluidized beds find increasing application in drying of agricultural materials, while they are being widely in use, in industries for drying of fertilizers, chemicals, pharmaceuticals and minerals. Increasing application of fluidized bed drying for agricultural materials is due to the evolving designs of fluidized bed, for fluidization of coarse material, which are rather difficult to fluidized. Fluidized beds as compared to other modes of drying offer advantages such as high heat capacity of the bed, improved rates of heat and mass transfer between the phases and ease in handling and transport of fluidized solids. Fluid bed processing involves drying, cooling, agglomeration, granulation, and coating of particulate materials. It is ideal for a wide range of both heat sensitive and non-heat sensitive products. Uniform processing conditions are achieved by passing a gas (usually air) through a product layer under controlled velocity conditions to create a fluidized state. In fluidized bed drying, heat is supplied by the fluidization gas, but the gas flow need not be the only source. Heat may be effectively introduced by drying surfaces (panels or tubes) immersed in the fluidized layer.

In fluid bed cooling, cold gas (usually ambient or conditioned air) is used. Conditioning of the gas may be required to achieve sufficient product cooling in an economically sized plant and to prevent pick up of volatiles (usually moisture). Heat may also be removed by cooling surfaces immersed in the fluidized layer. Agglomeration and granulation may be performed in a number of ways depending upon the feed to be processed and the product properties to be achieved. Fluid bed coating of powders, granules, or tablets involves the spraying of a liquidon the fluidized powder under strictly controlled conditions.

Particle fluidization gives easy material transport, high rates of heat exchange at high thermal efficiency while preventing over drying of individual particles. The properties of a given product are determined from drying rate data, i.e. how volatile content changes with time in a batch fluid bed operating under controlled conditions. Other important properties are fluidization gas velocity, fluidization point (i.e. the volatile content below which fluidization without mechanical agitation or vibration is possible), equilibrium volatile content, and heat transfer coefficient for immersed drying surfaces. These and other data are applied in a computational model of fluid bed processing, thus enabling dimensioning of industrial drying systems. Fluidized bed drying is suited for powders, granules, agglomerates, and pellets with an average particle size normally between 50 and 5,000 microns. Very fine, light powders or highly elongated particles may require vibration for successful.The main objectives of the present study are:Study and compare the drying characteristics of sorghum seeds by using the fluidized bed.To fit the experimental data obtained to semi empirical models widely used to describe the fluidized bed drying of sorghum seeds.

2. MATERIALS AND METHODS

The following materials are used for the experimental work in fluidized bed drying.

2.1 *MATERIAL USED*

Sorghum seeds obtained from local market used as material for fluidized bed drying.

The characteristics of the sorghum seeds are in the following table.

TABLE 1: CHARACTERISTICS OF SORGHUM SEEDS

Name of Material	Sorghum (Sorghum bicolor)
Shape of Material	non Spherical
Sphericity	0.901
Size dp(mm)	3.34
Particle density, kg/m^3	820
Minimum fluidization velocity, m/s	0.647
Terminal velocity, Ut (m/s)	13.9
Bed voidage at minimum fluidization velocity	0.342

2.2 EXPERIMENTAL PROCEDURE

Air at desired temperature and velocity was allowed to flow through the fluidization column. A known quantity of the sorghum with 20% moisture content on dry basis was introduced in to the column after ensuring the steady temperature and air velocity. The fluidization gas velocity was decided based on the minimum fluidization velocity of the sorghum. Fluidization velocities of approximately 1.5 to 2 times the minimum fluidization velocity were chosen for the experiments. The air to the fluidization column come from the air compressor and the air velocity is maintained by using a Rota meter. The temperature in the column was maintained by using the electrical heater. Drying of sorghum seeds is taking place in fluidized bed, so at every one minute wet bulb and dry bulb temperatures of inlet and outlet air were noted down. This procedure is continued till steady state reading in temperatures is attained. The experiments were repeatedly conducted for different temperatures, velocities and different weights. Schematic diagram of the experimental set up has shown in Figure 1.

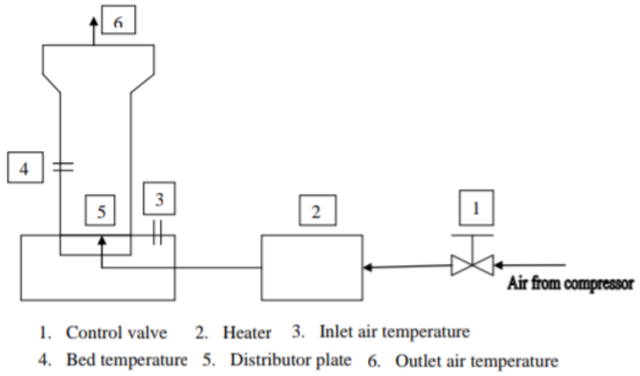

FIGURE. 1 EXPERIMENTAL SET UP SCHEMATIC DIAGRAM

3. RESULTS AND DISCUSSIONS

3.1 THE EFFECT OF DRYING MEDIUM TEMPERATURE ON DRYING KINETICS

The figures from 2 to 4 shows the effect of drying medium temperature by conducting experiments at various temperatures (40, 50 and 60°C) for initial moisture content (25gm), air velocities (1.05 and 1.32 m/sec) and initial weight of the sorghum seeds (0.100kg, 0.125kg and 0.150kg). All the data follows that at lower temperature the drying rate is slow where as at higher temperature it is faster. An increase in temperature of the drying medium increases the drying rate and it can be attributed to the higher bed temperature of particles in the bed, which increases the intra particle moisture diffusion leading to a higher drying rate. The increased transport properties of the fluids with increase in temperatures is well known and the experimental data are in concurrence with the basic concepts of mass transfer.

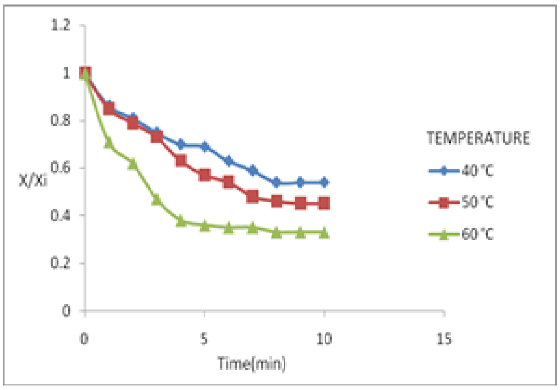

Figure. 2 Effect of the temperature of the drying medium (0.15 kg of sorghum seeds, 0.025kg of water, 1.32 m/sair velocity)

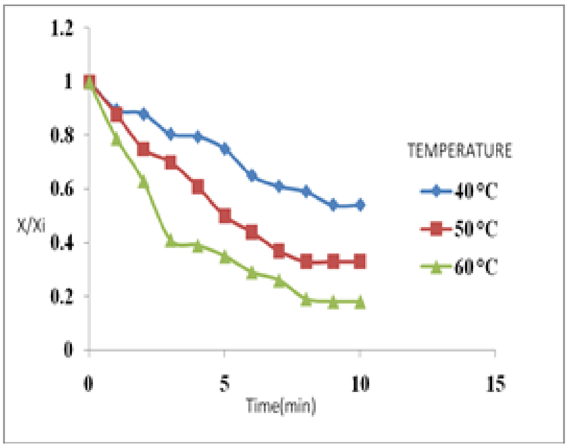

Figure.3 Effect of the temperature of the drying medium (0.125 kg of sorghum seeds, 0.025kg of water, 1.32 m/s air velocity

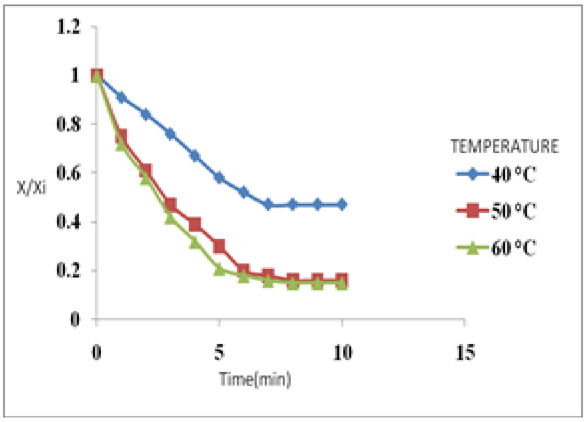

Figure. 4 Effect of the temperature of the drying medium (0.100 kg of sorghum seeds, 0.025 kg of water, 1.32 m/s air velocity)

3.2 MODELING OF DRYING KINETICS IN FLUIDIZED BED DRYING

The simple exponential time decay models, popularly known as Newton model, Page model, Henderson and Pabis models are used for fluidized bed drying. The models parameters were estimated using the experimental data as follows;

3.2.1 NEWTON MODEL

V.Mohammadpour, M.T. Hamed Mosavian and A. Etemadi [2007] described the Newton Model. According to the model, the moisture transfer from the sorghum seeds in fluidized bed drying can be seen as analogous to the flow of heat from a body immersed in cool fluid. This model assumes negligible internal resistance, which means no resistance to moisture movement from within the material to the surface of the sorghum seeds. By comparing these phenomena with Newton's law of cooling, the drying rate is proportional to the material being dried and equilibrium moisture content at the drying air condition as;

$$MR = \exp(-kt) \text{ -------------- ---------(3.1)}$$

Where; MR is the moisture ratio defined as:

$$MR = (X - X_e)/(X_i - X_e) \text{ ---------------- (3.2)}$$

The **ln(MR)** versus **t** is plotted in figure 5. Newton Model parameter is predicted forvarious operating conditions maintained in the fluidized bed Dryer.

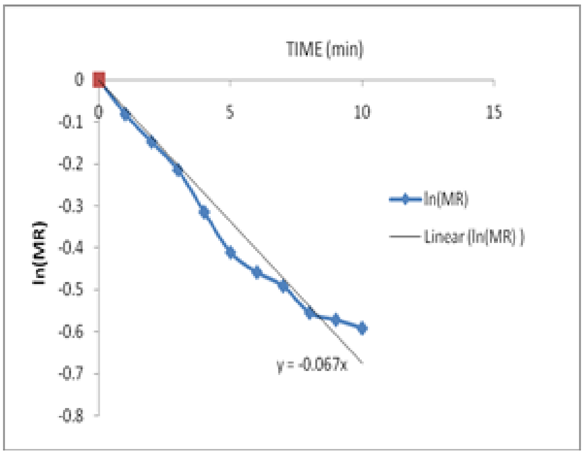

Figure.5 Prediction of Newton Model with the experimental data 0.125kg sorghum, 0.025 kg water, 1.32 m/s air velocity, 60°C temperature

3.2.2 *HENDERSON AND PABIS MODEL (HPB)*

V. Mohammadpour, M. T. Hamed Mosavian, A. Etemadi [2007] discussed Henderson and Pabis Model. According to the model, Diffusion model have been used by researchers in modeling the drying characteristics of millet seeds in fluidized bed drying. The simplest approximation from which only one term of the infinite series is used can be represented as

$$MR = a \exp(-kt) \text{ -------------------- (3.3)}$$

This model has been used to describe thin-layer drying characteristics of various sorghum seeds in fluidized bed drying. The slope of the plots **ln(MR)** versus **t** as shown in figures are used to estimate **k** and from the intercepts in the certain operating ranges **a** is obtained. The coefficient **k** is related to effective diffusivity when drying process takes place only in the falling rate period and liquid diffusion controls the process. They will be equal to one if drying is taking place in constant rate period.

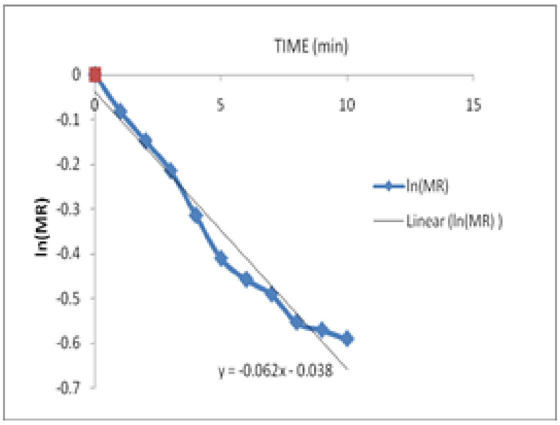

Figure.6 Prediction of H&P Model with the experimental data (0.125kg sorghum, 0.025 kg of water, 1.32 m/s air velocity, 60°C temperature)

3.2.3 Page Model

V. Mohammadpour, M.T.Hamed Mosavian, and A. Etemadi [2007] discussed about the Page Model. Page suggested a two constant empirical modification of the exponential model to correct its shortcomings. This model assumes that the duration of constant rate period was found to be insignificant, considering the total duration of drying. This model has produced good fits to describe drying of sorghum seeds in Fluidized bed drying. This model can be shown as follows:

$$MR = \exp(-kt^n) \text{ ------------------ (3.4)}$$

Experiments were conducted to assess the kinetics of drying for the variation in the inlet air temperature, the inlet air velocity and the solids holdup in the fluidized bed and it is observed that the duration of constant rate period was found to be insignificant, considering the total duration of drying.

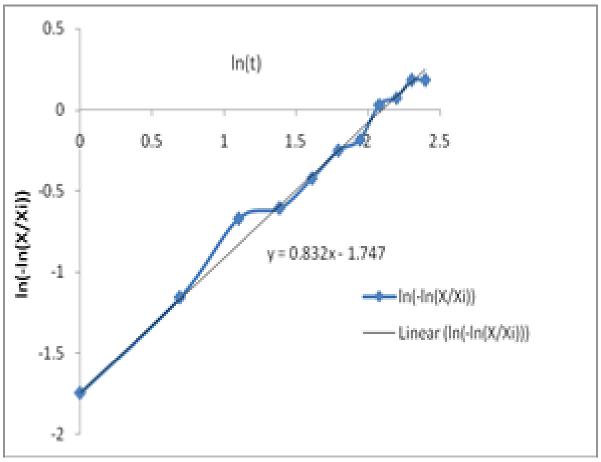

Figure.7 Prediction of Page Model with the experimental data (0.125kg sorghum, 0.025 kg of water, 1.32 m/s air velocity, 60°C temperature)

4. CONCLUSION

In the present work, experimental investigations were made in a fluidized bed dryer of having 5 cm ID and 50 cm height cylindrical fluidized bed column. The various operating conditions like air velocity (1.32 and 1.05 m/s), temperature (40, 50, 60°C) and Solid holdup (0.100,0.125 and 0.150 kg) were maintained. The drying kinetics in the fluidized bed was found at the fluidization conditions.The drying rate was found to increase significantly with increase in temperature and velocity of the drying medium, while decrease with increase in solids holdup. The duration of constant rate period was found to be insignificant, considering the total duration of drying. The kinetics of drying was tested with simple exponential decay models, like Newton Model, Page Model, and Henderson and Pabis Model. Page model was found suitable for the experimental data very closely with less root mean sum of square of error (RMSE) and χ^2 values between the model prediction and experimental data. Newton model and Henderson and Pabis Model was found not suitable for drying kinetics of sorghum as those model predictions vary with the experimental data.The effective diffusion was found to be within the range as per literature review.From design of experimental studies the solids hold up and temperature were effecting more to the system. As increasing the solid hold up, removal of moisture would be decreasing and as increasing the temperature, removal of moisture would be increasing.

Conflict of interest statement

Authors declare that they do not have any conflict of interest.

REFERENCES

[1] C. Srinivasakannan and N. Balasubramanian, "A simplified approach to the drying of solids in a batch fluidized bed", Vol. 19, No. 03, pp. 293 - 298, July - September 2002

[2] Julia ZH Gao, David B. Gray, Rajeshwar Motheram, and Munir A. Hussain, "Important of inlet air velocity in fluid bed drying of a granulation prepared in a high shear granulator", AAPS Pharm SciTech, 2000.

[3] Syahrul HUSAIN, Akihiko HORIBE and Naoto HARUKI, "Heat and Mass Transfer Analysis of Fluidized Bed Grain Drying", Memoirs of the Faculty of Engineering, Okayama University, Vol.41, pp.52-62, January, 2007.

[4] Chandrasekhar Srinivasa Kannan, "Modeling Drying Kinetics of Mustard in Fluidized Bed" International Journal of Food Engineering, Volume 4, Issue 3 2008.

[5] C. Srinivasakannan and N. Balasubramanian, " An Analysis on Modeling of Fluidized Bed Drying of Granular Material", Advanced Powder Technology 19, 73–82, 2008.

[6] Wlodzimierz Ciesielczyk, Mladen Stojiljković, Gradimir Ilić,Nenad Radojković, Mića Vukić," Experimental study on drying kinetics of solid particles in fluidized bed",UDK: 536.2:66.047, The scientific journal Facta universitatis Series: Mechanical Engineering Vol.1, No 4, pp. 469– 478, 1997.

[7] E. Kavak Akpinar, "Mathematical modeling and experimental investigation on sun and solar drying of white mulberry", Journal of Mechanical Science and Technology, journal of Mechanical Science and Technology 22, 1544~1553, 2008.

[8] C.Srinivasakannan,N.Balasubramaniam,"An Experimental and Modeling Investigation on Drying of Ragi (Eleusine corocana)in fluidized bed", Drying Technology,24:12,1683-1689, 2006.

[9] LI Jianguo, ZHAO Lijuan, CHEN Guohua, and ZHOU Ming, "Fluidized-bed drying of biological materials: Two case studies", Chinese J, Chem, Eng., 12 (6) 840 842, 2004.

[10] A.Karbassi, Z.mehdizadeh,"Drying rough rice in a fluidized bed dryer", J.Agric.Sci.Technol, vol.10:233-241, 2008.

[11] Y K Mohanty, G K Roy & K C Biswal,"Effect of column diameter on dynamics of gas solid fluidized bed: A statistical approach", Indian journal of chemical technology vol.16, January, pp. 17-24, 2009.

[12] C. Strumillo, T. Kudra, Drying: Principles, Applications and Design Gorden and Breach: New York, 1986.

[13] C. Srinivasakannan, S. Subbarao, Y.B.G. Varma, A kinetic model for drying of solids in batch fluidized beds, Ind. Eng. Chem. Res., 33, 363-370, 1997.

[14] N.I. Syromyatnikov, P.K. Vasanova, D.N. Shimanskii, D.N. Heat and Mass Transfer in Fluidized Bed, Khimia, Moscow, 1967.

[15] D. Kunni, O. Levenspiel, Fluidization Engineering, Wiley New York, 1969.

[16] N. Anantharaman, S.H. Ibrahim, Fluidized bed drying of pulses and cereals In Recent Advances in Particulate Science and Technology, Madras, 1982.

[17] A.N. Chandran, S. Subbarao, Y.B.G. Varma, Fluidized bed drying of solids AIChE J., 36(1), 29-38, 1990.

[18] P.P. Thomas, Ph.D thesis, Indian Institute of Technology, Madras, 1994.

[19] J.H.B.J. Hoebink, K. Rietema, Drying of granular solids in a fluidized bed I. Chem. Eng. Sci., 35, 2135 1980.

[20] J.H.B.J. Hoebink, K. Rietema, Drying of granular solids in a fluidized Bed II. Chem. Eng. Sci., 35, 2257 1980.

[21] J.B. Alebregtse, Fluidized Bed Drying: A mathematical model for Hydrodynamics and mass Transfer, in W.P.M. Van Swaajj, N.H. Afgan (Eds), Heat and Mass Transfer in Fixed and Fluidized Bed, Hemisphere Publishing Corp., New York, p.511, 1986.

[22] B.A. Palancz, Mathematical model for continuous fluidized bed drying, Chem. Eng. Sci., 38(7), 1045 1983.

[23] M. Parti, Evaluation of selected mathematical model for grain drying, in A.S Mujumdar, I. Filkova (Eds.), Drying 91, Elsevier, Amsterdam, 369, 1991.

[24] V.V. Kafarov, I.N. Dorokhov, Modeling and optimization of drying process, Int. Chem. Eng., 32(3), 475, 1992.

[25] Topuz, M. Gur, M.Z. Gul, An experimental and numerical study of fluidized bed drying of hazelnut, Applied Thermal Engineering, 24, 1534-1547, 2004.

[26] The World Sorghum and Millet Economics: Facts, Trends and Outlook. International center for Agriculture Research in the Semi-Arid Tropics (ICRISAT), 1996

[27] G. Ukan, S. Ulku, Drying of corn grains in batch fluidized , in: A.S. Mujumdar (Ed), Drying of Solids, Wiley Eastern Limited, New Delhi, 1986.

[28] J. Crank, The Mathematics of Diffusion, Oxford University Press, Oxford, 1975.

[29] P.P. Thomas, Y.B.G. Varma, Fluidized bed drying of granular food material, Powder Technology 69 (1992) 213-222.

[30] M. Parti, Selection of mathematical models for drying grain in thin layers, Journal of Agriculture and Engineering Research 54 (1993) 33-352

[31] J.A.Villegas, S.R. Duncan, H.G. Wang, W.Q. Yang, R.S. Raghavan, Department of Engineering Science, University of Oxford, 2006

[32] Mc Laren, J.S., Lakey, N., Osborne,J., Sorghum as a bioresources platform for future renewable resources. Proceedings 57th Corn and Sorghum Research Conference. CD ROM. American Seed Trade Association, Alexandria, VA, USA, 2003.

[33] McDonough, C.M., Rooney, L.W., Serna-Saldivar, S.O., The millets. In: Kulp, K., Ponte, Jr.,J.G. (Eds.), Handbook of Cereal Science and Technology. 2nd ed. Marcel Dekker, New York, 2000.