International Journal of Engineering Studies and Technical Approach
ISSN No. 2395-0900

Fluidized Bed Drying of Fruits and Vegetables: An Overview

Yashwant Kumar[*] and Seema. A. Belorkar[**]

[*]*Assistant Professor, Department of Food Processing & Technology, Bilaspur University, Bilaspur, Chhattisgarh, India*
[**]*Assistant Professor, Department of Microbiology and Bio-informatics, Bilaspur University, Bilaspur, Chhattisgarh, India*

ABSTRACT:

The quest for novel technologies in the area of food processing & preservation has led to the application of fluidization technique for enhancing the process capabilities, energy efficiencies and overall quality retention in the final products. However, this paper reviews the various fruits and vegetables dried in the fluidized bed dryer and their retention of sensory attributes in the dried products. This review states that fluidized bed drying indeed has proved better compare to conventional drying (i.e. tray/cabinet drying) in respect to drying time of fruits and vegetables.

Key-words: *Drying, fluidized bed drying, food preservation, food processing, and fruits & vegetables.*

INTRODUCTION

Fluidized bed dryer are found throughout all industries, from heavy mining through food, fine chemicals and pharmaceuticals. They provide an effective method of drying relatively free flowing particles with a reasonable narrow particles size distribution. The feed may take the form of powders, granules, crystals, seed, pre-forms and non-friable agglomerates. Fluidized bed dryers can process a wide variation of feed rates from pounds to several hundred tons per hour. Three principle types of fluidized bed dryers exist. The first type is referred to as a static fluid bed because the dryer remains stationary during operation. Static fluidized bed dryer can be continuous or batch operation and may be round or rectangular. The second type of fluidized bed dryers is a vibrating fluidized bed dryer where the body of the dryer vibrates or oscillates, assisting the movement of material through the unit. Vibrating fluidized bed dryers are almost exclusively rectangular in shape. Fluidized bed dryers are extensively used in particular solids drying because of their high rates of heat and mass transfer and the reduced drying times.

FLUIDIZATION

Fluidization is the state at which all the particles comes in the suspended form. When a fluid is passed upwards through a bed of particles the pressure loss in the fluid due to frictional resistance increase with increasing fluid flow. A point is reached when the upward drag force exerted by the fluid on the particle in the bed. At this point the particles are lifted by the fluids separation of the particle increases and bed becomes fluidized therefore the fluidization is the operation by which fine particles are transformed in to a fluid like state through gas or liquid.

ISSN No. 2395-0900
IJESTA
International Journal of
Engineering Studies and Technical Approach

The superficial gas velocity at which the packed bed becomes a fluidized bed is known as minimum fluidization velocity U_{mf}. This is also sometimes referred to as the velocity at incipient fluidization (incipient means about to begin). The effect of operation conditions in fluidized bed dryers is complex to estimate because of the interactions between them and also the intrinsic properties of the drying solids. In the description of these types of dryer mathematical models based in two phase's fluidization theory (bubble and dense phase) has been presented. These types of models allow predicting the effect of the operation condition of the coupled processes of heat and mass transfer.

The important parameter is the velocity of drying air in fluidized bed dryers, which differs from a fixed bed in bin dryer. A schematic drawing of fluidized bed dryer is shown in Fig. 1 and Fig. 2, Kernels in a fixed bed dryer remain in place due to relatively low flow rate of the air; they are suspended in air in a fluidized bed dryer. As the velocity of the air to a grain bed is increased, the static pressure of the drying air also increases until it reaches to the equivalent of the weight of the kernels per unit area of bed, and the kernels become suspended or fluidized in the air. Moderate mixing of the kernel results during the fluidization process. As the air velocity is further increased then rapid mixing of particle is occur which controlled by bubbles in the bed. Beyond that limit of air velocity particle start to convey & bed act as a pneumatic transport shown in Fig. 1.

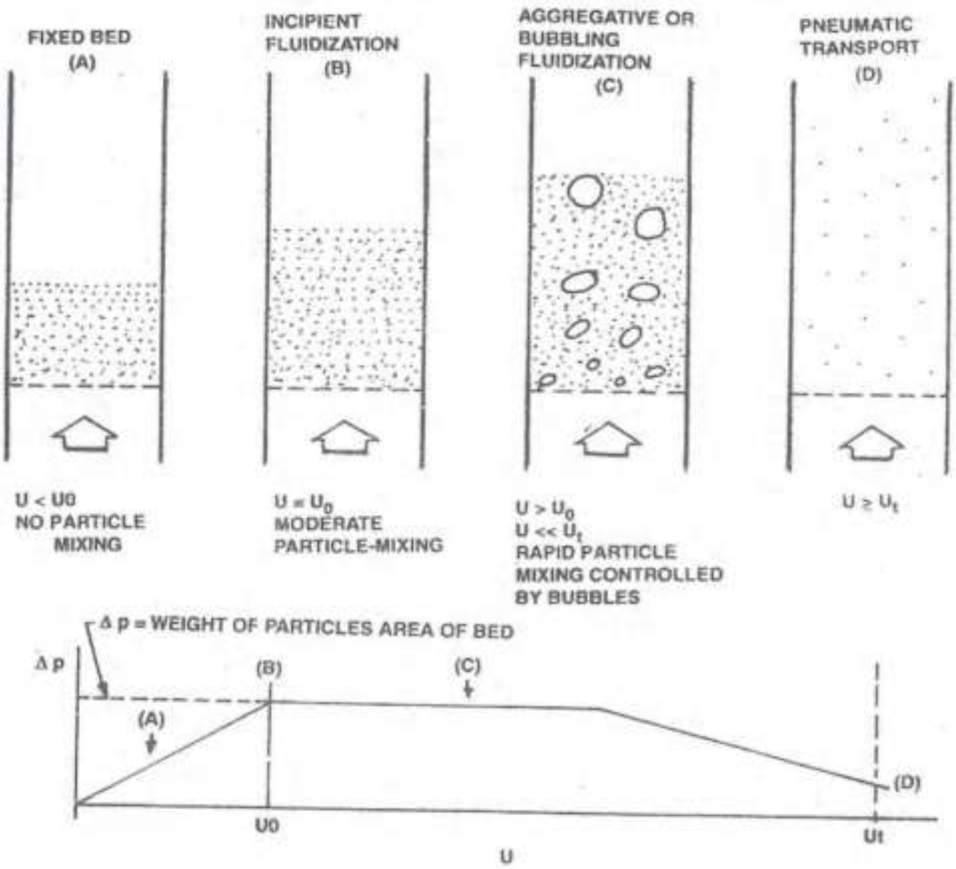

Fig. 1: *Region of fluidization (Brooker et al., 1992)*

U = air velocity; U_0 = air velocity for incipent fluidization; U_r = terminal fall velocity of particles; C = pressure drop over particle layer.

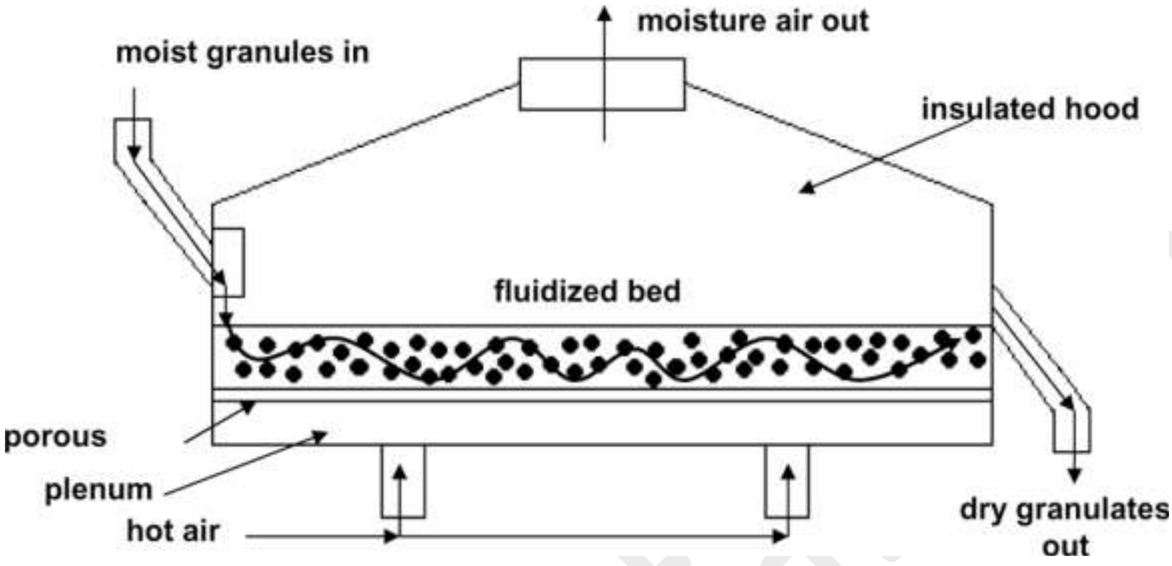

Fig. 2: *Concept of fluidized bed drying (Murthy and Joshi, 2007)*

The fluid bed consists of two phases:
(1) Particle phase: A homogeneous mass with the voidage and gas velocity.
(2) Bubble phase: Containing all excess gas and nearly free from particles. These gas bubbles are responsible for the mixing of the particulate phase.

APPLICATION OF FLUIDIZED BED DYRING

Fluidized bed drying is a boon for the drying of food especially fruits and vegetables. Some experiment were carried out by some researchers are discussed in this paper. Kaur and Bawa reported that pre-treated and fluidized bed dried pea samples, showed that the drying air temperature, volume of air, weight of sample and pre-treatments affected drying characteristics and quality. Unblanched, water-blanched and alkali-blanched pea samples (350 g) dried in a fluidized-bed-drier (blower speed of 6; and drying temperatures of 100, 120 and 140 °C) showed the best results in terms of dehydration characteristics. Mustard one of the popular oil seeds is investigated for drying in batch fluidized beds. Experiments were conducted to assess the kinetics of drying for the variation in the inlet air temperature, the inlet air flow rate and the solids holdup in the fluidized bed. The drying rate was found to increase significantly with increase in temperature and with flow rate of the heating 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 (Srinivasakannan, 2008).
Jingsheng *et al*. (2008) observed that Soybean seeds were contacted with silica gel in a fluidized bed, where mass transfer is driven by moisture concentration gradient. It has the advantage of well-mixing the solid adsorbent (silica gel) with the material being dried (soybean seeds) in fluidization state, and thus the dried seeds quality could be improved since they are in a uniform environment of low humidity.

An industrial-scale batch fluidized bed dryer was used to dry finely chopped coconut pieces. The effects of various operating parameters i.e. the values and patterns of inlet air velocity and temperature, on the drying kinetics and some selected quality attributes of dried coconut viz. color and surface oil content were then examined. The surface oil content of the product dried by any tested conditions was still higher than that of the reference sample, which is accepted by the market (Niamnuy *et al*., 2005).

Thakur and Gupta (2007) reported that the experimental investigations were carried for the determination of suitable rest duration and the stage; at which resting will provide better re-distribution of internal moisture in paddy grains subjected to fluidized bed drying. Incipient velocity was evaluated considering the drying conditions and the characteristics of the high moisture paddy. Intervening rest duration between first and second stage of drying, enhanced drying rate, reduced energy consumption and improved head rice yield. Energy requirement can be significantly saved (9–58 %) by providing rest durations (30–120 min) in comparison to the continuous drying.

According to Murthy and Joshi (2007) has been made to study the dehydration of aonla fruits. Aonla fruits, being highly perishable, cannot be kept for long periods. Aonla contains a very high amount of vitamin C, which is highly volatile and susceptible to heat. Sun drying required the longest period of drying 660 min (11 hrs), while the shortest time of drying is with fluidized bed drying at 80 °C with 115 m/min air velocity 120 min (2 hrs). The results indicate that there is great loss of most of the ascorbic acid in the aonla slices. The retention of ascorbic acid in the samples dried in fluidized bed drying is greater compared to those dried under sun and hot air tray.

There are several drying methods available for the drying of foods. One is fluidized bed drying, commonly used in drying particulate materials. Due to the rapid drying it has been considered as an economical drying method compared with other drying techniques (Borgolte and Simon, 1981; Giner and Calvelo, 1987).

Herguido *et al.* (1992) sawdust drying was studies of the gasification of sawdust in a fluidized bed indicate that the required moisture content is 8–12 %. The pulsed fluidized bed dryer is a modified conventional fluidized bed in which gas pulses cause vibration of the particle bed (Gawrzynski and Glaser, 1996).

Drying of foods is a major operation in the food industry, consuming large quantities of energy. Dried foods are stable under ambient conditions, easy to handle, possess extended storage life and can be easily incorporated during food formulation and preparation. The drying operation is used either as a primary process for preservation, or a secondary process in certain product manufacturing operations (Fusco *et al*., 1991; Senadeera *et al*., 2003).

Singh *et al*. (2007) reported that kinetics of sliced edible mushrooms was studied during fluidized bed drying at different temperatures (50, 60, 70, 80 & 90 °C). Prior to drying, sliced samples were treated: a) blanching, b) soaking in 0.5 % KMS (Potassium Metabisulphite) solution, c) soaking in 1 % KMS, 0.2 % Citric acid, 6 % sugar and 3 % salt. It was found that drying rate was proportional to temperature. The values of energy of activation ranged between 12.128 to 40.149 kJ/mol.

Drying of ginger flakes was studied under fluidized bed conditions in the temperature range of 50 to 80 °C and pretreatment of calcium oxide in the range of 1 to 2.5 %. Drying rate at 60 °C air temperature decreased from 0.43 to 0.17 g/s with the change in moisture content from 300 to 10 % db. The volatile oil in dried in dried flakes decreases from 1.2 to 0.99 % with increase in drying temperature from 50 to 80 °C (Singh *et al*., 2008).

An air velocity of 1800 cfm was used for the first 10 min and was gradually lowered to 900 cfm by the end of the drying. Drying of the granules was stopped when the sample taken from the fluid bed sampling port reached a Loss of Drying (LOD) value of 3 % to 4 % as measured by a moisture balance at 105 °C. To confirm that the drying was complete, samples were taken for LOD measurement using a sample from various locations in the conveying fluid bed. The drying speed was within 30 min and the temperature was also uniform. Drying process allowed proper fluidization of granules and provided enough time to allow diffusion of the moisture from the granulation core to the surface (Naveen *et al*., 2009).

According to Borgolte and Simon (1981) the energy required to accomplish this task is huge, and much work has been devoted to maximizing the thermal efficiency of dryers in order to reduce the necessary heat consumption. Fluid bed drying has been recognized as a smooth, uniform drying method, capable of drying down to very low residual moisture content with a high degree of efficiency. This process is characterized by high moisture and heat transfer rates and excellent thermal control capacity compared with conventional drying processes (Vanecek *et al*., 1966; Hovmand, 1987). It is also a very convenient method for drying heat sensitive food materials as it prevent them from overheating due to mixing (Gibert *et al*., 1980; Giner and Calvelo, 1987). Fluidized bed drying can be carried out as a batch or continuous process (Shilton and Niranjan, 1993).

OTHER APPLICATIONS OF FLUIDIZED BED DRYER

According to Lehmann (1992) the high demand for encapsulated material in the global market, fluid–bed coaters have become more popular. They are used for encapsulating solid or porous particles with optimal heat exchange. Guignon *et al.* (2002) reported that the fluid bed encapsulation process consists of spraying a coating solution into a fluidized bed of solid particles. After several cycles of wetting–drying, a continuous film is formed. Both qualitative and quantitative results are presented for several industrial applications. The main parameters affecting the process are flow-rate and pressure of the spraying liquid, composition and rheology of the coating solution, flow-rate and temperature of the fluidizing air.

The rate of heat transfer between the bed and submerged surfaces is very high and the intense solid mixing inside the bed causes a temperature distribution that is almost uniform inside all the fluidized bed. These facts allow for reducing the time of drying and the level of temperature of the input hot air required for drying the solid. Furthermore, the drying in fluidized bed avoids the formation of hot spots and makes easy the management of the solid as well as the overall control of the operation (Palancar *et al*., 2001).

Ulku and Uckan (1987) observed that the modeled a batch fluidized dryer as a homogeneous system; the bubbles are ignored and the rate of the internal diffusion inside the solid particles is the controlling step of the overall drying rate. The two-phase theory has been used by several authors to model the fluidized bed dryers (Lai *et al*., 1986; Donsi and Ferrari, 1992 and Zahed *et al*., 1995).

The fluidized bed dryer used in the study is a small pilot plant consisting of a cylindrical vessel 5.4 cm I. D. and 40 cm height (fluidized bed zone) joined by a conical device to an upper cylinder 19.2 cm I. D. and 30 cm height. The wet solid is fed from the hopper. The dried solid is discharged from the fluidized bed by means of another valve (Arago *et al*., 1998).

In conventional drying processes, the drying time is generally between 3 to 8 h. At these conditions it is hard to keep the taste or the color unchanged, due to the enzymatic browning. Using fluidized bed drying (FBD), the drying time can be considerably reduced and the whole material can be uniformly dried (Tirawanichakul *et al*., 2004; Bauman *et al*., 2005 and Kwauk *et al*., 2000).

The moisture content at the transition between constant and falling rate periods is called the critical moisture content (CMC). Further, the falling rate period can be subdivided into unsaturated surface drying region and internal movement of moisture-controlling region (Kundu *et al*., 2001 and Tanfara *et al*., 2002). If drying is continued for a long enough period of time, the value of moisture content approaches the equilibrium moisture content (EMC). For a given material this is a function of relative humidity and temperature. During the constant rate period, the fruit particle surface is wet enough for the air layer adjacent to the fruit surface to saturate. During this period the temperature of the particle surface remains constant at the wet bulb temperature of the air. The constant rate period and the falling rate period are dependent on the operating temperature of drying and the airflow (Bauman *et al*., 2005 and Kundu *et al*., 2001).

The fluidized bed drying process of green peas was optimized using the response surface methodology for the process variables: drying air temperature (60-100 °C), tempering time (0–60 min), pretreatment, and mass per unit area (6.3–9.5 g/cm^2). The green peas were pretreated by pricking, hot water blanching, or chemical blanching. Product quality parameters such as rehydration ratio, color, texture, and appearance were determined and analyzed. Optimum conditions of 79.4 °C drying air temperature, 35.8 min tempering time, pretreatment of the once pricked peas with chemical blanching in a solution of 2.5 % NaCl and 0.1 % $NaHCO_3$, and mass per unit area of 6.8 g/cm^2 were recommended for the fluidized bed drying of green peas. At these conditions the rehydration ratio was 3.49 (Burande *et al*., 2008).

Sokhansanj and Jayas (2006) fluidized bed drying is a well-known process that has been widely used in the dairy and pharmaceutical industries for drying, granulating, and coating operations. Fluidized bed drying process has been successfully used to dry many agricultural products of different particle sizes (ranging from 10 mm to 20 mm) such as wheat and corn grains; cut green beans; slices of carrot, celery, mango, or kiwifruit; button mushrooms; and green peas. In fluidized bed drying, the drying air is introduced at a velocity at which the material remains fully suspended in the hot air stream and dries with high rates of heat and moisture transfer. The high rate of heat transfer results in instantaneous evaporation of moisture at the entry point (Law and Majumdar, 2006).

Svetozarova and Burovoi (1965) developed mathematical models considering various idealizations to describe fluidized bed drying processes. These models are useful to study fluidized bed drying and to develop a computerized automated process control system.

CONCLUSION

This study concludes the importance of fluidized bed dryer over the conventional dryer for drying of fruits and vegetables. Due to increased energy and operational efficiencies they afford fluidized bed drying in industrial sectors. Fluidization gives maximum surface area for the higher heat and mass transfer during drying. Heating in this technique provide much benefit as compare to traditional one. But the high capital investment warns that they should be assisted with the conventional heating in commercial purpose also.

REFERENCES

i Arago, J.M., Palancar, M.C., Torrecilla, J.S. and Serrano, M., 1998. Drying a High Viscosity Solid-Liquid Waste in Fluidised-Moving Bed, Proc. 13th Intern. Congress of Chemical and Process Engineering, CHISA'98, 23–28 Aug., Czech Society of Chemical Engineering, Praha.

ii Bauman, I.; Bobic, Z.; Dakovic, Z.; Ukrainczyk, M. Time and speed of fruit drying on batch fluid-beds. Sadhana 2005, 30, pp. 687–698.

iii Borgolte, G. and Simon, E. J. 1981. Fluid bed processes in the manufacture of snacks products. CED review for chocolate, Confectionery and Bakery. 6(2), pp. 7-8, 10.

iv Donsi, G. and Ferrari, G., 1992. Modelling of Two-Component Fluid Bed Dryers: An Approach to the Evaluation of the Drying Time, Proc. Drying'92 pp. 493–502, Mujundar, A.S. (ed), Elsevier Sci. Pub.

v Fusco, A. J., Avanza, J. R., Aguerre, R. J. andGabritto, J. F., 1991. A difusión model for drying with volume change, Drying Technology,9(2): 397-417.

vi Gawrzynski, Z.; Glaser, R. Drying in a pulsed-fluid bed with relocated gas stream. *Drying Technology 1996*, 14 (5), 1121–1172.

vii Gibert, H., Baxerres, J. L., and Kim H., 1980. Blanching time in fluidized beds. In Food Process Engineeing; 1: Food Processing Systems, (P. Linko, Y. Malkki, J. Olkku and J. Larinkari Eds) pp. 75-85, Applied Science Publishers, London.

viii Giner, S. A. and Calvelo, A. 1987. Modelling of wheat drying in fluidized beds. *Journal of Food Science*, 52(5), pp. 1358-1363.

ix Guignon, Bérengère, Duquenoy, Albert and Dumoulin, Elisabeth D. (2002). 'Fluid Bed Encapsulation of Particles: Principles and Practice', *Drying Technology*, 20(2), 419-447.

x Herguido, J.; Corella, J.; Gonzales-Saiz, J. Steam gasification of lignocellulosic residues in a fluidized bed at small pilot scale. Effect of the Drying Sawdust in a Pulsed Fluidized Bed 485 type feedstock. *Industrial & Engineering Chemistry Research 1992*, 31 (5), 1274–1282.

xi Hovmand, S 1987. Fluidized bed drying. In hand booh of industrial drying. (A. S. Majumdar eds). Marcel Dekker, NY, USA.

xii Jingsheng Ye; Qiaojun Luo; Xiaolan Li; Qing Xu; and Zhanyong Li,. 2008. "Sorption Drying of Soybean Seeds with Silica Gel in a Fluidized Bed Dryer," *International Journal of Food Engineering*: Vol. 4: Iss. 6, Article 3. *Journal of Food Science*, 52(5), 1358-1363.

xiii Kaur Harjinder; Bawa, A. S. Studies on fluidized bed drying of peas. *Journal of Food Science and Technology* (Mysore).

xiv Kundu, K.M.; Datta, A.B.; Chatterjee, P.K., 2001. Drying of oilseeds. *Drying Technology*, 19, pp. 343–358.

xv Kwauk, M.; Li, J.; Liu, D. Particulate and aggregative fluidization-50 years in retrospect. Powder Technology 2000, 111, 3–18.

xvi Lai, S.F.; Yiming, C. and Fan, L.T., 1986. Modelling and Simulation of a Continuous Fluidised Bed Dryer, *Chem. Engng. Sci.*, 41(9) pp. 2419–2430.

xvii Law, C.L.; Majumdar, A.S., 2006. Fluidized bed dryers. In Handbook of Industrial Drying; Mujumdar, A.S., Ed.; CRC Press: Boca Raton, FL; pp. 173–201.

xviii Lehmann K., 1992. In microcapsules and nanoparticales in medicine and pharmacy (Ed. M.Donbrow) CRC Press Boca Ratin, pp. 73-97.

xix Murthy Z. V. P. and Joshi Dhruv, 2007. Fluidized Bed Drying of Aonla (*Emblica officinalis*). Drying Technology, 25, pp. 883 – 889.

xx Naveen S., Ramakrishna A. and Bawa A. S., 2009. Design and development of a hot air diffuser plate for fluidized bed technology – A mathematical model approach, *Beverage & Food World*, p 38-42.

xxi Niamnuy Chalida and Devahastin Sakamon. 2005. Drying kinetics and quality of coconut dried in a fluidized bed dryer. Journal of Food Engineering, 66(2), pp. 267-271.

xxii Palancar, María C., Aragón, José M. and Castellanos, José A. 2001. 'Neural Network Model for Fluidised Bed Dryers'. *Drying Technology*. 19(6), pp.1023-1044.

xxiii Senadeera, W.; Bhandari, B.R.; Young, G.; Wijesinghe, B., 2003.Influence of shapes of selected vegetable materials on drying kinetics during fluidized bed drying. *Journal of Food Engineering*, 58, pp. 277–283.

xxiv Shilton, N. C. and Niranjan, K.1993. Fluidization and its applications to food processing, Food Structure, 12, pp. 199-215.

xxv Singh K. K.; Tiroutchelvame D. and Patel S. (2008), Fluidized bed drying of ginger flakes, *Journal of Agricultural Engineering*, 45(1), p. 57.

xxvi Singh Sudhir Kumar, Narain Maharaj and Kumbhar B. K., 2007. Drying kinetics of button mushroom in fluidized bed, *Journal of Agricultural Engineering*, 11(1).

xxvii Sokhansanj, S.; Jayas, D.S., 2006. Drying of foodstuff. In Handbook of Industrial Drying; Mujumdar, A.S., Ed.; CRC Press: Boca Raton, FL; pp. 521–546.

xxviii Srinivasakannan, Chandrasekar (2008) "Modeling Drying Kinetics of Mustard in Fluidized Bed," *International Journal of Food Engineering*, 4(3), Article 6.

xxix Svetozarova1, G.I.; Burovoi, I.A., 1965. Mathematical models of drying processes in a fluidized bed. Journal of Engineering Physics & Thermophysics, 9, pp. 24-30.

xxx Tanfara, H.; Pugsley, T.; Winters, C., 2002. Effect of particle size distribution on local voidage in a bench-scale conical fluidized bed dryer. *Drying Technology*, 20, pp. 1273–1289.

xxxi Thakur A. K and Gupta A. K. Fluidized Bed Drying of High Moisture Paddy in Two Stages. *Journal of Agricultural Engineering*, 2007, 44(3).

xxxii Tirawanichakul, S.; Prachayawarakorn, S.; Varanyanond, W.; Tungtrakul, P.; Soponronnarit, S. Effect of fluidized bed drying temperature on various quality attributes of paddy. *Drying Technology*, 2004, 22, pp.1731-1754.

xxxiii Ulku, S. and Uckan, C., 1987. Corn Drying in Fluidised Beds, Proc. Drying'86, pp. 531–538, Mujumdar, A.S., (ed.), McGraw-Hill Hemisphere, New York.

xxxiv Vanecek, C., Markvart, M. and Drbohlar, R. 1966. Fluidized bed drying, Lenard Hill London, UK.

xxxv Zahed, A.H., Zhu, J.X. and Grace, J.R., 1995. Modelling and Simulation of Batch and Continuous Fluidized Bed Dryers, *Drying Technol.*, 13(1–2) pp. 1-28.