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Fluidized bed drying of food: A review

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ABSTRACT

Application of fluidized bed drying in food has been increased significantly in recent years. The fluidization technologies have been used for product development, energy efficiencies and overall quality in the final products in the area of food processing and preservation. However, this review paper evaluates different produces dried under fluidized bed dryer and to maintain the quality as well as the sensory characteristics of the dried products. This review paper suggests that fluidized bed drying certainly maintained a better drying compare to conventional drying (i.e. hot air cabinet drying) with respect to drying time, drying temperature and energy consumption of food.

Key words: Drying, fluidize bed drying, food products and quality attributes

INTRODUCTION

Drying of food products is very important because it is the easiest and the most common process of food preservation and it is one of the oldest and the most widely used methods of food preservations. Drying is indispensable unit operation at the final stage in processing of many food materials and hence, it determines, to a large extent, the quality of the product being manufactured. Drying of food is a major process 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 as a secondary process in certain product manufacturing operations (Fusco et al., 1991; Senadeera et al., 2003). Longer shelf life, palatability, product diversity and substantial volume reduction are the reasons for the popularity of dried products (Chauhan and Srivastava, 2009). This could be expanded further with improvements in product quality and process application. Drying is a thermo-physical and physico-chemical operation by which the excess moisture from a product is removed. It also lowers the cost of packaging, transportation and storing by reducing both weight and volume of the final produce (Chauhan and Srivastava, 2009). The use of fluidization is one of the best technologies commonly used in drying of agro food as well as other food materials. Fluidized bed drying has been recognized as a gentle, uniform drying method and capable of drying down to very low residual moisture content with a high degree of efficiency (Borgolte and Simon. 1981). This process is characterized by high moisture and heat transfer rates and excellent thermal control capacity compared to other conventional drying processes (Vanecek et al., 1966; Hovmand, 1987). It is also a very convenient method for drying heat sensitive food materials as it prevents them from overheating due to continuous mixing during the process (Gibert et al., 1980; Giner and Calvelo, 1987). Fluidized bed drying can be carried out as a batch or as a continuous process (Shilton and Niranjan, 1993). 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. It is regarded as a fourth generation of drying process. Simultaneous heat and mass transfer processes, wherein heating medium or internal heat generation helps in evaporation of free water molecules from the product.

FLUIDIZED BED DRYING

Fluidization is widely used in processing of solid particles by various technologies such as drying, combustion, synthesis etc. Generally, fluidized bed dryers are considered superior to other conventional dryers when processing of non sticky and small size distributed particles. Once, the air is allowed to flow through a bed of solid material with a velocity greater than the settling rate of the particle, the solid particle become blown up and become suspended in the air stream. At this stage, solid particle looks like as in a boiling stage; therefore this stage is called fluidized state. Use of hot air in the fluidized bed increases the drying rate of the material (Parlak et al., 2003; Sanadeera et al., 2006; Honrvar et al., 2011). Fluidized bed contains a stainless steel chamber having a removable perforated bottom known as the bowl. The product to be dried is placed in the bowl. Air is introduced from the bottom of the bowl and is heated at a required temperature by the heaters. The various advantages in the fluidized bed are good mixing with better heat and mass transfer, higher thermal efficiency, shorter drying time and close controllable temperature as drying gas mix intensively during its passing through the fluidized bed (Kumar and Belorkar, 2015). The general process flow of a fluidized bed drying of food is illustrated herewith in Fig.1

Process flow chart of a fluidized bed drying of food

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Collection of raw material

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Sample preparation: Sorting and grading

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Washing and removal of water

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Pre treatment if required

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Final preparation of samples for drying

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Dried in fluidized bed drier with various temperature and bed height

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Packaging and labelling

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Storage

Fig. 1. The general process flow of a fluidized bed drying of food

FLUIDIZED BED DRYING APPLICATION OF FOOD

Lehmann (1992) reported that due to the high demand for encapsulated material in the global market; fluidized bed coaters have become more popular which are used for encapsulating solid or porous particles with optimal heat exchange.

Guignon et al. (2002) studied fluidized bed drying of encapsulated solid particles. They stated that the fluid bed encapsulation process consists of spraying of a coating solution into a fluidized bed of solid particles. After several cycles of wetting and 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 reduction in the time of drying and level of temperature of the input hot air required for drying of the solid. Furthermore, the drying in fluidized bed avoids the formation of hot spots and makes it easy for the management of the solid as well as for the overall control of the operation (Palancar et al., 2001).

Pablo et al. (2004) investigated the drying of green peas in a fluidized bed heat pump dryer under normal and atmospheric freeze drying conditions. Three types of green peas having 8 mm and 10 mm diameter samples and two bed heights (2 and 4 mm) were used in the drying trials, operating either in isothermal conditions or on a combination of temperatures. The atmospheric freeze drying permits to obtain dried samples with high quality sensory properties. Drying kinetics was modelled with a diffusion model, and the effect of temperature on the effective diffusion coefficient follows the Arrhenius relationship. The activation energy values were 5046 and about 5910 kJ kg^{-1} for 8 mm and 10 mm diameter samples, respectively. The change in the color was negligible in the atmospheric freeze-dried samples. Additionally these dried green peas kept the original structure, yielding lower bulk density, higher values of floatability and improved rehydration ability when compared to samples dehydrated at temperature above freezing point.

Niamnuy and Sakamon, (2005) studied 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.

Senadeera (2005) studied the effects of fixed bed and fluidized bed drying and their comparison on physical properties changes in spherical food materials such as peas as the model material. The physical properties such as particle density, bulk density, shrinkage and bed porosity of fresh green peas were compared in fluidized bed drying with fixed bed drying at 50°C. The results revealed that physical properties changed during both the drying processes and can be modeled with respect to the moisture content. Volume shrinkage was linearly correlated and Particle densities of peas were correlated to non-linear models. In this comparison study, lower shrinkage was experienced in fluidized bed drying compared to fixed bed drying. Low bulk density was found for the fluidized bed compared to the fixed bed. Low bulk density was also attributed to the differences in shrinkage.

Senadeera et al. (2006) investigated the changes in fluidization behaviour of green peas particulates with change in moisture content during drying under a fluidized bed dryer. All drying experiments were conducted at 50 ± 2°C and 13 ± 2 % RH using a heat pump dehumidifier system. Fluidization experiments were undertaken for the bed heights of 100, 80, 60 and 40 mm and at 10 per cent moisture content levels. Fluidization behaviour was best fitted to the linear model of Umf = A + B m. where A, B are constants, U= Fluidization velocity, mf= Minimum fluidization and m= moisture content. A generalized model was also formulated using the height variation and which was used to compare minimum fluidization velocity with Ergun equation. The results revealed that there is a continuous change in the dimensions of the food particulates during fluidized bed drying resulting changes in minimum fluidization velocity. Change in minimum fluidization velocity was linear with the reduction of moisture content for spherical particulate (peas). It was also found that, the Generalized model and Ergun model can be used to predict minimum fluidization velocity with reasonable accuracy due to the spherical nature of the product shape.

Zhanyong et al. (2006) developed a modified fluidized bed termed as pulsed fluidized bed (PFB), to eliminate some limitations of the conventional fluidized bed (40, 50, 60, 70 and 80°C) by superposing a pulsating air stream (120-320 $m^3 h^{-1}$) with a desirable air temperature (80 and 90°C) on the continuously flowing fluidizing air. The PFB drying of green peas is superior to that in FB in terms of drying rates as well as colour preservation. The drying techniques are best suited for seat sensible agricultural products. Due to good dispersion of solids by the pulsing air flow, a higher drying rate is realized in PFB with lesser colour degradation and reduction in shrinkage of green peas.

Jingsheng et al. (2008) studied on soybean seeds which were contacted with silica gel in a fluidized bed, where the mass transfer was driven by moisture concentration gradient. It has the better 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. Separation of these two solids once desired moisture content is reached can be realized due to the size difference as well as the operation conditions of fluidization. The drying kinetics was compared under different mass ratios and fluidization conditions. The dispersion rate of soybean seeds was increased with addition of either silica gel particles, whereas the drying rate was improved with the gas velocity and mass ratio of silica gel. A scheme of sorption drying in a hybrid process of fluidized/fixed bed is proposed in the viewpoint of energy efficiency and product quality.

Singh et al., (2008) studied drying of ginger flakes under fluidized bed conditions in the air temperature ranges from 50 to 80°C and pretreatment of calcium oxide in the range of 1 to 2.5 per cent . They reported that drying rate at 60°C air temperature decreased from 0.43 to 0.17 g s^{-1} with the change in moisture content from 300 to 10 per cent (d.b.). The volatile oil in dried in dried ginger flakes decreases from 1.2 to 0.99 per cent with increase in drying temperature from 50 to 80 °C.

Srinivasakannan and Chandrasekhar (2008) reported fluidized bed drying of mustard seeds. Mustard is one of the popular oil seeds which were investigated for drying in batch fluidized beds with fluidization column of 0.245 m internal diameter and a height of 0.6 m.. Experiments were conducted to assess the kinetics of drying for the variation in the inlet air temperature of 60, 70 and 80 °C, 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. The drying rate was compared with various exponential time decay models and the model parameters were evaluated. The page model was found to match the experimental data very closely with the maximum root mean square error (RMSE) of less the 2.0%. The experimental data were also modeled using Fick's diffusion equation and the effective diffusivity coefficients was found to be within 1.69 × 10-11 to 3.26 × 10-11 $m^2 s^{-1}$ for the range of experimental data covered in the present study with RMSE less than 4%.

The variation of shrinkage and moisture diffusivity with temperature and moisture content for green peas under pilot scaled fluidized bed dryer (FBD) with inert particles assisted by an infra red (IR) heat source were studied by Honarvar et al. (2011). The shrinkage was only a function of moisture content; the moisture diffusivity was dependent upon both temperature and moisture content. The effective diffusion coefficients were evaluated in a temperature range of 35-70 °C and a moisture content range of 0.25 - 3.8 kg moisture per kg dry solids.

Deshmukh et al. (2015) assessed the drying characteristics of materials (pulses granules) in the fluidized bed dryer in drying temperature of 80 to 100°C with respect to the various operating variables and distributor plates. The drying rate increased as increasing the velocity of the drying air, while decreased with increases solids holdup. The drying rate was found to increase significantly with increase in temperature and flow rate of the heating medium as the time increases. Best result were found in case for moisture ratio and initial to the final moisture content is split pea gram and split red gram is found in case of mass in dry basis and wet basis. The drying rate was found to increase significantly with increase in temperature and flow rate of the heating medium as the time increases. Best results were found in case for moisture ratio and initial to the final moisture content in case of split pea gram. In case of split red gram, mass in dry basis and wet basis were found to be best. Many researchers round the globe have studied on fluidized bed drying and their major findings are presented in Table 1.

Table 1. Research findings on fluidized bed drying

Researchers	Findings
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).
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.
Thakur and Gupta (2007)	Paddy grains subjected to fluidized bed drying 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.
Murthy and Joshi (2007)	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^{-1} 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.
Herguido et al. (1992)	Sawdust drying was studied; the gasification of sawdust in a fluidized bed indicate moisture content need to be 8-12 %. The pulsed fluidized bed dryer is a modified conventional fluidized bed in which gas pulses cause vibration of the particle bed.

CONCLUSION

This review concludes the importance of fluidized bed drying of food. The application of fluidized bed dryer in industries has gain importance because of increase in energy and operational efficiencies. Fluidization gives higher benefits as compare to traditional method as it provides maximum surface area for higher heat and mass transfer rates during drying.

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