A Case Study on the Drying Performance of Batch Type Fluidized Bed Dryers at Constant Drying Temperatures

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Abstract: - Batch type fluidized bed drying is one of the most used and successful methods in food, pharmaceutical and chemical industries due to its higher efficiency. For this reason, many studies in lab- and industry-scales are continued on fluidized bed drying concept for improvements of their performance characteristics. This paper reports the recent significant experimental studies on batch type fluidized bed dryers giving their fundamental results. The signal acquisition and processing steps via daqboad, PC and program devised in LabView 2009SP1® for control and operation of the devices in a planned experimental study are introduced in the light of the literature survey. Moreover a case study is carried out in order to give the view point according to the conducted studies, in which the effects of particle types to be dried, drying medium velocities and heating methods on drying times are discussed at some constant drying temperatures.

Key-Words: - Fluidized bed, drying, moisture content, drying time, drying temperature, drying velocity

1 Introduction

Drying process can be simply defined as removal of moisture from a wet material to give a long shelf-life or to facilitate further processing. Since drying is an energy intensive operation, and due to the sharp increase in energy cost over the last few years, it has become the prime concern of the researchers to find the means of attaining optimum process conditions for good quality products, which leads to energy savings. Easy controlling of continuous flow inside fluidized bed, providing a homogenous drying due to being an isothermal systems, having higher efficiencies of heat and mass transfer when compared with other conventional drying systems, having shorter drying time due to high thermal efficiency and having higher drying capacity are the most important advantages of fluidized bed dryers. Fluidized bed dryers can be classified as is seen in Fig. 1.

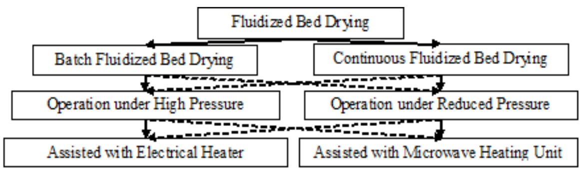

Fig.1 Classification of fluidized bed drying

Considering the flammability properties of the material, it is unfavourable to exceed above certain temperatures. This is one of the most important disadvantages of fluidized bed dryers. In food industry, relatively high operating temperature and remaining of thermolabile material for a long time in the dryer can cause deterioration of the material. In pharmaceutical industry, excessive temperature and the long process time in a dryer can cause the evaporation of the organic solvents, exceeding the limit of the flammability, and for this reason increasing of the risk of explosion. Using fluidized bed dryer systems under vacuum pressures is a way for eliminating these problems. The more reliable drying processes with lower operating temperature can be carried out efficiently under low even vacuum pressures.

As a result of existing literature survey, the studies are seen as those which operate under either high or low pressures. It is observed that there are few studies which are related with fluidized bed dryers operated under low (vacuum) pressures. On the other hand, the studies related with fluidized bed dryers assisted by microwave have recently been observed. The reason for preference of fluidized bed dryers assisted by microwave heating is predicted due to high energy efficiency, short drying time, low risk of losing colour, flavour and nutritional value of food.

Fluidized bed drying of solids can be batch or continuous type. Batch operation is preferred for

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small-scale production and for heat sensitive materials. The main advantages of a batch fluidized bed dryer are that process conditions can be selected easily and the products in a batch type have uniform quality because of homogeneity of the bed at any time. However, in continuous fluidized bed dryers, product from the dryer under steady-state operation corresponds in its properties to the material within the dryer due to high degree of solids mixing.

In this paper, the experimental setup that is going to be used for the control and operation of a batch type fluidized bed dryer is introduced. The setup is going to be controlled and operated by means of the triggered and acquired signals via the daqboard, PC and the devised program in LabView 2009SP1® environment.

2 Batch Type Fluidized Bed Drying of Particles

The first studies related with the fluidized bed dryers are seen in 1960s. In this section, the studies related to the batch type fluidized bed drying are introduced drawing attention to its advantages and disadvantages. Generally, the effects of drying air velocity, drying air temperature, initial moisture content, particle size and type on drying rate and/or performance were investigated in batch fluidized bed drying processes in the literature.

2.1 Batch type fluidized bed drying assisted with electrical heater at high pressures

Thomas and Varma [1] researched the drying kinetics of green and black pepper and mustard in batch fluidized bed dryer and found that the drying rate and the critical moisture content were dependent on the air velocity and temperature, as well as the particle size and mass of solids. Later Soponronnarit et al. [2] found the similar results with the reference [1] in their study for corn drying. Syahrul et al. [3] investigated that the thermal efficiencies were higher at the beginning of drying and then began to decrease subsequently to the final stage for wet corn drying process. On contrary to above mentioned statements, no significant effect of drying air temperature on thermal efficiency was found. However, in the study of Çalpan and Erşahan [4], the drying rate of Turkish lignite was found to be increased with increasing air flow rate and air temperature. Beside these, Niamnuy and Devahastin [5] investigated the influences of air velocity and drying air temperature not only on drying kinetics for finely chopped coconut but also on some other qualities such as color and surface oil content. They found the significant effect of drying air temperature on the color of the dried coconut while the effect of air velocity on the quantity of surface oil. They stated that the higher drying rate was obtained at the highest inlet air velocity, but it caused a lot of oil on the surface of the dried coconut. Hence they proposed other alternative drying techniques such as vacuum drying. Gazor and Mohsenimanesh [6] found that the increase in temperature was found to decrease in the drying time for canola. On contrary to some above-mentioned studies, Topuz et al. [7] observed no significant effect of air velocity on the drying rate as was drying air temperature for hazelnut drying process.

2.2 Batch type fluidized bed drying assisted with micro-wave unit at high pressures

Reyes et al. [8] analyzed the drying performance of potato slices in a fluidized bed dryer assisted with micro-wave unit and in a tunnel dryer. In any cases of dryer used, increasing air temperature was found to decrease the drying time. It was seen that the shortest drying time for 12% final moisture content was achieved using fluidized bed dryer with microwave-assisted without producing an appreciable deterioration of the color parameters when compared with that using tunnel dryer. However, increasing air velocity could not affect the drying rate as was observed in the studies on dryers assisted with electrical heater.

2.3 Batch type fluidized bed drying assisted with electrical heater at reduced pressures

Kozanoğlu et al. [9] investigated the hydrodynamics of fluidization under reduced pressure operations. It was seen that decreasing pressure caused increase in minimum fluidization velocity. A very similar hydrodynamic behavior at atmospheric pressure beds was observed in reduced pressure operations. Kozanoglu et al. [10] analyzed the change of pressure in vacuum fluidized bed drying. Lower pressure was found to provide higher drying rate for silica gel particles. However, lower operating pressure caused lower drying rate for lentil seed. The reason of converse behavior of drying rates of lentil seed and silica gel was having different internal structures. Kozanoglu et al. [11] also researched the effect of particle size on the vacuum-fluidized bed drying process using two different sizes of pepper seeds. In constant drying rate period, the small particles were found to have stronger drying rates. In the beginning of the falling rate period, the small particles presented higher drying rates whereas the larger particles showed stronger drying rates than the small ones toward the end of the period. Tatemoto et al. [12] investigated the drying characteristics of silica gel beads which were immersed in a bed of hygroscopic porous particles fluidized under reduced pressure. They stated that the dryer under reduced pressure had advantages such as low sample temperature, high drying rate, and small amount of drying gas.

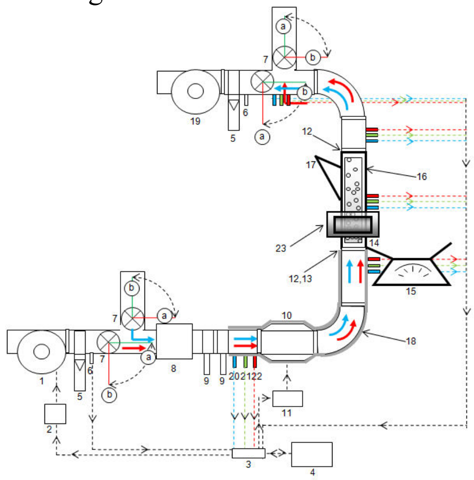
2.4 Batch type fluidized bed drying assisted with micro-wave unit at reduced pressures

Pere and Rodier [13] researched the drying performance of initially water saturated packing of glass beads and of unsaturated packing of pharmaceutical granules under vacuum pressures with microwave assisted heating system. It was seen that the absorption ability of microwaves was decreased when the water was no more free at the end of drying. Drying of pharmaceutical particles did not put in evidence any other limitation than the absorption of microwaves by hygroscopic water.

3 Experimental Setup

Design, production, computer-aided control of a conventional- and microwave-assisted fluidized bed dryer which operates under both high and low (vacuum) pressures, evaluation of the experimental results in terms of energy, exergy and cost analyses and comparison of the experimental results with theory are aimed for drying of harvested high moisture content legumes such as green pea, corn, cracked wheat, green lentil and chickpea for the next step of this study. The system has a drying feature in which operates optionally under both high pressures with a blower type fan and vacuum pressures with a vacuum pump. The drying performance in terms of humidity rate, drying time, temperature and drying rate etc. is going to be investigated in both types of drying techniques. The fluidized bed which operates under atmospheric and vacuum pressures is going to be run by means of both conventional and microwave assisted heating methods under some fixed parameters. Drying performances are going to be compared with each other taking into consideration of color loss, shrinkage and loss of nutritional value of foods. The experimental study is going to be fully-automated computer-controlled in order to minimize man-induced errors.

The schematic layout of the planned test rig is shown in Fig. 2.



1	Blower	12	Sieve
2	Speed Control Unit	13	Flow Conditioner
3	DAQ	14	Product Outlet
4	PC	15	Scale
5	Rotometer	16	Fluidized Bed
6	Flow Meter	17	Material Inlet
7	Flow Direction Valve	18	Insulation Material
8	Air Dryer	19	Vacuum Pump
9	Air Filter	20	Pressure Transmitter
10	Heater	21	Moisture Meter
11	Heating Control Unit	22	Temperature Sensor
		23	Micro-Wave Unit

Fig.2 Schematic diagram of the setup

Controlling and triggering of the machines and measuring devices which are used in the experiment, acquisition and processing of the experimental data are going to be performed by a program that is devised in LabView 2009SP1®. The calculations on heat and mass transfer in the fluidized bed are going to be performed. Thermodynamic (energy and exergy analyses) and economic performances of the fluidized bed dryer which operates under the both types of pressures (high and vacuum) are going to be examined. The results are going to be compared with the theoretical approaches in the literature. Usage of the conventional heating- and microwave-assisted fluidized bed dryer which operates under both atmospheric and vacuum pressures simultaneously in the same test rig for the same foods, that is not found in previous studies, detection of the resemblances and/or differences of the methods and performance comparisons of these drying methods are going to provide scientifically a contribution to the literature and are going to satisfy a model application which is going to be put into industrial practice.

4 Case Study Related with Effects of Drying Parameters on Drying Time

As a consequence of the literature survey, a case study is carried out to give a portrait and to provide a contribution to the available literature. Herein the related studies are analyzed in terms of the instantaneous moisture content (MC) on dry basis with respect to the drying time and they have been put together into some common basis.

Fig. 3 shows the variations of the moisture content (MC) with respect to the drying time which were obtained from many studies at constant drying temperature of T=50ºC for the different particles [14-21]. As can be seen, the moisture content of the particles decreases with time. However the characteristics of the decreasing lines are different because of the different types of particles. Although the drying times for mushroom, olive pomace, Chlorpropamide, macaroni beads, canola oil seeds, corn, bean, chickpea and ripe peppercorn are considerably short, the drying times for Jinda chili are very longer [14-21]. On the other hand it can be understood simply from the figure that the drying characteristics of the ripe peppercorn is quite different than others when the fluidized bed drying assisted with conventional electrical heating is used. However, if the microwave assisted one is used for the drying of ripe peppercorn, the same drying characteristics with those of the other particles is seen. Therefore it is deduced that both particle type and the heating method in drying process have major effects on the drying time. Moreover Fig. 4 shows the effect of the particle type to be dried and the heating method at different constant temperature of T=90ºC [14, 18-20, 22, 23]. The different drying characteristics of ripe peppercorn during the process with the conventional electrical heating assisted one can easily be seen at T=90ºC. At T=90ºC, the different particles which are waxy rice, canola oil seeds, Jinda chili, mushroom, white pepper seeds and ripe peppercorn which is dried by microwave assisted method have definitely the same drying characteristics except ripe peppercorn which is dried by conventional electrical heater as was observed at T=50ºC. Therefore the effects of particle type and used heating method such as drying with microwave and/or electrical heater cannot be underestimated.

Another important effective parameter is the velocity of drying medium. The effects of both heating method and velocity during the drying process of macaroni beads at T=50ºC [17] can be seen in Fig. 5. When microwave assisted drying was used, the drying time of the same particle (macaroni bead) at the same temperature was seen to decrease. Also the favourable effect of the velocity on drying time can also be seen from the figure. The drying time was observed to decrease when the drying velocity was increased during the microwave assisted process [17].

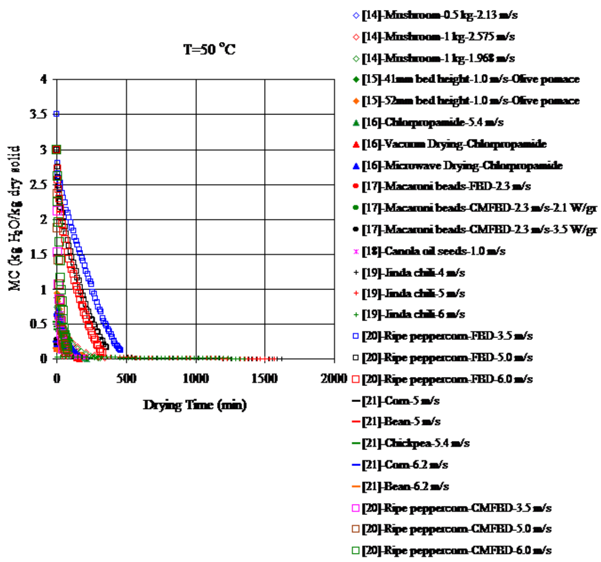


Fig.3 Effects of particle type and heating method on drying time at constant temperature T=50ºC [14-21]

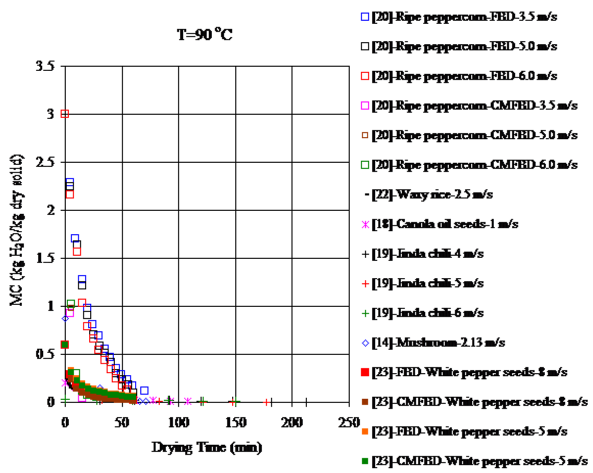


Fig.4 Effects of particle type and heating method on drying time at constant temperature T=90ºC [14, 18-20, 22, 23]

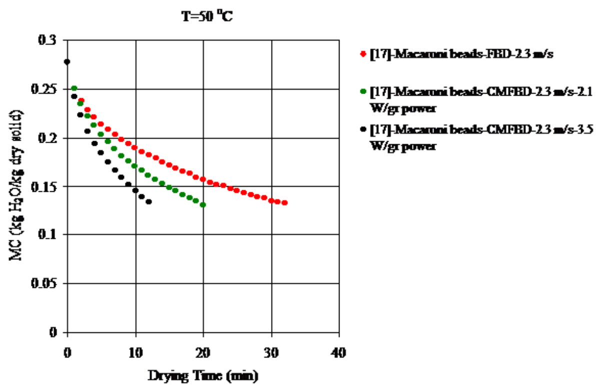


Fig.5 Effects of drying velocity and heating method on drying time at T=50ºC for macaroni beads [17]

Kaensup and Wongwises [20] studied on the drying performance of ripe peppercorn. The effects of different drying velocities and heating methods at T=50ºC in their study can be seen in Fig. 6. The microwave assisted process is seen to be more efficient than the other with the conventional fluidized bed drying process. On the other hand the favourable effect of drying medium velocity is observed for conventional fluidized bed drying process while no considerable effect of drying medium velocity on the drying time during the microwave assisted process.

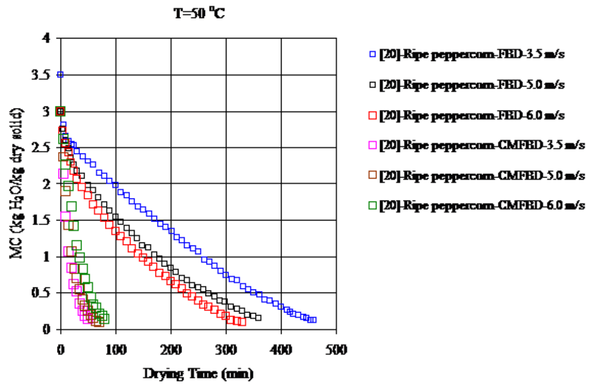


Fig.6 Effects of drying velocity and heating method on drying time at T=50ºC for ripe peppercorn [20]

On contrary to the above mentioned statements, Çil and Topuz [21] found that the variation in drying medium velocity did not have a considerable effect on drying time for the same particle at the same temperature of T=50ºC as is seen from Fig. 7. Furthermore the drying times for corn, bean and chickpea were found to be almost same at T=50ºC regardless of particle type and drying medium velocity.

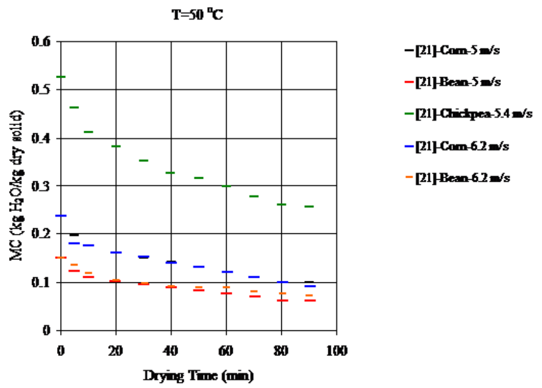


Fig.7 Effect of drying velocity on drying time at T=50ºC for corn, bean and chickpea [21]

When the drying processes at T=50ºC and T=90ºC are considered, it can be stated that the favourable effect of drying velocity is found to be significant at lower temperature.

In the light of the conducted experimental studies, the case study herein contributes a considerable portrait in terms of the effectiveness of some parameters such as the effects of particle type, drying velocity and heating method on drying time. As well as the similarities among the observed results, there are some conflicting ones according to this case study such that the effects of the particle type, the drying velocity and the used heating method during any drying process should be re-examined at the constant temperatures.

5 Conclusion

Some remarks as a result of the comprehensive literature survey and the conducted case study can be outlined as follows;

1) Drying rate is observed to increase with increasing air flow rate/air velocity and air temperature. However there are also some conflicting results such that Topuz et al. [7] observed no significant effect of air velocity on the drying rate as was drying air temperature.

2) An increase in drying temperature results in decrease of drying time.

3) A decrease in operating pressure plays a favorable role in drying process such as low temperature, high drying rate, small amount of drying gas and no risk of explosion for flammable particles. However it can be deduced that there are very few studies related on the batch type fluidized bed dryer operated at reduced pressures.

4) One of the effective parameters on the drying time is the particle type. At any constant drying temperature, the drying times differ from each other according to the particle type.

5) It can be stated that the higher the drying velocity, the more efficient the drying performance, especially at low drying temperatures.

6) The heating method of the fluidized bed dryers (electrical or microwave assisted) has a major role on the drying characteristics such that the effect of heating method is found to be more significant than the effect of drying velocity.

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