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Spatial homogeneity of drying in a batch type food dryer with diagonal air flow design

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ABSTRACT

Batch type dryers are some of the most widespread equipment used for food dehydration. One major drawback of dryer is the spatial heterogeneity of air distribution in the drying chamber. A new batch type dryer with diagonally airflow inlet channel (along the length of drying chamber) has been developed. This feature caused drying uniformity by exposing the entire food product to incoming warm air. A flow simulation software, ANSYS-Fluent has been used to predict the profile of air distribution in drying chamber. A spatial homogeneity of air distribution was found. To validate the designed geometry of dryer and its performance evaluation, experiments were conducted using potatoes (slices, 4 mm thickness) as drying material. The result, expressed as drying curves for all food buckets, showed high R^2 value. The simulated results of airflow were compared with experimental measured data. This comparison revealed a good correlation coefficient of 87.09% for airflow distribution.

1. Introduction

Batch type dryers are widely used due to simple design requirement. But problem of uneven air distribution encounter in most batch type drying systems. This leads to problems of low drying efficiency and lack of homogeneity of the products being dried (Mirade, 2003; Misha et al., 2013). Most of the research in batch drying processes has targeted the effect of temperature and air velocity as primary influencing parameters for the quality of dried products while the lack of uniformity in air flow is a crucial factor. Taking air distribution as primary design parameter has been the main objective in past few research (Adams and Thompson, 1985; Ayensu and Asiedu-Bondzie, 1986; Mathioulakis et al., 1998; Kiranoudis et al., 1999; Shawik et al., 2001; Mirade, 2003; Babalis et al., 2005; Margaris and Ghiaus, 2006; Gül ah and Cengiz, 2009; Amanlou and Zomorodian, 2010; Jacek et al., 2010; Tzempelikos et al., 2012; Darabi et al., 2013). Therefore, the design of airflow is one of the most important factors in batch type dryers. The process of drying, the drying medium and the geometry of the drying chamber determine the uniformity of drying and thus the quality of the finished products (Tzempelikos et al., 2012). It means that after selecting a drying process and drying medium, configuration of drying chamber is the critical design parameter. It decides the uniform air flow over the product. Non uniformity in air drying occurs mostly in drying chamber in fixed bed dryers. Therefore, the use of baffle plates/air straighter is a common practice to overcome this problem in large drying chamber (Janjai et al., 2006; Roman et al., 2012). Apart of their benefits to use, they cause not only increase in dryer construction cost but also result in velocity pressure drop. So more energy is consumed in drying process.

The present study was conducted to design a new batch type dryer to get uniform drying with uniformly distributed air flow in drying chamber. Normally, in fixed-bed batch dryer, air flows from one side of drying chamber to the other side. Due to this, air gets gradually moist while moving through the product lying at start, and its drying potential is therefore reduced at the time of its flow over the product lying at the end (Kröll, 1978; Müller and Heindl, 2006). So, the inlet side of food buckets within the drying chamber was designed diagonally to maintain velocity pressure as well as to avoid the use of baffle plates. The main concept was to make possibility for whole drying material to be exposed with the incoming warm air without baffle plates.

The main objectives of this study were:

- To design an air flow pattern with the application of ANSYS Fluent in batch type food dryer without baffles in such a way that the entire product should be exposed to warm air.

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- To develop dryer with the designed airflow pattern, evaluate the design using sample product (potatoes) and comparing the experimental data of air flow with the simulated data.

2. Description of the dryer

A new batch dryer was designed and developed (11 m × 1.20 m × 1.25 m) with diagonal air flow channel in the drying chamber at the inlet side of food buckets. It comprised on three major parts named as connector, lower half and upper half which is also called as drying chamber. Lower half of the dryer was of the shape of a channel converging towards the lower side of connector. It included a constant speed axial tube fan (Dia. 0.7 m, 453 m^3/h, 2.2 kW) for airflow and an electric water–air heat exchanger to heat up the incoming air. A water pump was used for the circulation of water into the system along with a pressure gauge and thermal expansion valve (to absorb excess water pressure). A connector (made of galvanized iron) was used to make a connection of lower half to the upper half of the dryer (Fig. 1). In the upper half of the dryer, twenty-five food buckets (each was of dimension 0.6 m × 0.4 m × 0.29 m) were arranged diagonally on a rolling track (for easy loading and unloading of food buckets). Each bucket covered a distance of 0.4 m in the drying chamber.

The inlet sides of these diagonally arranged buckets gave a shape of diagonal airflow channel at an angle of 1.42° with the wall of drying chamber in longitudinal direction (Fig. 2). It is the distinct designing feature of the dryer which would cause the flow through all the buckets evenly. The walls of dryer were made of rock-wool sandwiched into galvanized iron sheets for easy machining and excellent insulation. Two opening doors (each was of dimension 0.65 m × 0.36 m) were kept for the loading and unloading of buckets at both sides of the upper half of the dryer. At the outlet side of buckets, a rectangular passage was kept just before the outlet door (0.30 m × 0.15 m) for the recirculation of air. This passage was covered and opened with the flap of outlet door. The working of outlet door (opening/closing time of flap) was controlled with a controller based on set temperature. A control panel was used to set temperature and time (three different temperatures can be set for three different intervals of drying time).

3. Simulation of the design

3.1. Simulation details

Fluent has been used for simulation purpose in ANSYS workbench. It provides a comprehensive suite of computational fluid dynamics (CFD) software for modeling fluid flow and other related physical phenomena (Fluent user's guide, 2005). The geometry of the dryer was modeled and analyzed for two configurations of air flow channels in the drying chamber namely, straight air flow channel and diagonal air flow channel ($\theta = 1.42°$). The simulation with straight flow channel was done to assess the suitability of diagonal air flow design and to show a comparative change in airflow regime in the dryer compartment.

To study the profile of air distribution was the concern in simulation, so only the influencing parts of the dryer (connector and drying chamber) were designed and simulated in 3D model. The purpose of 3D model was also to assess flow variation along the depth of drying chamber as well which was not assessable in 2D model. Keeping in view the importance of air flow pattern, the case was simulated as steady state condition. For boundary conditions, lower part of the connector was taken as air inlet which received heated air coming out from heat exchanger. A value of 5 m/s normal to air inlet was assigned as inlet velocity. k–ε standard turbulence model was used for air flow turbulence. The characteristics and settings of simulations are tabulated in Table 1.

The resistance to air flow due to the food layer (single) was assumed negligible due to its smaller thickness (4 mm thick slices). That is why food was not modeled as solid objects or as porous media. Practically, these food layers were at successive distances in a bucket, so application of porous media was not applicable as food resistance. The main concern was that if a food bucket gets uniform distribution of air flow, it would facilitate a uniform drying of the material lying in that bucket.

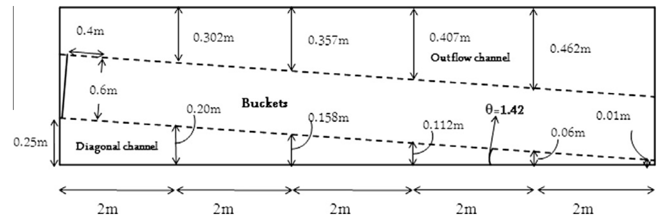

Fig. 2. Diagonal design of the airflow channel in drying chamber. It is line diagram of the drying chamber which shows the diagonal placement of food buckets to make airflow diagonal at their inlet side.

3.2. Simulated results

Fig. 3 shows comparative path lines of velocity for straight (a) and diagonal (b) air flow channels. In straight airflow channel, as

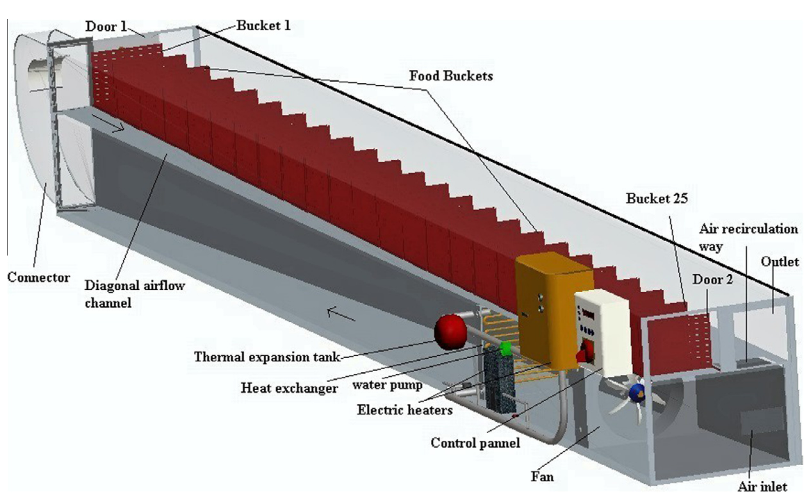

Fig. 1. 3D model of new designed batch type dryer. The complete geometry of the dryer is made using Pro. Engineering CAD software. It shows all the parts of dryer.