Temperature Profile during the Drying of Anhydrous Lactose in a Square Fixed Bed Dryer

Luis Obregón Quiñones¹, Guillermo Valencia Ochoa² and Jorge Duarte Forero²

¹ Research Group on Sustainable Chemical and Biochemical Processes
Universidad del Atlántico, km 7 Antigua via Puerto, Colombia

² Efficient Energy Management Research Group, Universidad del Atlántico
km 7 Antigua via Puerto, Colombia

Abstract

The behavior of temperature of most of the industrial processes in the chemical, petrochemical, food, and pharmaceutical sectors is of high importance because it helps to understand all the phenomena happening during the product processing. In this work, it was studied the temperature profile of anhydrous lactose in a square fixed bed dryer to analyze the behavior of the conduction and convection process inside the equipment. The factors analyzed were the conduction heat transfer rate at the bottom of the dryer through electrical coil tubes and a convection heat transfer at the top of the dryer. It was obtained the variation of temperature with the help of six temperature sensors. The heat of the blower has no effect on the temperature profile of the dryer. The parameter with the highest effect was the flow of air in the small hoses. The rate of increase of the temperature of sensor 3 without airflow in the small hoses was about 1.14°C/(10min), and with the airflow of 0.08m/s was 1.82°C/(10min).

Keywords: Heat transfer, convection, anhydrous lactose, temperature, drying

1. Introduction

All unit operations in the chemical, petrochemical, pharmaceutical, and food processing industries are very important because they are the heart of the production
of their products and the quality they obtain. One of the ways to monitor the quality and speed of production of the industrial processes is through the monitoring of the temperature inside the equipment [1]. This monitoring allows us to understand the different phenomena that are occurring in a given process [2, 3]. Temperature monitoring also helps to know if there are operating problems [4]. A unit operation of great importance especially in food is the drying process. The study of the temperature in this process helps to understand the phenomena of convection and conduction inside the wet solid, helping to take measures in the operating conditions or in the design of new equipment in order to increase its efficiency. One way to increase the drying efficiency is by making research on this topic. Liu et al., 2016, optimized a spray drying process of Lactobacillus reuteri to increase the survival rate of bacteria [5]. Battista et al., 2017, optimize the microencapsulation of phytosterols by the process of spray drying as well [6]. Temperature monitoring also helps to know the endpoint detection of a process [7]. As mentioned before, the temperature monitoring is an important factor to study in all kind of dryer dryers.

In the present work, it is studied the temperature profile of anhydrous lactose in a square fixed bed dryer to analyze the behavior of the conduction and convection process. The influence of air flow at room temperature inside the dryer, the hot air on the surface of the dryer, and the heat transfer rate in the bottom of the dryer are the factors used in the study.

2. Methodology

The experiments were made in a square fixed bed dryer at laboratory scale that has a controllable source of heat supply installed at the bottom, six thermocouples and four small hoses coupled in the walls of the vessel, and a thermal blower connected to the top of the dryer, see figure 1. The average initial humidity of the solids inside the dryer was 14%.

![Figure 1. Diagram of the square fixed bed dryer at laboratory scale.](image-url)
The dryer size specifications are 20 cm side and 15 cm high. The manufacturing material of the dryer is stainless steel. The dryer has 4 thermocouples connected on one side (T3, T4, T5, T6) and 2 thermocouples on the top (T1, T2). The two last thermocouples are used to monitor the temperature of the dry bulb and wet bulb to determine the conditions of entry and exit of air. The thermocouples are connected to a display to measure the corresponding temperatures in the different zones. In the lower part of the dryer, there are 3 coil tube heaters. In the top, there is an inlet and exit of air connected to a 3 cm diameter pipe where the air was circulated by a thermal blower at different temperatures. Four low power compressors were adapted in one of the sides of the dryer to introduce air at room temperature inside the solid. The dryer was divided into two zones, Zone 1 corresponding to the zone from the middle of the dryer to the top, and Zone 2 corresponding to the zone from the middle of the dryer to the bottom. The variables measured and the number of experiments performed are summarized in Table 1.

<table>
<thead>
<tr>
<th>Factor</th>
<th>Levels</th>
<th>LowValue</th>
<th>High value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat-resistances, QR</td>
<td>2</td>
<td>1 (\rightarrow) (0 KW)</td>
<td>2 (\rightarrow) (0.8 KW)</td>
</tr>
<tr>
<td>Heat-blower, QB</td>
<td>2</td>
<td>1 (\rightarrow) (6 KW)</td>
<td>2 (\rightarrow) (0.7 KW)</td>
</tr>
<tr>
<td>Air flow in the hoses, FA</td>
<td>2</td>
<td>1 (\rightarrow) (0 m/s)</td>
<td>2 (\rightarrow) (0.08 m/s)</td>
</tr>
<tr>
<td>Repetitions</td>
<td></td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Number of experiments</td>
<td></td>
<td></td>
<td>16</td>
</tr>
<tr>
<td>Response variable</td>
<td></td>
<td></td>
<td>% of the moisture content of the solid</td>
</tr>
</tbody>
</table>

3. Results and Analysis

The results were obtained running the experiments with the operating conditions shown in table 1.

In figure 2a, b, c and d, it can be seen the effect of the flow of the small hoses in the temperature. Figure 2a and 2b show that the heat of the blower has no effect on the temperature profile of the dryer. It happens because the air of the blower does not penetrate the solid avoiding the convective heat transfer inside it. Considering that the solid has low porosity, the heat transfer is only given by conduction. The water inside the solid remains practically without exit causing a constant temperature profile in both figures. However, when the flow of the small hoses is turned on, the porosity of the solid increases allowing the hot air of the blower to penetrate a depth where the sensor 3 is located. It causes a convective heat transfer because of the enhanced contact air solid increasing the rate of evaporation of the water allowing a better drying of the powder in all that zone. We can see this effect in figure 2c with the linear increment of the temperature of sensor 3. The rate of increase of the
temperature of sensor 3 with no air flow in the small hoses is about 1.14°C/(10min), and with the airflow of 0.08m/s is 1.82°C/(10min). It means that the increment of the rate of temperature when the air penetrates is of 59.4%. The effect is even more marked when the heat of the blower is increased, see figure 2d. The warmer air allows more driving in the direction to the bottom increasing, even more, the temperature of the sensor 3 as evidenced in figure 2d. The rate of temperature increases to 119% when the air of the small hoses penetrates, and with the heat of the blower is on the maximum. Having heated the surfaces of the particles in this area, the heat continues to be transported to the bottom by conduction causing an increase in the temperature of the sensor 4.

Figure 2. Effect of the air flow in the hoses, heat in the bottom of the dryer, and heat in the blower on the humidity of the solid in zone 1

Figures 3a and 3b show the effect of introducing heat by conduction with the coil tube heater in the bottom. The temperature of the sensor 6 increases linearly. This causes that the water contained in the solid that is in contact with the bottom to increase its vapor pressure causing a fast evaporation. As the evaporated water rises between the particles, it causes an increase in the total porosity of the solid, which helps the blower air at the top to penetrate a depth where the sensor 3 is. This is evidenced by the increase in the temperature of sensor 3, which is linear too. This phenomenon causes a better heat and mass transfer inside the dryer, improving its efficiency. The aforementioned effect is even more marked when the air is introduced through the small hoses as it causes a higher increase in the porosity of the powder increasing as well the heat transfer rate by convection in the area surrounding the sensor 3 resulting in a temperature increase in this sensor. Once the particles that are in this zone are heated, the heat conduction step is taken towards the bottom. This rate of heat transfer, added to the heat transfer introduced in the bottom by the coil tube heater, causes the temperature of sensor 6 to increase as shown in figure 3d. The temperature sensors 4 and 5 remain at all times without any variation. The cause of this situation might be a sensor nonfunctioning because
they do not follow a logical behavior. The turning on of the coil tube resistances has an average increase in the rate of temperature of sensor 3 of 80.68%.

Figure 3. Plot of the interactions of the main variables that affect humidity of the solid in zone 1

The results shown in these figures help to understand the importance of making a connection to the dryer by means of hoses or another type of pipe through which an air flow is entered by the sides of the tray dryers. This adaptation improves the mass and heat transfer process resulting in better drying and therefore high efficiency.

4. Conclusions

It was studied the effect of heat of a blower, the heat of a coil tube heater and the side flow of air in the drying of anhydrous lactose in a laboratory-scale square fixed bed dryer. The heat of the blower has no effect on the temperature profile of the dryer. It happens because the air of the blower does not penetrate the solid avoiding the convective heat transfer inside it. The parameter with the highest effect was the flow of air in the small hoses. The rate of increase of the temperature of sensor 3 with no air flow in the small hoses is about 1.14°C/(10min), and with the airflow of 0.08m/s is 1.82°C/(10min). It means that the increment of the rate of temperature when the air penetrates is of 59.4%. The effect of the air in the small hoses is even higher when the heat of the blower on the top works at the higher value, causing an increase in the rate of temperature of 119%. The rate of heat transfer of the blower in the top of the dryer, added to the heat transfer introduced in the bottom by the coil tube heater, causes the increase of temperature of sensors 3 and 6. These conditions cause a better heat and mass transfer inside the dryer, improving its efficiency. The turning on of the coil tube resistances has an average increase in the rate of temperature of sensor 3 of 80.68%.
References


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