Effect of the Operating Conditions in the Drying of Anhydrous Lactose in a Square Fixed Bed Dryer

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Abstract

Drying is a very important unit operation highly used in the chemical, pharmaceutical, food industries, among others. In the present research project, a laboratory-scale square fixed bed dryer was built to dry anhydrous lactose. The parameter studied was the humidity of the lactose in different zones of the dryer to analyze the behavior of the convection and conduction process inside the equipment. A conduction heat transfer rate at the bottom of the dryer of 0.8 KW was applied through electrical resistances, and a convection heat transfer rate of 0.7 KW was transmitted through hot air of a blower. Profiles of humidity were obtained as a function of time, measuring the dry and wet bulb temperatures at the entry and exit of the air. The variable of highest influence in the drying process was the flow through the hoses. The small induced air flow despite having a relatively lower temperature than the inside temperature of the solid in the container, helps to increase the porosity of the powder and therefore to improve the drying contact area air-wet solid.

Keywords: Heat transfer, convection, anhydrous lactose, moisture

1. Introduction

Dryers are commonly used to remove liquids from granular materials such as those
used in pharmaceutical and food industries. There are different drying processes used in the industry that depend on the type of material to be dried, the mechanism of drying accepted, and the conditions that are required for the process [1, 2]. Drying processes in fluidized beds are usually preferred to favor the fluidity on the final product [3] and to obtain a high production by decreasing the operating times [4]. On the other hand, when carrying out the drying procedures using a fixed bed, the most common types of dryers are the tray dryers [5], where the contact surface is usually increased by decreasing the thickness of the layer of the wet powder to be dried. With these dryers, the problem of dust generation is eliminated, but the operating times are increased. Another great advantage obtained with fixed bed dryers is that the particle size distribution remains constant so the final granulometry of the solid material is not affected. In many other types of dryer, it is a weakness because of the breaking of particles [6]. The disadvantage of these type of dryers is the slow rate of drying, the production is by lots and the drying is not homogeneous.

To achieve the best possible drying in the shortest possible time, it is necessary to understand different drying processes. In the present work, the drying process of lactose anhydride in a square fixed bed dryer is studied. The influence of air flow at room temperature inside the dryer and hot air on the surface of the dryer will be studied. In the same way, the effect of the heat transfer rate in the bottom of the dryer will be studied.

2. Methodology

A square fixed bed dryer was designed at laboratory scale. It has a controllable source of heat supply installed. Six thermocouples were coupled to the vessel in order to measure the temperature at different heights of the solid filled inside the dryer, see figure 1. The initial humidity of the solids inside the dryer was 14%.

![Diagram of the square fixed bed dryer at laboratory scale.](image)
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 installed on one side (T3, T4, T5, T6) and 2 thermocouples on the top (T1, T2) to measure the temperature of 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 electrical resistances of 60 Watts each. In the top, there is an inlet and exit of air connected to a 3 cm diameter pipe where the air was circulated at different temperatures. Four low power compressors were adapted in one of the sides of the dryer to simulate the entry of air at room temperature. 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 1. Experimental design

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

3. Results and Analysis

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

3.1. Plot of the effects for zone 1

As can be seen in figure 2, the variable that has the higher effect in the drying process is the flow in the hoses. Even when this flow is extremely small, it helps to dry the solid in a higher percentage than the other variables. When the air enters inside the solid, the porosity of the powder increases causing an increase in the contact area air-solid increasing the mass transfer rate of the water as well, resulting in a better drying.
On the other hand, the heat of the blower has a significative effect in the drying. The air in the top of the dryer affects only a small layer of the solid. This air does not penetrate the solid to the bottom. It only penetrates a small depth. For this reason, the effect is small but it is still significative. It happens because the first layer of the solid gets dried quickly causing a diffusion of the water in the direction bottom to top. The effect of the resistance is low. In fact, visually it seems to cause an unfavored drying. Practically the effect in this zone is null because the coil tube heater is far.

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

Figure 3. Plot of the interactions of the main variables that affect humidity of the solid in zone 1
Figure 3 shows the interactions between the variables. As can be seen, the interaction of all of them is not significative. Table 3 shows the statistic of the variables resumed in the p-value obtained by using an ANOVA. It evidences the behavior seemed in figure 2 and 3. The flow of air in the hoses and the heat of the blower are the only significative variables.

Table 2. Statistic of the main variables that affect the drying in zone 1

<table>
<thead>
<tr>
<th>Main Variable</th>
<th>FA</th>
<th>QB</th>
<th>QR</th>
</tr>
</thead>
<tbody>
<tr>
<td>P-value</td>
<td>0.017</td>
<td>0.043</td>
<td>0.082</td>
</tr>
<tr>
<td>Interactions</td>
<td>FA·QB</td>
<td>FA·QR</td>
<td>QB·QR</td>
</tr>
<tr>
<td>P-value</td>
<td>0.753</td>
<td>0.321</td>
<td>0.645</td>
</tr>
</tbody>
</table>

### 3.2. Plot of the effects for zone 2

Figure 4 shows again that the variable with the highest effect is the air flow in the hoses. It indicates the great importance of using orifices in the trays that let the air enter to the recipient to be in contact with the solid. In this zone, the effect of the heat of the blower is so low. Practically it has no effect due to the fact that the air in the top of the dryer does not penetrate to the bottom.

![Plot of the effects for zone 2](image-url)
On the other hand, it can be seen that the heat given by the resistances in the bottom of the dryer is high. It happens because the zone 2 is in contact with the resistances causing a high evaporation of the water resulting in a decrease in the humidity of the powder.

![Figure 5. Plot of the interactions of the main variables that affect humidity of the solid in zone 2](image)

Figure 5 shows the interaction of the factors. Visually the interaction seems to have a low effect. Table 3 corroborates that the effect of these interactions is null. Only the factors FA and QR have significative effect in this zone evidencing the explanation given before.

**Table 3. Statistic of the main variables that affect the drying in zone 2**

<table>
<thead>
<tr>
<th>Main Variable</th>
<th>FA</th>
<th>QB</th>
<th>QR</th>
</tr>
</thead>
<tbody>
<tr>
<td>P-value</td>
<td>0.028</td>
<td>0.084</td>
<td>0.029</td>
</tr>
<tr>
<td>Interactions</td>
<td>FA·QB</td>
<td>FA·QR</td>
<td>QB·QR</td>
</tr>
<tr>
<td>P-value</td>
<td>0.052</td>
<td>0.861</td>
<td>0.120</td>
</tr>
</tbody>
</table>

**4. Conclusions**

The design and construction of a laboratory-scale square fixed bed dryer was done to dry anhydrous lactose. The study was done dividing the dryer into two zones. The superior zone (zone 1) and the inferior zone (zone 2).
The factor with the highest significative effect in the powder drying in zone 1 and zone 2 was the flow of air entering in one side of the dryer by the use of 4 hoses connected to the walls of the recipients. This flow causes an increase in the porosity of the powder increasing the contact area air-solid resulting in an increase of the mass transfer rate of the water improving the drying.

The heat of the blower has a high effect in the zone 1 because this zone is in direct contact with the powder in the top of the dryer. This factor is null in the zone 2 because of the air of the blower does not penetrate to the bottom. The effect of the heat of the resistances in the bottom is null in zone 1 because the resistances are far from this zone. In zone 2 this factor has a significative effect because of the direct contact of the soli with the resistances causing a high evaporation of the water in this zone.

References


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