Brazilian Journal
of Chemical
Engineering

ISSN 0104-6632
Printed in Brazil
www.abeq.org.br/bjche

Vol. 24, No. 01, pp. 95 - 100, January - March, 2007

DRYING IN THE ROTATING-PULSED FLUIDIZED BED

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(Received: March 28, 2005 ; Accepted: December 19, 2006)

Abstract - There are particulate materials that are cohesive when wet. Although they are Geldart's group A dry powders, they show difficulties in fluidizing in a conventional fluidized bed, which could be diminished by modifying the fluidization equipment. Therefore, the objective of this work was to study the drying of cohesive particulate material using a rotating-pulsed fluidized bed. The material used in the drying study was 2-hydroxybenzoic acid because its cohesive forces are stronger when wet. The drying experiments were carried out according to the following parameters: frequency of disk (5 and 15 Hz), initial moisture content of the material (high and low) and gas temperature at 85°C. From the drying kinetic curves and visual observations during the experiments, it could be concluded that the rotating-pulsed fluidized bed is an alternative for the processing of cohesive solids that preserves the final quality of the dry solids.
Keywords: Drying; Fluidized bed; Particulate material.

INTRODUCTION

The chemical industry uses the thorough fluidization of particulate materials with a gas stream because it offers high rates of heat and mass transfer between the gas and solid phases. In addition to the technological and economic advantages of using a fluidized bed, the increase in the active surface of the solids, the rapid movement of solid particles in the contact areas, its use in continuous processes and the possibility of automating the process can also be mentioned.

According to Strumillo and Kudra (1986), dryers with gas stream pulsation are called pulsofluidized bed dryers. As the vibrations caused by them affect the drying process, fluidization of the material is easier and the structure of the bed is improved. They can be used for materials with a high unbound moisture content and also for materials which do not contain this type of moisture. The scientific literature is also limited and more research is necessary to discover the real advantages and disadvantages of pulsofluidized bed equipment.

Pulsation of the gas current offers advantages over the conventional fluidized bed, especially due to a considerable reduction in the gas flow. Industrial-scale studies using the pulsed fluidized bed showed an energy savings greater than 50% (Jezowska, 1993).

In the rotating-pulsed fluidized bed, the multiorifice gas distributors are divided into two independent elements: a conventional multiorifice gas distributor for static bed support and a flat rotating disk, which periodically distributes the gas over the cross-sectional area of the supported plate. When the rotating disk is fixed, one or more spouts

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are formed – depending on the number of holes – and the process behaves as a spouted bed. When the rotation velocity of the disk is low, the spouts rotate and between them there are areas of fixed bed. When the rotation velocity of the disk is high, the total system is fluidized as a conventional fluidized bed (Elenkov and Djurkov, 1992).

The main advantage of the rotating-pulsed fluidized bed over the spouted bed and the conventional fluidized bed is that in the whole area of the bed the gas in the holes of the rotating disk reaches high speeds. In this case areas with a low filtration of the gas through the bed do not exist. A high disk rotation speed produces an internal and uniform movement of the particles inside the bed (Elenkov and Djurkov, 1992).

The pulsed fluidized bed creates new perspectives for the drying of granular materials of different types, as studied by Blacha-Jurkiewicz et al. (1987) and Gawrzynski et al. (1989). In these studies it can be observed that batch drying in a pulsed fluidized bed is characterized by the uniform distribution of moisture throughout the whole solid mass being processed with a considerable reduction in the consumption of gas.

The rotating-pulsed fluidized bed can be applied in the drying of crystalline products that have the capacity to aggregate and stick together (crystal sugar, sea salt, etc) as well as high-moisture biological products (wet-separated sesame and sunflower seeds, cocoa, etc) (Djurkov, 1998; Gawrzynski and Glaser, 1996; Elenkov and Djurkov, 1992).

Gawrzynski et al. (1996) studied the drying of crystal sugar and they observed that the pulsation of hot air caused fluidization of the bed, providing an intense mixing of the solids and the development of an interfacial area that improved the drying process.

Jinescu et al. (2000) studied the process of drying powdered biomaterials, and they verified an intensification of the fluidization process due to pulsation of the gaseous stream. A decrease in pressure drop and in minimum fluidization velocity with the increase in disk rotation frequency was observed as well as the energy contribution of the pulses to the decrease in interparticle forces.

The objective of this work was to study the drying of 2-hydroxybenzoic acid in a rotating-pulsed fluidized bed (RPFB). The drying experiments were conducted for two different frequencies of the rotating disk (responsible for the pulsation effect), two values of initial moisture content of the solid and a constant inlet air temperature of 85°C.

MATERIAL AND METHODS

Material

The material used in the drying study in the rotating-pulsed fluidized bed (RPFB) was 2-hydroxybenzoic acid, which is obtained as white crystals and fine needles or fluffy white crystalline powder. This material has been used in the paints, cosmetics, pharmaceutical and perfume industries, among others.

In Table 1 the solids properties that were very important for this work (Kirk-Othmer, 1982) are shown.

In spite of belonging to Group A dry powders, according to Geldart's classification (Geldart, 1986), preliminary tests showed that this solid shows difficulties in fluidizing in a conventional fluidized bed (CFB) due to its cohesiveness when wet. In addition, channeling occurred when the gas flowed through the bed, lowering the quality of fluidization.

Table 1: Properties of the solids

$\overline{d_p}$ (μm)	T_s (°C)	ρ_s (g/cm^3)
80	76	1.443

The Rotating-Pulsed Fluidized Bed Dryer (RPFB Dryer)

The main difference between a rotating-pulsed fluidized bed dryer and a conventional fluidized bed dryer is the gas distribution system. The distribution of air is possible due to a disk installed upstream of the drying chamber. This disk has an opening – a circle with 60º angle – through which the gas passes. As the disk rotates, the gas is alternately distributed between the sections of the drying chamber, which causes the pulsation effect.

The experimental apparatus used in this work is shown schematically in Figure 1.

The experimental system has as its main elements a stainless steel cylindrical bed with an internal diameter of 14.3 cm and a height of 70 cm, which is the drying chamber (7); a system of pulsed air distribution (5, 6 and 15); and a blower (1) that feeds the bed with air. As the drying gas used is air with a variable relative humidity, a bed of silica gel is introduced into the feeding line (3) with the objective of removing the moisture from the air. In the electric heater (4), the air is heated up to the desired temperature.

The multiorifice gas distributor (15), located in the lower part of the cylinder, is divided into two parts, both of stainless steel: a perforated distributor plate to support the bed of particles and to distribute the gas uniformly and a flat rotating disk with an opening of 60°,, coupled to the axis of the motor (6), which periodically distributes the gas over the cross-sectional area of the supported plate.

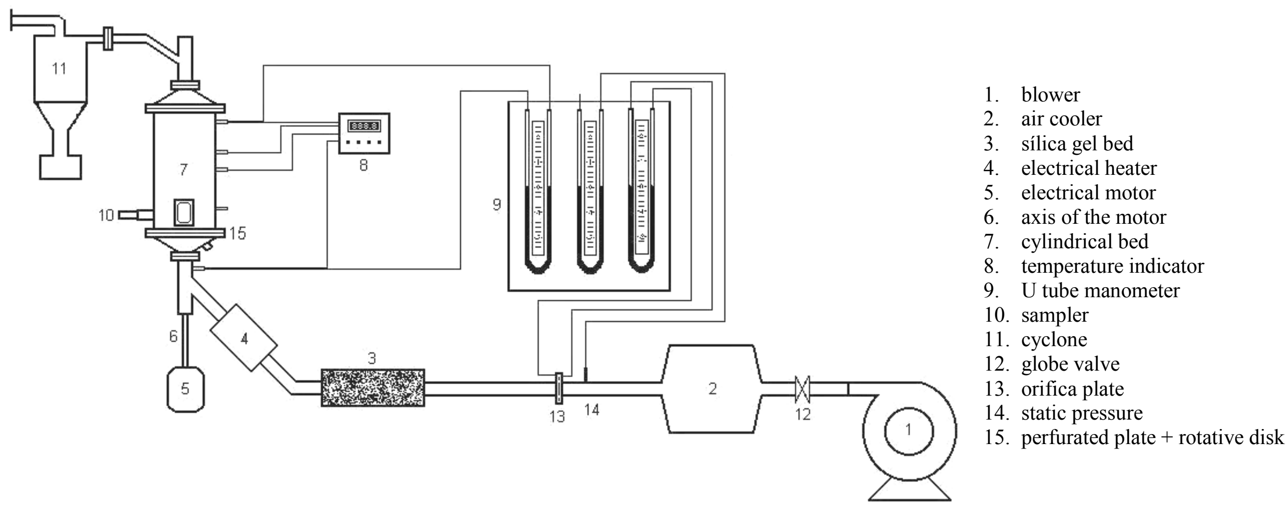


Figure 1: A schematic diagram of the drying system

Drying Experiments

In this study, the effect of frequency of pulsation and of initial moisture content of the solid, maintaining the temperature of the drying gas constant, were analyzed. The combination of variables used in each experimental run are listed in Table 2.

The airflow used in the experiments was about 1.40 m/s, based on fluid dynamic studies of the same dry material, as described in Ugri (2003), and assuming $v_g \approx 3 * v_{pmf}$.

The initial moisture content (X_i) of the material was classified as high (6.5-10.0 % d.b.) and low (3.5-5.5 % d.b.) for the two different lots. The value of X_i for each experimental run was also defined according to the lot used.

The solids mass used (900 g) in the drying study in the RPFB was defined based on a fluid dynamic study conducted for the same dry material, as described in Ugri (2003).

For the construction of the drying kinetics curves, samples were taken every 2 minutes at the beginning of then at drying and ten-minute intervals, starting at 15 minutes and continuing until the end of the experiment at about 1h 20min.

Each sample removed was analyzed by the Karl-Fischer method to determine the moisture content at each point in the experiment (Ugri, 2003). After obtaining the value for moisture content, the curve X/X_0 *versus* t was traced for each experiment.

Table 2: Operational parameters

Experimental run	X_i (% d.b.)	$f_{rotation}$ (Hz)	T_{gas} (°C)
1	9.61	5	85
2	3.72	15	85
3	10.0	15	85
4	4.52	5	85

RESULTS AND DISCUSSION

The curves obtained for the drying kinetics of 2-hydroxybenzoic acid in the rotating-pulsed fluidized bed (RPFB) are shown in Figures 2 and 3 for the experiments where the initial moisture content (X_i) varied and T_{gas}, $f_{rotation}$ and v_{gas} were maintained constant The drying curves show two drying periods, a constant rate period and a falling rate period, and most of the moisture was removed from the solid during the constant rate period, which was the predominant period during the drying process.

In Figure 2 the two experiments carried out with the smallest $f_{rotation}$, 5 Hz, under the process conditions described in Table 2 are shown. In this figure it can be observed that the value of X_i had an effect on drying time, since the larger the value of X_i, the longer the drying constant rate period, about 20 minutes.

Figure 3 contains the drying curves obtained for the largest $f_{rotaion}$ value (15 Hz) and for the process conditions described in Table 2. The results obtained show the same behavior as that shown in Figure 2, since for the highest value of X_i the constant rate period was the longest, about 20 minutes.

Comparing the results presented in Figures 2 and 3, it can be concluded that maintaining the external conditions constant (T_{gas}, $f_{rotation}$ and v_{gas}) the variation in the value of X_i, had an effect on the drying time during the constant rate period, because the larger the X_i of the solid studied, the longer the drying constant rate period.

The effect of $f_{rotation}$ on the drying curves, maintaining the values of T_{gas}, X_i and v_{gas} constant, is shown in Figures 4 and 5.

Analyzing Figure 4 it can be observed that the drying curve profiles were close when X_i (high moisture content) was maintained approximately constant and the value of $f_{rotation}$ varied and the constant drying rate period for a $f_{rotation}$ of 15 Hz ended slightly before the experiment carried out for a $f_{rotation}$ of 5 Hz.

In Figure 4, the value of the constant drying rate period for experimental run 3 was longer than the value obtained for experimental run 1; this ocurred because a higher rotation frequency facilitates the movement of the particles and improves the change in heat and mass during the drying process.

In Figure 5 the behavior for low values of X_i, is the same as that in the results presented in Figure 4. In Figure 5 it should be observed that the constant drying rate period for the experiment with a $f_{rotaion}$ of 15 Hz was much longer than that found in the experiment with a $f_{rotaion}$ of 5 Hz.

The results for the drying process obtained in this work show that the values of final moisture content (X_f) were around 2000 ppm, which is the accepted commercial range for 2-hydroxybenzoic acid.

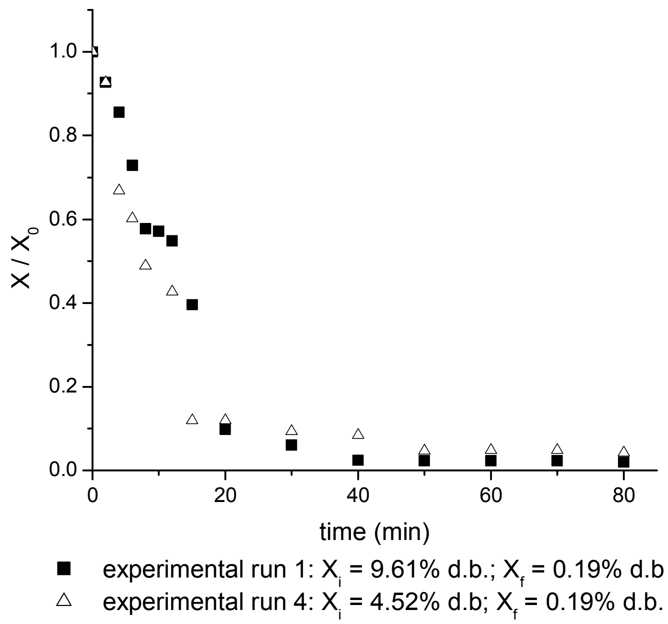


Figure 2: curves for the RPFB. T_{gas} = 85°C, $f_{rotation}$ = 5 Hz, v_{gas} = 1.4 m/s

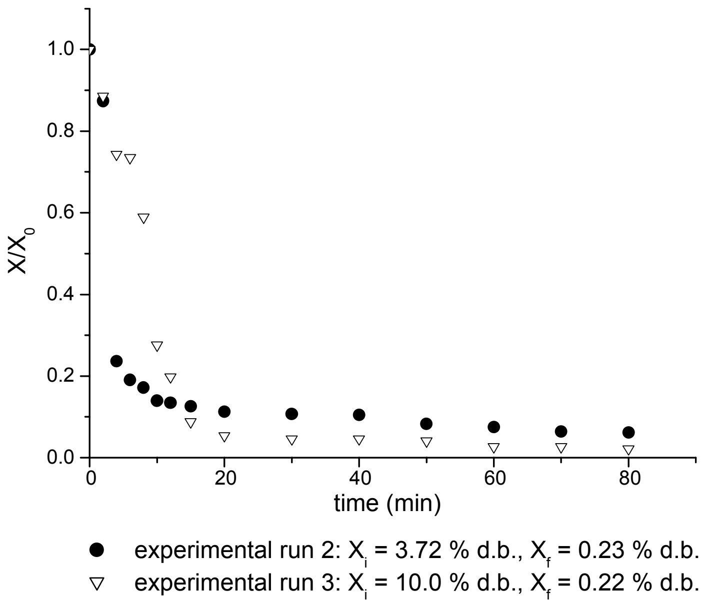
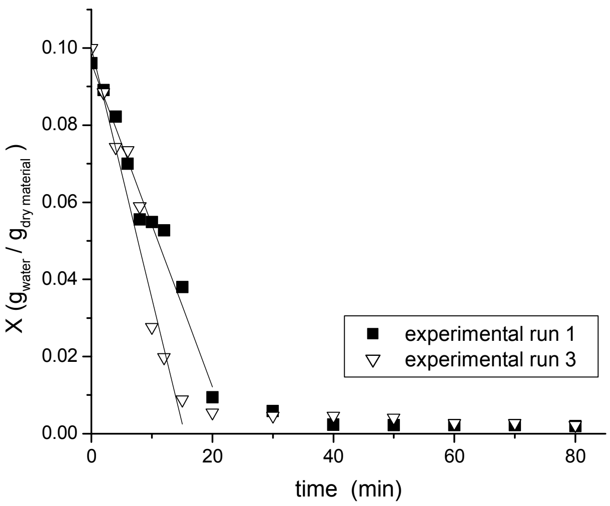
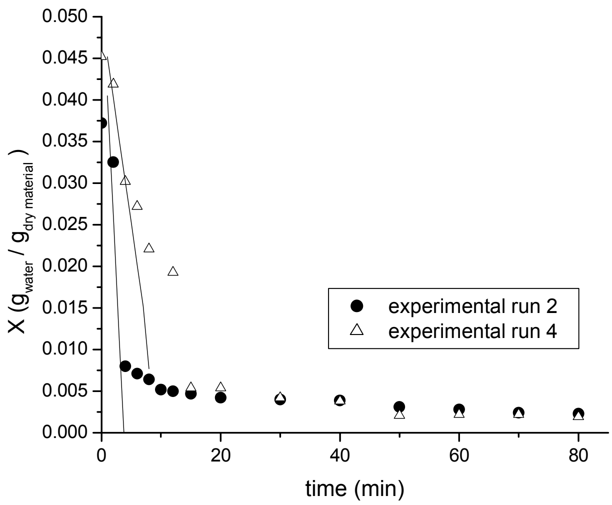


Figure 3: Drying curves for the RPFB. T_{gas} = 85°C, $f_{rotation}$ = 15 Hz, v_{gas} = 1.4 m/s



Experimental run 1: $f_{rotation}$ = 5 Hz, X_i = 9.61 % d.b., X_f = 0.19 % d.b., $-(dX/dt)_{constant}$ = 0.0042 (g_{water} / $g_{dry\ material}$.min)
Experimental run 3: $f_{rotation}$ = 15 Hz, X_i = 10.0 % d.b., X_f = 0.22 % d.b., $-(dX/dt)_{constant}$ = 0.0065 (g_{water} / $g_{dry\ material}$.min)

Figure 4: Drying curves for the RPFB. T_{gas} = 85°C, v_{gas} = 1.4 m/s



Experimental run 2: $f_{rotation}$ = 15 Hz, X_i = 3.72 % d.b., X_f = 0.23 % d.b., $-(dX/dt)_{constant}$ = 0.0071 (g_{water} / $g_{dry\ material}$.min)
Experimental run 4: $f_{rotation}$ = 5 Hz, X_i = 4.52 % d.b., X_f = 0.19 % d.b., $-(dX/dt)_{constant}$ = 0.0025 (g_{water} / $g_{dry\ material}$.min)

Figure 5: Drying curves for the RPFB. T_{gas} = 85°C, v_{gas} = 1.4 m/s

CONCLUSIONS

The study of drying in a rotating-pulsed fluidized bed showed that this equipment can be used to dry a cohesive particulate material, resulting in the uniform distribution of the gas inside the bed and providing a uniform drying of the solid.

Analyzing the effects of X_i and $f_{rotation}$ in relation to the time of drying in the constant rate period, it can be concluded that the time is reduced with the increase in $f_{rotation}$ (inside the range studied and for a constant X_i), which allows the reduction in the flow or the temperature of the drying gas. Maintaining the external conditions constant ($f_{rotation}$, T_{gas}, v_{gas}), the drying time is decreased to the smallest values of X_i.

The drying curves obtained show the two drying periods and most of the moisture in the solid was removed during the constant drying rate period, the most important stage of this drying process. The drying rate of 2-hydroxybenzoic acid was affected by the frequency of disk pulsation under the conditions tested. Thus, the reduction in air consumption achieved by the pulsation of the airflow is feasible, and as a consequence the production yield increases.

ACKNOWLEDGMENTS

We acknowledge the financial assistance received from Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq).

NOMENCLATURE

Latin Letters

$\overline{d}_p$	average diameter of the particle	(μm)
$f_{rotation}$	frequency of disk rotation	(Hz)
RPFB	rotating-pulsed fluidized bed	(-)
T_{gas}	gas temperature	(°C)
T_s	sublimation temperature of the solid	(°C)
v_{gas}	gas velocity	(m/s)
v_{pmf}	pulsed minimum fluidization velocity	(m/s)
X_i	initial moisture content of the solid	(% d.b.)
X_f	final moisture content of the solid	(% d.b.)
-(dX/dt)	drying rate	(g_{water} / $g_{dry\ material}$.min)

Greek Letter

ρ_s	density of the solid	(g/cm^3)

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