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The Influence of Distributor Design on Fluidized Bed Dryer Hydrodynamics

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THE INFLUENCE OF DISTRIBUTOR DESIGN ON FLUIDIZED BED DRYER HYDRODYNAMICS

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ABSTRACT

The influence of perforated plate, punched plate and Dutch weave mesh distributor designs on fluidized bed dryer hydrodynamics was studied for a range of bed loadings and superficial gas velocities. The punched plate showed improved performance over the other designs at a gas velocity of 1.5 m/s and bed loadings greater than 1.0 kg.

INTRODUCTION

An important component of any fluidized bed is the gas distributor. The role of the distributor is to evenly distribute the fluidization gas across the bed inlet and hence to initiate effective gas-solids contacting. Various distributor designs have been created to improve on the operational concerns that can be encountered in fluidized bed processes. These designs can influence the bed hydrodynamics and therefore potentially alter the rate of heat and mass transfer in fluidized bed processes, including dryers.

Many industries, including the pharmaceutical industry, which is the focus of the present study, have traditionally used the perforated plate distributor for fluid bed drying. This design however, can lead to dead zones between orifices, uneven air distribution across the bed and overall poor bed utilization (1). The Dutch weave mesh and the punched plate represent alternative distributor designs that have been implemented in order to overcome the operational concerns associated with the perforated plate. The Dutch weave mesh consists of wires, typically of two different sizes, that are woven to create small, curved, triangular openings. These fine apertures eliminate the potential for dead zones between orifices, as well as solids backflow. However, the small bubbles generated by the weave may not carry sufficient energy to fluidize the larger particles in the bed (2). This may result in particle segregation or even zones of defluidization depending on fluidization conditions. The punched plate imparts a lateral direction to the gas flow through the introduction of horizontal gas jets. These gas jets generate a swirling motion in the lower regions of the fluidized bed that leads to more thorough mixing of solids (3).

Few comparative studies regarding the influence of distributor design on fluidized bed hydrodynamics have been put forth in literature (4-7). Of these studies, Ouyang and Levenspiel [5] were the first to introduce the concept of the swirling fluidization distributor plate. This study was later followed by the work of Chyang and Lin (7), which draws parallels to the distributor designs commonly employed in the pharmaceutical industry. This study compares the hydrodynamics induced by a perforated plate versus a multi-horizontal nozzle design. The multi-horizontal nozzle design created a swirling flow pattern which greatly improved fluidization quality as compared to the perforated plate. Smaller and more frequent bubbles were generated due to the unpredictable detachment of bubbles from the swirling jets created by the horizontal nozzle orientation. This limits bubble coalescence, thus improving gas-solids contacting in the fluidized bed.

The study of Chyang and Lin (7) has illustrated the relative influence of distributor designs on dry bed hydrodynamics. While these results may be used to infer the potential influence of the distributor design on fluidized bed dryer performance, there have been no such studies that have examined this directly. Therefore, the current study focuses on the influence of the Dutch weave mesh, perforated plate and punched plate distributor designs on the hydrodynamics resulting from the fluidized bed drying of pharmaceutical granulate.

MATERIALS AND METHODS

Granulation

The placebo granulate was comprised of the ingredients listed in Table 1. A T.K. Fielder PMA25 high shear granulator (GEA Process Engineering Ltd. Aeromatic-Fielder) was used for preparing the wet granulate. A detailed description of the apparatus and the granulation procedure are explained elsewhere (8).

Table 1: Placebo Granulate Formulation

Component	Percentage by Mass (wet basis)
Lactose Monohydrate (filler)	35
Microcrystalline Cellulose (filler)	31
Hydroxypropyl Methylcellulose (binder)	3
Croscarmellose Sodium (disintegrant)	1
USP Distilled Water	30

Fluid Bed Apparatus

The fluidized bed used in this study is a Glatt GPCG-1 fluidized bed dryer (Glatt Air Techniques Inc.). The Glatt GPCG-1 product bowl has a cone entrance angle of 18° with a 0.145 m inlet diameter and a 0.305 m outlet diameter. The fluid bed allows for control of both inlet air temperature and superficial gas velocity. The relative humidity of the air drawn by the fluidized bed was 25 ± 2% under ambient conditions.

Dense bed pressure fluctuations, product temperature and moisture content were measured to monitor the drying process. Pressure fluctuations were measured using a single high frequency piezoelectric dynamic pressure transducer. The pressure transducer was flush mounted to the inner wall of the conical bed 9 cm above the distributor plate. Pressure fluctuation data was collected at 400 Hz and filtered between 0.5 and 170 Hz. The product temperature was measured with a thermocouple immersed in the dense region of the fluidized bed. Finally, the moisture content of the granulate was determined by taking samples via a sample thief. The granulate samples were analyzed for moisture content (loss on drying) using a moisture balance. A detailed description of the fluid bed apparatus and its data acquisition systems are described elsewhere (8).

Distributor Designs

The three distributor designs that were investigated are illustrated in Fig. 1 with enhanced details of their design shown in Fig. 2. The Dutch Weave mesh distributor was a 24 x 110 mesh supplied by NIRO Inc. The weave creates openings that are triangular shaped with base and height dimensions of approximately 25 and 90 μm, respectively. Using microscopy, the percent open area was estimated to be 15 ± 1%. The perforated plate distributor design consisted of 256 holes of 2.7 mm diameter drilled on a 7.5 mm square pitch. This design resulted in an open area of 9.5%. Finally, the punched plate was designed with hooded openings of 5.75 mm by 1 mm. The openings were orientated in a circular pattern with 3 mm between adjacent rings. This orientation is designed to produce a swirling effect in the bed. The open area calculated based on these openings was 9.6%. It is important to note that these high percent open areas are typical of pharmaceutical fluidized bed dryers.

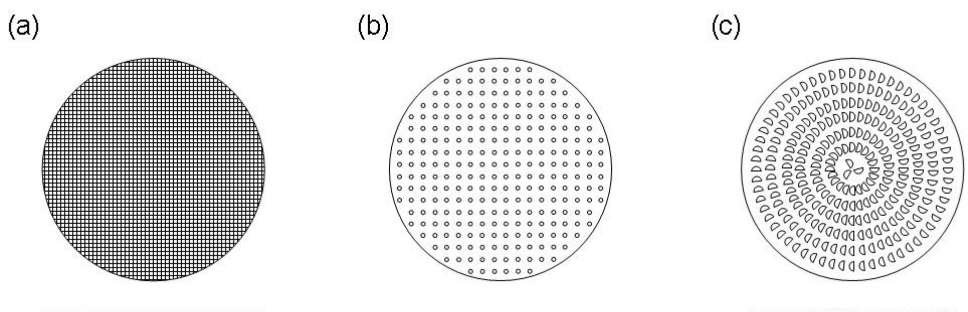

Figure 1: Distributor Designs (a) Dutch Weave Mesh; (b) Perforated Plate; (c) Punched Plate

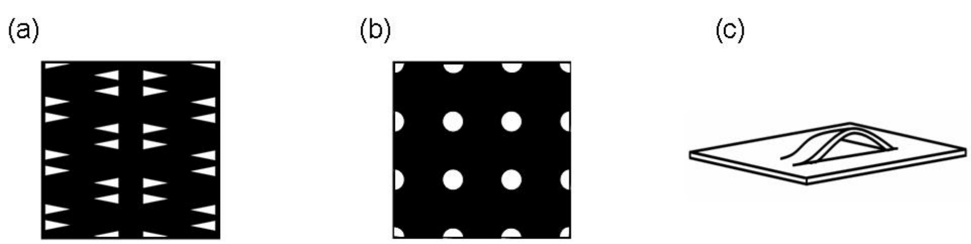

Figure 2: Details of Distributor Designs (a) Dutch Weave Mesh; (b) Perforated Plate; (c) Punched Plate

Operating Conditions

Wet bed loadings of 1.0, 2.5, and 3.0 kg were used which resulted in initial static bed heights of 12, 22, and 24 cm, respectively. The two higher bed loadings were fluidized by air at superficial gas velocities of 1.5 and 3.0 m/s. The 1.0 kg bed loading was fluidized at 1.5 m/s only because operation at 3.0 m/s resulted in a high rate of particle entrainment. This led to the depletion of a distinct dense bed phase rendering a fluidization state not appropriate for this study. Elevated velocities of 2.0 and 3.5 m/s were required for the first ten minutes of the 1.5 and 3.0 m/s drying experiments, respectively, in order to properly fluidize the wet granulate. The need for these elevated velocities was based on visual observation through a sight-glass in the product bowl. It should also be noted that pressure fluctuations could not be obtained for the 1.0 kg bed loading experiments. This bed loading resulted in a shallow bed where the pressure sensor was inadequately covered by material in the dense region of the fluid bed. The results obtained from the 2.5 and 3.0 kg bed loading experiments will therefore be used to infer upon the influence of distributor design on the dryer performance in the 1.0 kg bed loading experiments.

The inlet fluidization air was heated to 65ºC with the end of drying being attained when the product temperature reached 40ºC. When dried, the static beds heights of the bed loadings noted above are approximately 8, 15, and 17 cm, respectively. The particle size distributions of the granulate from each of the distributor design experiments are very similar with modes of 250 and 3500 µm and an average mean mass diameter of 258 ± 8 µm. The particle density of the dry granulate is 830 kg/m^3. This results in a Geldart particle classification in the B/A transition region. Each experimental run was repeated twice to test the reproducibility of the data.

RESULTS

Conventional dryer monitoring techniques, including product temperature and moisture content profiles, were used along with pressure fluctuations to analyze dryer performance. As illustrated by representative product temperature profiles from 1.5 m/s drying (see Fig. 3), differences between distributors begin to emerge as bed loading is increased from 1.0 to 3.0 kg. The punched plate distributor dries the 3.0 kg load the fastest, followed by the Dutch weave then the perforated plate. The respective drying times based on product temperature endpoint determination are 81, 85 and 88 minutes, respectively. Moisture content profiles also support this trend. Fig. 4 illustrates the average moisture content for both the 1.0 and 3.0 kg bed loadings dried at 1.5 m/s. For the 1.0 kg bed loading, the drying curves are virtually identical for the different distributor designs. As bed loading is increased, a separation in the drying profiles between the punched plate and the other designs appear between the 20 and 40 minute mark. This difference in moisture content profiles is carried throughout the drying process. The 2.5 kg bed loading dried at 1.5 m/s behaves similarly to that of the 3.0 kg bed loadings. Under 3.0 m/s drying conditions, product temperature and moisture profile are similar between distributor designs for both the 2.5 and 3.0 kg bed loadings.

In order to better quantify dryer performance for all the conditions studied, the arithmetic average of the drying times of duplicate experiments for a given experimental condition was determined. The average drying times were then normalized based on the lowest average drying time amongst the distributor designs at specific bed mass and velocity. The normalized drying times are summarized in

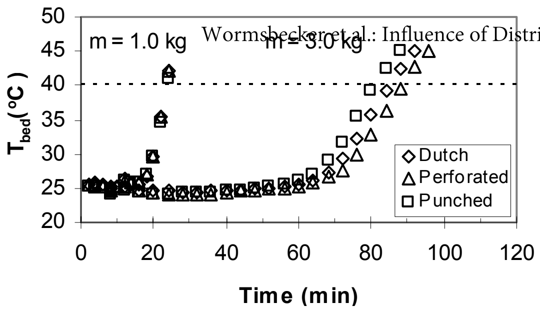

Figure 3: Product Temperature Profile for Drying at 1.5 m/s

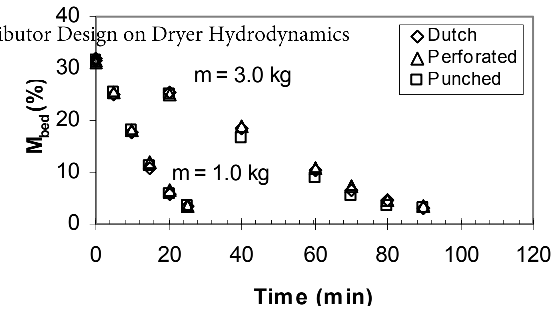

Figure 4: Moisture Content Profiles for Drying at 1.5 m/s

Table 2: Normalized Drying Times

Distributor Design	Bed Mass (kg) U = 1.5 m/s 1.0	2.5	3.0	U = 3.0 m/s 2.5	3.0
Dutch Weave	1.00	1.03	1.07	1.01	1.03
Perforated	1.03	1.06	1.10	1.00	1.00
Punched	1.00	1.00	1.00	1.03	1.02

Table 2. These times imply that for a 1.0 kg bed loading dried at 1.5 m/s there is negligible difference in performance between the distributor designs as the average normalized times are within 3% of one another. However, as the bed loading increases to 3.0 kg, favourable bed hydrodynamics induced by the punched plate distributor design are more evident. The Dutch weave and the perforated plate distributors lead to drying times that are 7 and 10% longer, respectively, than the punched plate. Under 3.0 m/s drying conditions, the average normalized drying times between distributor designs for both the 2.5 and 3.0 kg wet bed loadings are within 3% of eachother. This suggests that increasing the fluidization velocity results in similar fluid bed hydrodynamics between distributor designs at high bed loadings.

Standard deviation and power spectrum analysis of the pressure fluctuations were also used to analyze the hydrodynamic behaviour of the bed during the drying process. Fig. 5 is a representative profile of the standard deviation of the dense bed pressure fluctuations for 3.0 kg bed loadings dried with each distributor design. The standard deviation of the pressure fluctuations demonstrates a sigmoid-like profile over the drying process for all distributor types. In the early stages of drying, the standard deviations are relatively low and constant. Eventually, the pressure fluctuations begin to increase steadily until another constant state is reached. This signifies that moisture removal is slowing and that the endpoint of drying is near.

The profiles of the standard deviation of the pressure fluctuations are different between distributors for the 1.5 m/s drying velocity. Initially, the standard deviation profiles are all relatively constant, but after the 36 minute mark of the drying process the standard deviation begins to increase for the punched plate. Increases in the standard deviation profiles of the perforated plate and Dutch weave mesh do not occur until after 44 and 48 minutes into drying, respectively. In addition, the standard

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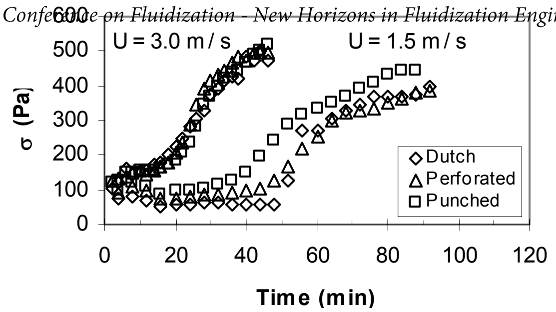

Figure 5: Standard Deviation of Pressure Fluctuations for 3.0 kg Bed Loading

deviation profile for the punched plate is larger in magnitude throughout the drying process as compared to the other designs. Similar to the 3.0 kg bed loading data, the standard deviation for the 2.5 kg bed loading dried at 1.5 m/s takes on a sigmoid-like curvature with the standard deviation profile of the punched plate increasing before the other designs. Under the higher drying velocity conditions of 3.0 m/s, little to no difference in the standard deviation of the pressure fluctuations occurs.

Using power spectral density analysis, details regarding the hydrodynamic behaviour throughout the drying process were also examined. In the early stages of the drying process (Fig. 6(a)), the punched and perforated plates exhibit similar hydrodynamic behaviour with a dominant frequency of 5.2 Hz and a secondary frequency of 0.7 Hz. The dominant frequency represents the bubbling frequency in the bed where the secondary frequency is associated with the step-wise movement of particles down the wall of the bed that was observed visually at approximately this frequency. The Dutch weave does not display a distinct dominant bubbling frequency; however, it does exhibit the same low frequency movement of material at the bed wall. At the 32 minute mark, differences in the hydrodynamic behaviour are evident. The punched plate exhibits a power spectrum that is stronger in intensity and contains a dominant frequency that is slightly higher than the dominant frequencies of the perforated plate and Dutch weave designs. The dominant frequency of the punched plate is 5.2 Hz whereas the frequencies are 4.9 and 4.7 Hz for the perforated plate and Dutch weave designs, respectively. Figs. 6(c) represents the middle to latter portion of the drying period. The power associated with the power spectrums is a scale of magnitude larger than seen in the earlier stages of the drying process. This increase in power is attributed to larger fluctuations in the bed as moisture is removed (see Fig. 5). The dominant frequencies have also shifted from a higher to lower frequency indicating that bubble coalescence has increased. Differences in the power spectrums between distributor designs still exist, with the punched plate illustrating a higher power bubbling frequency as compared to the other designs. Finally, Fig. 6(d) compares the hydrodynamic behaviour between distributor designs during dry bed operation. The power spectrums of the different distributors are very similar indicating that distributor design has no influence on hydrodynamics under these conditions. The most likely reason for this is the significant amount of excess gas in the system which results in a high degree of bubble coalescence and therefore negating the impact of the distributor on the system. Similar to the standard deviation analysis for the 3.0 m/s drying experiments, no differences in drying hydrodynamics exist between distributor designs when the fluidization velocity is elevated to 3.0 m/s.

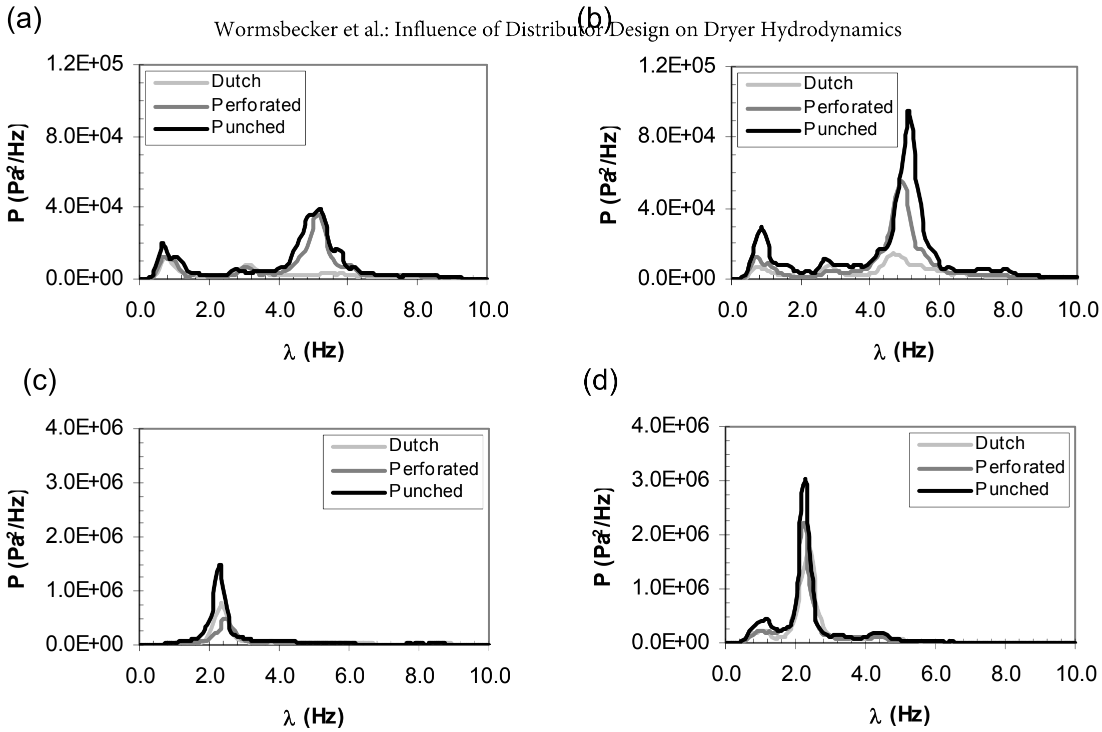

Figure 6: Power Spectrum for 3.0 kg Loadings Dried at 1.5 m/s (a) 16 minutes into drying; (b) 32 minutes into drying; (c) 56 minutes into drying; (d) 88 minutes into drying

DISCUSSION

It is believe that similar to the horizontal nozzle distributor used by Chyang and Lin (7), the punched plate promotes the formation of a swirling flow pattern via horizontal gas jets which in turn promotes lateral gas mixing. Horizontal gas jets produce bubbles from their tips as they penetrate the bed (9). Due to the presumably random nature of the jet formation and subsequent bubble detachment, bubble coalescence is reduced resulting in a higher bubbling frequency. The punched plate illustrates this higher frequency bubbling phenomenon (see Fig. 6(b)) and also demonstrates improved lateral gas mixing through the larger magnitude of its standard deviation profile; improved lateral gas mixing explains the increase in pressure fluctuations with the presence of a higher bubbling frequency as less attenuation of the pressure wave occurs due to the presence of bubbles closer to the bed wall where the sensor is located. The smaller, more frequent bubbles along with the improved lateral gas mixing generated in this portion of the drying period explains the improved dryer performance for 2.5 and 3.0 kg bed loadings dried at 1.5 m/s with the punched plate.

The similarities in drying hydrodynamics between distributor designs at 3.0 m/s are thought to be related to improved radial gas dispersion with the perforated plate and Dutch weave distributors under such conditions. With these types of distributor designs, gas dispersion is more centralized at low gas velocities. This results in limited potential for lateral gas mixing in the fluidized bed (10). However, as gas velocity increases, gas permeates to the periphery of the bed resulting in improved gas-solids contacting (11).

CONCLUSION

The present study has found that the punched plate distributor design provides shorter drying times than the Dutch weave and perforated plate designs when wet bed loadings of 2.5 kg and above are dried at superficial gas velocities typical of the pharmaceutical industry (1.0 to 1.5 m/s). This study was carried out on a laboratory scale fluidized bed dryer. It is possible that in larger diameter fluidized beds, such as clinical and production scale dryers, the positive influence of the punched plate may be more pronounced as bed loadings, and therefore bed depths, become greater.

NOTATION

m	bed mass, kg
M_{bed}	granule moisture content (mass basis), %
P	frequency spectrum power, Pa^2/Hz
T_{bed}	product temperature, °C
U	superficial gas velocity at bed inlet, m/s
λ	frequency, Hz
σ	standard deviation of pressure fluctuations, Pa

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