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GELDART GROUP INDICATION FROM POWDER MEASUREMENTS WITH A ROTATING DRUM INSTRUMENT

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ABSTRACT

Data have been collected with a GDR, for powders from each Geldart Group, over a rotation rates in the range 0-22 r.p.m.. Composite plots of avalanching frequency , slumping rate and rotation rate, show that power spectral density for Groups D and B is qute different from that observed for Groups A and C.

INTRODUCTION

The flow behaviour of a bed of a particulate material in a rotating drum is strongly dependant on the rotation rate of the drum. Typically, at low rotation rates particle movement is largely the result of discrete avalanches traversing a static bed of powder. As rotation rate increases, the mode of flow changes and the particles flow as a rolling layer over the bed; further increases in rotation rate cause particles to be projected into the space above the bed; see for example Henein et al (1) and Mellmann (2). While the effect of drum speed has been the focus of considerable research attention, the effect of the physical properties of the powder on flow behaviour in a rotating drum is not well documented.

The approach taken in this paper, which extends earlier work by Webster and Davies (3), has been to use a dedicated instrument that monitors the motion of the material in it by tracking changes in the centre of gravity of the particle bed, as first proposed by Davies et al (4) (5). A drum is mounted on a framework which acts on a load cell, and changes in the position of the centre of gravity of the particle bed cause changes in the force on the load cell. Results are interpreted using a simple model, initially developed by considering the motion of an ideal avalanche, whereby avalanche activity is related to the variance of the measured force on the load cell. An index based on the average of variance has been shown to be a powerful discriminator in the assessment of flowability of a wide range of pharmaceutical powders (6).

In early trials with the instrument, while results for a particular material were reproducible, it was apparent that there were differences in the general form of plots of variance versus drum rotation rate for different materials. Davies (7) has suggested that these may be associated with Geldart Group, and that the behavior of a powder in a rotating drum could be used to identify Geldart Group where inference from density and mean size is not practicable, as can be the case with some fine materials, or with materials with extreme or unusual shape descriptors.

In an investigation that was systematic, but limited to four materials only, Webster and Davies (3) identified two general trends. Geldart Groups D and B, *viz* free flowing materials, had a relatively high variance at low rotation rates which initially decreased as drum speed increased, and then increased. For Geldart A and C materials, variance was low at low drum speeds and increased as rotation rate increased. The Group A material, which was spent FCC cracking catalyst, showed a maximum value in the variance plot. The Group C material, finely ground agricultural limestone, exhibited behavior similar to the cracking catalyst, but at the highest rotation rate tested, had not shown a maximum; see Figure 1 where the data have been normalized with respect to the mass of powder in the drum.

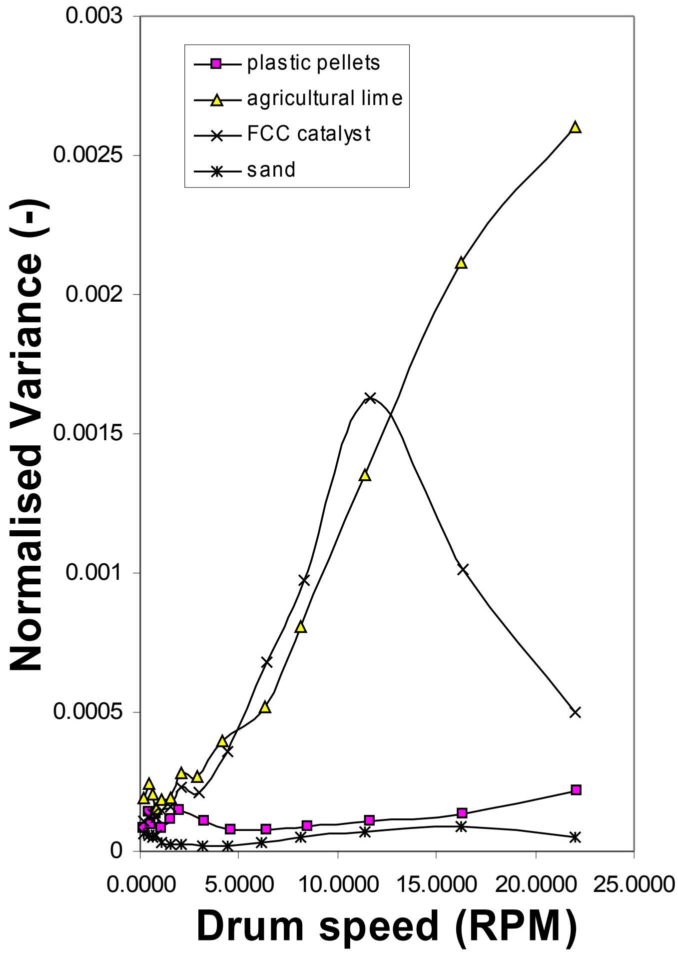

Figure 1 **Normalized** variance versus drum speed for plastic pellets, agricultural lime, FCC catalyst and sand., after Webster and Davies (3).

EXPERIMENTAL

The apparatus used in this work is depicted schematically in Figure 2, and is essentially the same as that previously described by Davies et la (4). The drum was made of Perspex, with an inside diameter of 130 mm; it was 25.4 mm wide. The drum and drive motor were mounted on a frame, pivoted as shown, that acted on a load cell attached to a base plate. This arrangement allows changes in the position of the center of mass of the powder in the drum, arising from the drum motion, to be tracked.

The torque requirements of the system over the range of drum speeds used, 0-25 revolutions per minute (r.p.m.) were met by using two different motors, both made by Maxon; for low speeds, 0-2 r.p.m., the gear ratio was 200:1 and for the range 2-25 r.p.m., the gear ratio was 18:1. Speed monitoring was achieved using an optical rotor encoder from a QM-E1 mouse. The pulse information from the encoder was recorded through an analog input using LabVIEW ™ software over 50 seconds. A sinusoidal fit was taken to find the average frequency, which was then converted to r.p.m.. This method gave extremely good resolution of low speeds.

In all experiments, the load cell was mounted directly under the axis of rotation of the drum, and not offset as drawn in the schematic Figure 2. A layer of silica sand, -355µm + 250 µm, was glued to the curved surface of the drum wall to roughen them. The flat walls of the drum were not roughened.

Four materials were used, one from each of the Geldart group: (i) Group D, plastic pellets 3.5-4 mm in diameter, 1.7-2.3 mm long and a particle density of ~1000 kg m^{-3}; (ii) Group B, silica sand, surface–volume diameter ~135 µm and particle density, 2480 kg m^{-3}; (iii) Group A, spent FCC catalyst; (iv) Group C, finely ground agricultural limestone; this material was cohesive, and attempts to obtain a sieve analysis resulted in blinding of the screens and adhesion of the powder to the walls sieve surfaces; the as-received powder did not flow freely, and has ben designated C or A/C.

The system was calibrated with the drum at rest, by placing weights on a platform precisely positioned above the drum axis. In all experiments, the mass of material was chosen so that the fraction of the drum volume filled was 20%; the mass was recorded and used in the data analysis to normalize the calculated signal variance of each material.

Data acquisition was by a National Instruments 6211 M Series Multifunction DAQ card, using software developed in LabView which also enabled filtering, file management and data analysis. Nine speeds in the range 0 -5 r.p.m. and 5 speeds in the range 5 – 22 r.p.m. were used for each material; 10,000 data points were collected at each speed, logged at 200 Hz.

To aid analysis of avalanching a Sony video camera (DCR-TRV11UE) was used to capture ~30sec at each rotational speed. An LED was added to the digital output of the LabVIEW ™ acquisition card to allow recording of the first avalanche and synchronization between the camera and the data acquisition system. A video recording synchronized to the data acquisition system allows avalanching trends to be compared visually with movements of powder. Video footage allows an accurate record of the type of avalanching occurring at different drum speeds.

ANALYSIS

The drum was not perfectly balanced and the primary data signal, the load cell output, contained a sinusoidal component of the same frequency as the angular rotation rate of the drum. This was removed by superimposing a signal with the same amplitude and frequency, but 180° out of phase. The data were then filtered using a 5th order IIR Butterworth band pass filter, with a low frequency cut off at 0.1 Hz and a high frequency cut off at 6 Hz.

Signal variance calculated for each rotation rate, and normalized with respect to the mass of the material in the drum, provides an averaged measure of material displacement over the sampling period of 50 seconds. Variance was calculated for each material for a total of 14 different rotation rates as outlined above.

Mean avalanching frequency, termed slumping frequency here, was determined at each rotation rate using software written to distinguish between rapid transitions and the gradual changing moment due to drum rotation. These criteria were decided after a period of experimentation and were were: i) a moment force change of greater than 1mN and ii) a positive going edge. A 15 sample running average was used to eliminate rapid transients and removed false triggering due to drum rotation moment changes. It had the effect of lessening peak amplitudes, but gave greatly increased reliability in accurately detecting avalanches, *viz* events as defined by these criteria.

Power spectral density was determined with respect to slumping frequency for each rotation rate.

RESULTS

Variance data for each material, have previously been reported by Webster and Davies (3), and have been summarized in the Introduction above.

The the relationships between power, drum speed (rotation rate) and slumping frequency as determined according to the criteria given in the Analysis section above are shown in Figures 3-6.

Figures 3 and 4 show the relatively coarse materials, the plastic pellets and the sand respectively.

Figure 5 is the composite plot for spent FCC catalyst, and Figure 6 is for Agricultural limestone.

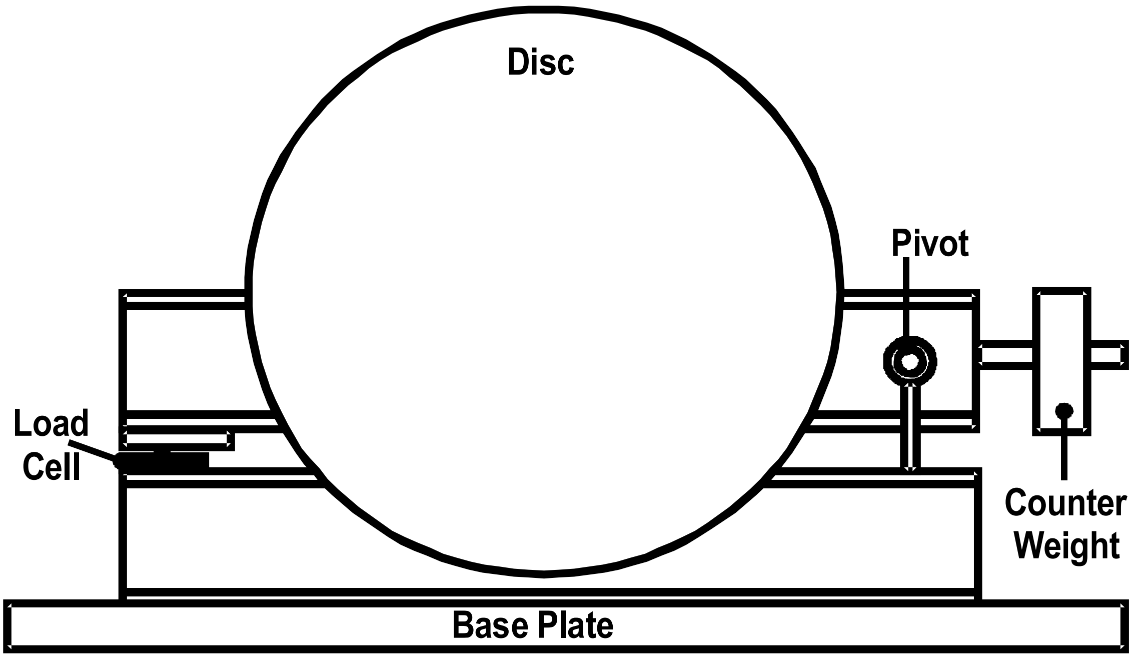

Figure 2 Schematic diagram of apparatus, after Davies et al (4).

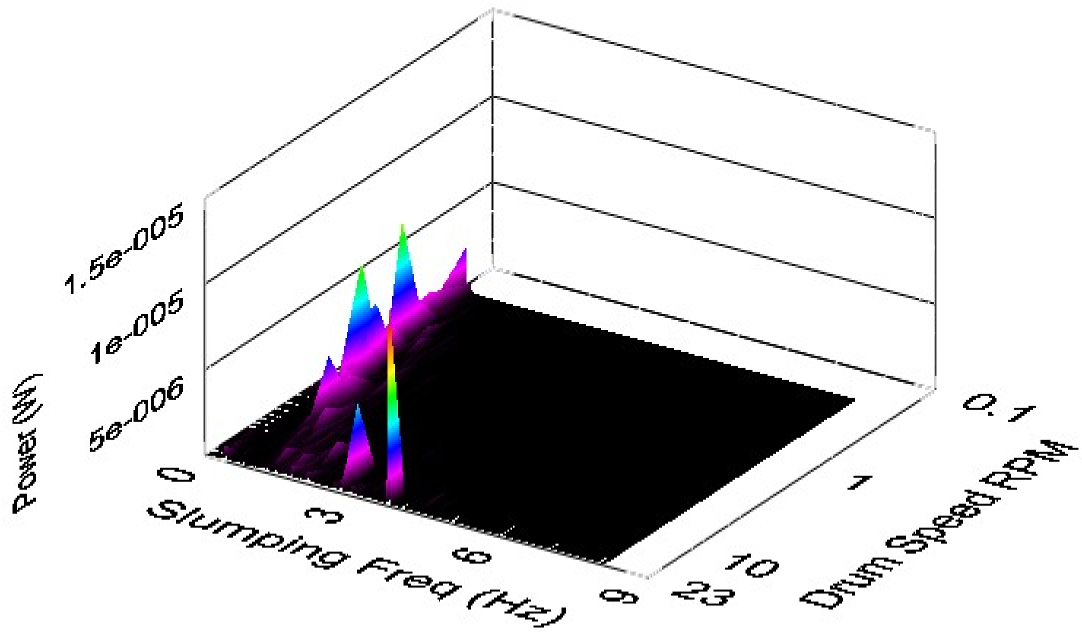

Figure 3 Composite plot of power, slumping frequency and drum speed for plastic pellets, Geldart Group D.

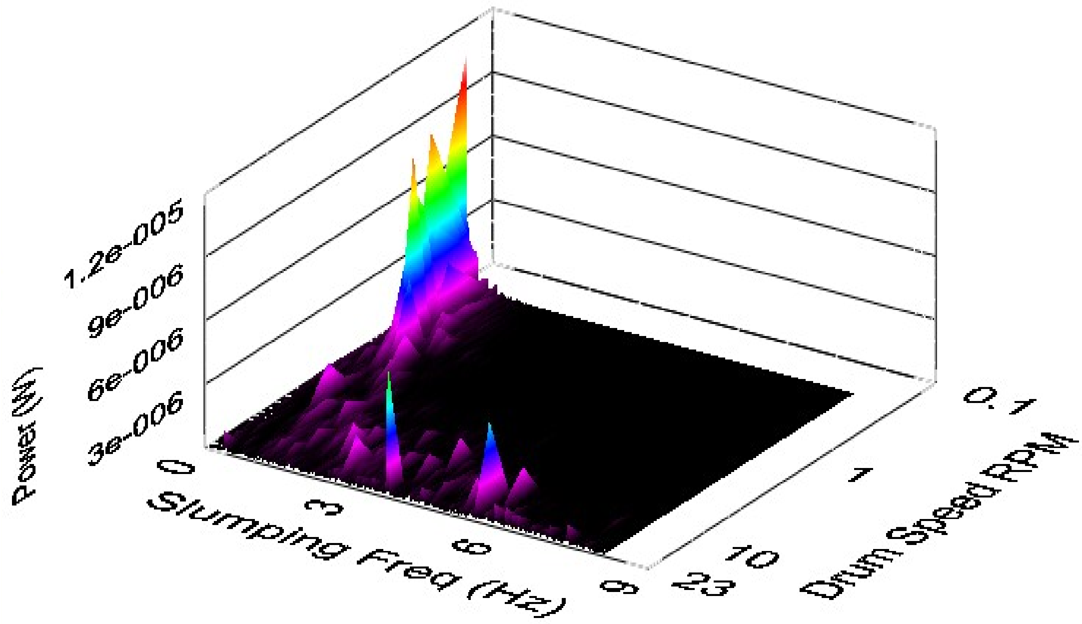

Figure 4 Composite plot of power, slumping frequency and drum speed for sand, Geldart Group B.

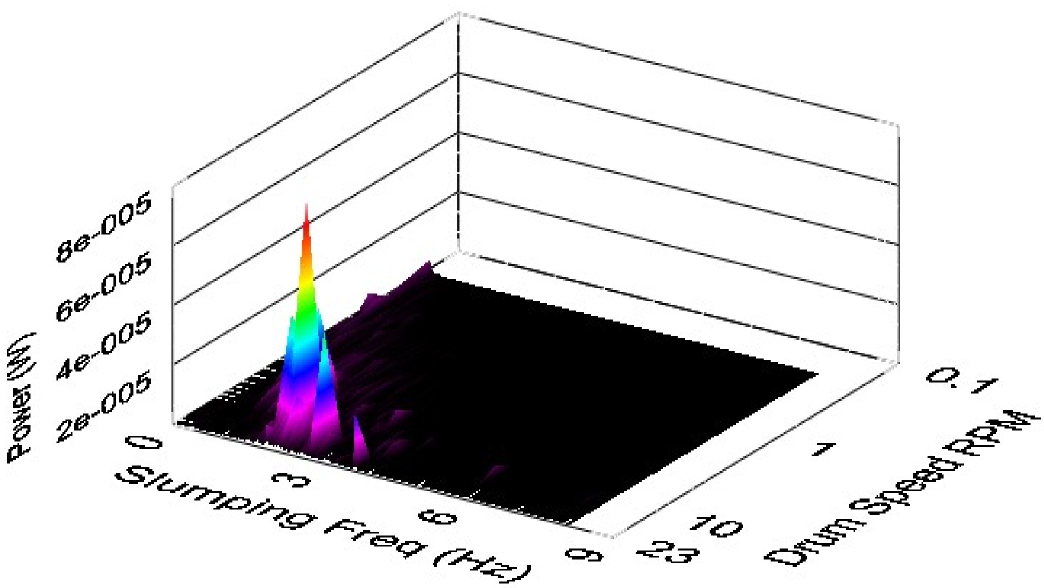

Figure 5 Composite plot of power, slumping frequency and drum speed for FCC catalyst, Geldart Group A.

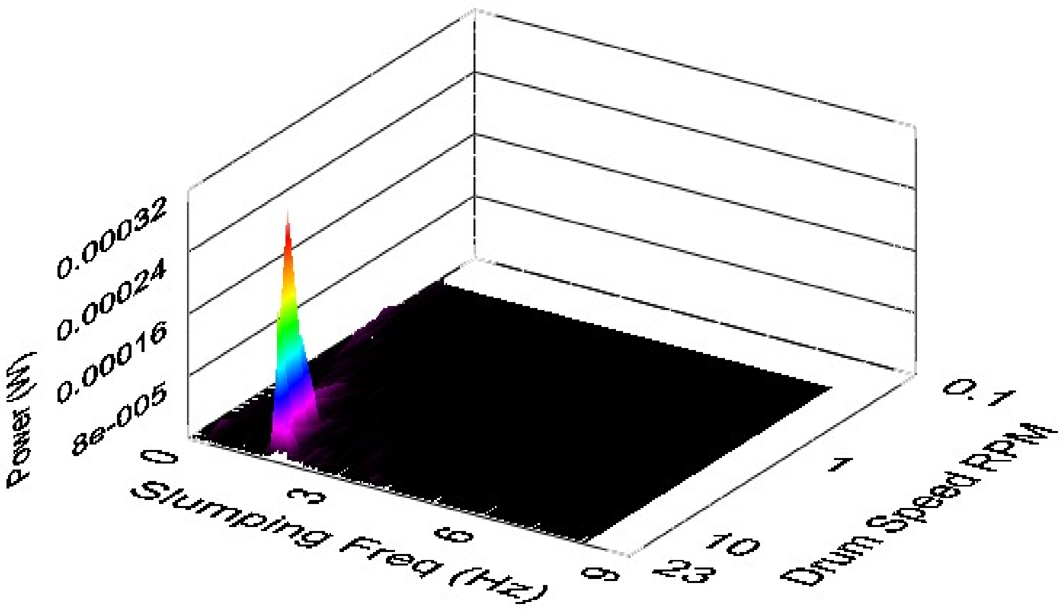

Figure 6 Composite plot of power and slumping frequency and drum speed for agricultural limestone, Geldart Group C.

DISCUSSION

For Geldart Groups D and B most avalanching activity occurs at drum speeds below about 5 r.p.m.,. but spread fairly uniformly over these speeds; the associated slumping frequencies are less than 1 Hz. Powders in Geldart Groups A and C show significant avalanching at drum speeds greater than ~5 r.p.m. with associated slumping frequencies of the order of ~1-~3 Hz.

The 3D patterning seen in the composite power spectral density plots for the essentially free flowing Group D and B powders is quite different from that observed for Group A FCC and the agricultural limestone, Group C. The data set used here is limited, and further work is needed with a larger range of materials, but these early results provide further support for the suggestion (7) that the GDR could have a role in identifying Geldart Group, potentially useful for some fine powders or powders with unusual shapes.

CONCLUSIONS

A GDR has been used to collect data on the avalanching behavior of four materials, one from each Geldart Group at rotation rates in the range 0-22 r.p.m.. These data have been analyzed to provide avalanching frequency, also termed slumping frequency, and power spectral density in terms of the slumping frequency. Composite plots showing slumping frequency, power, and drum rotation rate show distinct differences in the frequency distributions for the free flowing Groups D and B and the more cohesive Group A and C powders. For Group D and B powders, the power is largely distributed over a range of frequencies at rotation rates less than 5 r.p.m. and slumping rates are less than 1 Hz. For Groups A and C, power is largely manifested at rotation rates above 5.r.p.m.. and associated slumping rates are in the range 1-3 Hz.

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