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Ask Joe! Column

“Spider Diagrams” : A novel way of predicting Powder Flow

Guest article by E. McGee, Ajax Equipment and D. McGlinchey, Glasgow Caledonian University

Introduction

Accurately predicting flow behavior of particulate solids during storage and feeding has eluded all but the most experienced in solids handling. Often the chemical and process engineer is faced with the awkward task of making sense of bulk behavior.

A powder sample held in a jar may appear to be free flowing but “hammer rash” on plant suggests a different story highlighting the interaction of material characteristics, equipment design and interfacing, flow regimes and operational circumstances. Perhaps the most meaningful parameters that affect plant performance are how the material slides against a contact surface, how strong it gets and how the bulk density varies with all of these factors often affected by the compaction or stress conditions imposed.

As ever when faced with complexity it is tempting to reduce a powder’s flow behavior to a single number or even a flow function. However this inevitably gives a limited insight to its bulk performance. In this article, Eddie McGee of Ajax Equipment, based on a joint paper with Don McGlinchey of Glasgow Caledonian University presented at the 7th World Congress of Chemical Engineering, (McGee & McGlinchey, 2005) looks at a more meaningful way of interpreting powder characteristics to aid the predictability of bulk solid flow.

Every industrial sector including petrochemical and plastics, bulk and fine chemicals, pigments, agrochemicals and detergents, is involved in handling bulk solids in raw ingredient form, intermediate processing or right up to the ‘point of sale’. A prodigious variety of bulk solids are stored in hoppers or silos in quantities ranging from a few kilos to hundreds and, in some cases, thousands of tonnes. Unfortunately many installations - regardless of their size - suffer from unreliable flow caused by the contents forming stable arches and rat holes.

Figure 1, Pigment arch in V-shaped hopper and Figure 2, Rat hole in conical hopper

Even plant that has historically operated well can develop problems as a consequence of formulation and raw feed changes. Assessments of a bulk solid’s flow properties are therefore important features of plant design and problem solving.

Powder Testing for Flow

Two main characteristics are important for flow: - how the product slips on a contact surface (wall friction) – product has to slide down the walls of a hopper or along the flight of a screw- and the resistance offered by the powder bulk to deformation/flow (shear strength) – arches and ratholes form when the material develops sufficient strength. These characteristics are influenced by the 'condition' or 'compaction' of the bulk – a tightly packed bed is less free flowing than a loose aerated powder. This 'condition' is directly related to the bulk density. In hoppers the stress influences the bulk density.

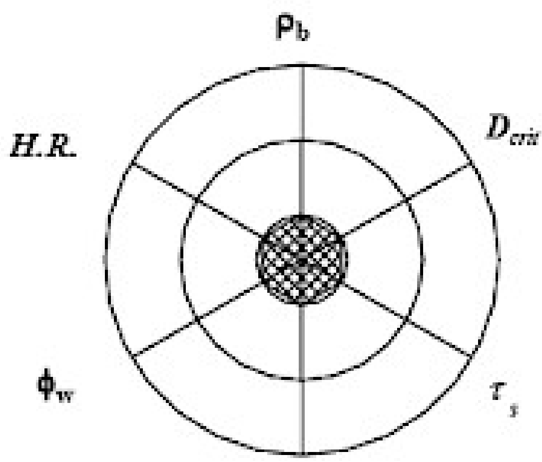
Consequently wall friction, shear strength and bulk density are three properties of bulk solids that need to be measured to design for mass flow in a hopper and avoid arching at the outlet. Mass flow brings a number of benefits for example, reducing segregation and offers the best approach for flow towards the outlet. Even non mass flow hoppers require a flow channel sufficiently large to destabilize any 'rathole' that may form and a wall angle steep enough to self-clear if they are to function well.

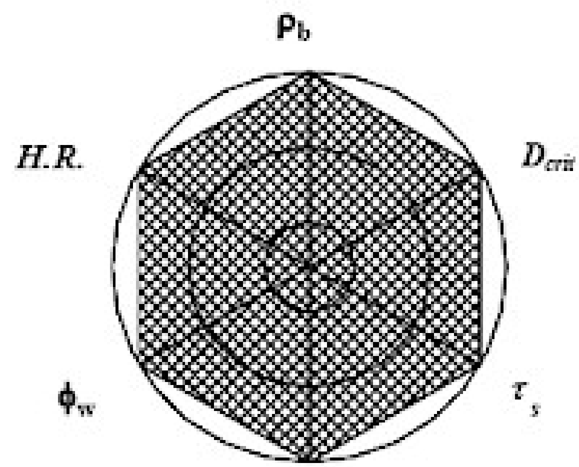
Characterization of bulk solids

Predicting the behavior of bulk solids in every case has led some to look for a single number to use as a guide to flow. This reductionist approach however is fraught with problems. For example, there is no obvious reason why a bulk solid that has high friction should also have a strong cohesive tendency or vice a versa, so whilst the situation may worsen for flow when both these features are present they are not necessarily correlated.

A more meaningful approach to predicting flow behavior is to take the characteristics of wall friction, shear strength, bulk density and add three further factors: hopper wall angle, outlet size (shear strength/bulk density ratio) and Hausner ratio (The ratio of tapped to loose bulk density. The greater the ratio the more sensitive the powder is to how it is handled.). Using these factors we can produce a 'spider' diagram.

Figure 3, Easy flowing material and Figure 4, Poor flowing material





To produce the diagram a series three of concentric circles are divided by axes for each of the characteristics. These axes intersect with the smallest diameter circle where that particular characteristic describes 'easy flow' with subsequent bigger diameter circles defining 'modest' and 'poor flow'. Two idealized situations can then be presented figures 3 and 4 for an 'easy flow' material and a 'poor flow' one with the in-filled part of the 'web' detailing the particular characterization attributes.

The spider web diagrams can be more than qualitative if the data from the tests on 150 different materials with a very wide range of flow behaviors is used to define the 'easy', 'modest' and 'poor' flow circles.

Table 1, Parameters suggested by the tests reported in McGee (2005)

Circle	Wall friction (deg)	Bulk Density (kg/m3)	Shear strength (N/m2)	Hausner ratio	Outlet size (cm)	Mass flow Wall angle
Easy flow	< 20	1200	300	1.1	15	65
Average	25	800	1000	1.25	50	73
Poor flow	> 30	400	2000	1.5	100	80

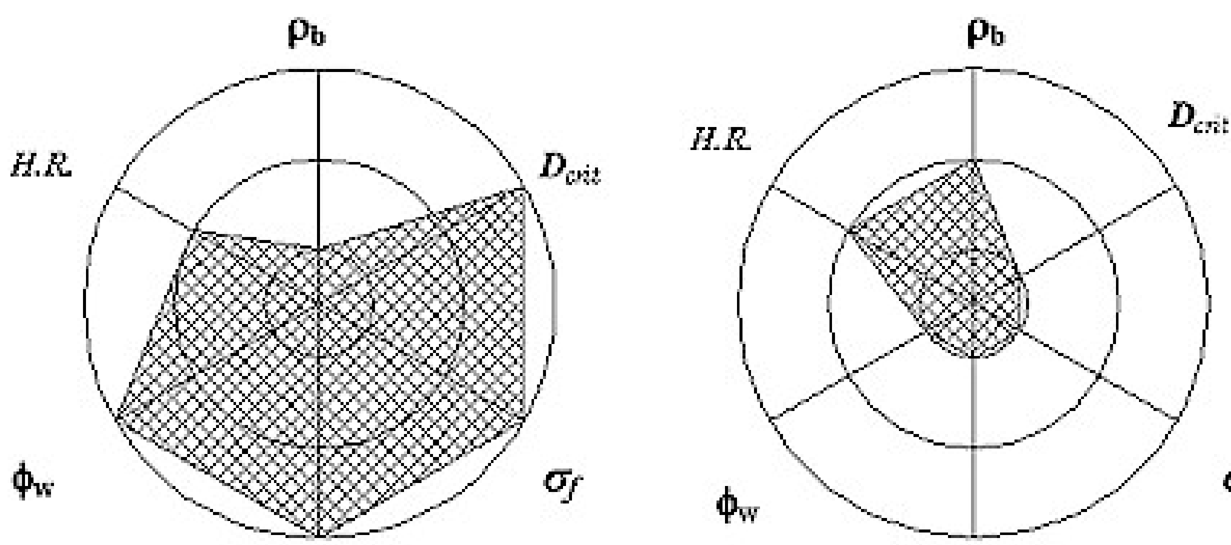
Note that the bulk density axis is the reverse of the others because decreasing bulk density usually means poorer flow. A practical example to justify this assertion is that most milling operations lower bulk density and worsen flowability of powders when they are stored.

Table 2, Parameters form a number of different bulk solids (McGee, 2005)

Product	Wall friction (degs)	Bulk Density (kg/m3)	shear strength (N/m2)	Hausner ratio	Outlet Size (cm)	Mass flow wall angle (degrees)
Limestone	33	927	2377	1.35	104.6	82.6
Icing sugar	30.5	548	2144	1.49	159.5	79.6
Cement	26.1	1356	2685	1.27	80.7	74.3
Flavouring 1	18.2	941	273	1.43	11.8	65
Flavouring 2	18.7	842	946	1.28	45.8	65.4
Press cake	34	720	3420	1.60	193.7	83.8
Tio2 – grade 2	33.8	1281	2374	1.26	75.6	83.5
Pigment 1	30.9	725	1021	1.24	57.4	80
Agrochem 1	26.6	646	143	1.21	9	75
Agrochem 2	33.8	790	731	1.52	37.7	83.8
Carbowax	15.5	681	200	1.19	12.0	61.6
Pharma powder	35.2	398	86	1.31	8.6	85
Pigment 2	33.0	2546	364	1.91	5.8	82.6
Intermediate 1	9.3	738	2945	1.28	163.2	54.2
intermediate 2	16	1101	373	1.24	13.8	62.2

To show the usefulness of the spider diagram as a data handling technique diagrams are constructed for a particular grade of Titanium dioxide and Carbowax.

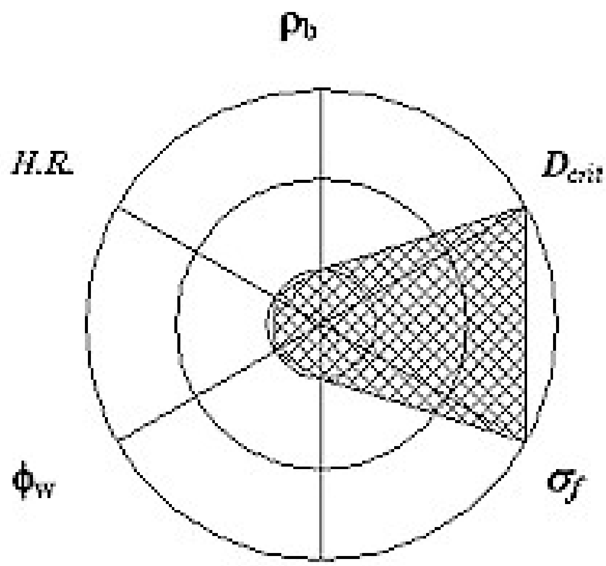
Figure 5, Titanium dioxide and Figure 6, Carbowax

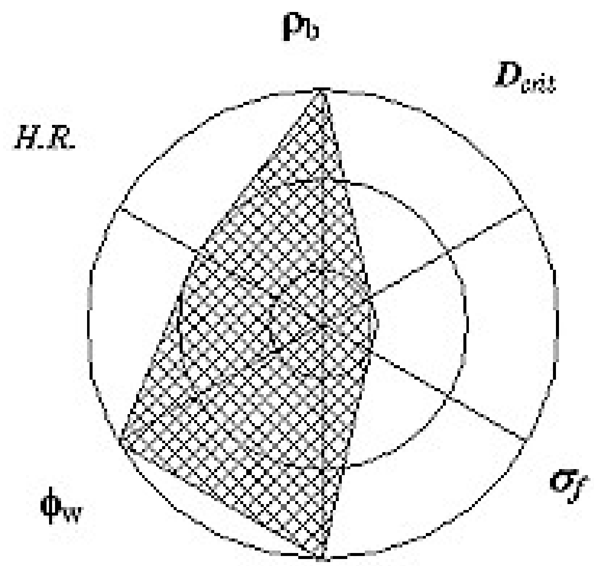


Titanium dioxide is close to matching the idealized poor flow material and is borne out by much experience in plants handling this material where arching and rat holing are commonplace (Figure 2). Another material Carbowax closely follows the idealized good flow material profile and this too is confirmed by practical experience.

This technique when applied to two other examples highlights particular aspects of the 'profile' that merit special attention. The Figure 7 shows the resultant diagram for a chemical intermediate 1; all aspects for flow are good except the shear strength and outlet size. Indeed practical application for batch handling of this material required invertible bins that upset the consolidation of the material to ensure reliable flow to process.

Figure 7, Chemical Intermediate and Figure 8, Pharmaceutical powder





A pharmaceutical powder, Figure 8, has high wall fiction but low shear strength. Difficulties with chute work featuring insufficiently steep slope and sharp corners would have been quickly identified with this information. This directs attention towards examining the effects of surface finish and using generous radiused corners as practical solutions.

Conclusion

In conclusion, a novel spider diagram integrating the three measured wall friction, shear strength, bulk density, and three calculated parameters: hopper wall angle, outlet size (shear strength/bulk density ratio) and Hausner ratio, offers a more rounded and direct picture of flow characteristics.

Exciting prospects include comparison between different grades of the 'same' material and refining of the scales of the axes to provide greater sensitivity. The technique incorporates hopper design criteria and so offers the possibility to fine tune axes scales to suit experience with particular plant/product combinations. The technique acknowledges that there are many aspects that affect bulk flow behavior.

Refinement of this approach to include other factors such as internal friction, lateral stress ratio along with increased definition in scale can only improve the chemical engineers ability to match plant performance / design to bulk solids characteristics for reliable handling.

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Welcome to Ask Joe!, a monthly column by our resident materials handling guru, Joe Marinelli of Solids Handling Technologies. Joe addresses the issues that bug you the most. And Joe knows!! Formerly with Jenike & Johanson, Solids Flow and Peabody TecTank, Joe is an expert on materials handling.

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