Understanding Powder Behavior

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Why are powders so unique?

Liquids and Gases are well understood…

- Mostly behave in a mathematically predictable way
- Mathematics can be used to predict their response to external variables, such as strain rates, temperature and pressure (the main external variables)
- Many instruments have been developed to directly measure their behavioural characteristics
- Extensive databases of material properties exist and can be used in R&D, Processing or QA

Powders are more complex than liquids and gases

Powders are neither a solid, liquid or gas, but exhibit characteristics of each

- They can behave like a solid if they've been consolidated
- They can flow like liquids if aerated / fluidised
- They can be compressed like a gas

No mathematics available to predict behaviour of powders (exception of Jenike stress theory - hopper flow)

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Observational Behaviour

Loose packing state

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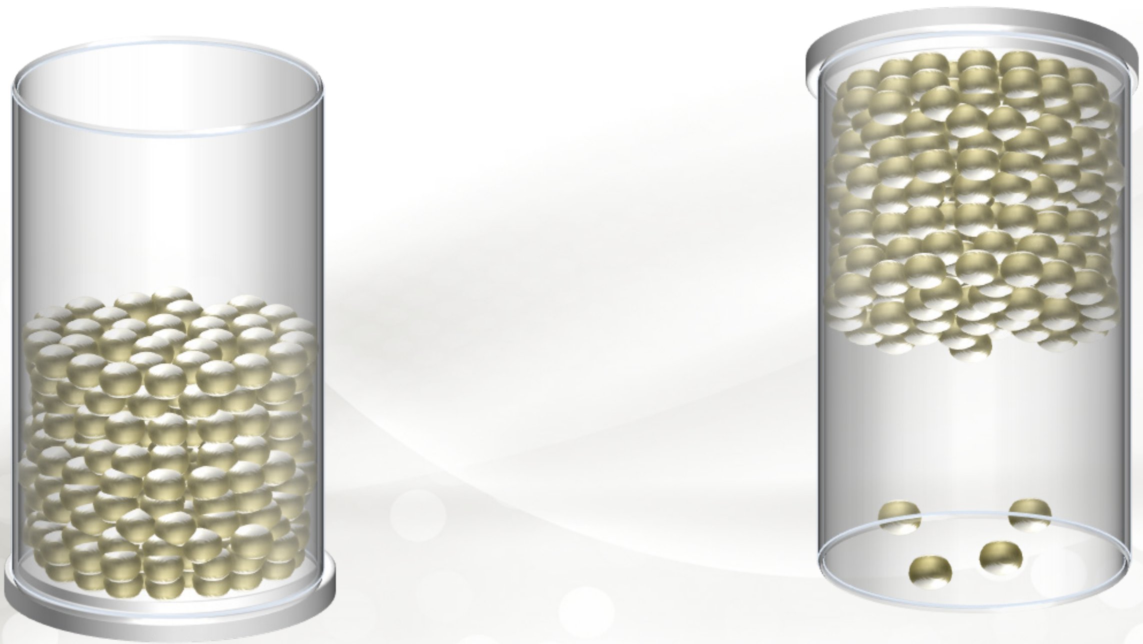
But, storage, feeding, processing through a hopper, transport (vibration), and many other process steps can induce a…



Consolidated packing state (same particles)

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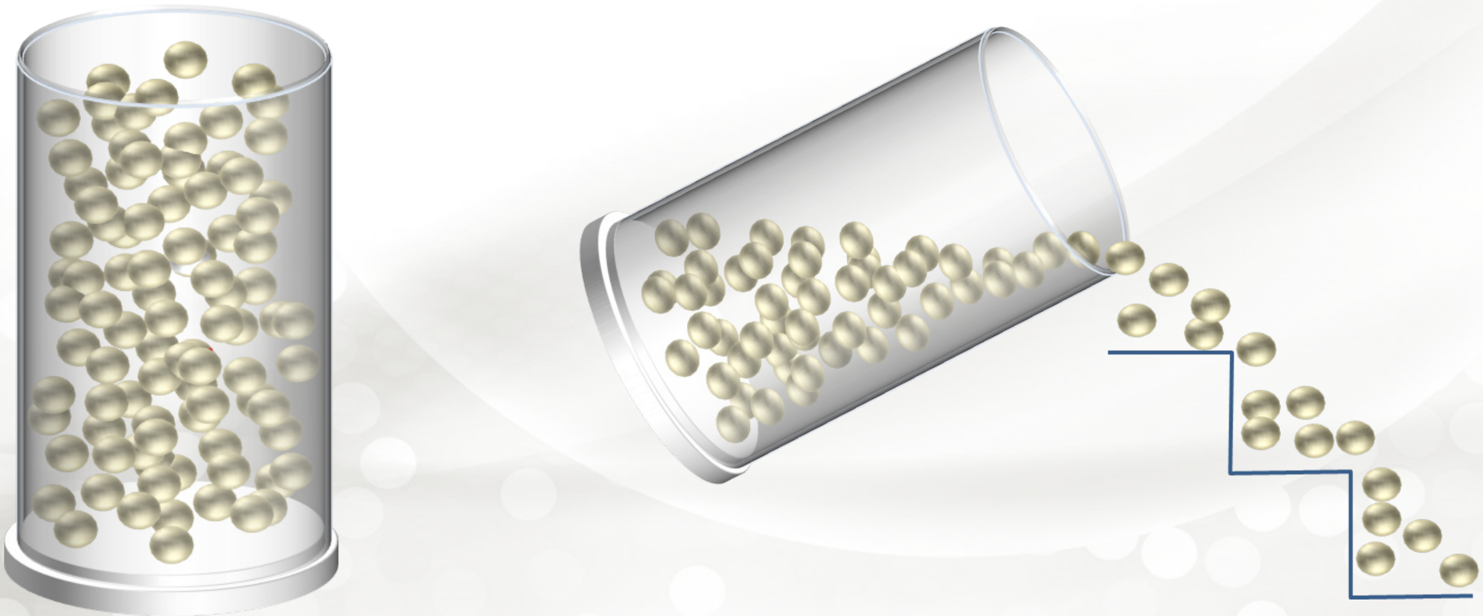
Conversely, blending, discharge from a container, emptying a keg, low stress filling can result in an…



Aerated / Fluidised packing state (same particles)

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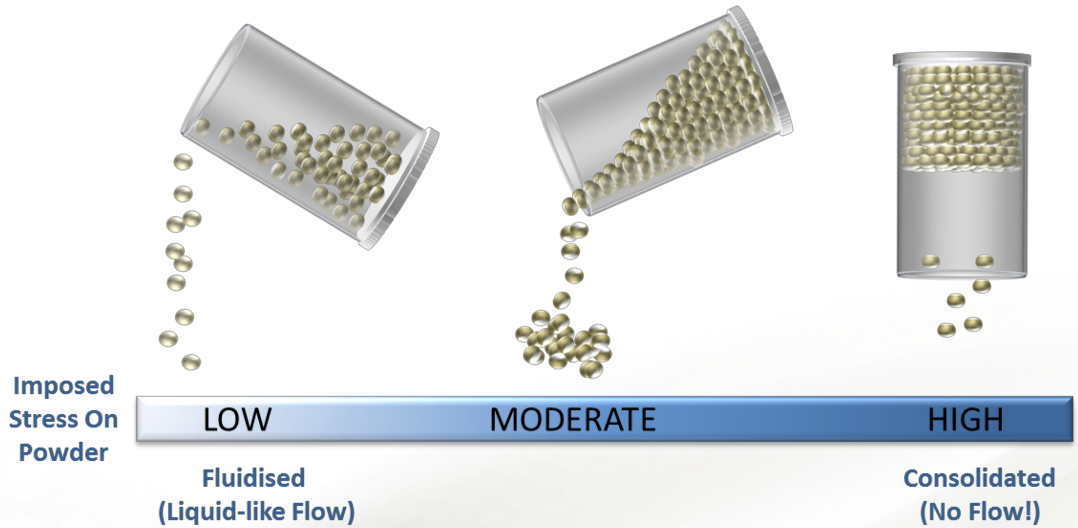

- Same powder can be fluid like at low stress, or a single solid entity if consolidated (or anything in between)
- Particles have same physical properties (size, distribution, shape, etc.) but the powder can behave very differently
- Processing powder unavoidably subjects it to a range of different environments (stresses, shear rates, container surface effects, etc.)
- Must ensure that powder's characteristics and behaviour is compatible with process conditions imposed by type and configuration of equipment employed
- Incompatibility will compromise process efficiency and/or properties and quality of material leaving the process

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External Variables

Variable	When & Where?	Effect
Consolidation	• Vibration / Tapping • Direct Pressure – hopper IBC, keg, truck	• Increase in particle contact pressure, contact area & number of contact points • Reduction in air content between particles (reduced porosity)
Aeration	Often unavoidable, during:- • Gravity discharge from bins / hoppers • Blending • Pneumatic conveying • Aerosolisation	• Reduction in particle contact pressure, contact area & number of contact points • Increased air content between particles (increased porosity)
Flow (shear) rate	• Mixer impeller speed • Feed rate of screw feeder • Powder shears against itself and equipment wall	• Non – Newtonian • Greater resistance to flow at lower flow rates!

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External Variables (cont.)

Variable	When & Where?	Effect
Moisture	• Storage • Processing • Intentionally introduced – granulation	• Increase particle adhesion • Reduces particle stiffness – more compliant but increased contact surface area • Change in electrical conductivity
Electrostatic charge	• Discharge from a hopper • Pneumatic conveying • High shear mixing	• Increase bond strength between particles • Adhesion of powder to equipment
Storage time	• Raw materials / intermediates	• Consolidation • Caking • Permanently affecting downstream performance?

What do we mean by powder 'behaviour'? What are its behaviour properties?

- A powder may **flow** well, into a die, or from a hopper, or it may bridge and block.
- It will be **compressible** – changing density when subjected to consolidating stress – but how compressible?
- A powder can be adhesive – sticking to containing equipment, or perhaps it can separate easily?
- Air can pass between particles – powder is **permeable**, but how permeable?
- Some powder may be sensitive to **electrostatic charge**, others less so.
- A powder may change its characteristics if its moisture content increases. Some powders are **hydrophobic**, others **hydrophilic**.
- Particles may break down if subjected to stress. They are prone to **attrition**.
- If a powder readily aerates, and retains the excess air, it can behave like a liquid and **flooding** may occur. Other powders de-aerate quickly and will never flood.
- Powders often behave differently when made to flow at different flow rates (mixing speeds, for example). They are **flow rate** sensitive, and often more resistant to flow at lower rates.

Powders have many behavioural characteristics and it's these that determine their in-process performance and the quality of the finished product

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Why might the powder processing industry be interest in understanding powder behaviour?

Typical questions might be:

- Can the powder be mixed to an acceptable blend uniformity?
- Does it consolidate if left in storage and after vibration?
- Does it flow efficiently out of a hopper?
- Does it change its behaviour if exposed to high humidity?
- Can fill weight be accurately and consistently achieved if the filling equipment or tablet press is run at an increased speed?
- Does high shear blending induce electrostatic charging on the surface of the particles, and therefore a period of relaxation is required, before the blend can be further processed in a consistent manner?

It is important to understand the most relevant powder characteristics in relation to a given process

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How to interpret measured behavioural characteristics?

What is known from measurements?

- Powder flowability is not greatly affected by consolidation, but powder is very flow rate dependant.

What does this tell us about its likely in-process performance?

- It will not compact excessively in a hopper or filling shoe, and will discharge consistently, but blend uniformity can only be achieved if a high enough shear rate is employed in the up-stream mixing process.

Question – How many properties need to be measured to enable us to predict:

- Whether the powder will blend effectively?
- It is likely to fluidise?
- The impact of consolidation on flow properties?
- Its flow rate sensitivity?
- The influence of water on flowability?
- Whether the powder will cake with time during storage?
- Does it slide easily against the wall of the process equipment?
- Can air be released efficiently during high speed compression?
- ….

- These examples illustrate why **powder behaviour is so complex** and why **characterisation is equally challenging**

- Powders are complex and cannot be described by a single number. They exhibit a range of (often unrelated) behavioural traits, any of which could be influential in the processing environment, or to the products critical quality attributes

- To accurately predict powder behaviour it is essential to measure a range of behavioural characteristics, and the powder's sensitivity to **every** external variable

Conclusion

Powders are complex materials because:-

- They consist of particles with a wide range of physical properties
- Their behaviour is influenced by a range of external variables, many of which are imposed during processing (level of consolidation, flow rate, moisture content, etc.)

Understanding in-process behaviour of powders is challenging because:-

- The process environment is complex and diverse, with many unit operations (mixing, granulation, drying, size reduction, filling, compression, etc.) each subjecting the powder to a different set of conditions
- Each unit operation can be configured in many ways (e.g. mixing time, mixing speed, geometry of mixer) and the behaviour of the powder in the process and its properties after being processed will depend on the process configuration

Finished products are diverse in nature, with a range of functional requirements. It could be a 25mg pharmaceutical tablet, a 500g cartridge of toner, a 10kg bag of dessert mix, or a tanker full of calcium carbonate

The properties of the powder need to be optimised to ensure efficient processing and to achieve the requirements and functionality of the product in final application

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