



Industrial/Academic Thoughts on Future Research in Particle/Powder Cohesion

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My three B's

- **Background** – 36 years with The Dow Chemical Company (retired Sept 2018), Fellow/Founder Solids Processing Lab
- **Bias** – I am a “bulker” – I worried about making both solids products/process without necessarily knowing all the “why” fundamentals – this is often the way of the industrial engineer/researcher
- **Blindspots** – All the fundamentals with respect to things like cohesion modeling, I learned from Jim Michaels last October/November – I think there is GREAT value in this education model – leave your ego at the door and you can learn a lot!



My “bulk solids soul” – the loading of the Michipicoten, Marquette Harbor – August 3, 2017 – 6:07 AM – observed with my daughter, Emma.



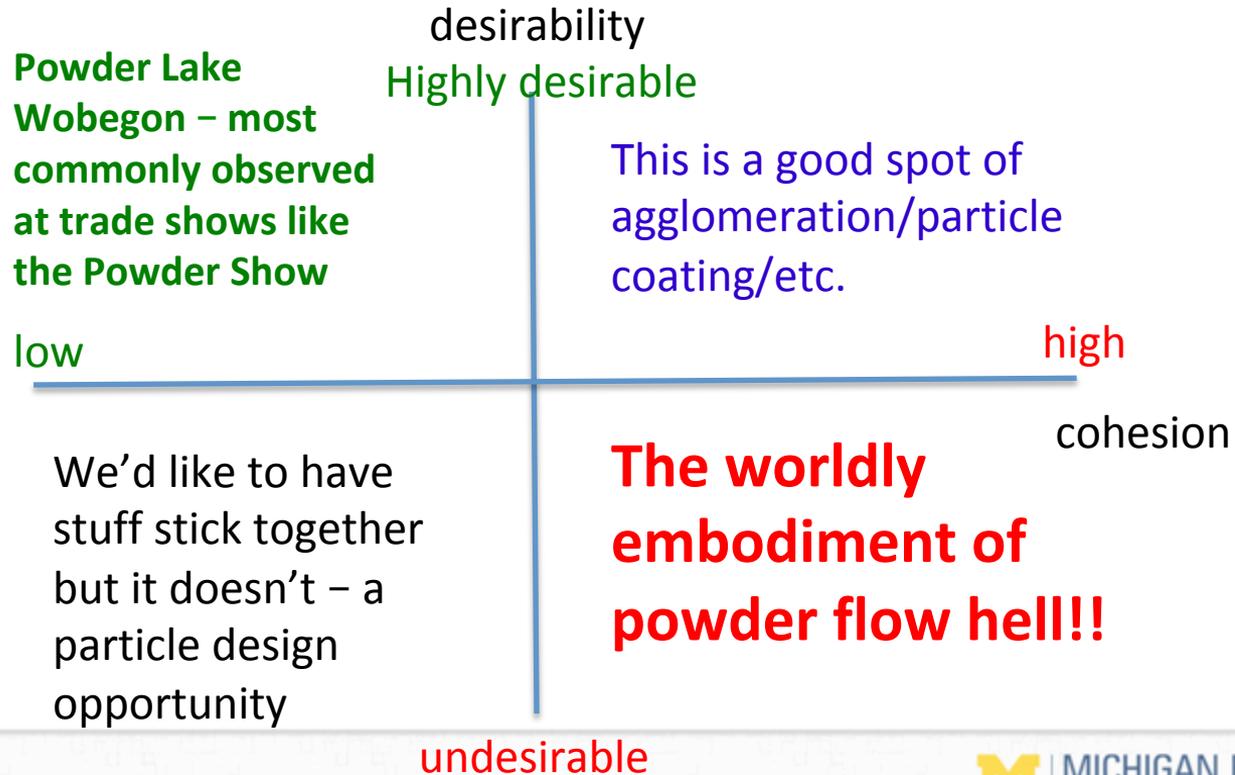


Boundaries for today's discussion

- Dry systems in play
- Moist systems like one might observe in a dryer or agglomerater
- NOT IN PLAY are traditional wet systems like slurries/pastes – this is a whole additional field of particle engineering research
- We won't discuss shear testers. With the work of Freeman Technology and Dietmar Schulze, we can now be very confident in the results produced by these devices, essentially changing the game from debating the instruments to useful discussions about the results!



The powder cohesion landscape





Observation from the last 1.5 days

- Nobody has touched on the impact of cohesion on the cradle to grave life of a particle.
- I'd encourage you to think about all aspects of how cohesion impacts the overall life cycle of a particulate product.



Powder/Particle Life Cycle and Cohesion

Product/
Process
Design

Production

Storage and
Shipment

Customer Use

Recycle/
Disposal

- Prepare for potential cohesion issues – blockages, rinds, caking, etc.

- Must address issues with cohesion in order to make product
- Hopper – wide spot in the line, BUT if it doesn't work...

- Caking
- Segregation
- Understand how material segregates under vibration
- Dust explosion issues

- Is the material sufficiently free flowing to be recycled?
- Is it in a product form that lends itself to recycling
- Plastics/ elastomers



Six items for future research consideration

1. Large particles
2. Electrostatics
3. Not round
4. Consider bulk properties beyond bulk cohesion and wall friction
5. Water matters, A LOT!
6. Strategies for surface modification – degree of decoration and spherical chickens



We often think about cohesion only in the small particle context (say $<100\ \mu\text{m}$), but we shouldn't forget about large particle systems.

- Sticky plastic pellets – CGCT/Metallocene chemistry polyolefins
- Coffee – 2nd largest commodity in the world



Large Particle Issues – The Jacob kitchen



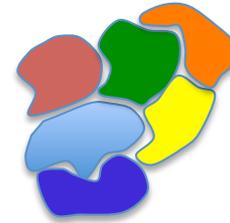
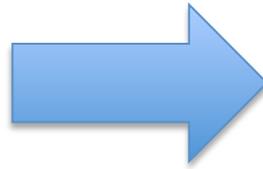
Observation: Starbucks House Blend Beans do not arch; French Roast Beans do!!



Top view of pitiful coffee bean hopper – 17 cm L x 7 cm W x 5 cm deep

While my poking of the coffee machine is mostly just an irritation for me, it represents in a small way a failure to recognize the cohesion of darker roast beans.

Large Particle Issues - Elastomers



This issue is more than just pellets!

- Agricultural materials
- Recycled goods

- Issues
 - Long term creep
 - Short term elastic wind-up
 - Sticky particle surfaces
- Conventional Jenike theory doesn't work
- Anti-block/Anti-caking theory empirical at best



Challenge of Electrostatics



- I had been machining Plexiglas® using a router. This piece of aluminum ducting was sitting on my Formica® covered router table and shavings about 4 mm square shot from the bit and attached to the ducting. It remained that way for a number of days.
- Several days later, I placed the duct onto my CAST IRON bandsaw table. Within 15 minutes, this pile formed at the base of the duct.



Thoughts on my “accidental” electrostatics experiment

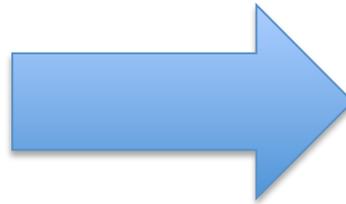
- Charge is very fleeting so controlled experiments are difficult to do.
- “Chain of Custody” for the bulk solid is very important
- Plants routinely observe very erratic behavior for solids that are prone to charging – EVEN WITHIN SAME BATCH/TRUCK/RAILCAR!

Electrostatics – cont'd

- Flow is often VERY difficult due to low bulk density of materials, limiting flow rate issues and additional electrostatics forces.

How do we measure this?

$$B = \frac{f_c H(\theta)}{\gamma g}$$



$$B = \frac{(f_{c,e}) H(\theta)}{\gamma g - dP / dz}$$

Ordinary flow



Electrostatics – Moving Forward

- Good collaboration by U of C/PSRI
- Excellent work done by Dan Lacks and his team at Case Western Reserve
- Still very important industrial problem – google “sheeting in polyethylene reactors”!
- Charge retention can be so long such that “sample history” of the powder is very important!
- What charge transfer agents are useful? How much? Are there agents beyond water suitable for GMP use?



Throw away the mica surfaces and PS latex particles...

- While the above system is wonderful for AFM analysis because it allows a very carefully controlled geometry, it is far from reality (HJ excepted!!)
- Most real particles are not round – we need to seriously address those that are acicular in nature. This is hard, very hard! Think of the budesonide particles from yesterday.
- Statistics will help up deals with the uncertainties due to differences in shape/size. We've got to starting crawling forward here in development of irregular particle contact mechanics. This will help underpin and validate any modeling efforts.



Bulk properties beyond the norm...

- Normally we consider many of the common bulk properties – unconfined yield stress, wall friction, adhesion, caking, etc.
- Need to think hard about things other than powder flow (and I love powder flow!) because they are extremely important to the entire discussion around making particles that work for us rather than living with sub-standard particulate products.



Some sample useful properties...

- Particle packing
- Thermal conductivity
- Dissolution
- Particle adhesion to a surface
- Power draw in mixers and blenders
- And many more...



Water Matters, A LOT!!

- Ben and I were working on the drying and flowability of an agricultural active chemical
- At 40% H₂O, the outlet size was unacceptably large. Blending with dry product to 20% and 10% yielded no improvement. Only at 5% did we see noticeable improvement.
- Water also shows its ugly head during drying in the process of ball/agglomerate formation and rind formation in dryers usually to great detriment to good dryer operability.



Water – Moral of the Story

- Irregular surfaces – macro-shape and micro roughness
- Surface chemistry/surface energy/wetting
- Amount of water/shape of interface
- Solubility of particle
- Degree of consolidation

**Very hard
problem!!**



Cohesion Control – Particle Coating

- We coat particles in order to control cohesion – CaCO_3 , stearates, carbon black, fumed silica, etc.
- Levels of protectant are largely determined experimentally
- Simple start is to do the “spherical chicken calculation” – how many perfectly round coating particles are required to put a monolayer round particle?
- But do we need a monolayer?

Particle Coating/Surface Modification

- Work of Fulcini, et.al., Powder Tech. (2017) shows that less than monolayer coverage can be effective in reducing cohesive strength

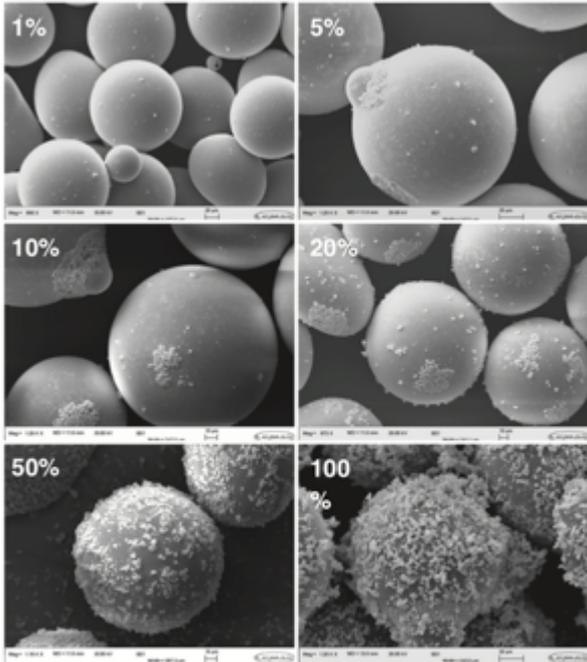


Fig. 8. SEM micrographs of particles coated with ZA, from top left to bottom right: 1, 5, 10, 20, 50, 100% of SAC.

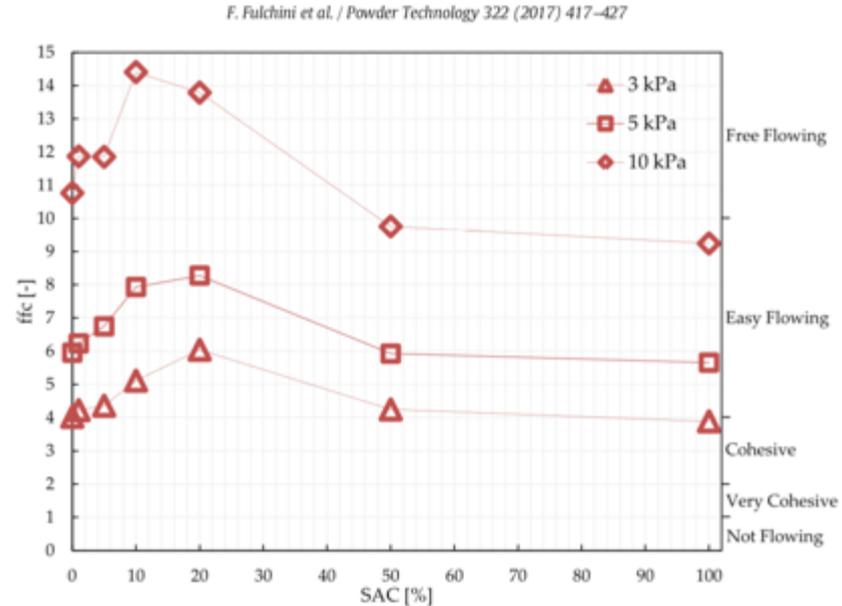


Fig. 10. ffc of SGB coated with ZA.



Particle Coating Questions

- How much do we need?
- Will it stick and will the coating stay on through the supply chain?
- Physical properties of host and the coating particles
- Intensity of mixing
- Potential long term deformation of the host
- Degree of acceptability of coating particles (FDA, GMP, OSHA, NFPA, etc.)
- Etc.



Conclusions

- Lots of good problems to work on
- Don't forget about your particle cohesion thru the entire life cycle
- This is not just a “my hopper is plugged” problem
- Many lifetimes of work to do but the glass is half full – be optimistic about our potential progress!