TECHNICAL
DIFFICULTIES
PLEASE
STAND
BY

Setting up a Powder Flow Characterization Laboratory

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How do we define flowability?

- Angle of repose
- Compressibility
- Flow index
- Funnel time
- Flow energy

How do we define flowability?

- Angle of repose
- Compressibility
- Flow index
- Funnel time
- Flow energy

None will predict flow behavior!

Good flowability

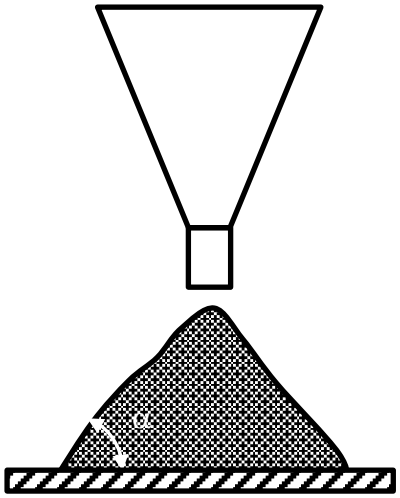
Poor flowability

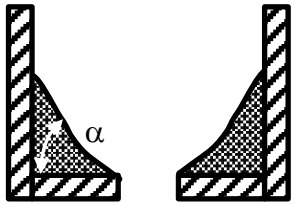
Testers

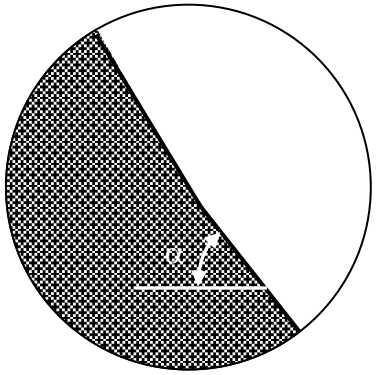
- Rank “flowability”
- Predict powder flow behavior

Angle of repose

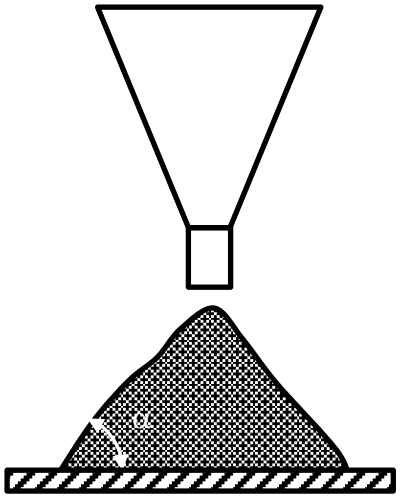
Angle of Repose	Flow
< 25	Excellent
25 - 30	Good
30 - 40	Passable
> 40	Very Poor







Angle of repose

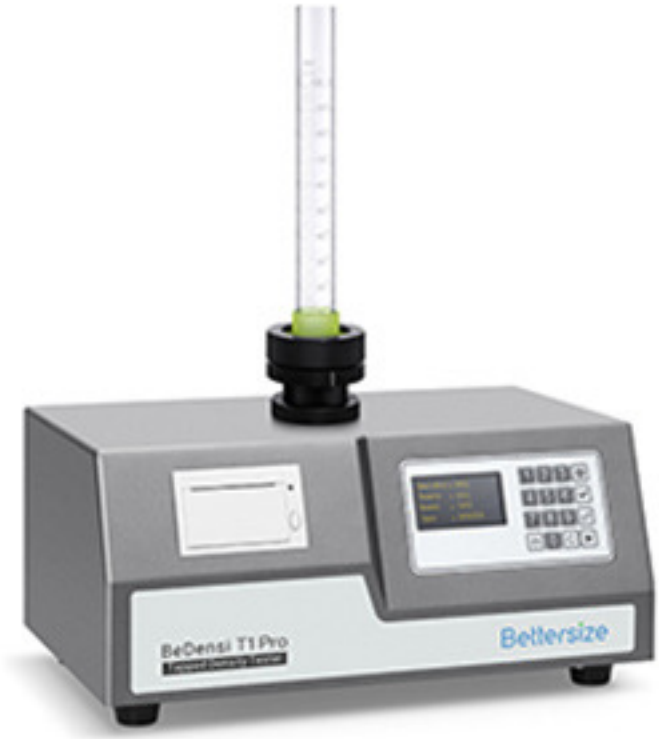


Angle of Repose	Flow
< 25	Excellent
25 - 30	Good
30 - 40	Passable
> 40	Very Poor

" The angle of repose… is only useful in the determination of the contour of a pile, and its popularity among engineers and investigators is due not to its usefulness but to the ease with which it is measured."

- A.W. Jenike, *Storage and Flow of Solids,* Utah Engineering Experiment Station Bulletin 123

Hausner and Carr Ratios



$$C = 100\frac{\rho_T - \rho_B}{\rho_T}$$

$$H = \frac{\rho_T}{\rho_B}$$

Carr Index

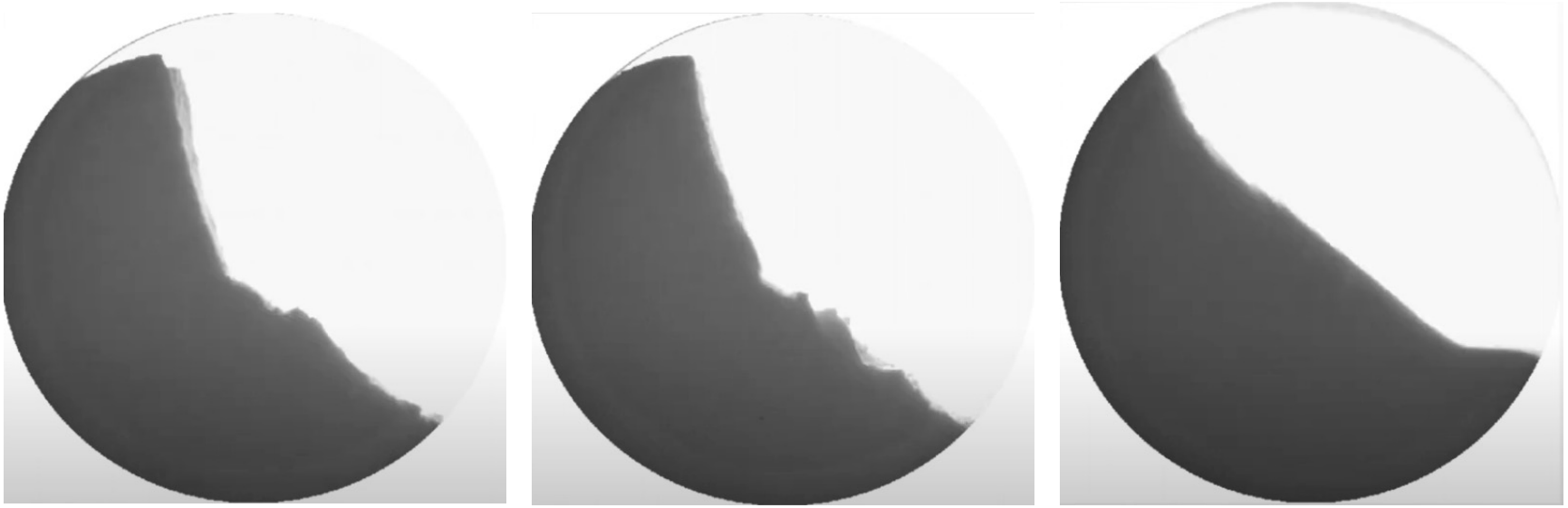
Hosokawa Micron

Tribocharge Tester

Score	Flowability and Performance
90-100	Excellent
80-89	Good
70-79	Fair
60-69	Passable
40-59	Poor
20-39	Very Poor
0-19	Very, Very Poor

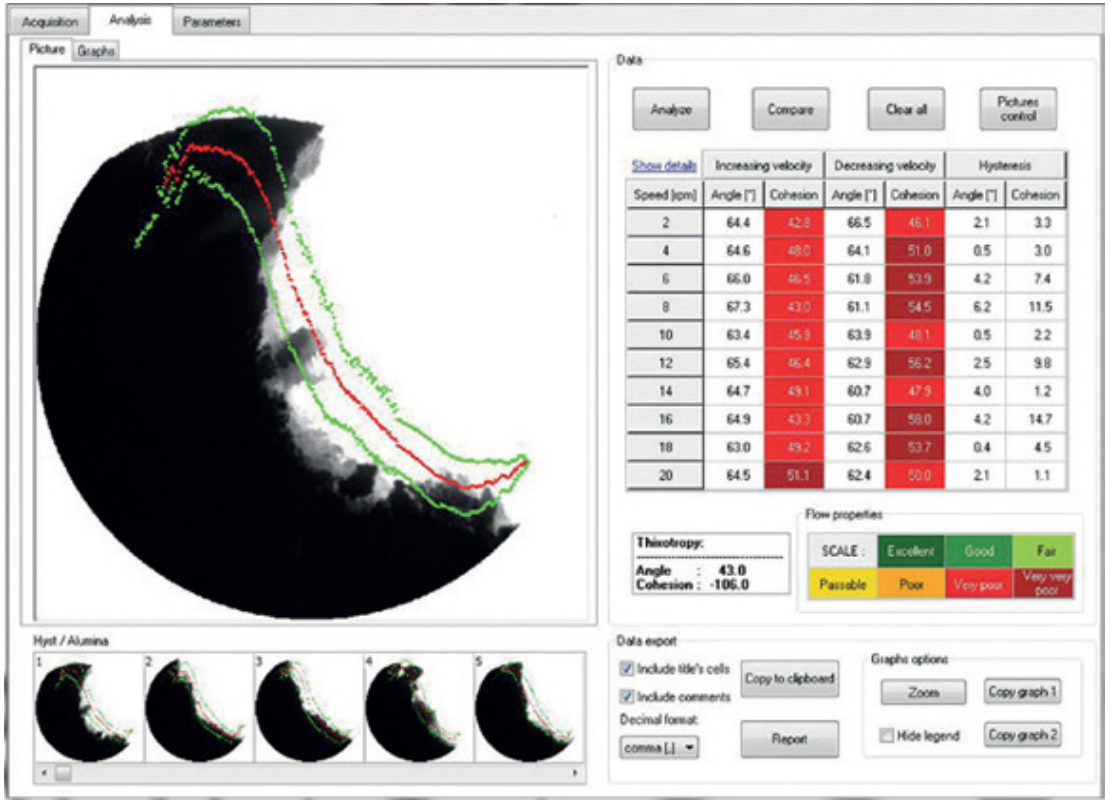
Silica	Flow Index
None	44.3
A	54.0
B	56.0
C	59.0
D	59.5

Avalanching

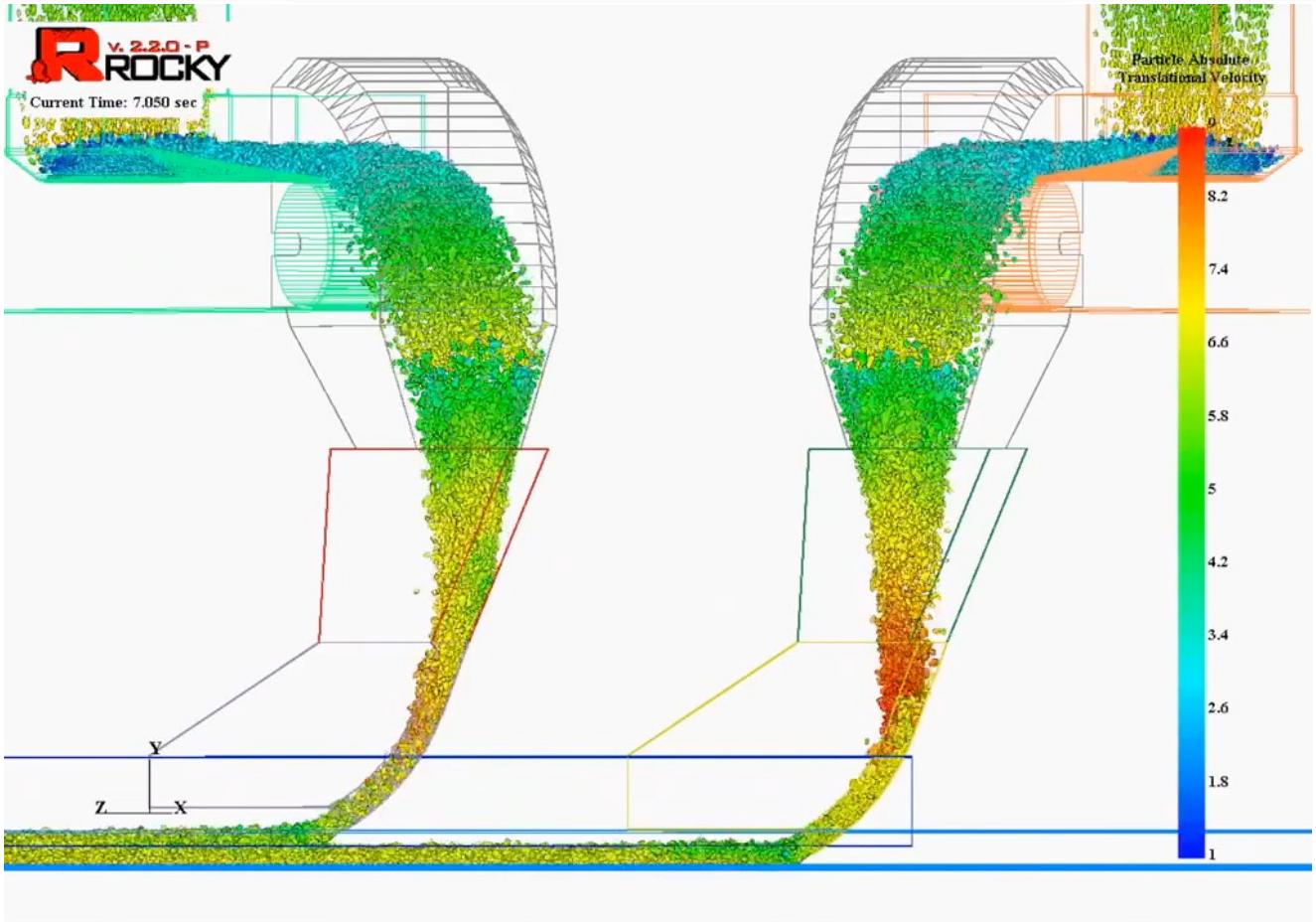


Avalanching

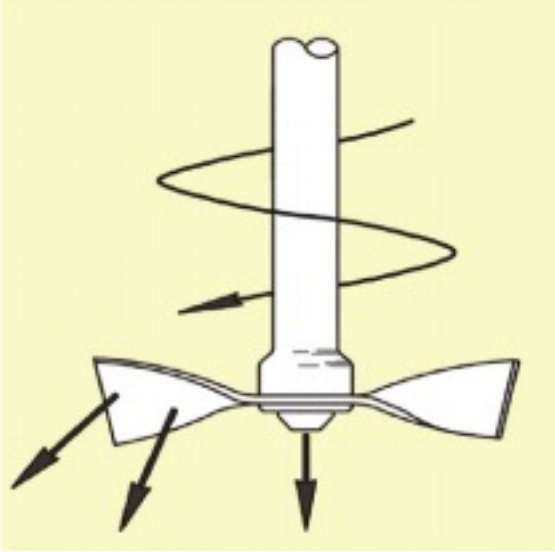
Granutools'
GranuDrum



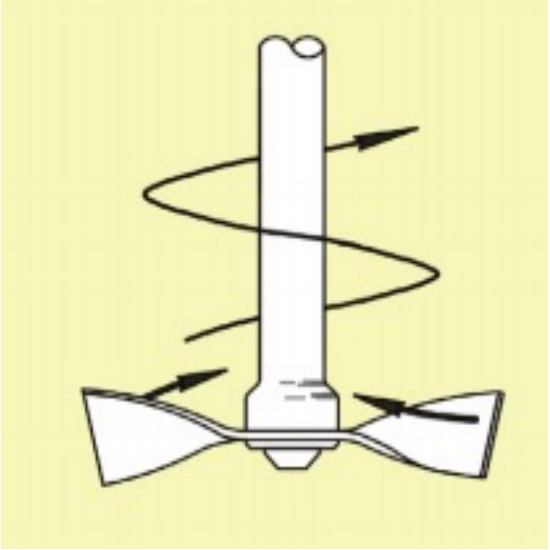
DEM


v. 2.2.0 - P
ROCKY
Current Time: 7.050 sec
Particle Absolute Translational Velocity
8.2
7.4
6.6
5.8
5
4.2
3.4
2.6
1.8
1
Y
Z
X

Flow energy

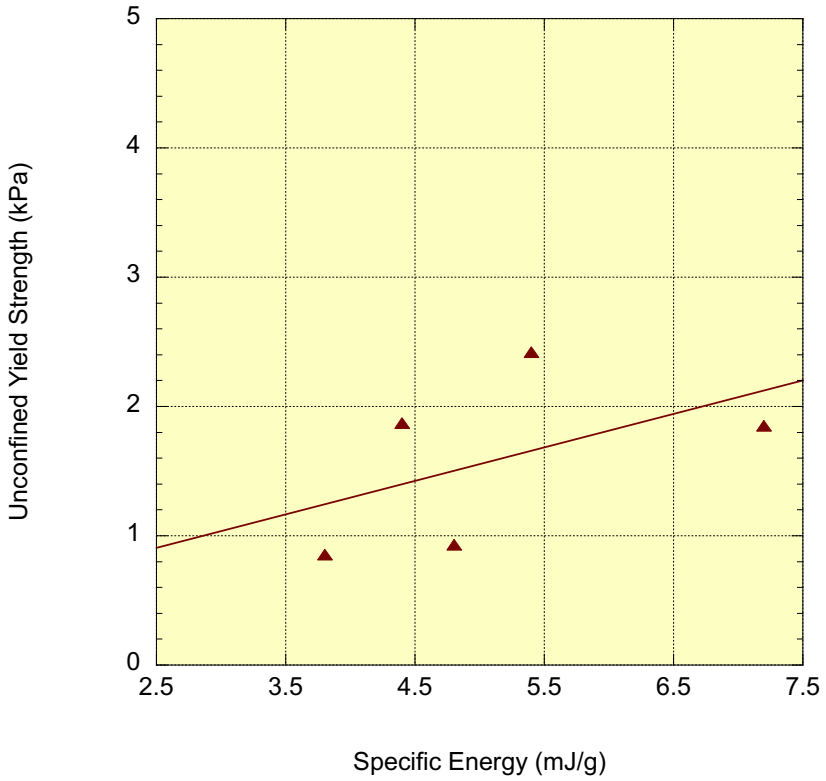


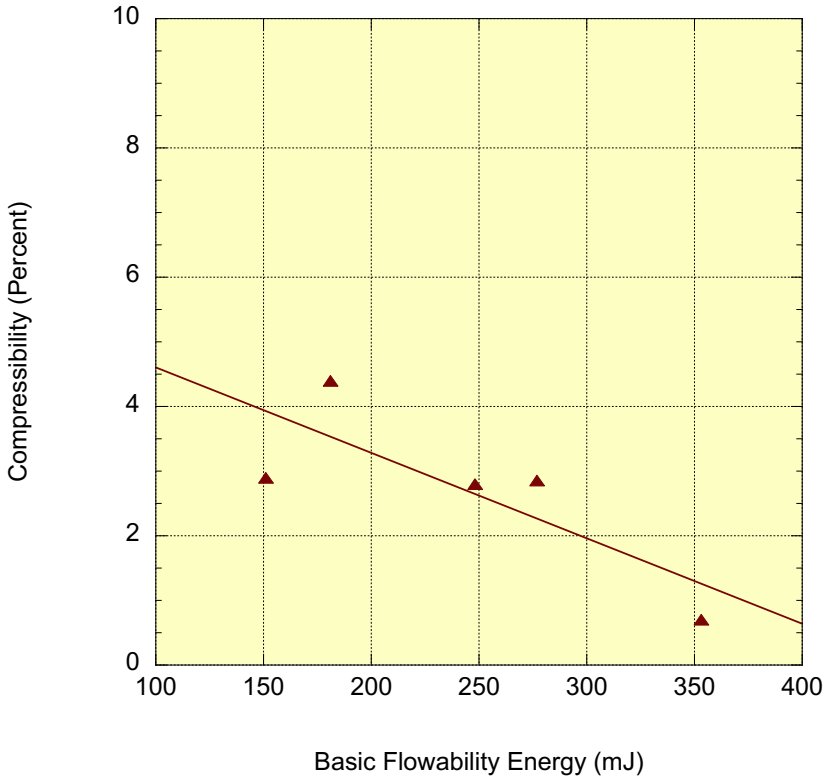
Basic Flow Energy



Specific Energy

Flow energy


Unconfined Yield Strength (kPa)
0
1
2
3
4
5
2.5
3.5
4.5
5.5
6.5
7.5
Specific Energy (mJ/g)


Compressibility (Percent)
0
2
4
6
8
10
100
150
200
250
300
350
400
Basic Flowability Energy (mJ)

Testers

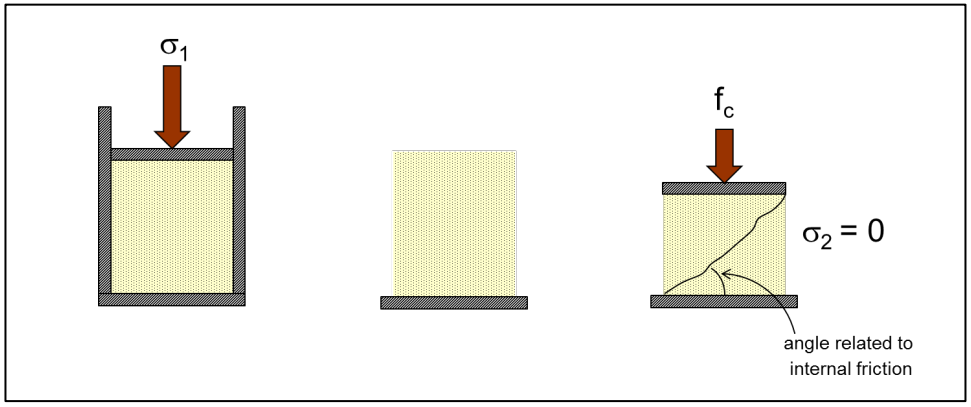
- Rank flowability or categorize
- Provide fundamental properties

Flowability

Neurotic	move awkwardly - poor flowability - sticky or tacky
Sadistic	attack their surroundings - abrasive - explosive
Masochistic	suffer from their surroundings - friable - degradable
Schizophrenic	change their behavior pattern - hygroscopic - electrostatic

Woodcock and Mason, 1987

Uniaxial compression



Uniaxial compression

Freeman Technology
Uniaxial Powder Tester

Edinburgh Powder Tester

Shear cell testers

Jenike
Direct
Tester

Schulze
RST-XS.s

Brookfield
Engineering
PFT

Anton Paar
MCR

Micromeritics
Freeman
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FT4

Fundamental properties

- Cohesive strength
- Internal friction
- Compressibility
- Wall friction
- Permeability

Fundamental properties

- Cohesive strength
- Internal friction
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Can be used to *predict* flow behavior rather than rank flowability

Flow stoppages

Arching

Ratholing

Storage vessels

Mass flow

Flow patterns

Funnel flow

Fundamental properties

- Cohesive strength
- Internal friction
- Compressibility
- Wall friction
- Permeability

Allows calculation of hopper outlet dimensions required to prevent flow obstructions or predict flow stoppages

Fundamental properties

- Cohesive strength
- Internal friction
- Compressibility
- Wall friction
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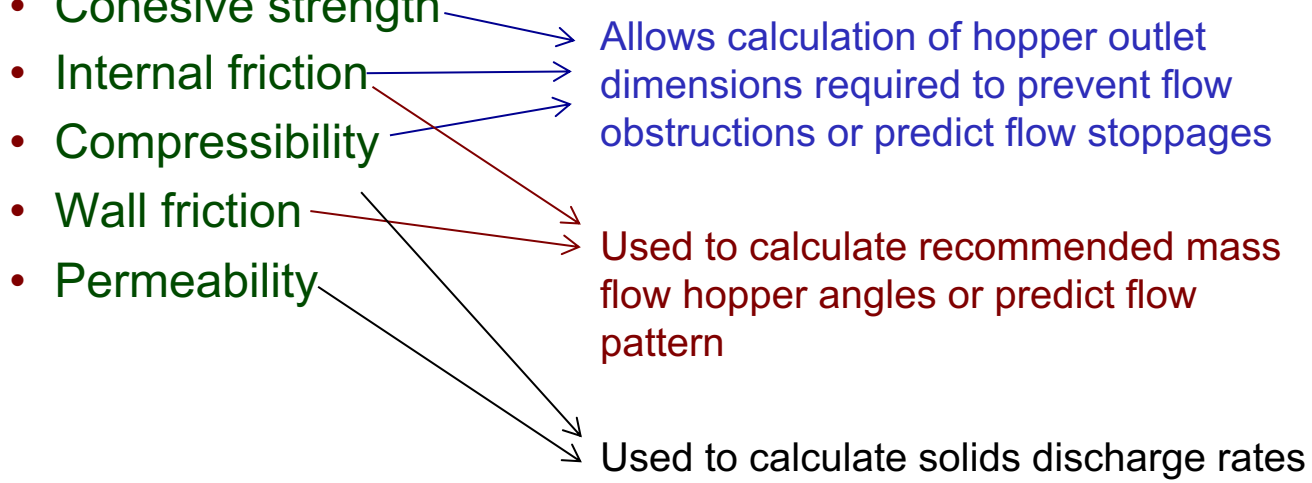
Allows calculation of hopper outlet dimensions required to prevent flow obstructions or predict flow stoppages

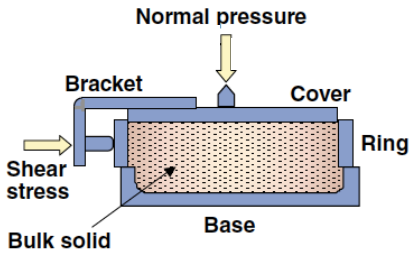
Used to calculate recommended mass flow hopper angles or predict flow pattern

Fundamental properties

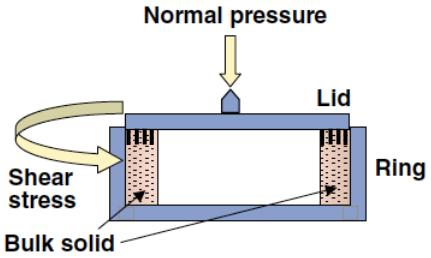
- Cohesive strength
- Internal friction
- Compressibility
- Wall friction
- Permeability



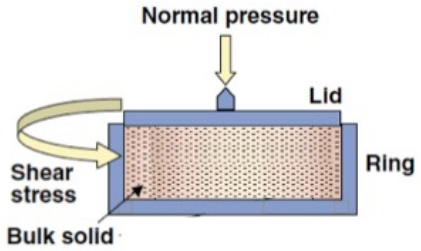
Shear cell testers



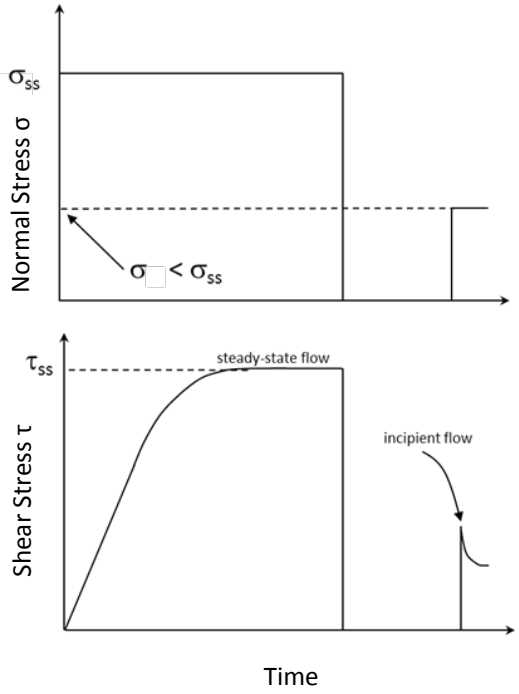
Direct



Annular

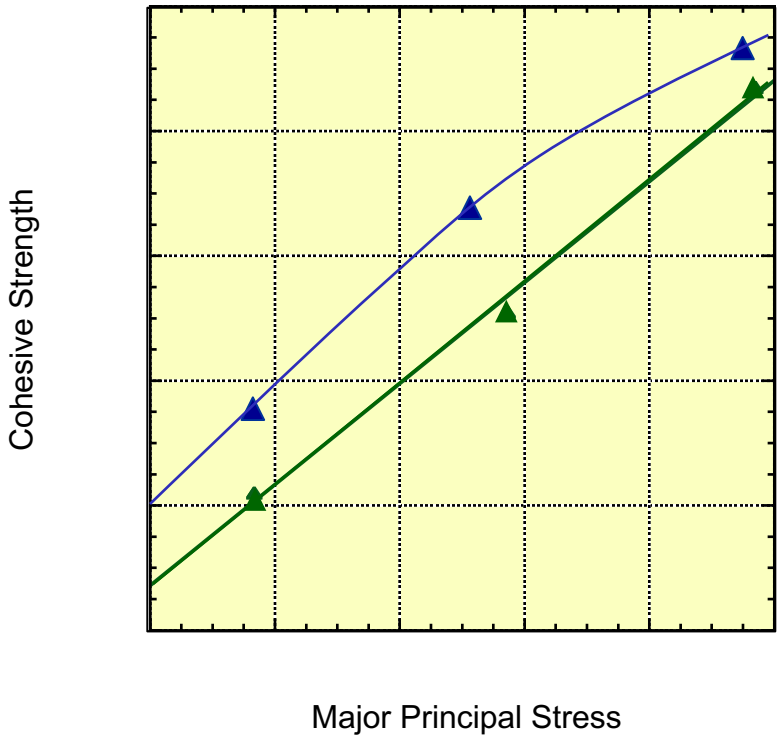


Torsional

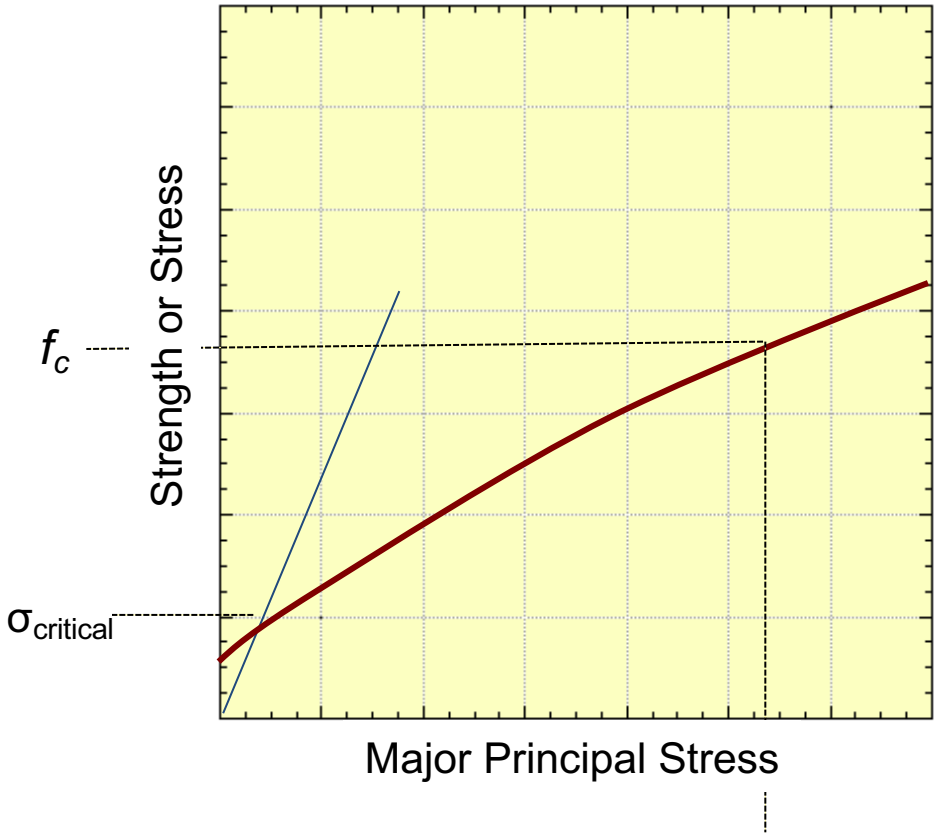


Shear cell testers

Flow function



Critical hopper outlet dimensions



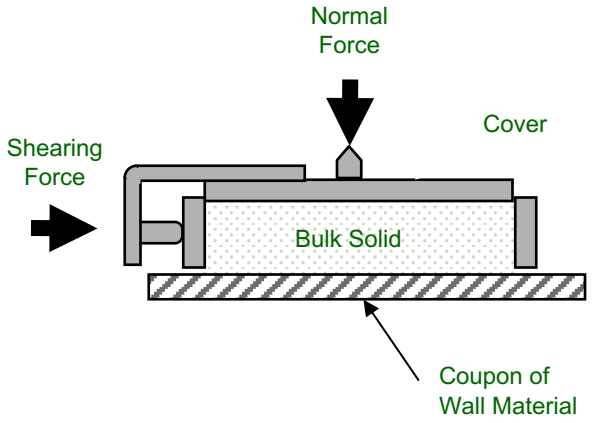
Arching:

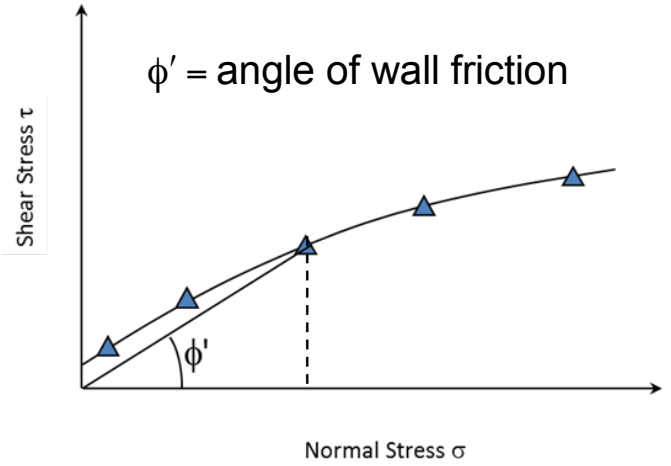
$$B_{\min} = \frac{H(\theta')\sigma_{critical}}{\rho_b g}$$

Ratholing:

$$D_F = \frac{G(\phi_t)f_C}{\rho_b g}$$

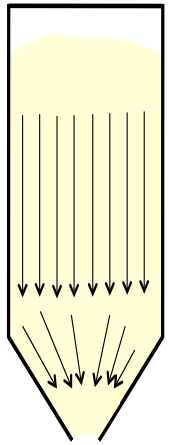
Wall friction

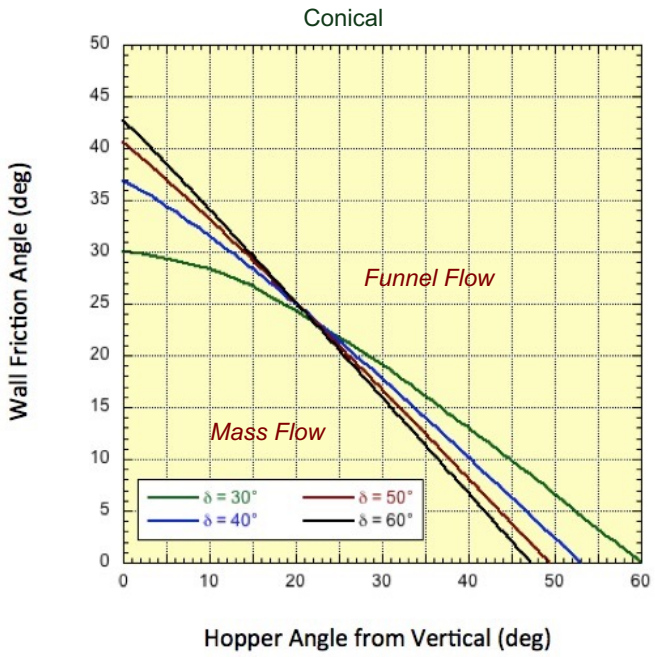


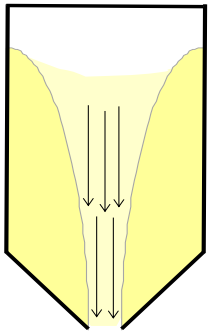


$$\tan\phi' = \frac{\text{Shear Stress}}{\text{Normal Stress}} = \mu$$

Mass flow hopper angles







Shear cell testers

Jenike
Direct
Tester

Schulze
RST-XS.s

Brookfield
Engineering
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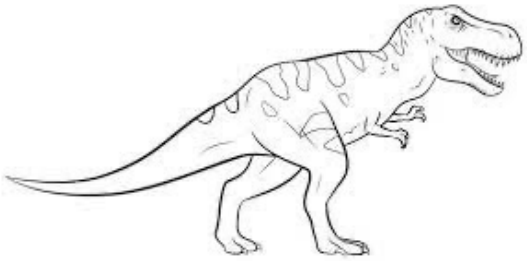

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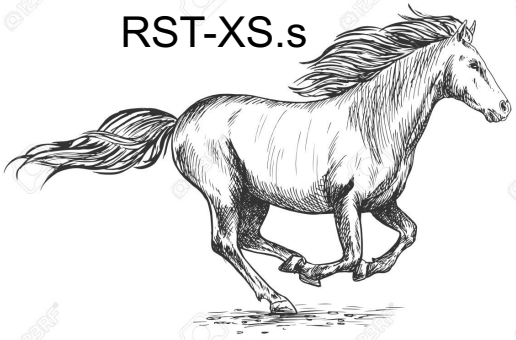

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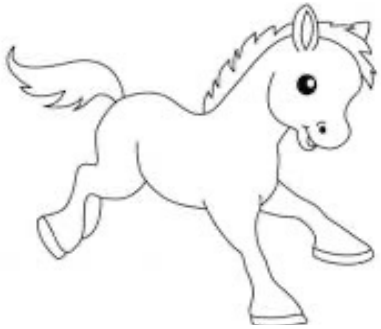

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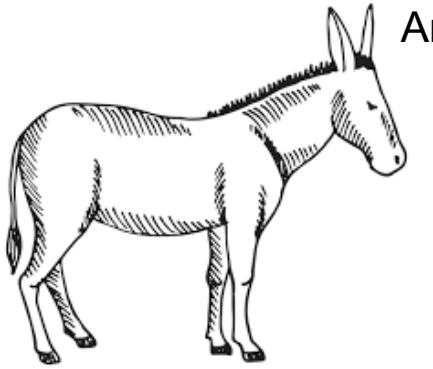

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MCR

Shear cell testers

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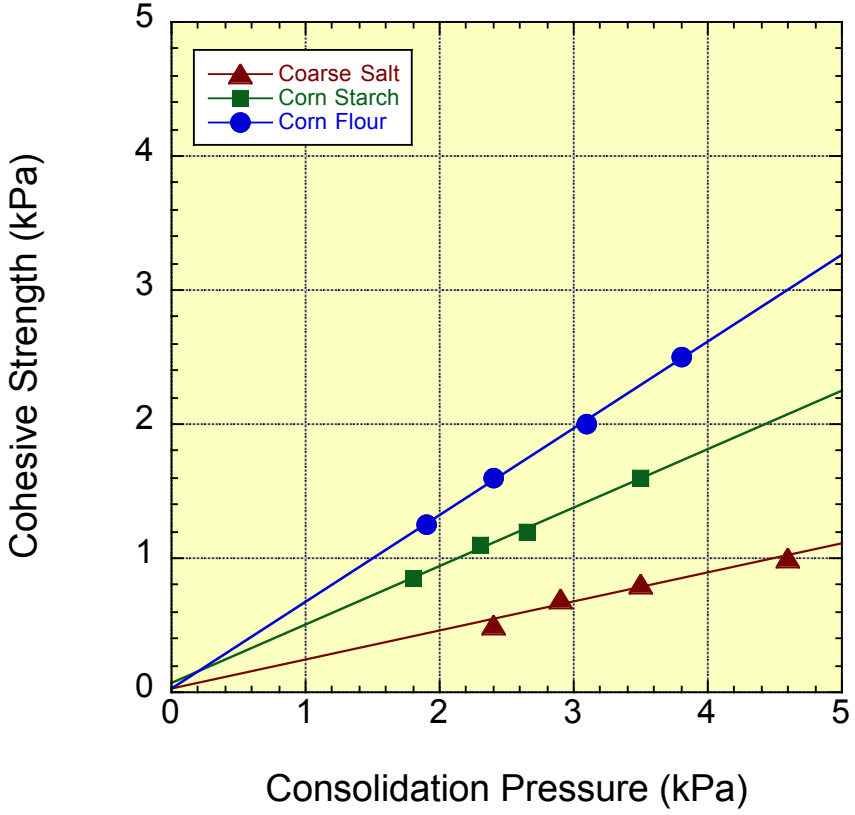
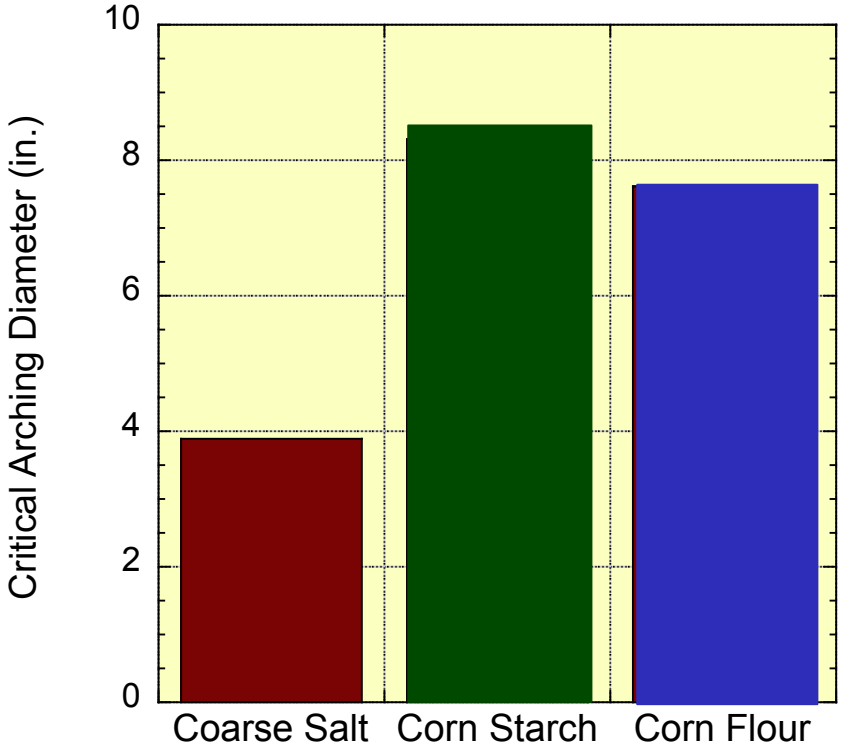
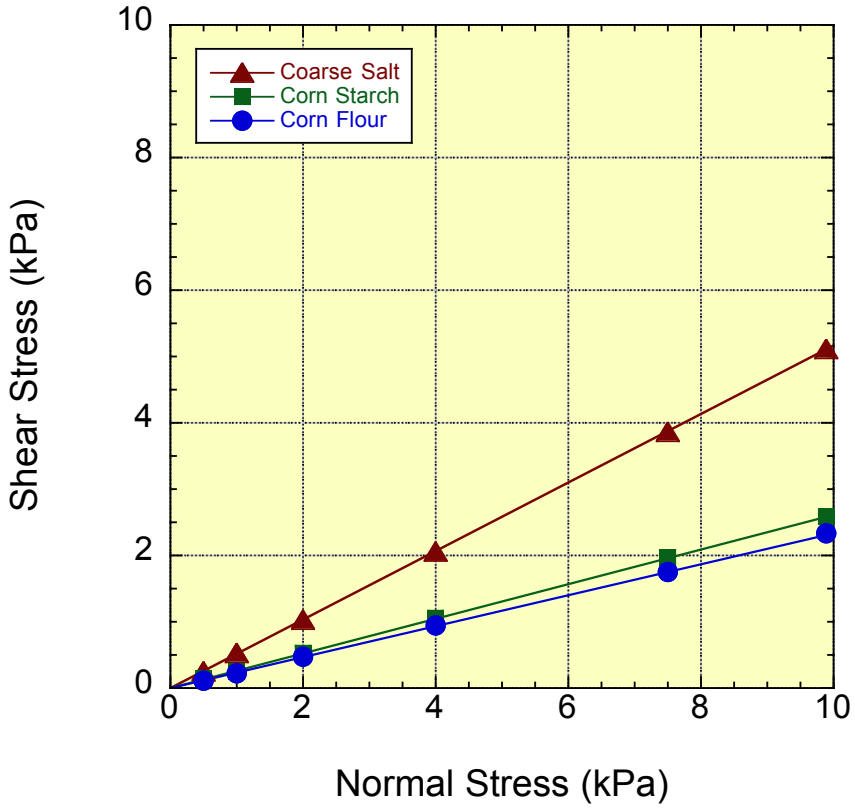
Example

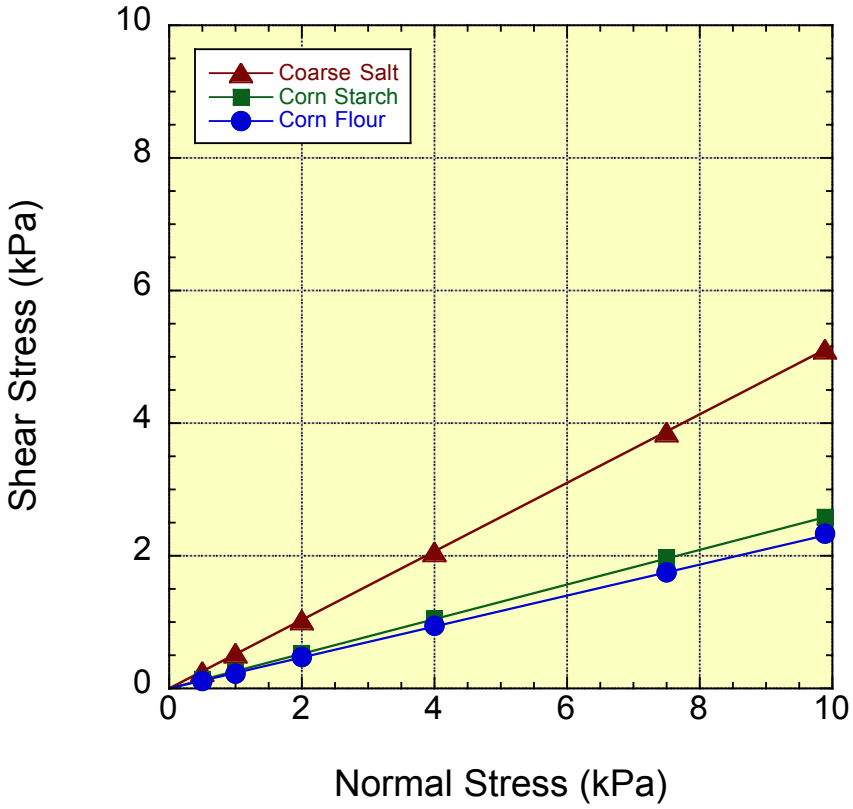

Coarse Salt
Corn Starch
Corn Flour
Cohesive Strength (kPa)
Consolidation Pressure (kPa)
0
1
2
3
4
5

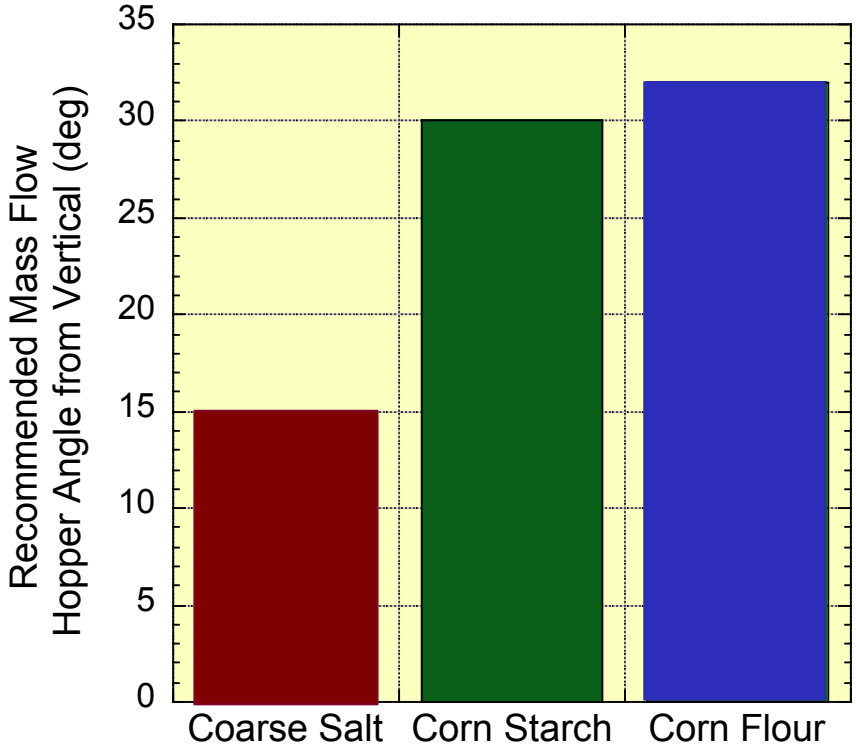

Critical Arching Diameter (in.)
0
2
4
6
8
10
Coarse Salt
Corn Starch
Corn Flour

Example


Coarse Salt
Corn Starch
Corn Flour
Shear Stress (kPa)
Normal Stress (kPa)
0
2
4
6
8
10

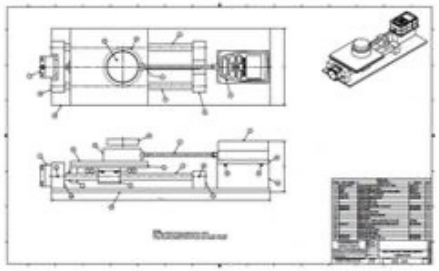
Example

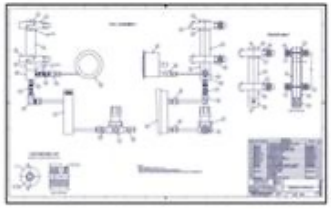

Coarse Salt
Corn Starch
Corn Flour
Shear Stress (kPa)
Normal Stress (kPa)
0
2
4
6
8
10


Recommended Mass Flow
Hopper Angle from Vertical (deg)
0
5
10
15
20
25
30
35
Coarse Salt
Corn Starch
Corn Flour

Other

- Wall friction tester
- Permeability tester
- PSD
- Riffle Splitter





Flow indices *vs.* Fundamental properties

Flow indices

- Simple and quick
- Rank similar materials
- Sometimes adequate for QC testing
- Do not necessarily predict flow behavior
- Ignore time effects

Fundamentals

- Measures properties over a range of known solids stresses
- Predicts flow behavior in storage vessels
- Used to recommend or design powder handling equipment
- Can quantify time effects

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Get yourself a shear cell tester!

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