
TECHNICAL
DIFFICULTIES
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BY

Flow and Storage of Powders

Greg Mehos, Ph.D., P.E.
gmehos@uri.edu
greg@mehos.net
www.mehos.net
https://www.linkedin.com/in/gmehos/
978-799-7311

Flow and Storage of Powders

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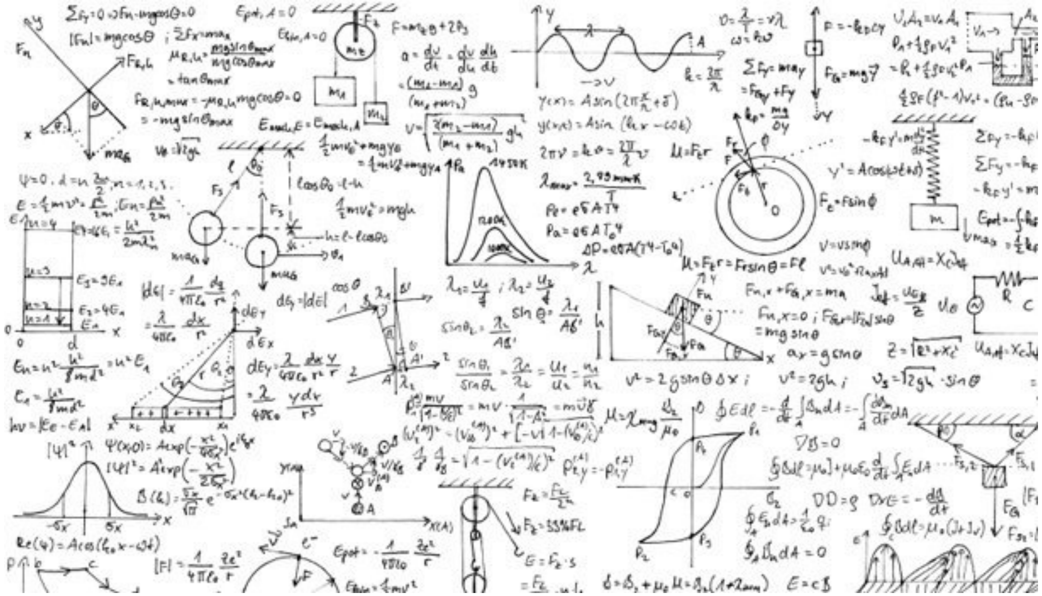

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Flow and Storage of Powders

Flow and Storage of Powders

Goals

- Understand *fundamental* powder flow properties
- Predict flow behavior of powders
- Know how to design/modify equipment for reliable powder handling

Goals

Goals

Definitions

Bulk solid

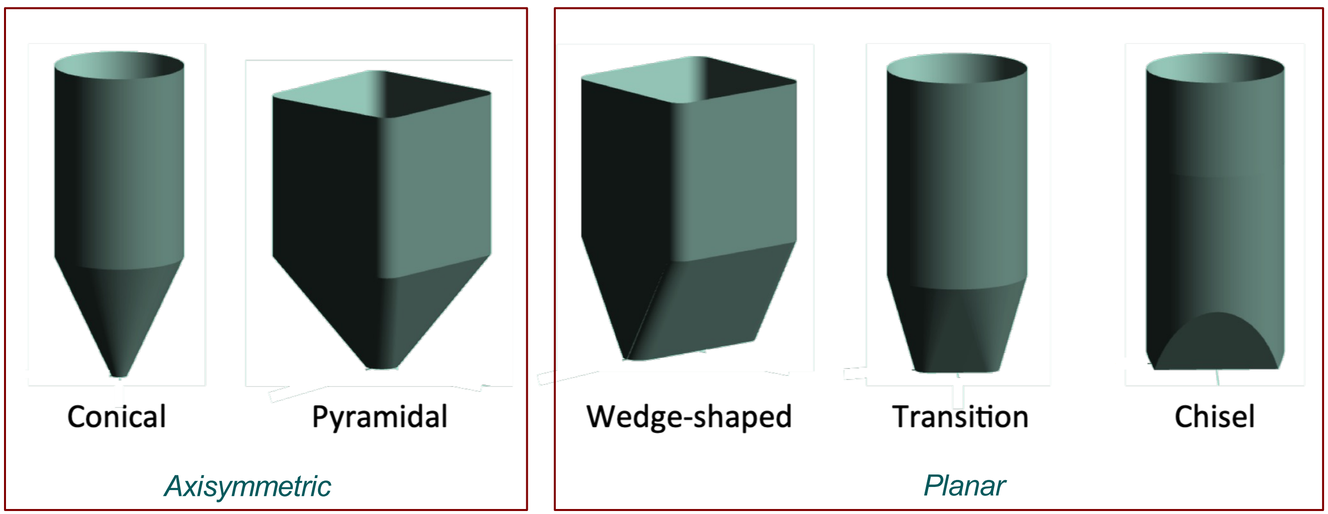
“Powder”

Definitions

Biomass

Definitions

Hopper, bin, or silo



Liquids *vs.* solids

	Liquids	Solids
Friction	Frictionless	Frictional
Compressibility	Nearly incompressible	Generally compressible
Isotropy	Isotropic	Anisotropic

Classification of liquids

Newtonian	Stress is proportional to strain rate
Viscoelastic	Combination of viscous and elastic behaviors
Rheopectic	Viscosity increases over time
Thixotropic	Viscosity decreases over time
Pseudoplastic	Viscosity increases with increased stress
Dilatant	Viscosity decreases with increased stress

Classification of bulk solids

"Normal" *Stable and consistent behavior*
- Very predictable, even, and uniform nature
- Insensitive to handling and environment
- Invariable with time and place
- Easy to accommodate and control

"Neurotic" *Awkward to handle*
- Behavior varies widely with circumstances
- Unstable in state and condition
- Sensitive to surroundings and handling
- Prone to run amok and lose mobility

"Schizophrenic" *Behavior changes completely*
- Absorbs liquor, hardens, or dries out
- Sensitive to heat, aggregates easily
- Forms strong, unwelcome bonds

"Masochistic" *Suffers readily*
- Fragile, delicate, easily breaks down
- Degrades, sensitive to contamination
- Deteriorates rapidly, has to be handled with care

"Paranoid" *Hypersensitive to own condition*
- Sensitive to size, shape, appearance, purity
- Alarmed by unquantifiable concerns
- Plagued with constraints or quality considerations
- Obsessed by regulation, bounds of acceptance

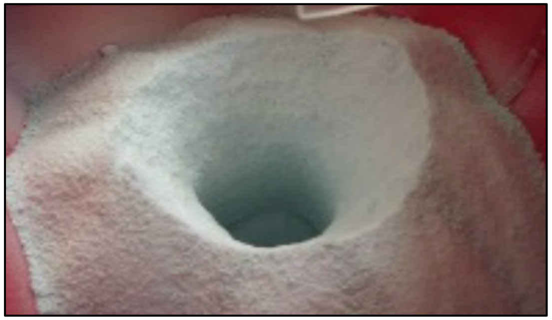
"Sadistic" *Aggressive to surroundings*
- Abrasive, toxic, hot, or inflames readily
- Unpleasant to touch or be near, irritates
- Fouls or contaminates the locality, corrosive

"Plane nasty" *Obstinate, dangerous, hazardous*

Credit: Lyn Bates!

Flow problems

- Ratholing



Flow problems

- Ratholing
- Arching/bridging

Bridging

Flow problems

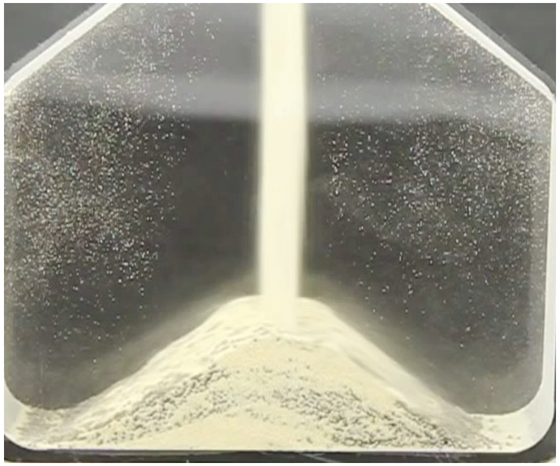
- Ratholing
- Arching
- Caking

Flow problems

- Ratholing
- Arching
- Caking
- Flooding

Flow problems

- Ratholing
- Arching
- Caking
- Flooding
- Segregation



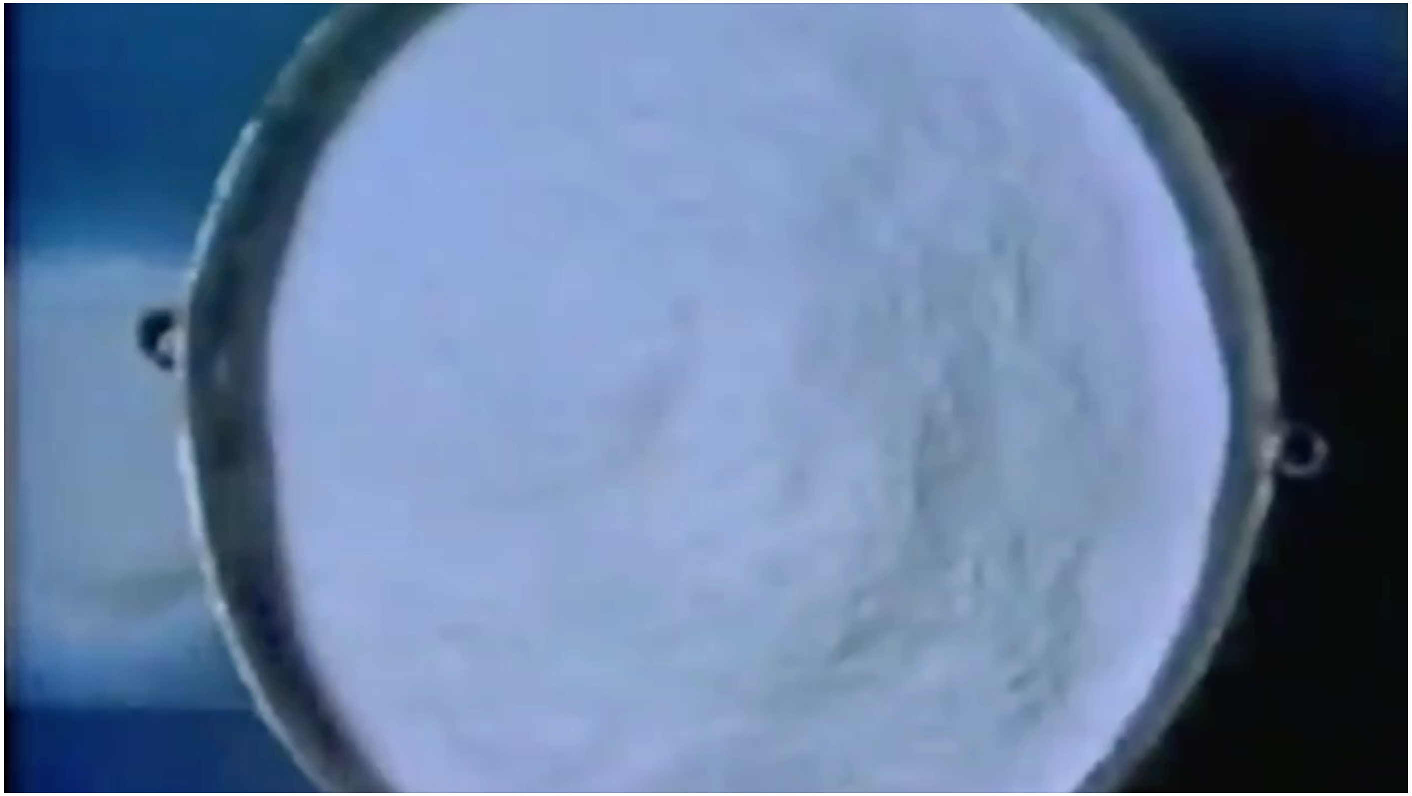
Flow problems

- Ratholing
- Arching
- Caking
- Flooding
- Segregation
- Limiting discharge rate

Solids flow patterns

- Funnel flow
- Mass flow

Funnel flow



Mass flow

Mass flow



Funnel flow

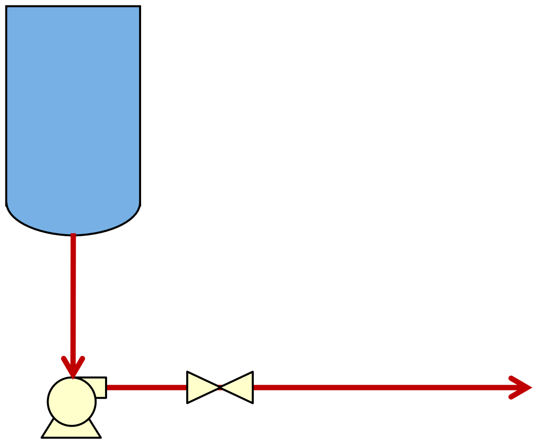
No flow

Preventing flow problems

- Ensure properly sized outlet
- Design/modify to allow mass flow
- Need powder flow properties

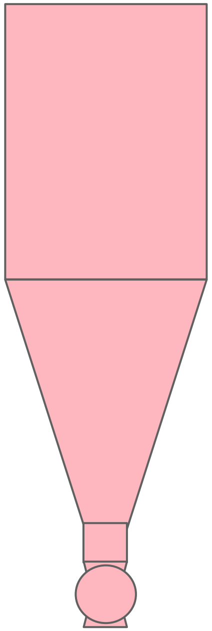
Fundamental properties

- Viscosity
- Density
- Vapor pressure



Fundamental properties

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



Andrew Jenike

Fundamental properties

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

Cohesive strength, Internal friction, Compressibility → 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

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

Used to calculate solids discharge rates


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CHEMICAL ENGINEERS' HANDBOOK
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CHEMICAL ENGINEERS' HANDBOOK
THIRD EDITION
McGRAW-HILL
PERRY'S CHEMICAL ENGINEERS' HANDBOOK
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Test equipment

- Shear cell testers
  - Cohesive strength
  - Internal friction
  - Compressibility
  - Wall friction

Jenike & Johanson

Dietmar Schulze

Brookfield Engineering

Anton Paar

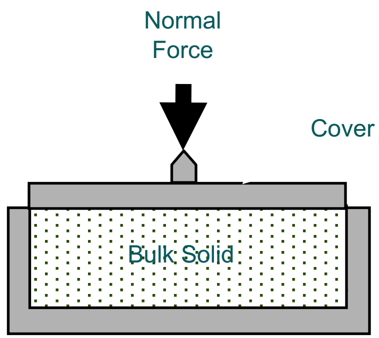
Freeman Technology

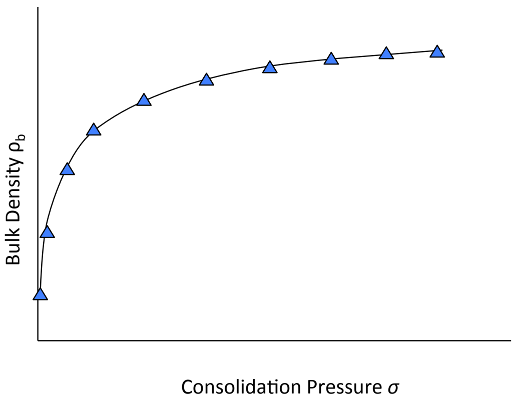
E&G Associates

- Permeability testers

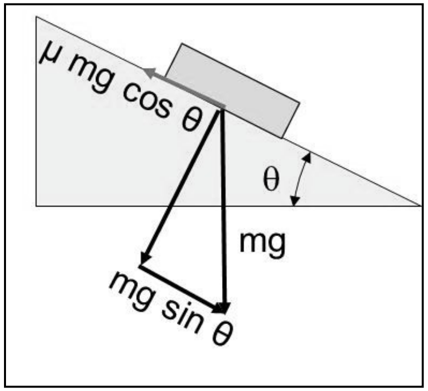
Compressibility

Compressibility





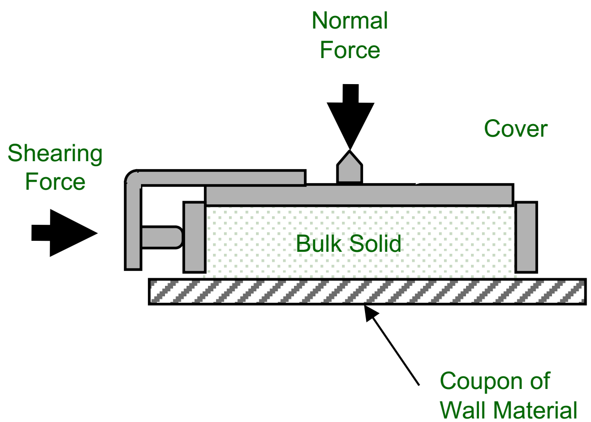
Wall friction

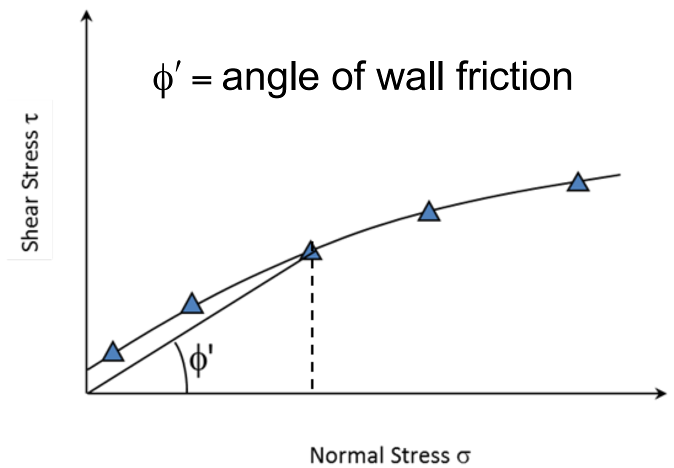


$$mg \sin\theta = \mu\, mg \cos\theta$$

$$\mu = \tan\theta$$

Wall friction

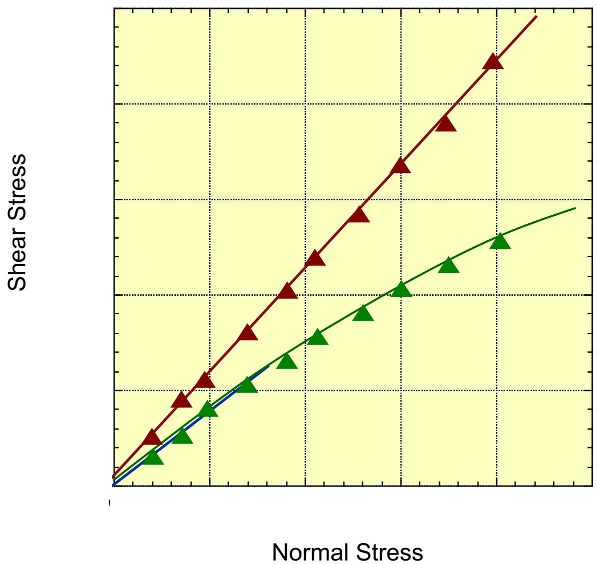




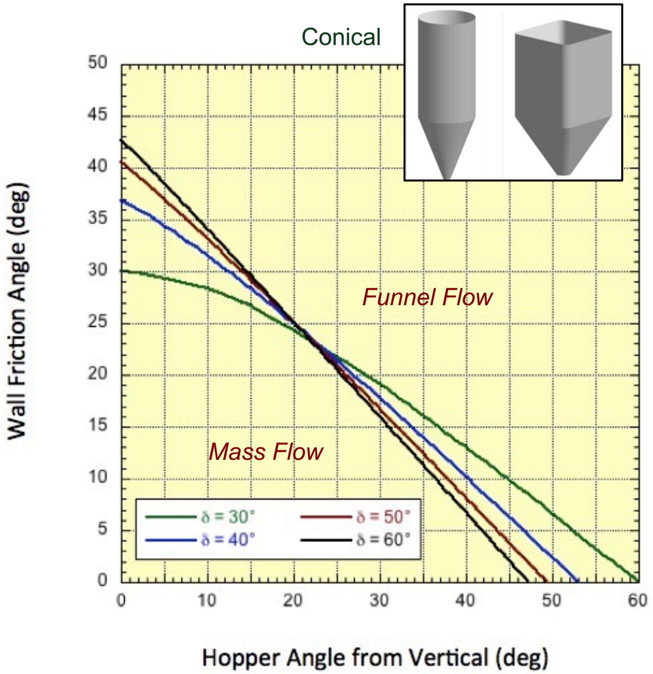
$$\tan\phi' = \frac{\text{Shear Stress}}{\text{Normal Stress}} = \mu$$

Wall friction

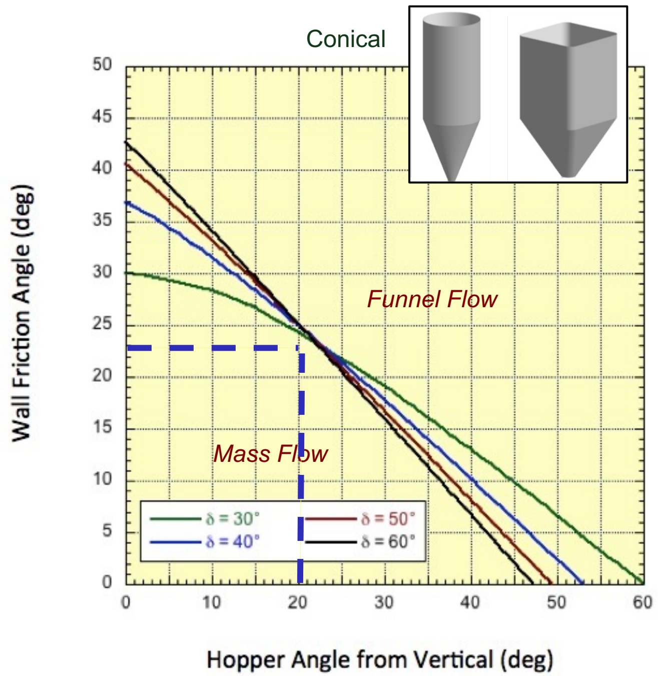
Wall yield locus



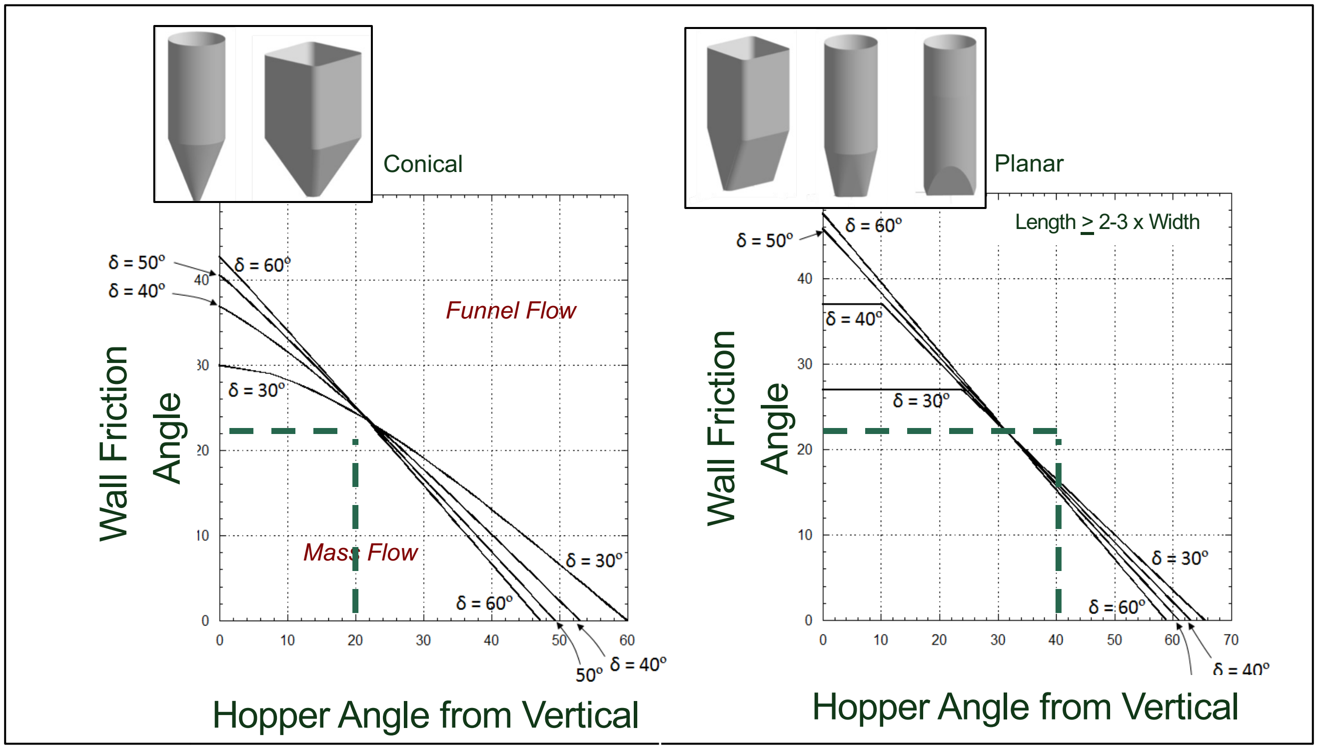
Mass flow hopper angle



Mass flow hopper angle

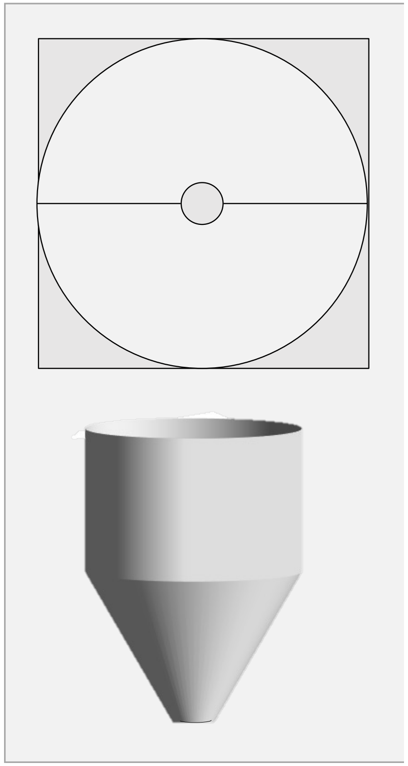


Mass flow hopper angles

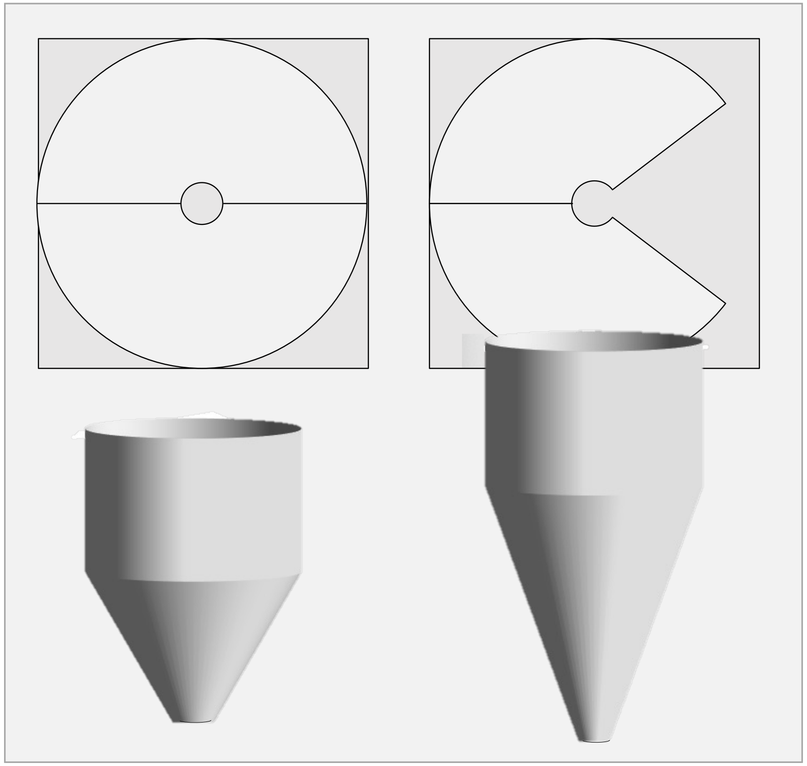


From Jenike Bulletin 123

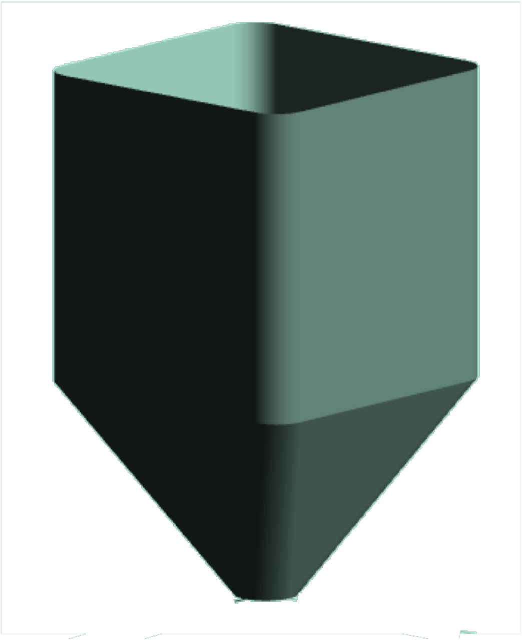
Mass flow hopper angle



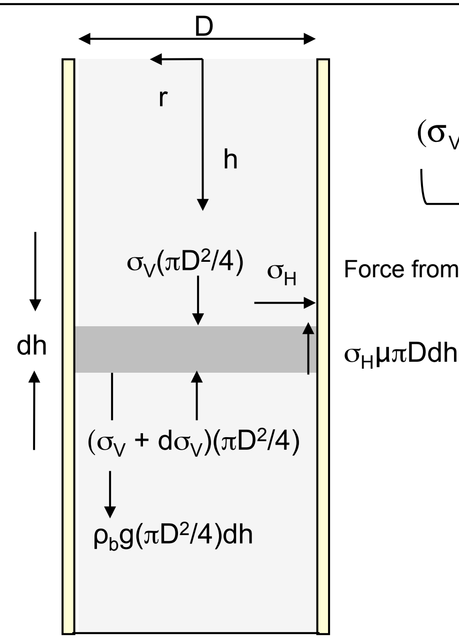
Mass flow hopper angle



Valley angles



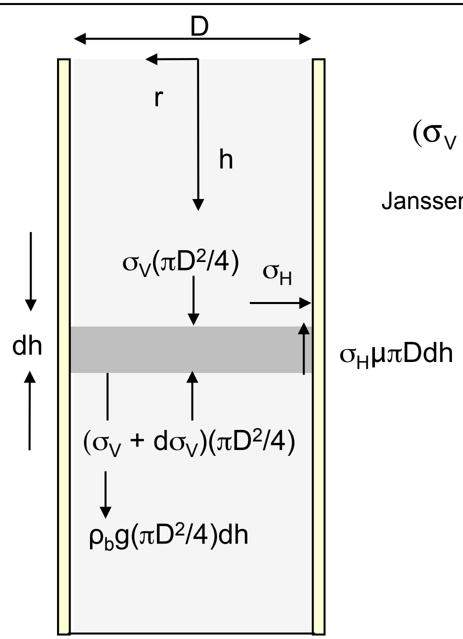
Pressure distribution



Cylinder

$$\underbrace{(\sigma_V + d\sigma_V)\frac{\pi D^2}{4}}_{\text{Force from powder below}} + \underbrace{\sigma_H \mu \pi D\, dh}_{\text{Force due to wall friction}} = \underbrace{\sigma_V \frac{\pi D^2}{4}}_{\text{Force from powder above}} + \underbrace{\rho_b g \frac{\pi D^2}{4} dh}_{\text{Force due to gravity}}$$

Pressure distribution



Cylinder

$$(\sigma_V + d\sigma_V)\frac{\pi D^2}{4} + \sigma_H \mu \pi D\, dh = \sigma_V \frac{\pi D^2}{4} + \rho_b g \frac{\pi D^2}{4} dh$$

Janssen coefficient

$$k = \frac{\sigma_H}{\sigma_V} \cong 0.4 - 0.6$$

$$\frac{D}{4}\frac{d\sigma_V}{dh} + k\mu\sigma_V = \frac{D}{4}\rho_b g$$

1st order linear differential equation

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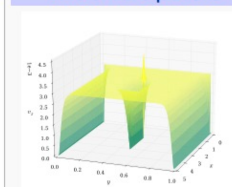
Integrating factor

From Wikipedia, the free encyclopedia
(Redirected from Integration factor)

In mathematics, an **integrating factor** is a function that is chosen to facilitate the solving of a given equation involving differentials. It is commonly used to solve ordinary differential equations, but is also used within multivariable calculus when multiplying through by an integrating factor allows an inexact differential to be made into an exact differential (which can then be integrated to give a scalar field). This is especially useful in thermodynamics where temperature becomes the integrating factor that makes entropy an exact differential.

Contents [hide]

Differential equations



Navier–Stokes differential equations used to simulate airflow around an obstruction.

Scope	[show]
Classification	
Types	[show]
Relation to processes	[show]
Solution	
General topics	[show]
Solution methods	[show]
People	[show]

v·t·e

Use in solving first order linear ordinary differential equations [edit]

Integrating factors are useful for solving ordinary differential equations that can be expressed in the form

$$y' + P(x)y = Q(x)$$

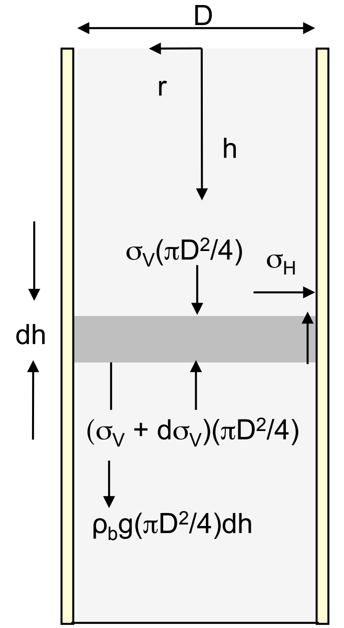
The basic idea is to find some function $M(x)$, called the "integrating factor," which we can multiply through our DE in order to bring the left-hand side under a common derivative. For the canonical first-order, linear differential equation shown above, our integrating factor is chosen to be

$$M(x) = e^{\int_{s_0}^{x} P(s)ds}$$

In order to derive this, let $M(x)$ be the integrating factor of a first order, linear differential equation such that multiplication by $M(x)$ transforms a partial derivative into a total derivative, then:

$$(1) \qquad M(x)\underbrace{(y' + P(x)y)}_{\text{partial derivative}}$$

Pressure distribution



Cylinder

$$(\sigma_V + d\sigma_V)\frac{\pi D^2}{4} + \sigma_H \mu \pi D\, dh = \sigma_V \frac{\pi D^2}{4} + \rho_b g \frac{\pi D^2}{4} dh$$

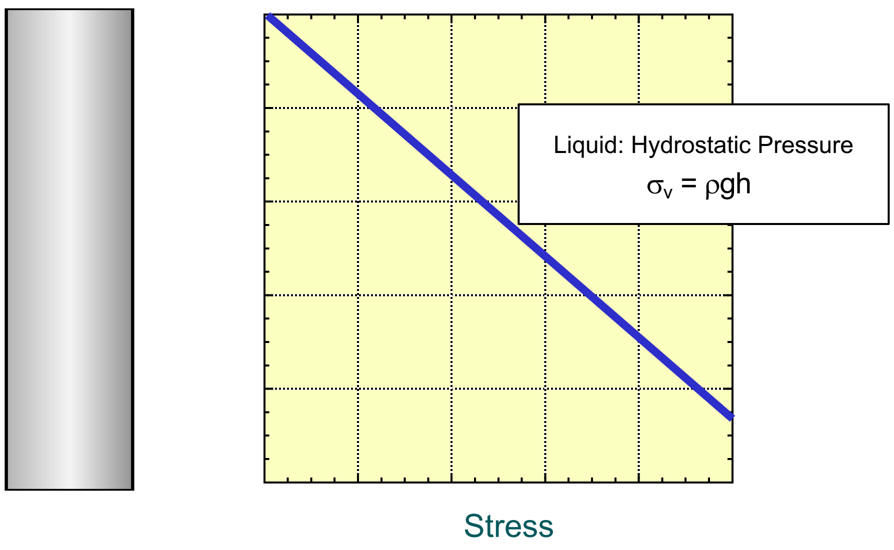
$$k = \frac{\sigma_H}{\sigma_V} \cong 0.4$$

$$\frac{D}{4}\frac{d\sigma_V}{dh} + k\mu\sigma_V \quad \frac{D}{4}\rho_b g$$

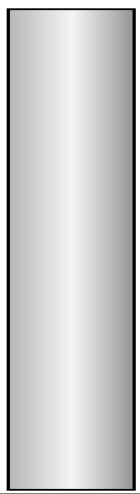
Janssen Equation:

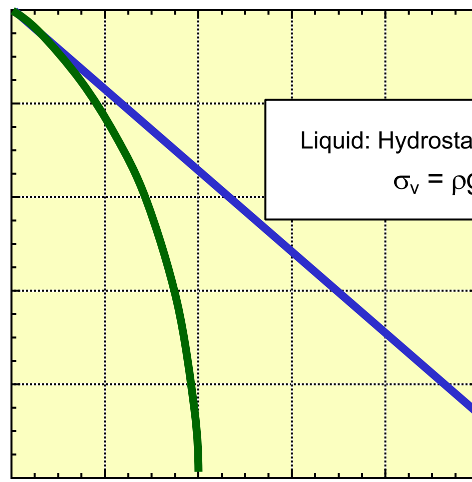
$$\sigma_v = \frac{\rho_b g D}{4k\mu}\left[1 - \exp\left(\frac{-4k\mu h}{D}\right)\right]$$

Pressure distribution



Pressure distribution





Liquid: Hydrostatic Pressure

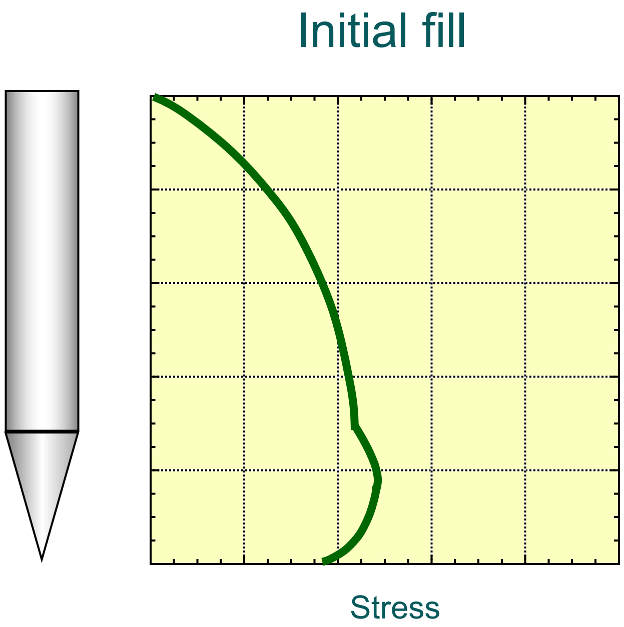
$\sigma_v = \rho g h$

Janssen Equation:

$$\sigma_v = \frac{\rho_b g D}{4k\mu}\left[1 - \exp\left(\frac{-4k\mu h}{D}\right)\right]$$

Stress

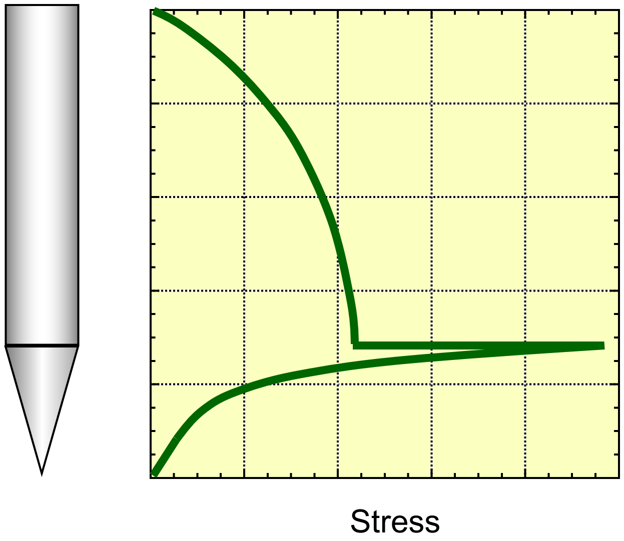
Pressure distribution



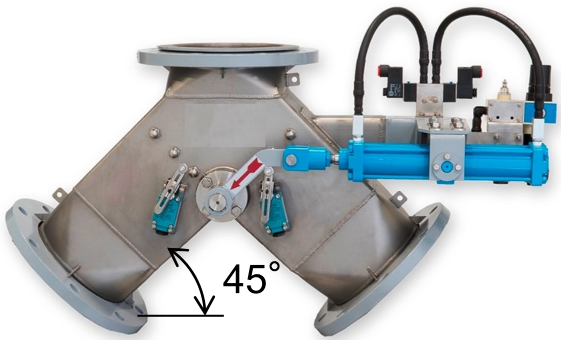
GM&A

Pressure distribution

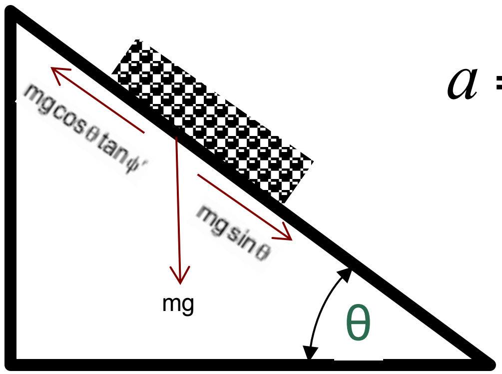
After discharge (mass flow)



Transfer chutes and diverter valves



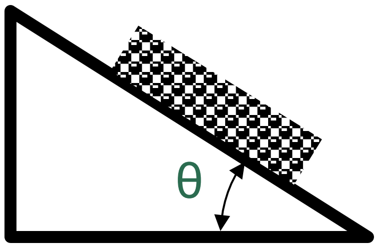
Transfer chutes



$$a = g(\sin\theta - \cos\theta\tan\phi')$$
$$= g\cos\theta(\tan\theta - \tan\phi')$$

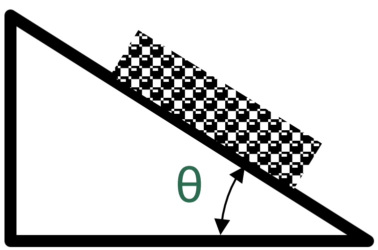
For dependable flow, $\theta' = \phi' + 5^\circ$

Transfer chutes



$$a = g\cos\theta(\tan\theta - \tan\phi')$$

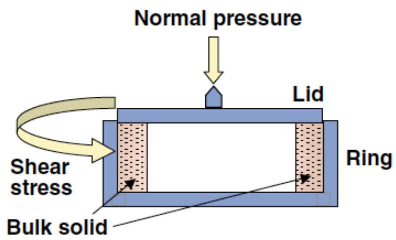
Transfer chutes

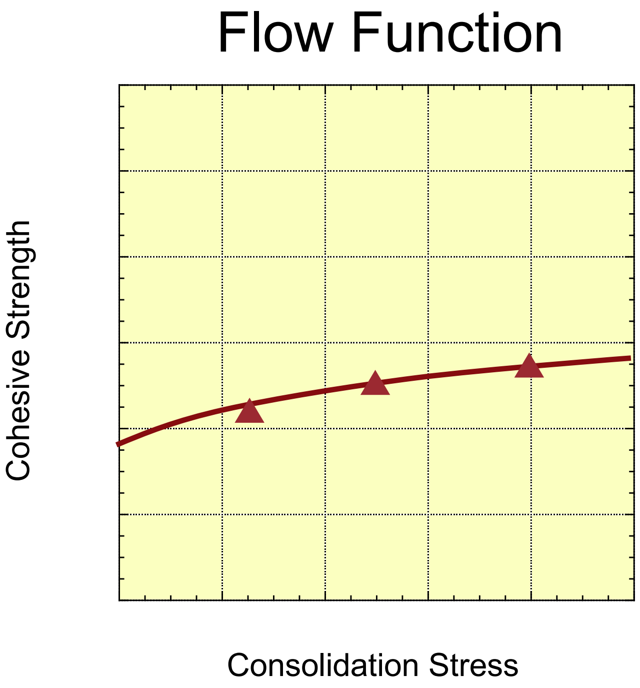


$$a = g\cos\theta(\tan\theta - \tan\phi')$$

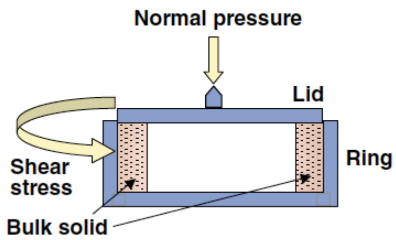
Cohesive strength

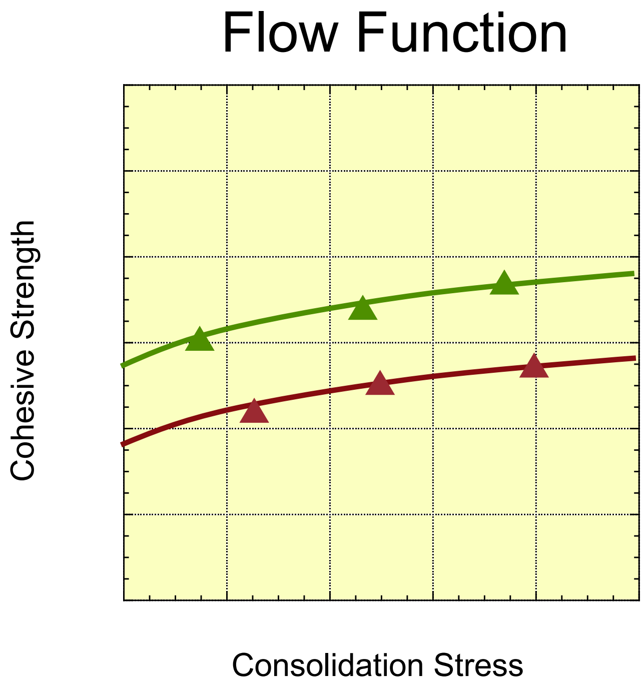
Cohesive strength





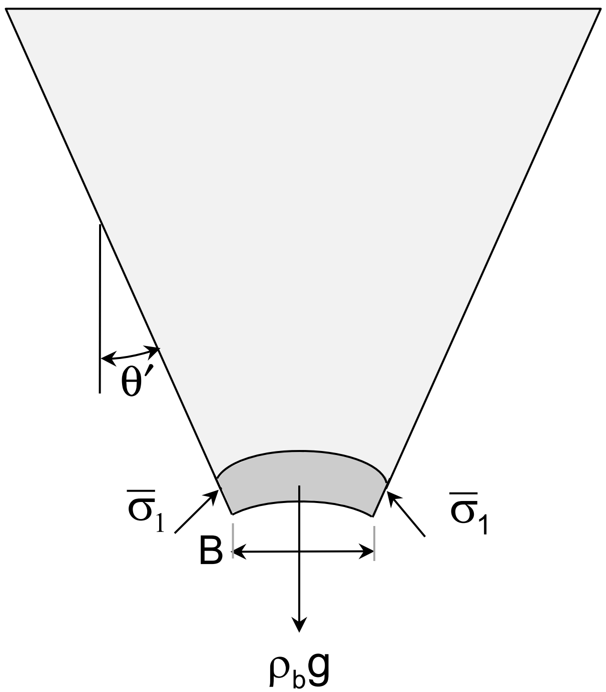
Cohesive strength





Arch stress

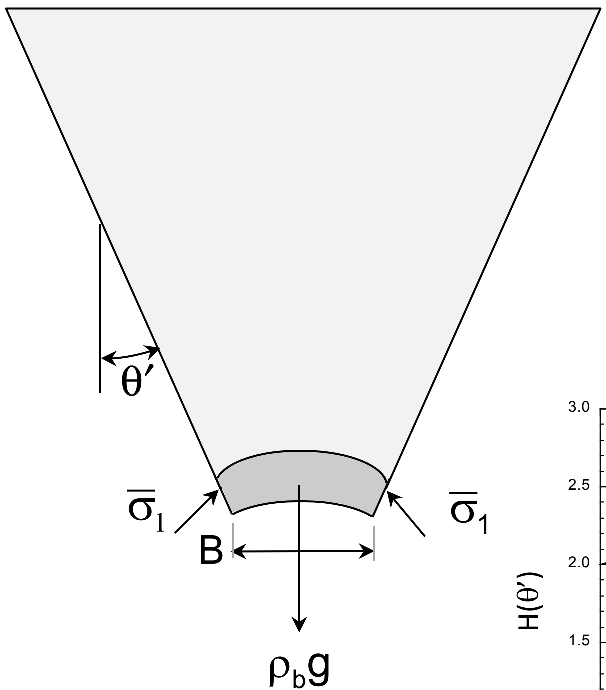
Arch stress



Stress on abutments of arch:

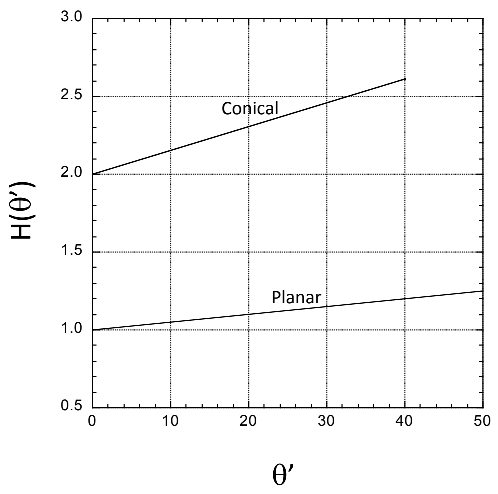
$$\overline{\sigma}_1 \approx \frac{\rho_b g B}{2}$$

Arch stress



Stress on abutments of arch:

$$\bar{\sigma}_1 = \frac{\rho_b g B}{H(\theta')}$$

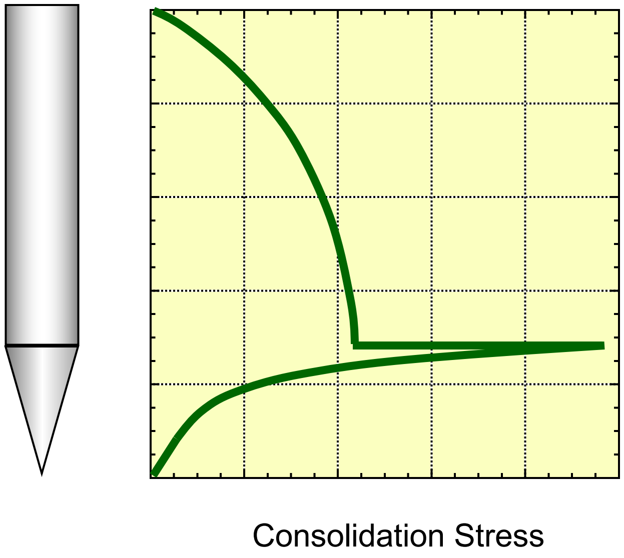


Conical: $H(\theta') \approx 2$

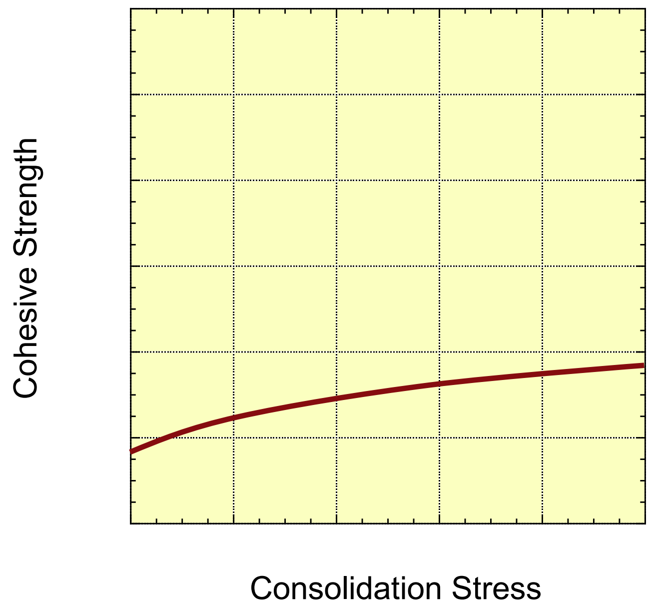
Slot: $H(\theta') \approx 1$

Pressure distribution

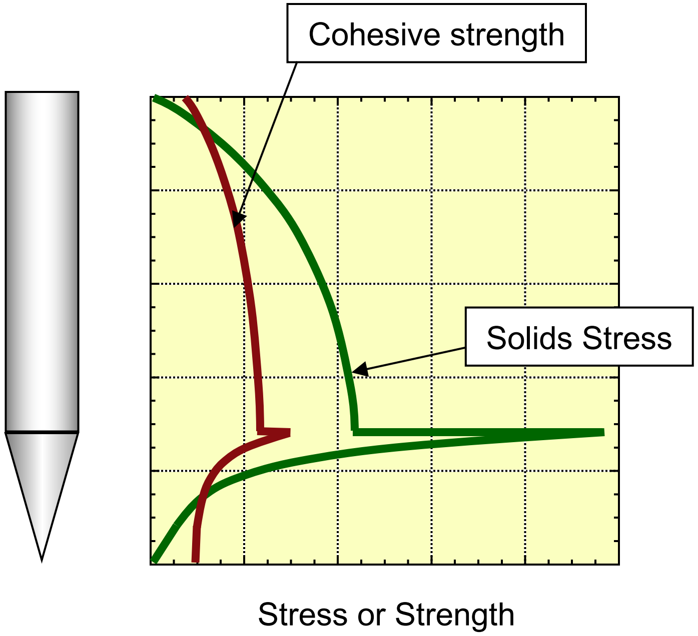
After discharge (mass flow)



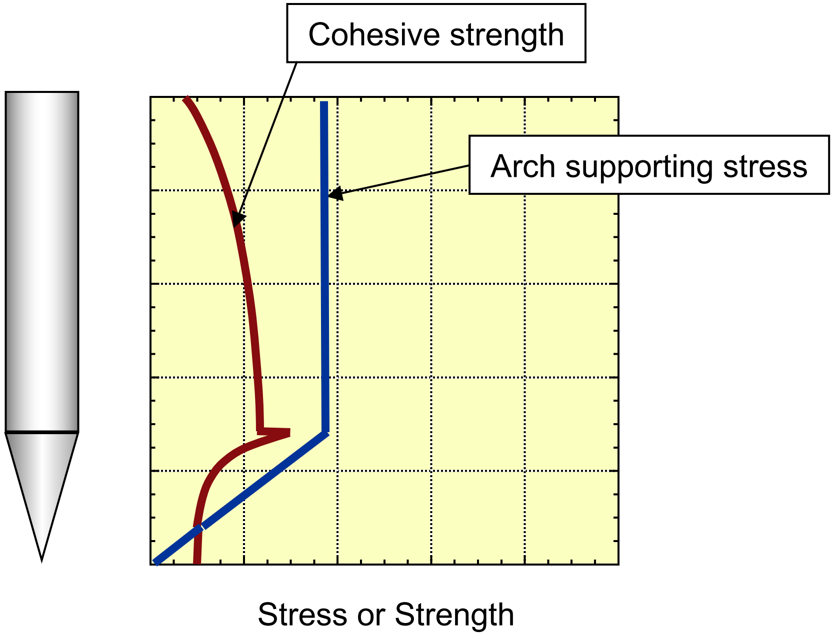
Cohesive strength



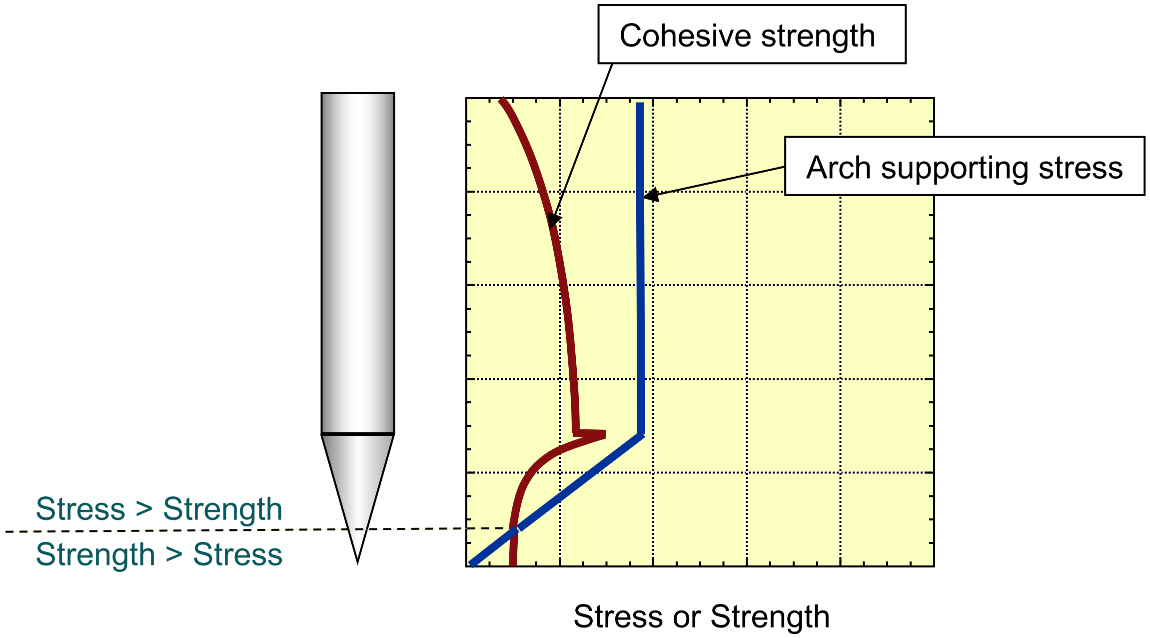
Cohesive strength



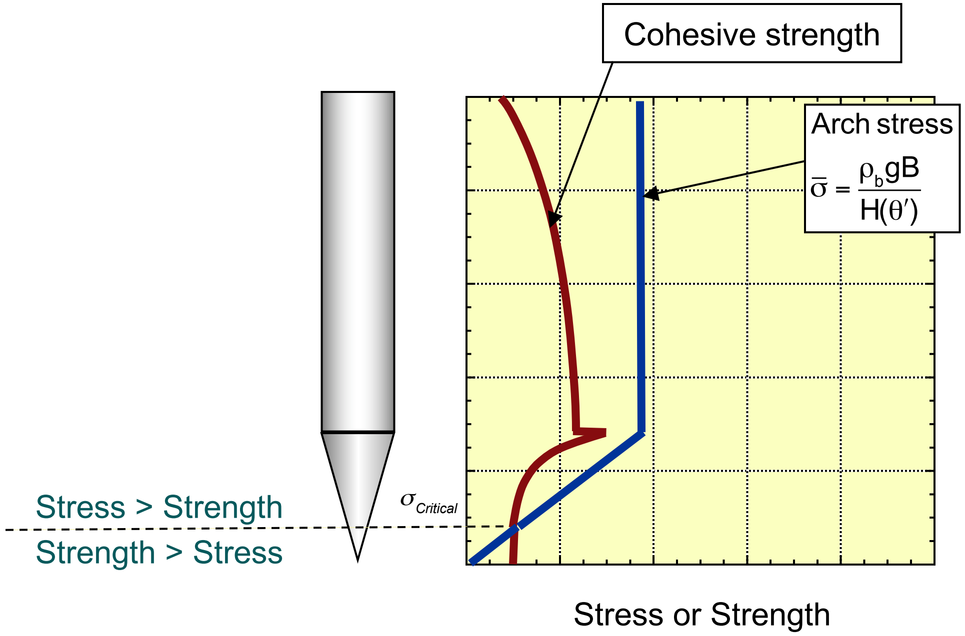
Arch stress


Cohesive strength
Arch supporting stress
Stress or Strength

Arch stress


Cohesive strength
Arch supporting stress
Stress > Strength
Strength > Stress
Stress or Strength

Critical arching diameter

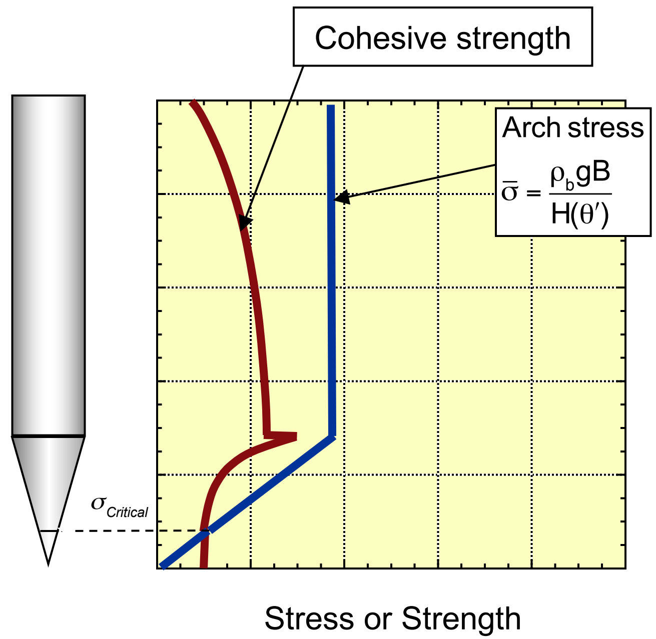


Critical arching diameter

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

Critical stress

Stress = Strength



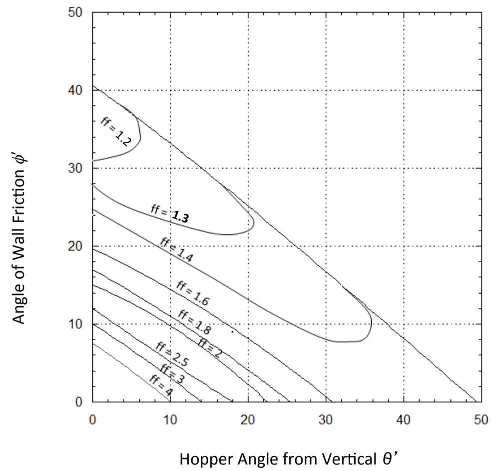
Flow factor

- Flow function (FF)
  - Relationship between consolidation stress and cohesive strength
- Flow factor (ff)
  - Ratio of consolidation stress and arch supporting stress

$$ff = \frac{\text{consolidation stress}}{\text{arch stress}}$$

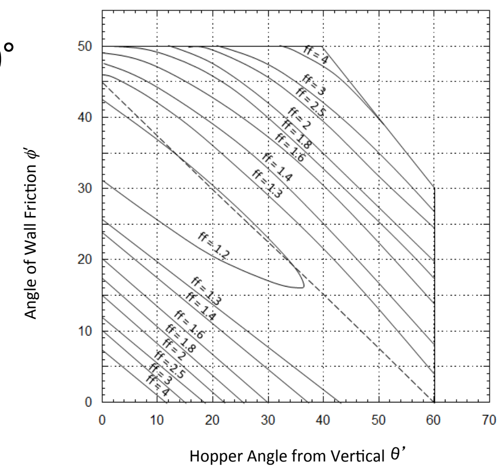
Flow factor

Conical



$\delta = 50^\circ$

Planar

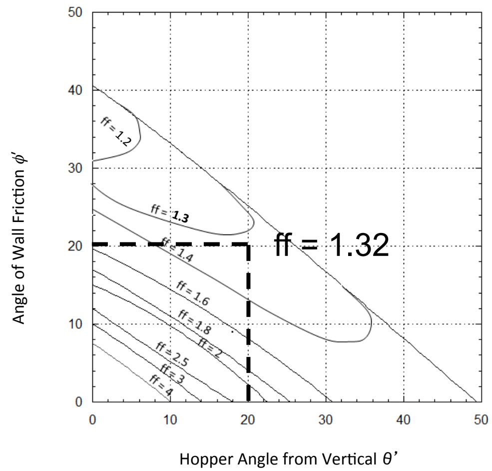


From Jenike Bulletin 123

$$ff = \frac{\text{consolidation stress}}{\text{arch stress}}$$

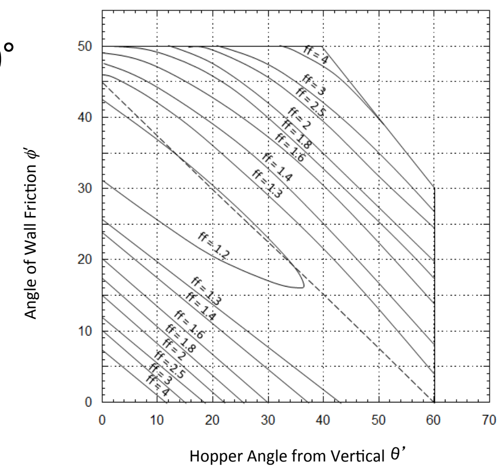
Flow factor

Conical



$\delta = 50°$

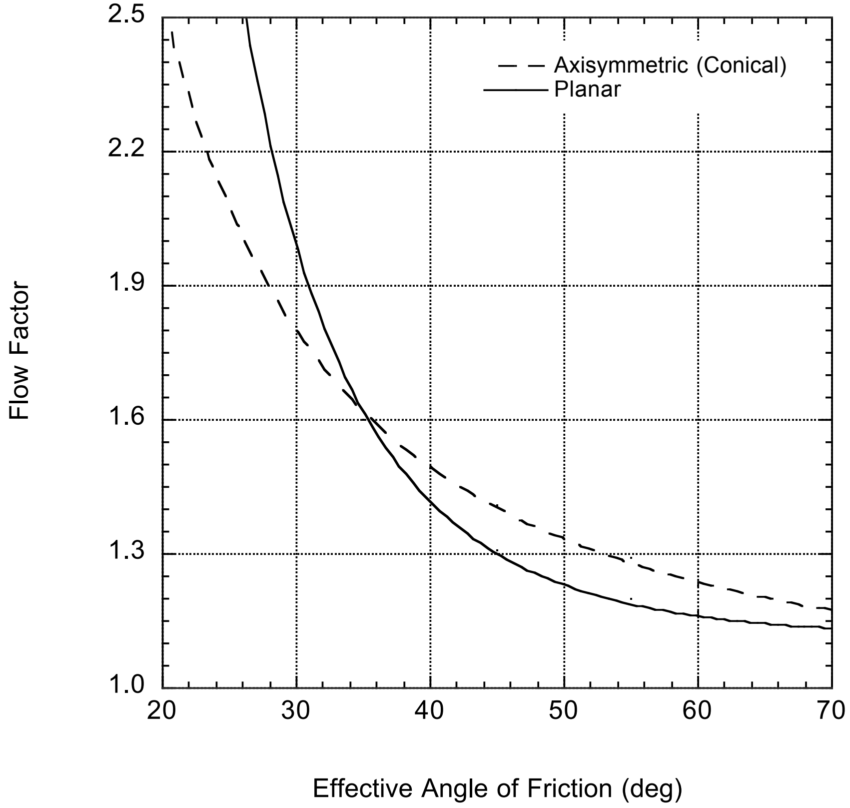
Planar



From Jenike Bulletin 123

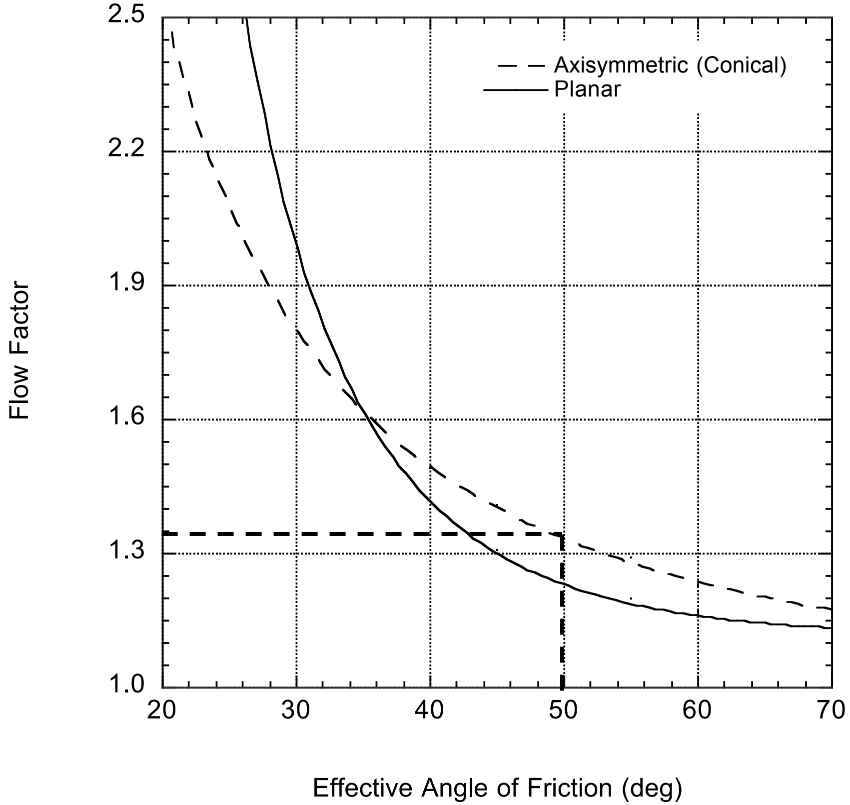
$$ff = \frac{\text{consolidation stress}}{\text{arch stress}}$$

Critical flow factor



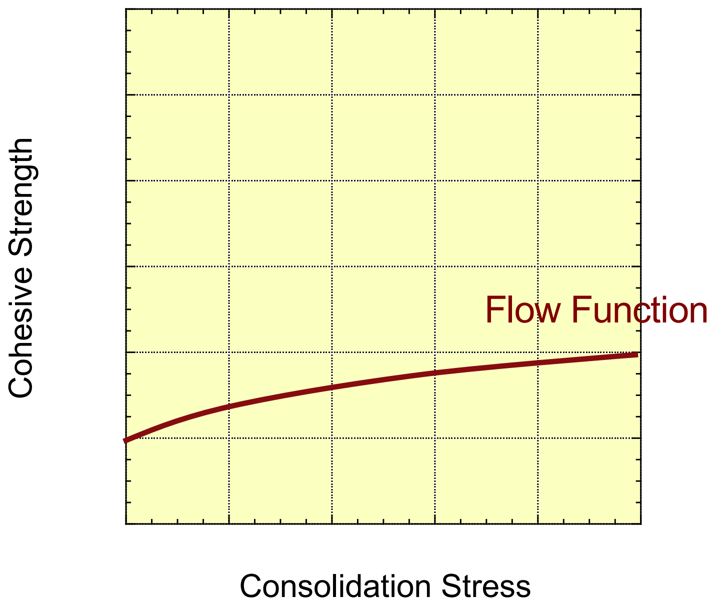
from Jerry Johanson's chapter in McGlinchey, Bulk Solids Characterization, 2005

Critical flow factor

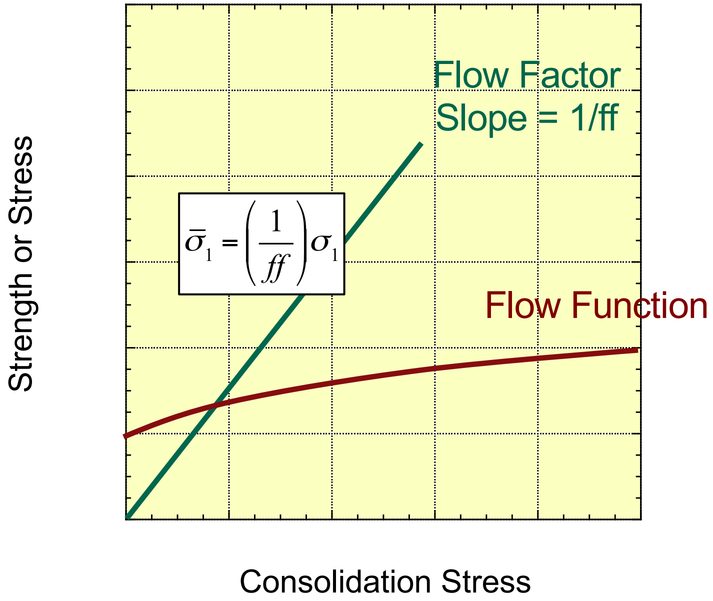


from Jerry Johanson's chapter in McGlinchey, Bulk Solids Characterization, 2005

Flow function

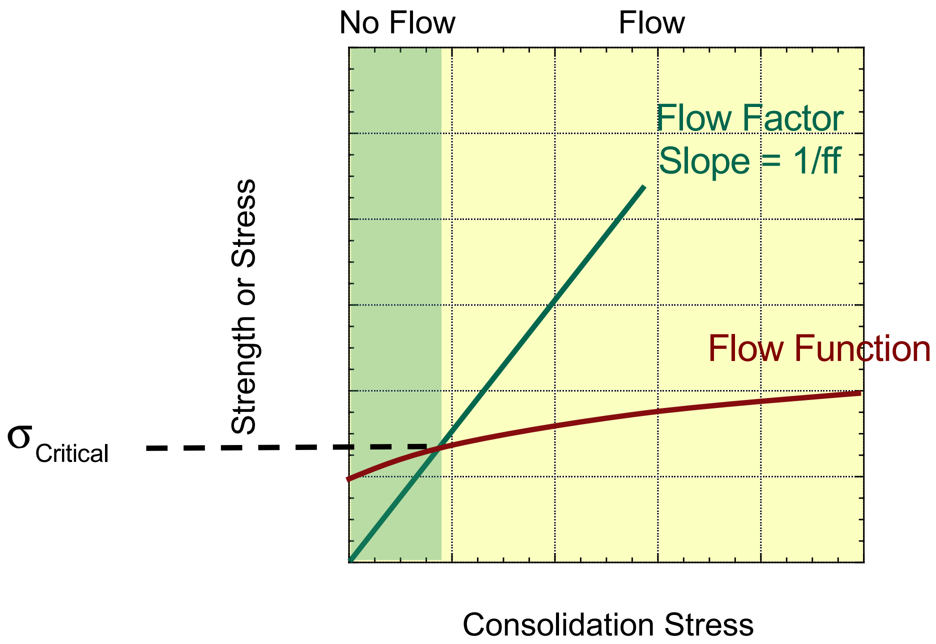


Flow factor

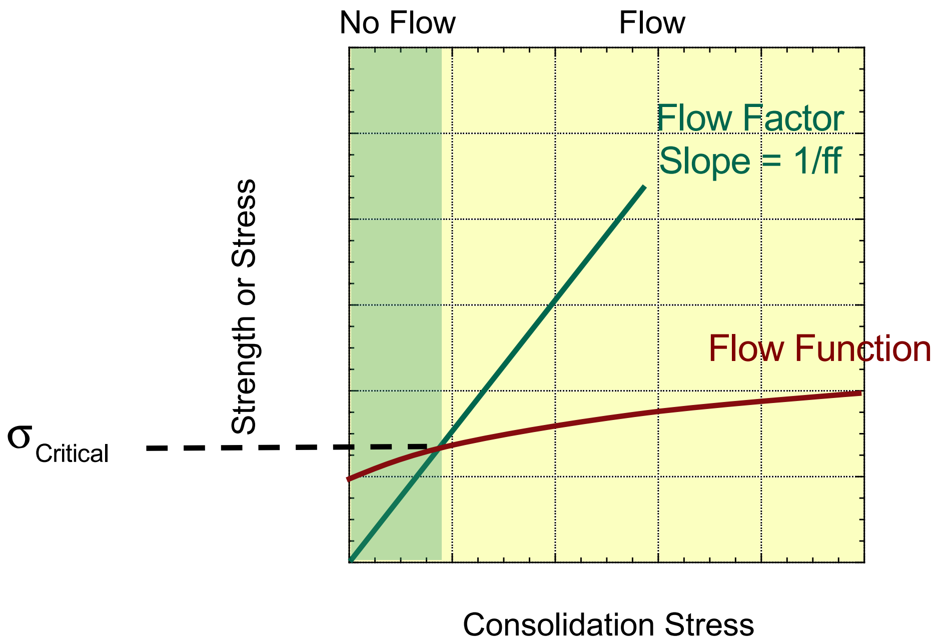


Flow Factor
Slope = 1/ff
$\bar{\sigma}_1 = \left(\frac{1}{ff}\right)\sigma_1$
Flow Function
Strength or Stress
Consolidation Stress

Critical stress



Critical stress



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

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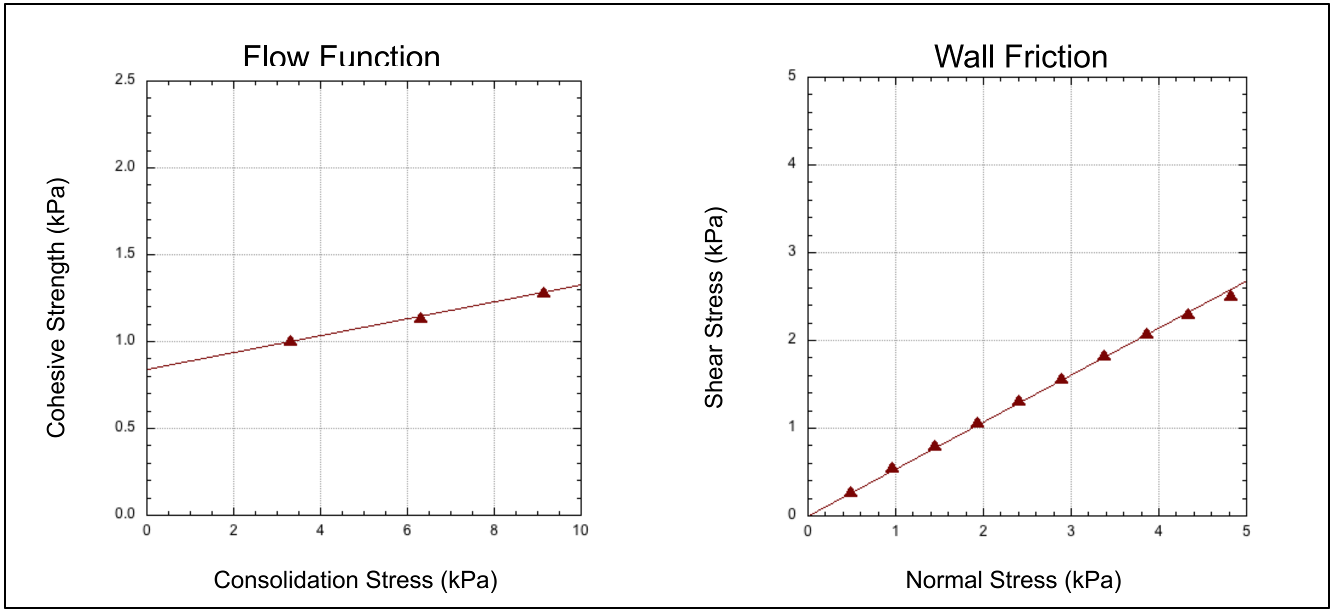
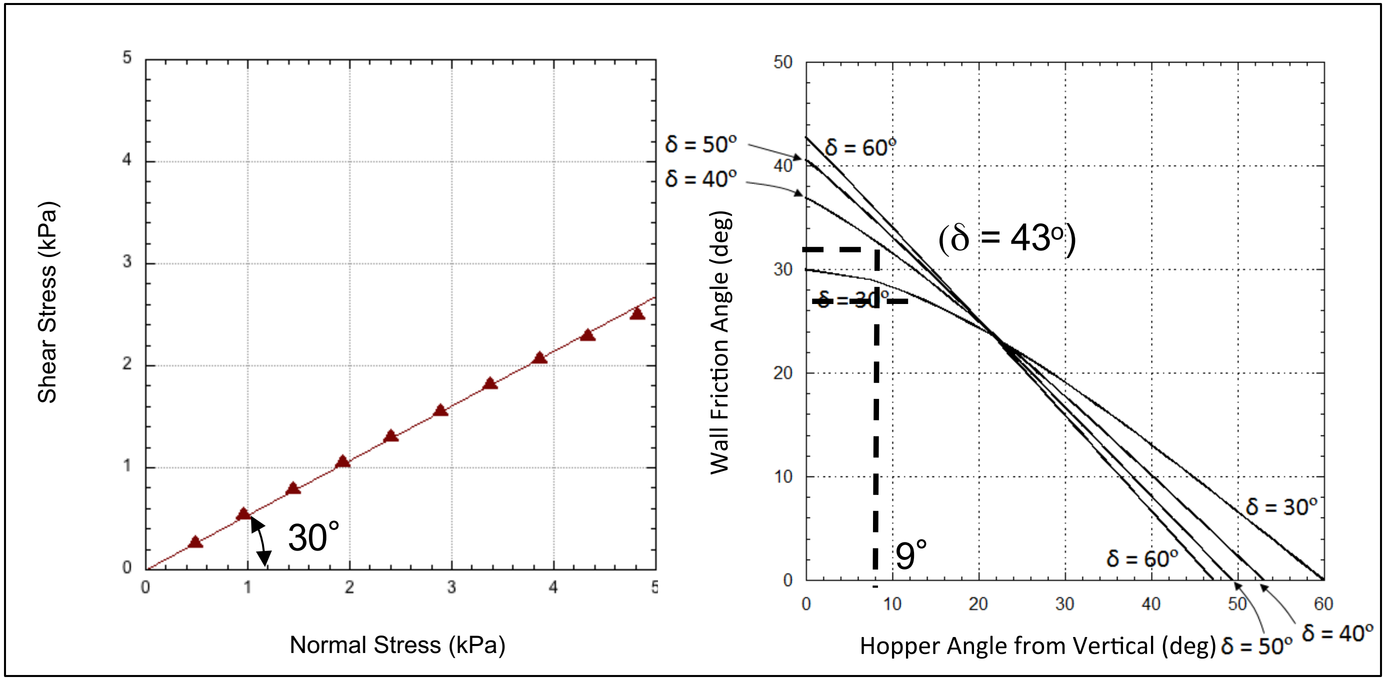
Example

Design a hopper that reliable handles 67/29/4 blend of acetaminophen/Avicel/hydroxypropyl cellulose

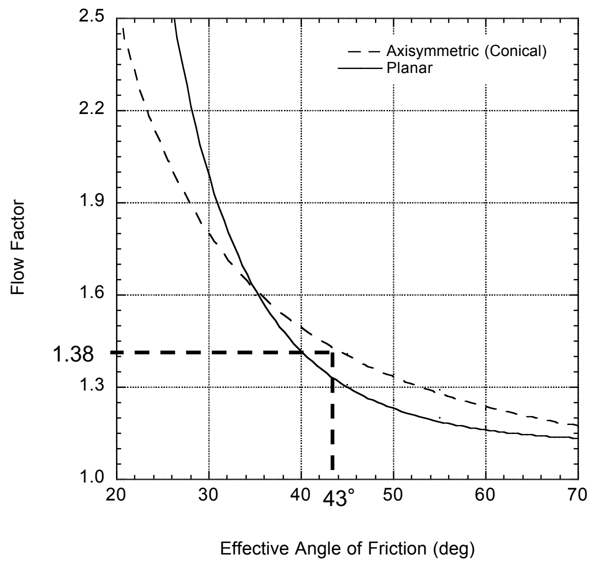


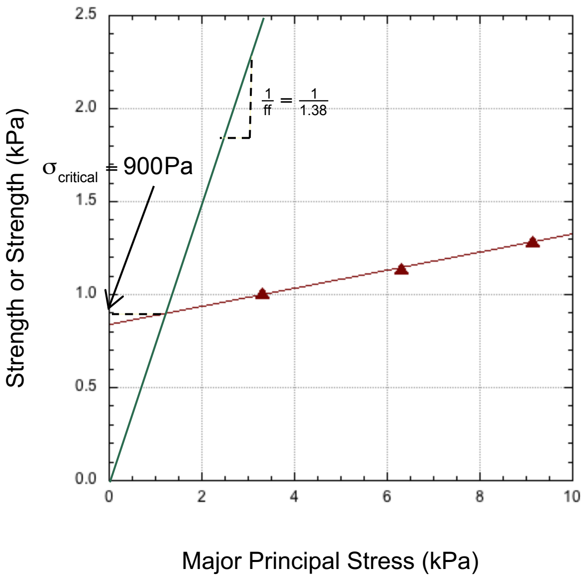
Example



Shear Stress (kPa)
Normal Stress (kPa)
30°
Wall Friction Angle (deg)
Hopper Angle from Vertical (deg)
δ = 60°
δ = 50°
δ = 40°
δ = 30°
(δ = 43°)
9°

Example





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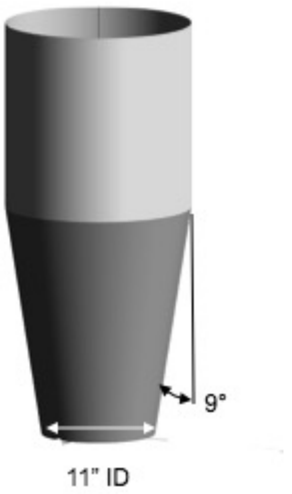
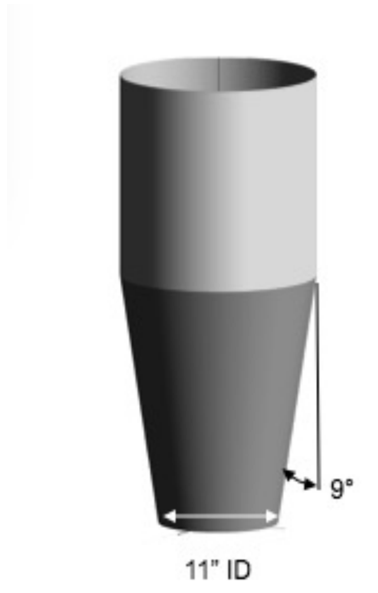
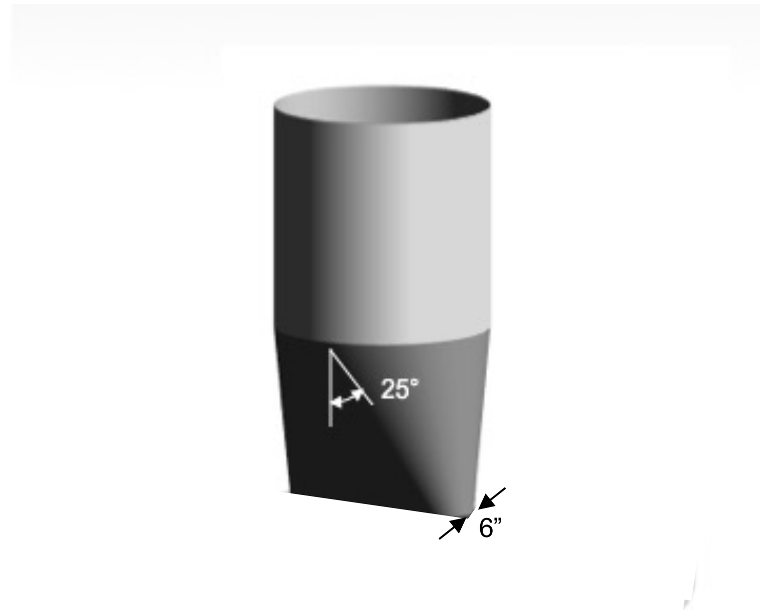
Example

$$B_{\min} = \frac{H(\theta')\sigma_{Critical}}{\rho_b g} = \frac{(2.14)(900)}{(690)(9.8)} = 0.28 \text{ m} = 11 \text{ in.}$$

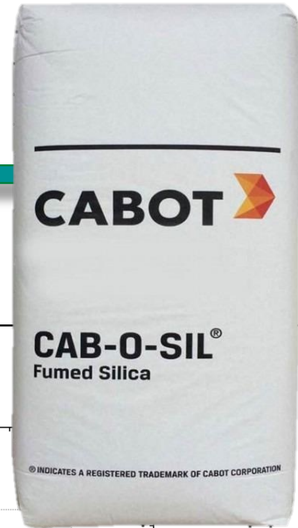


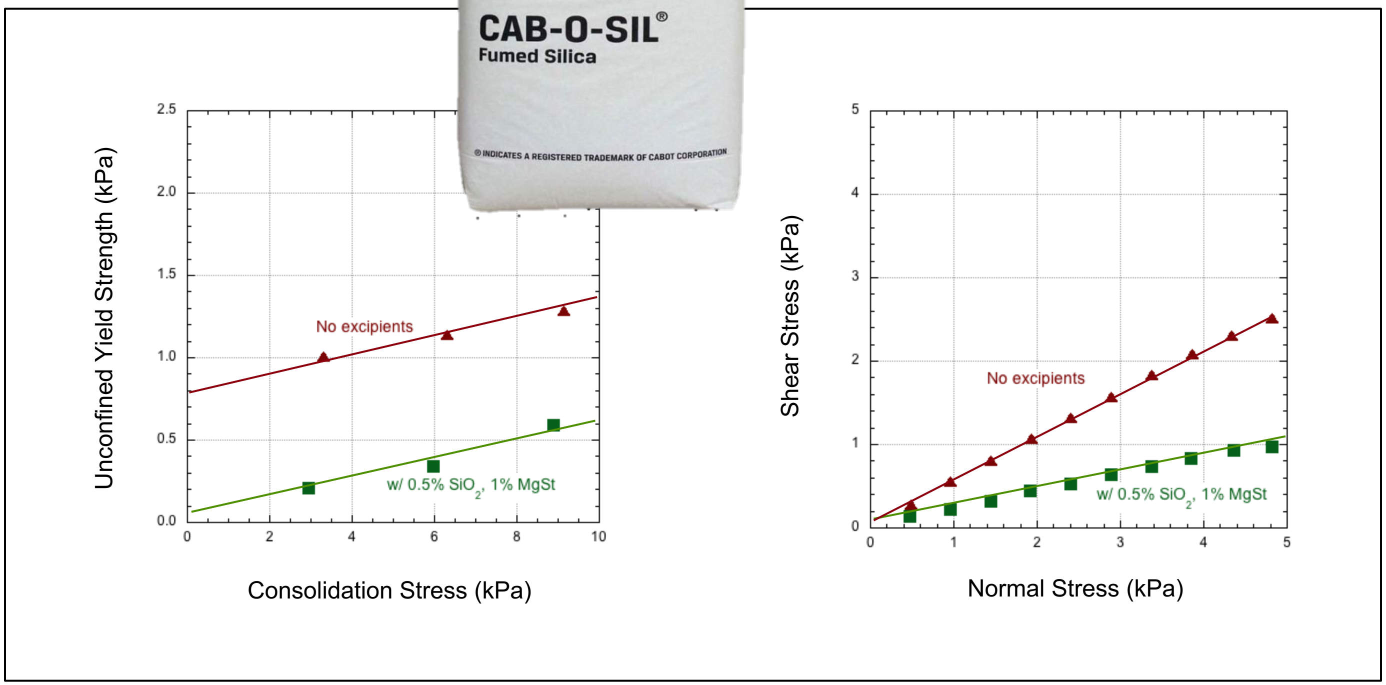
Example



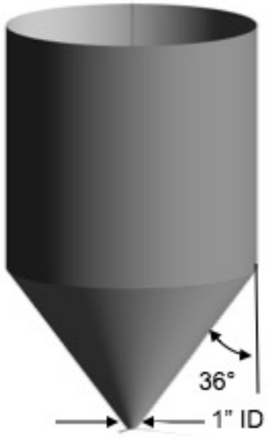


Example


CABOT
CAB-O-SIL®
Fumed Silica
® INDICATES A REGISTERED TRADEMARK OF CABOT CORPORATION

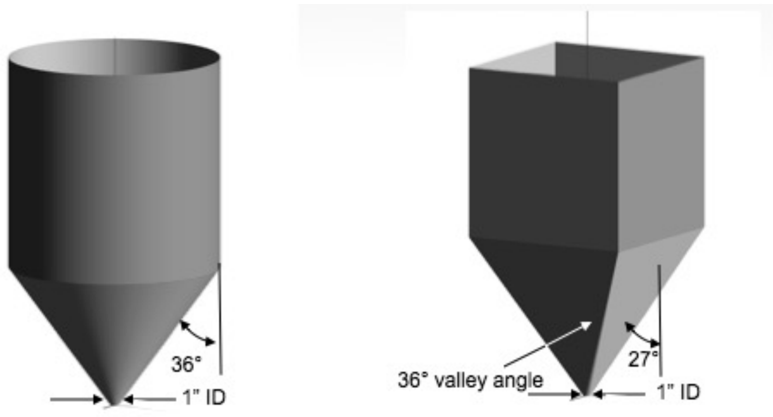

Unconfined Yield Strength (kPa)
Consolidation Stress (kPa)
No excipients
w/ 0.5% SiO_2, 1% MgSt
0.0
0.5
1.0
1.5
2.0
2.5
0
2
4
6
8
10
Shear Stress (kPa)
Normal Stress (kPa)
No excipients
w/ 0.5% SiO_2, 1% MgSt
0
1
2
3
4
5

Example

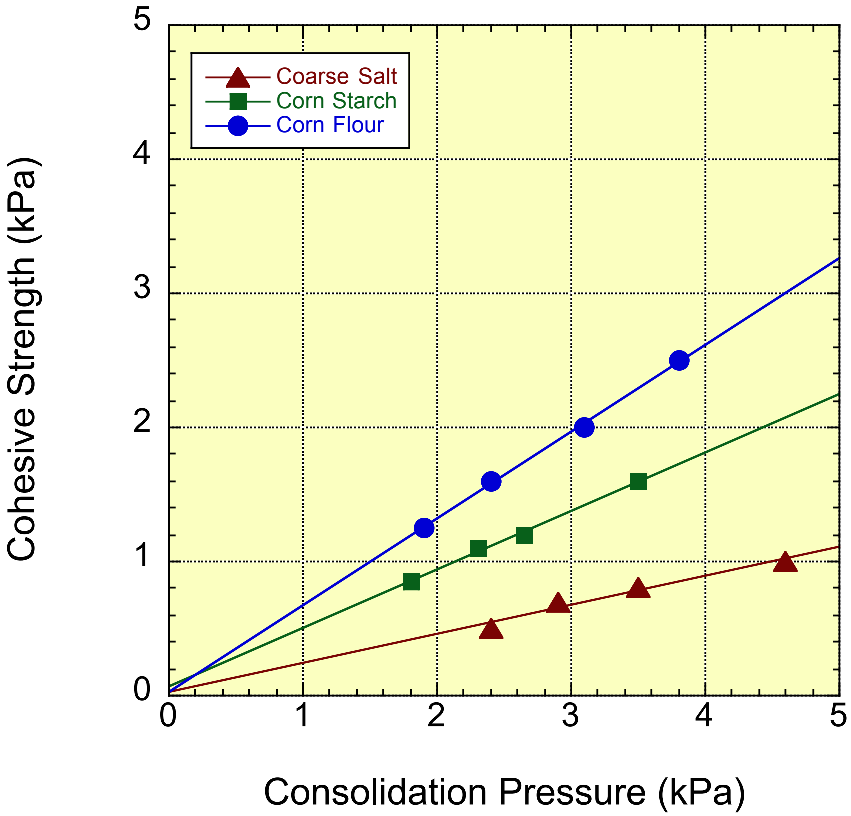


Note ♪: need to confirm outlet size will allow required discharge rate

Example

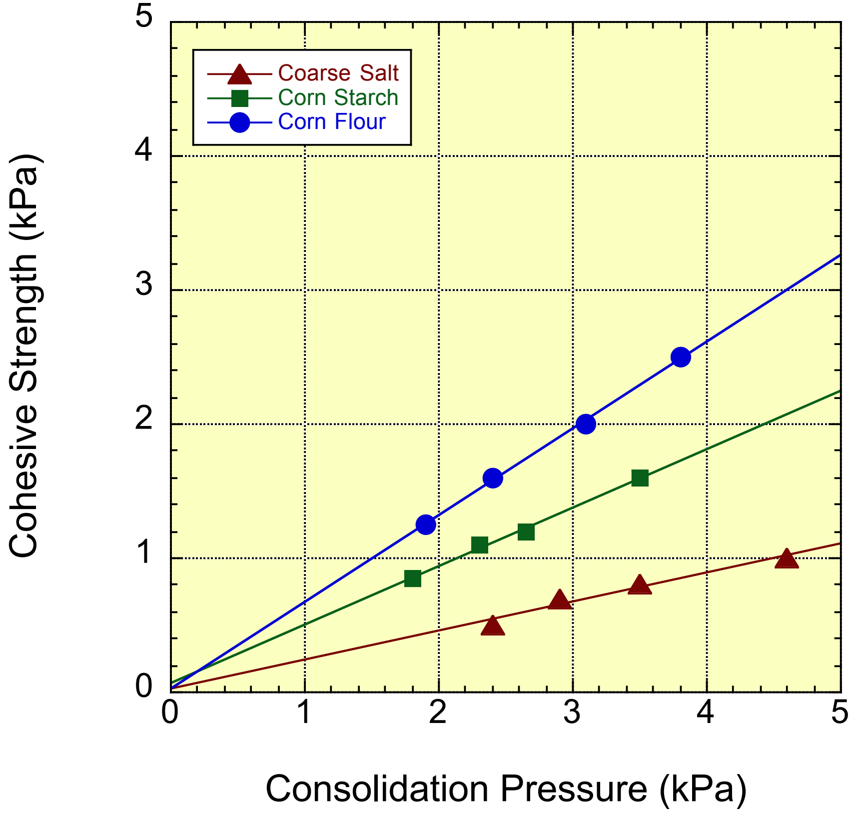


Example

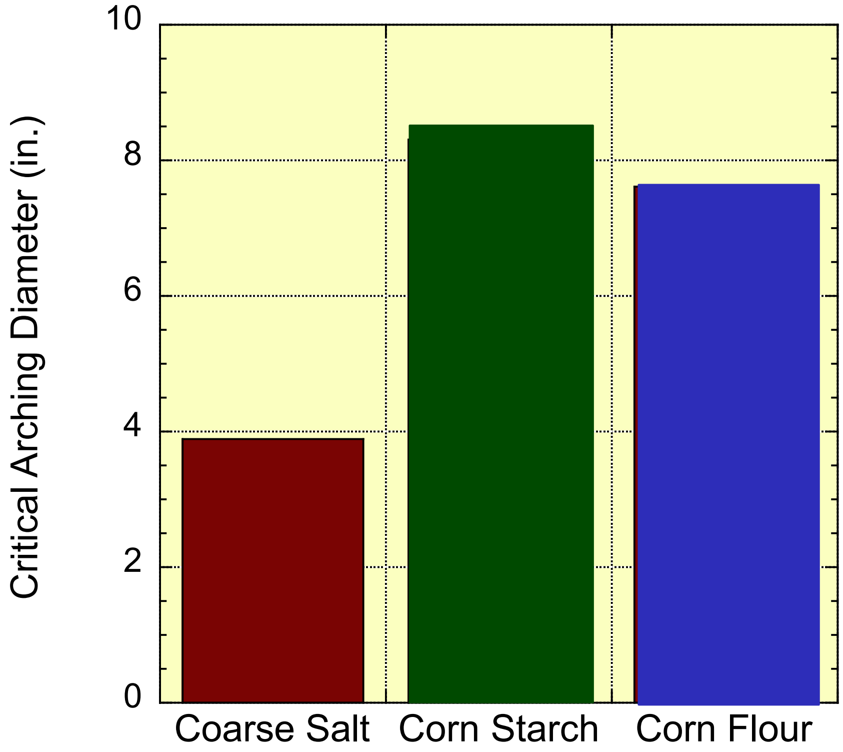


Coarse Salt
Corn Starch
Corn Flour
Cohesive Strength (kPa)
Consolidation Pressure (kPa)
0
1
2
3
4
5

Example

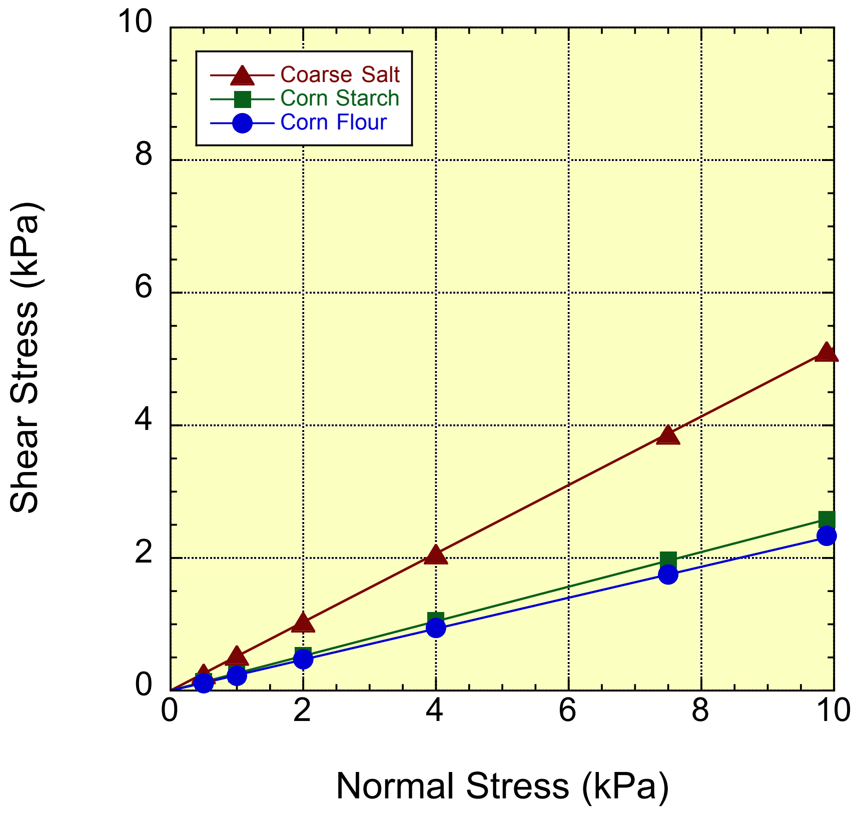


Cohesive Strength (kPa)
Consolidation Pressure (kPa)
Coarse Salt
Corn Starch
Corn Flour
0
1
2
3
4
5



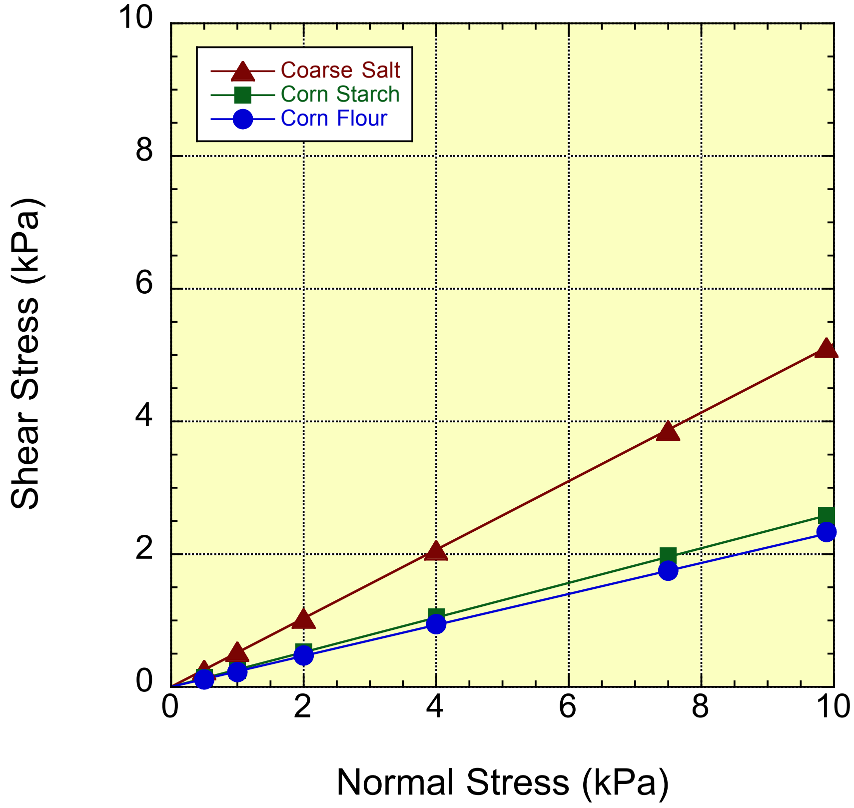
Critical Arching Diameter (in.)
0
2
4
6
8
10
Coarse Salt
Corn Starch
Corn Flour

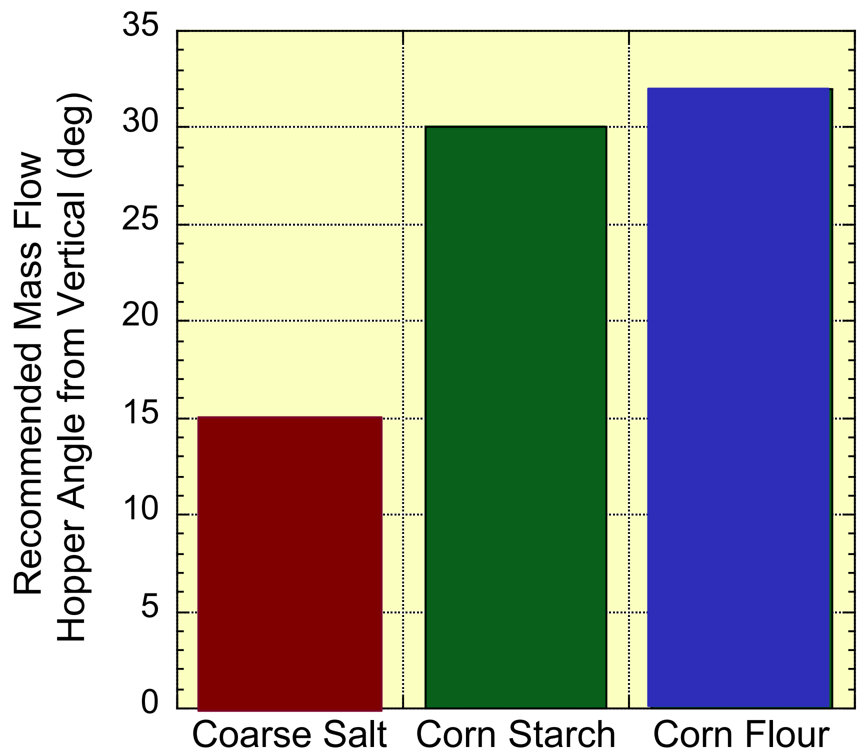
Example



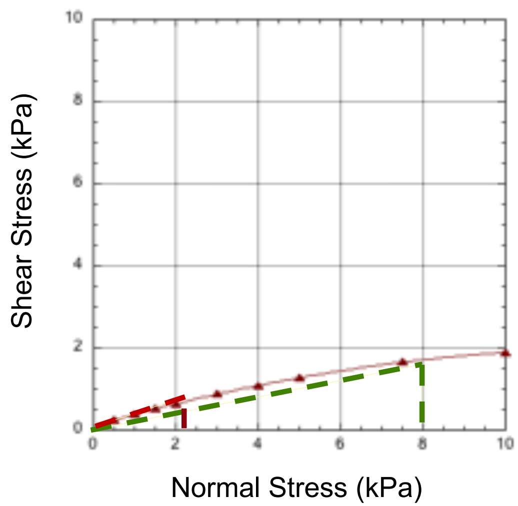
Coarse Salt
Corn Starch
Corn Flour
Shear Stress (kPa)
Normal Stress (kPa)
0
2
4
6
8
10

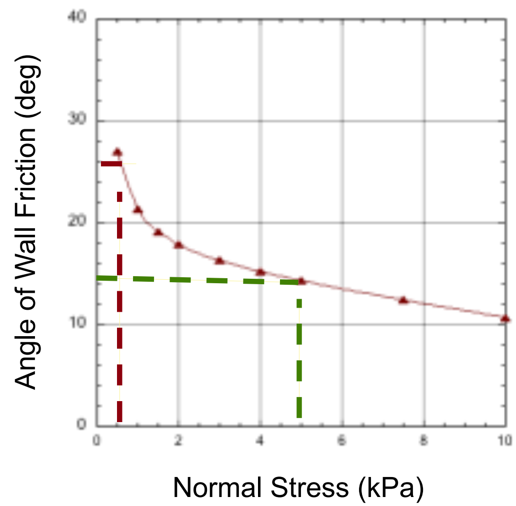
Example

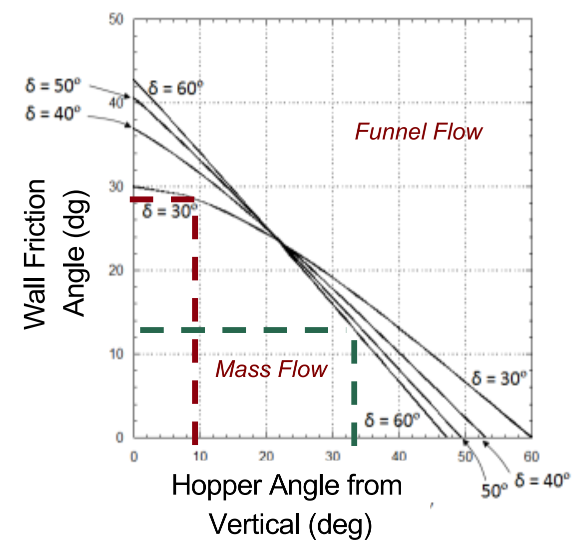

Coarse Salt
Corn Starch
Corn Flour
Shear Stress (kPa)
Normal Stress (kPa)
0
2
4
6
8
10


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

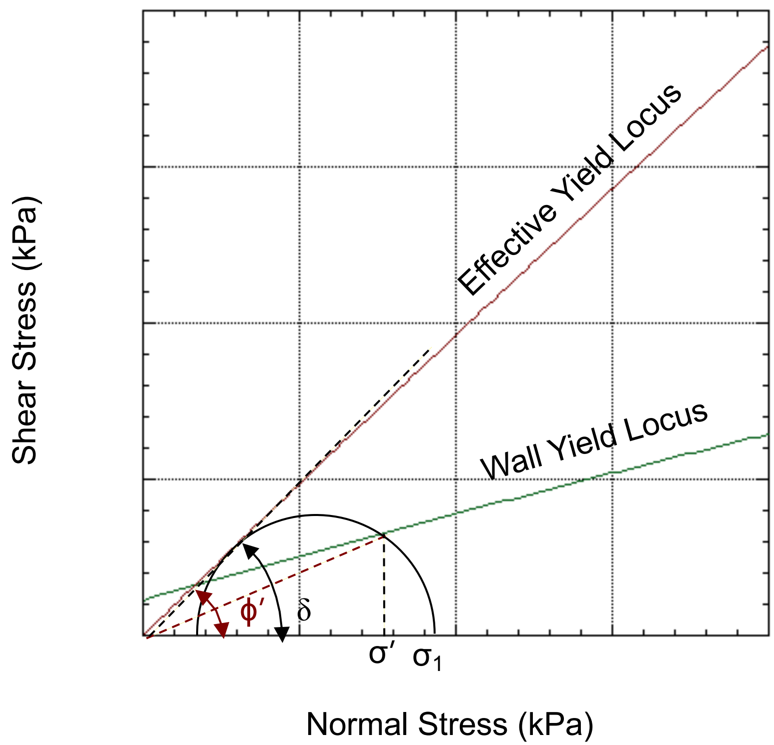
Mass flow hopper angle

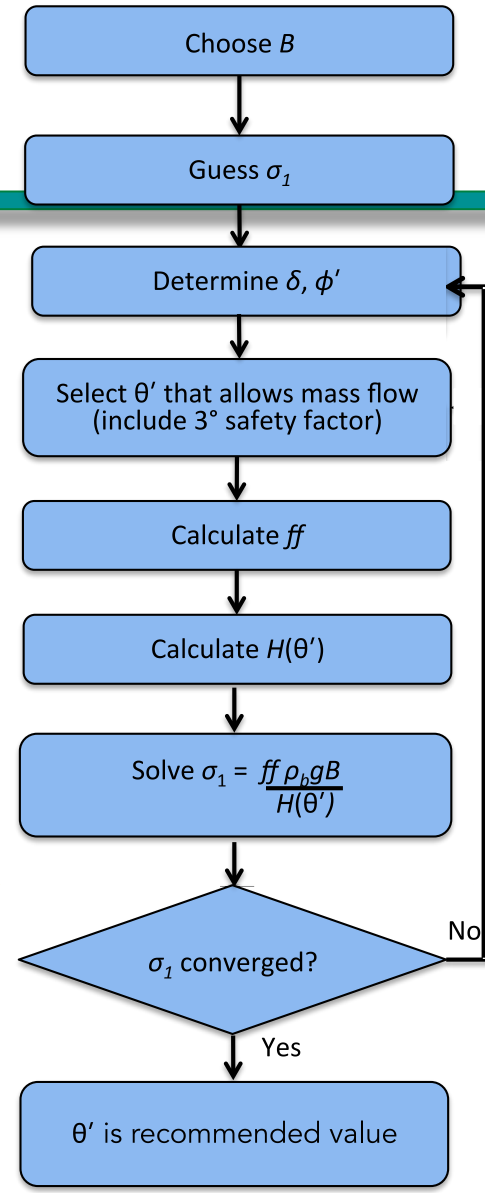






Mass flow hopper angle





Mass flow hopper angle

TUNRA

The University of Newcastle Research Associates
Shortland, NSW 2307, Australia

Flow factors

i = 1: conical, i = 0: planar, slotted outlet

$$ff = \frac{Y(1+\sin\delta)H(\theta')}{2(X-1)(\sin\theta')}$$

$$X = \frac{2^i \sin\delta}{1-\sin\delta}\left[\frac{\sin(2\beta+\theta')}{\sin\theta'}+1\right]$$

$$Y = \frac{[2(1-\cos(\beta+\theta'))]^i \sin\theta'(\beta+\theta')^{1-i} + \sin\beta \sin^{1+i}(\beta+\theta')}{(1-\sin\delta)\sin^{2+i}(\beta+\theta')}$$

$$H(\theta') = \left(\frac{130^\circ+\theta'}{65}\right)^i \left(\frac{200^\circ+\theta'}{200^\circ}\right)^{1-i}$$

Mass flow hopper angles

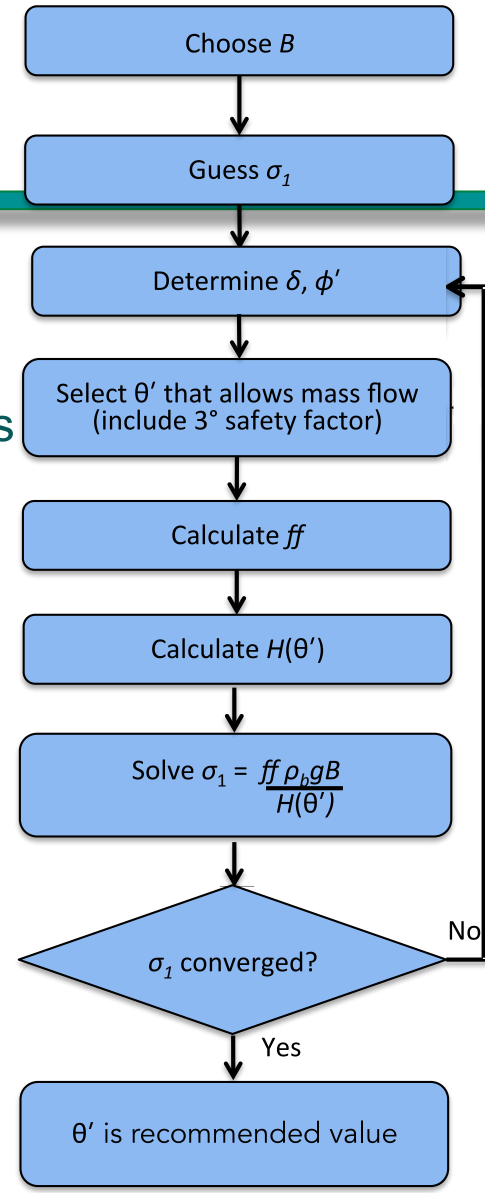
Conical

$$\theta' = 90^\circ - \frac{1}{2}\cos^{-1}\left(\frac{1-\sin\delta}{2\sin\delta}\right) - \beta$$

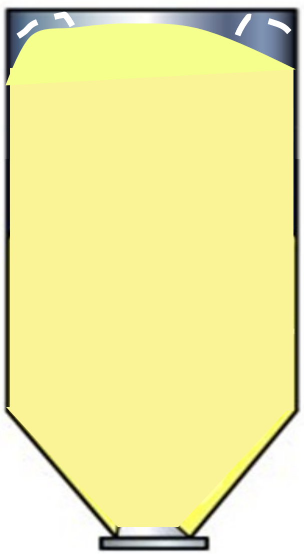
$$2\beta = \phi' + \sin^{-1}\left(\frac{\sin\phi'}{\sin\delta}\right)$$

Planar, slotted outlet

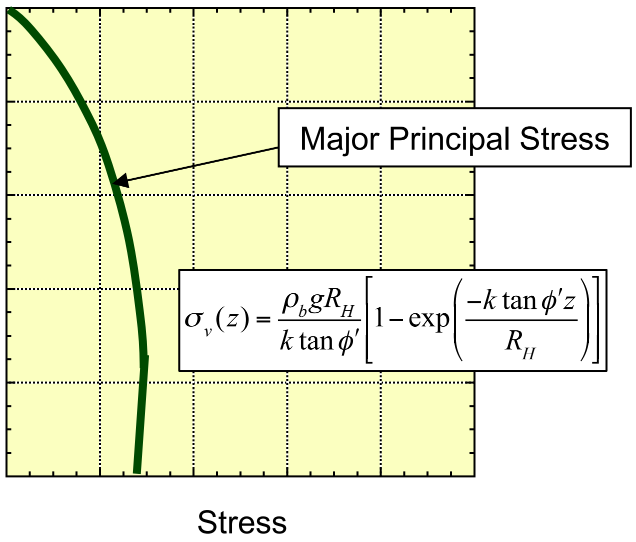
$$\theta' = \frac{\exp[3.75(1.01)^{(\delta-30^\circ)/10}] - \phi'}{0.725(\tan\delta)^{1/5}}$$



Funnel flow bins

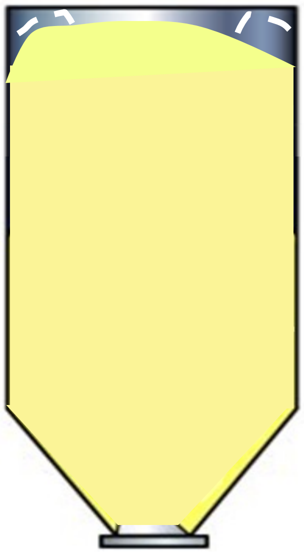


D = diameter of round outlet or
diagonal of slotted outlet

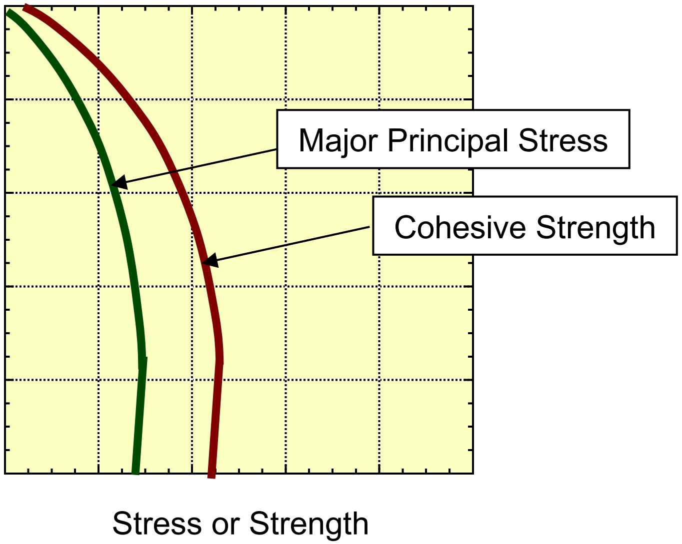


$$\sigma_v(z) = \frac{\rho_b g R_H}{k \tan\phi'}\left[1 - \exp\left(\frac{-k \tan\phi' z}{R_H}\right)\right]$$

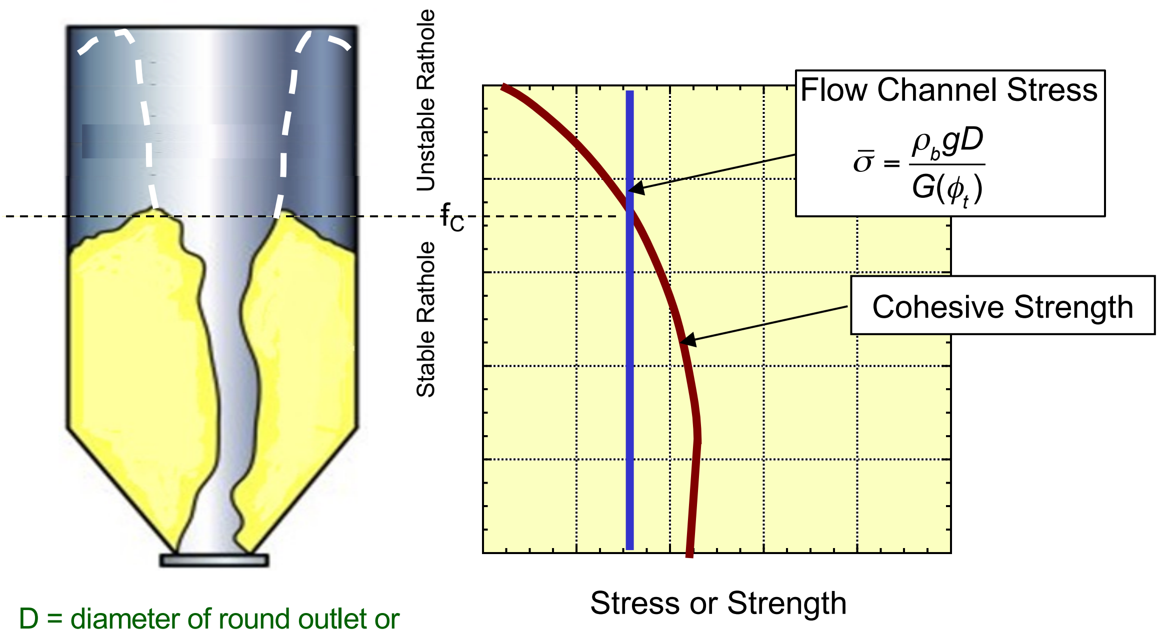
Funnel flow bins



D = diameter of round outlet or
diagonal of slotted outlet



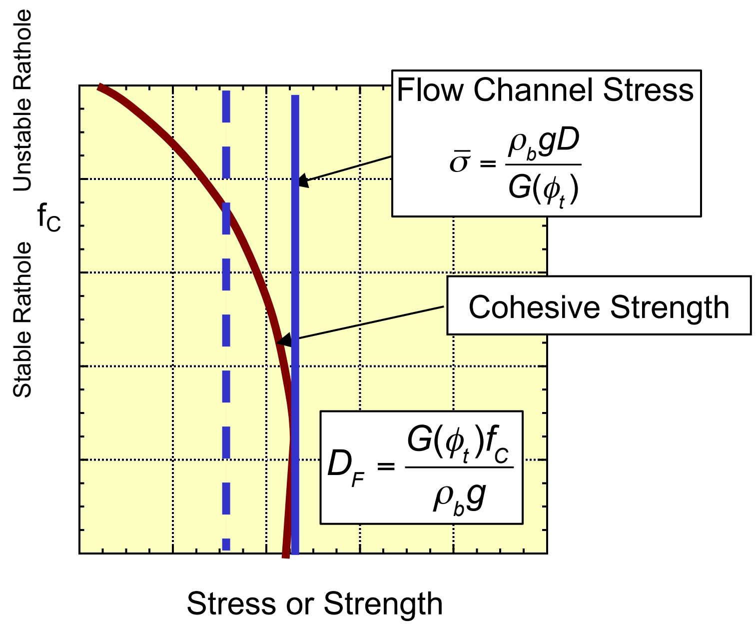
Funnel flow bins



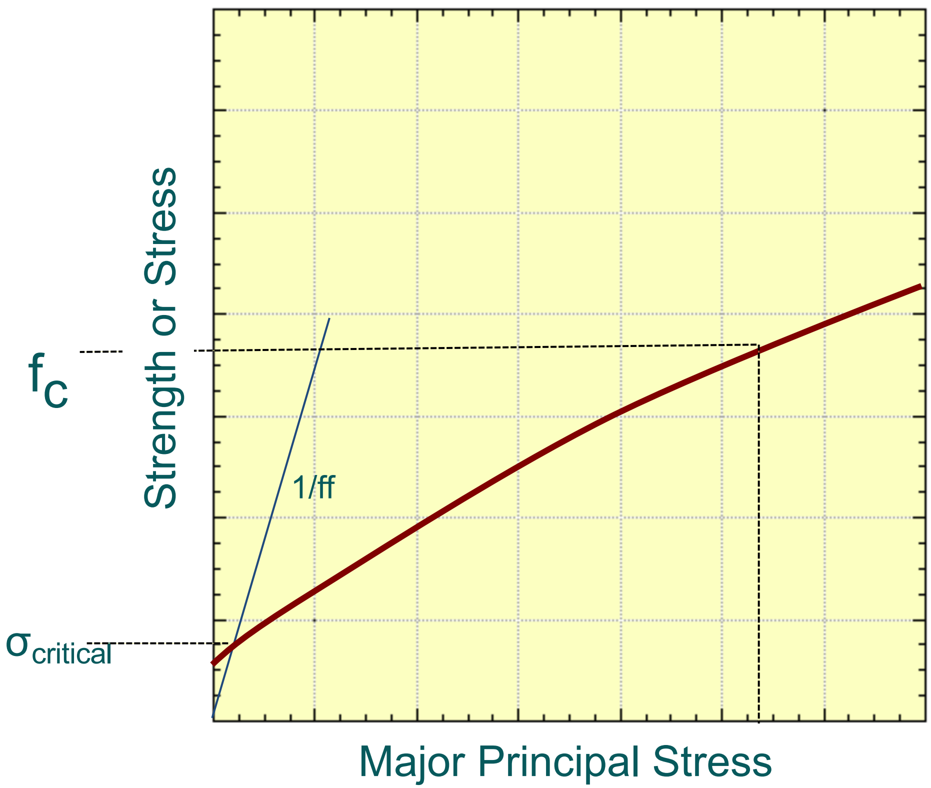
D = diameter of round outlet or *diagonal* of slotted outlet

Funnel flow bins

D = diameter of round outlet or *diagonal* of slotted outlet



Mass flow *vs.* funnel flow



To prevent arching in a mass flow bin:

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

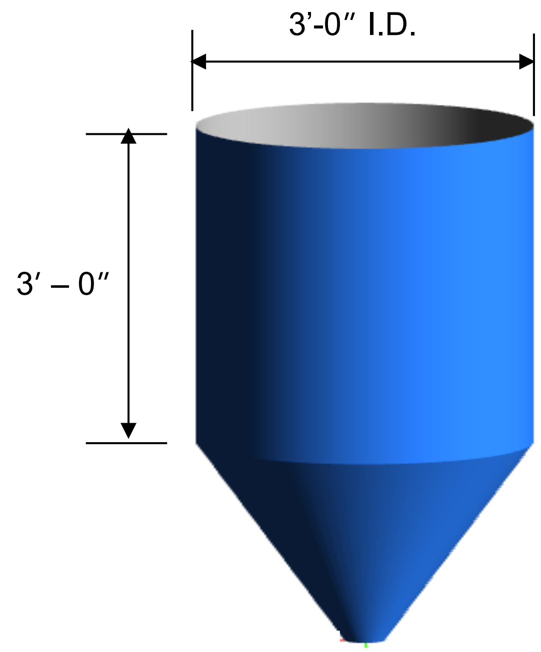
To prevent a stable rathole in a funnel flow bin:

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

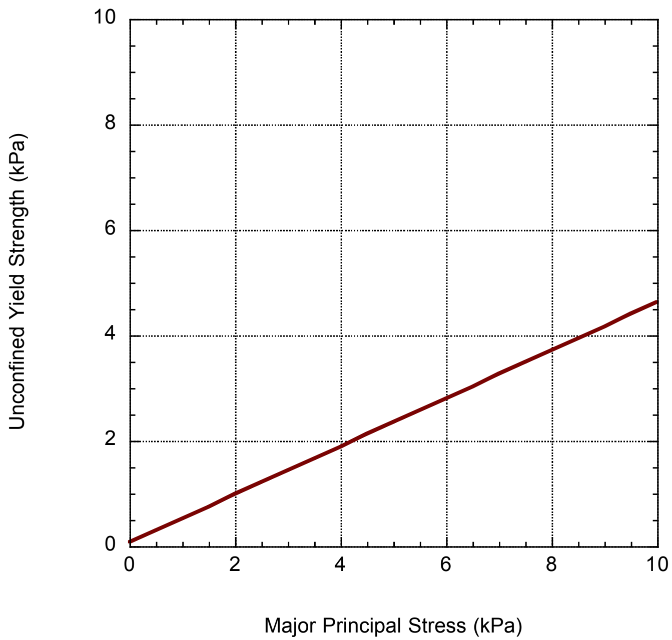
$$\sigma_v(z) = \frac{\rho_b g R_H}{k \tan\phi'}\left[1 - \exp\left(\frac{-k \tan\phi' z}{R_H}\right)\right]$$

Funnel flow hopper design

Critical rathole diameter depends on dimensions of cylinder section

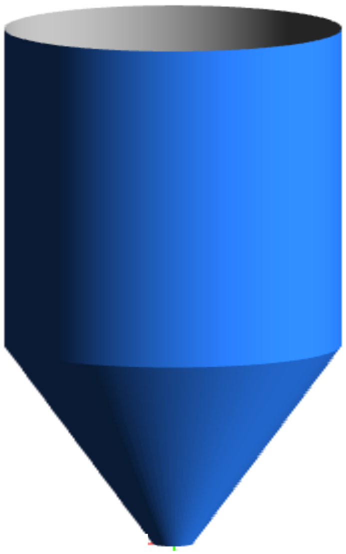


Funnel flow hopper design

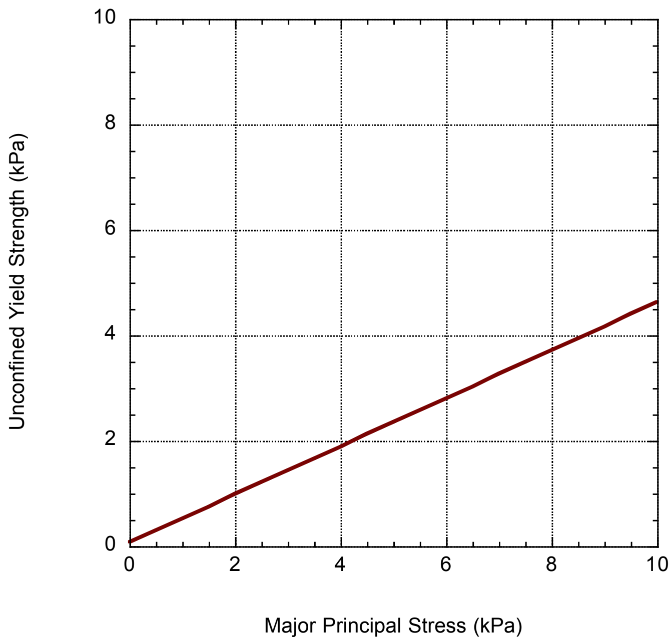


$$D_F = \frac{G(\phi_t) f_C}{\rho_b g}$$

$$\sigma_1 = \frac{\overline{\rho_b} g R_H}{k \tan \phi'} \left[1 - \exp\left(\frac{-k(\tan \phi')h}{R_H} \right) \right]$$

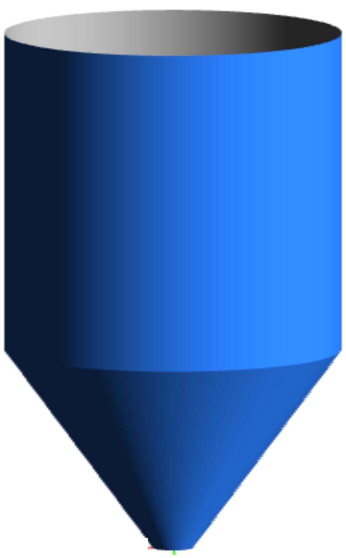


Funnel flow hopper design



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

$$\sigma_1 = \frac{\overline{\rho_b} g R_H}{k \tan\phi'}\left[1 - \exp\left(\frac{-k(\tan\phi')h}{R_H}\right)\right]$$



$$\sigma_1 = \frac{(615)(9.8)(0.914/4)}{(0.4)\tan(21^\circ)}\left[1 - \exp\left(\frac{-(0.4)\tan(21^\circ)(0.914)}{0.914/4}\right)\right] = 4100 \text{ Pa}$$

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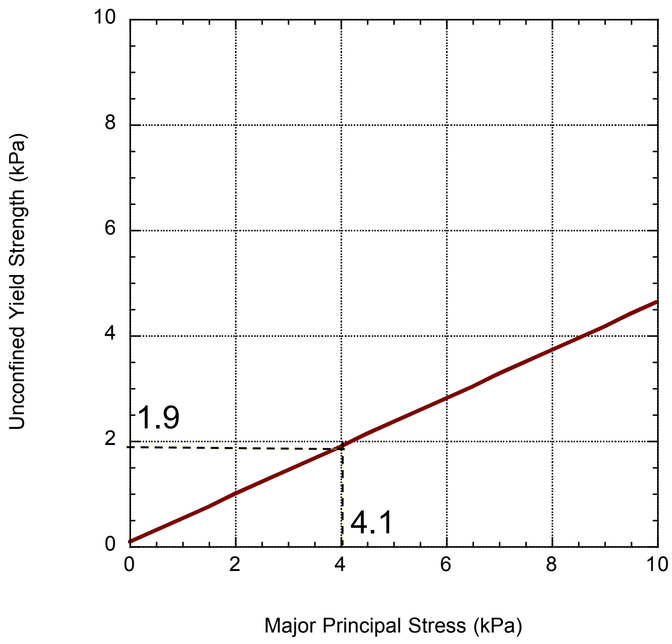
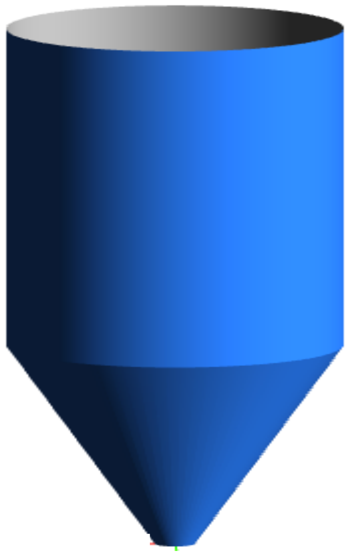
Funnel flow hopper design

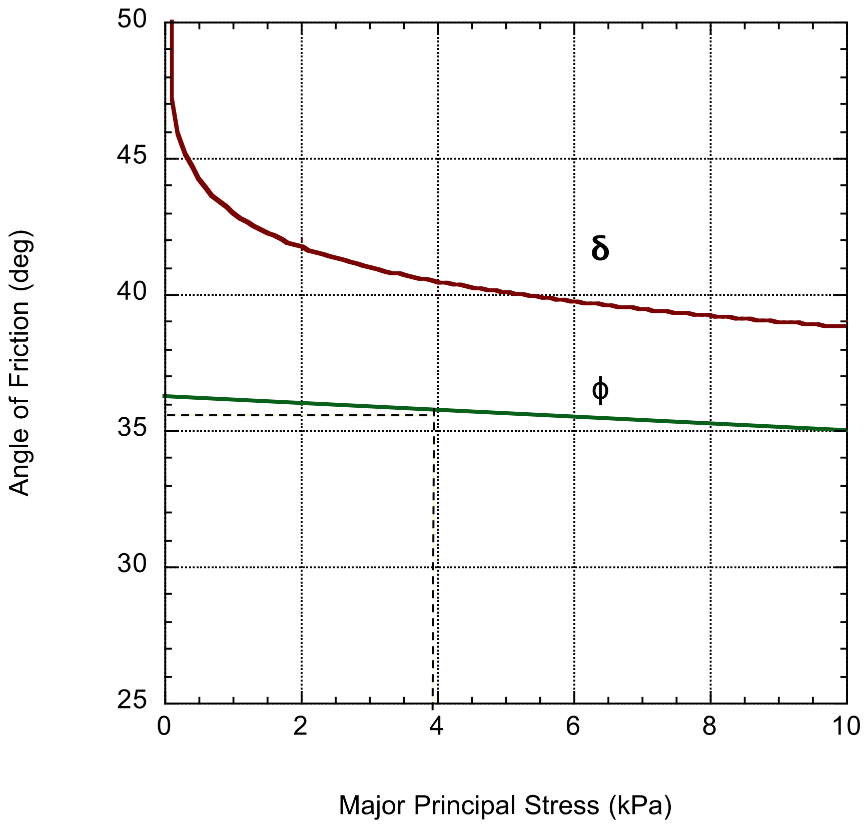


$$D_F = \frac{G(\phi_t) f_C}{\rho_b g}$$

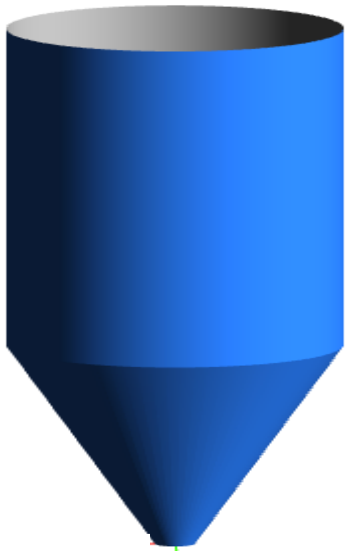
$$f_C = 1.9 \text{ kPa}$$



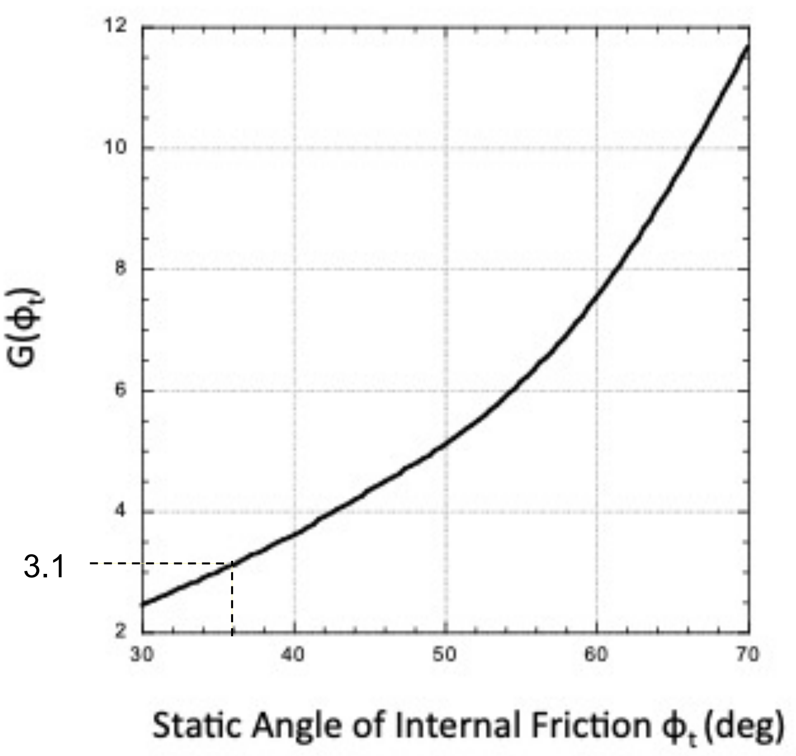
Funnel flow hopper design



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



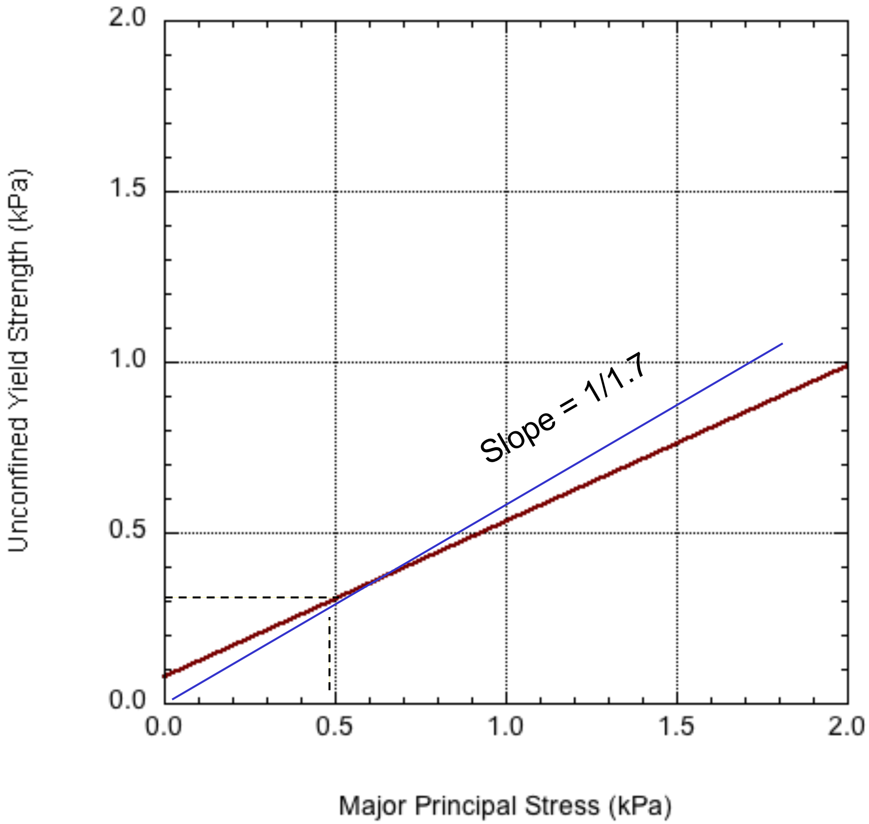
Funnel flow hopper design

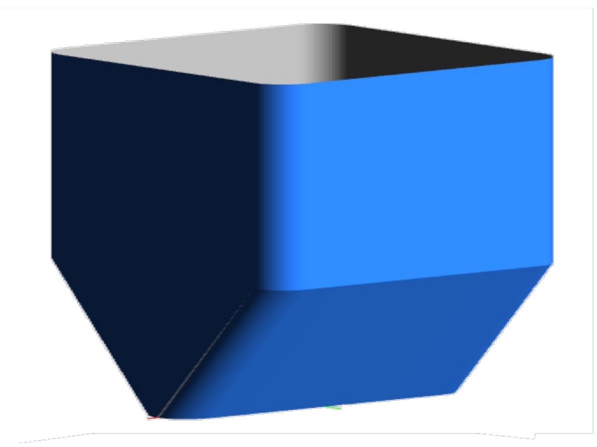


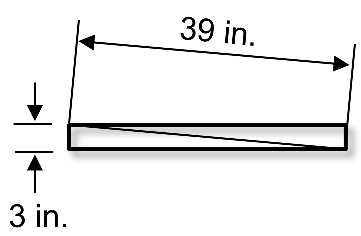
$$D_F = \frac{G(\phi_t) f_C}{\rho_b g}$$

$$= \frac{(3.1)(1.9)}{(618)(9.8)} = 1.0 \text{ m} = 39 \text{ in.}$$

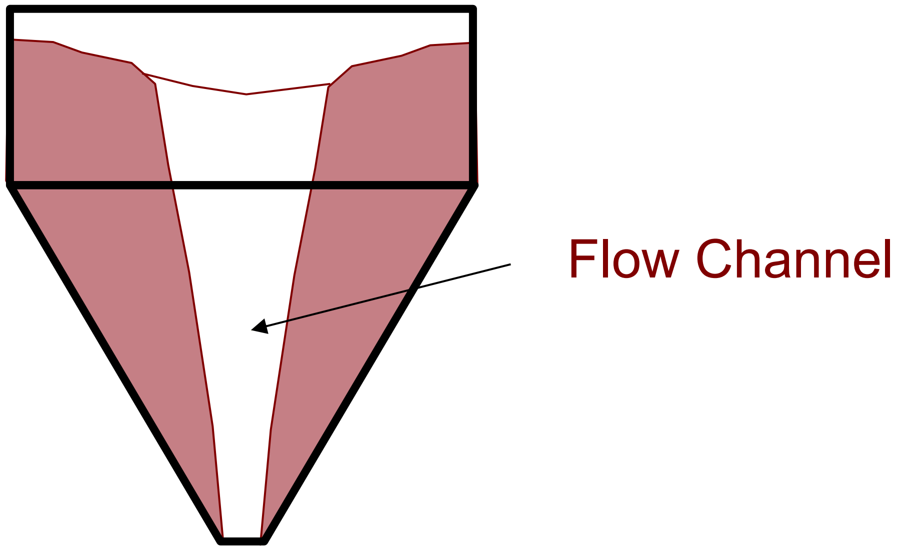
Funnel flow hopper design





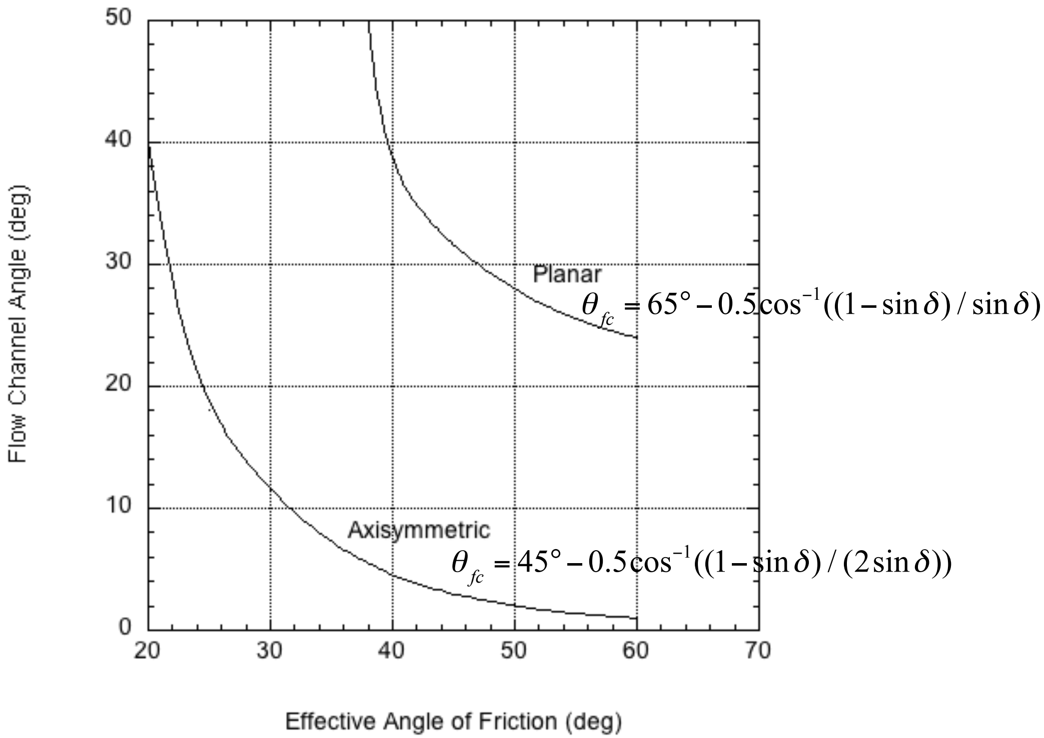


Flow channel



Flow channel

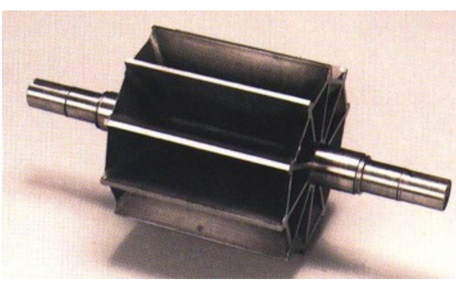
Flow channel

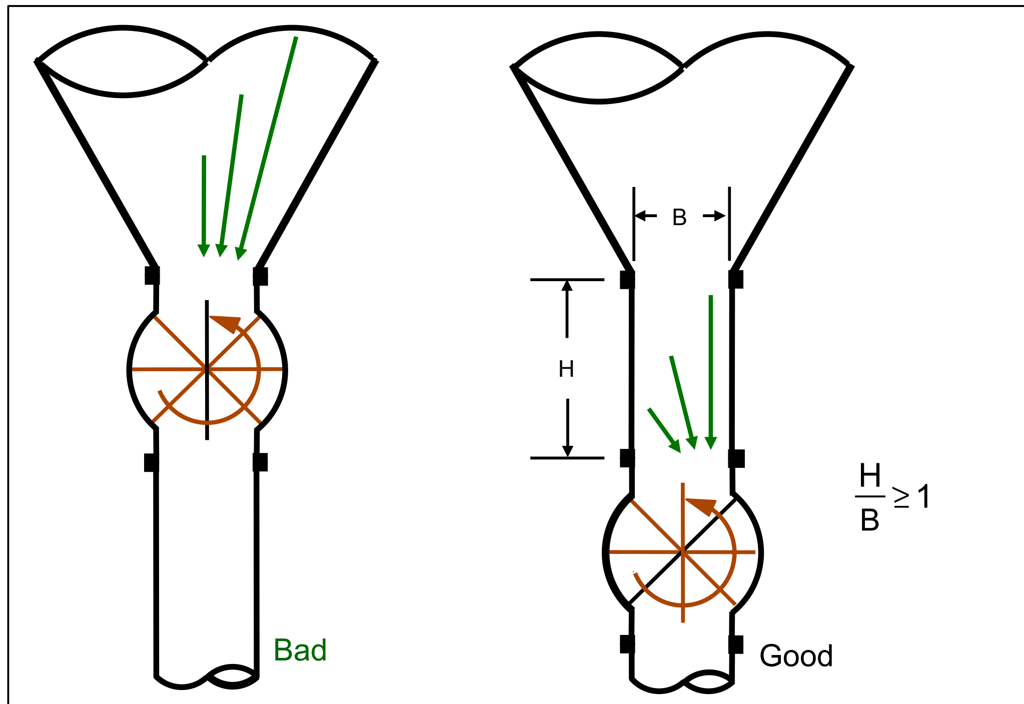


Feeders

- Used to modulate the discharge rate of a powder from a hopper, bin, or silo
- Outlet must be large enough to prevent flow obstruction and allow desired discharge rate
- Slide gates should never be used to control discharge rates

Rotary valves

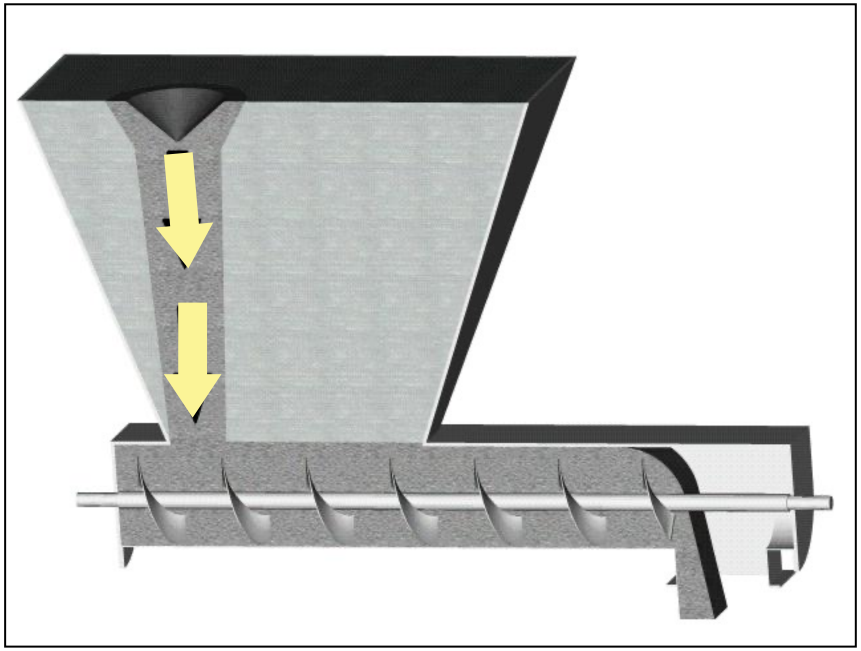




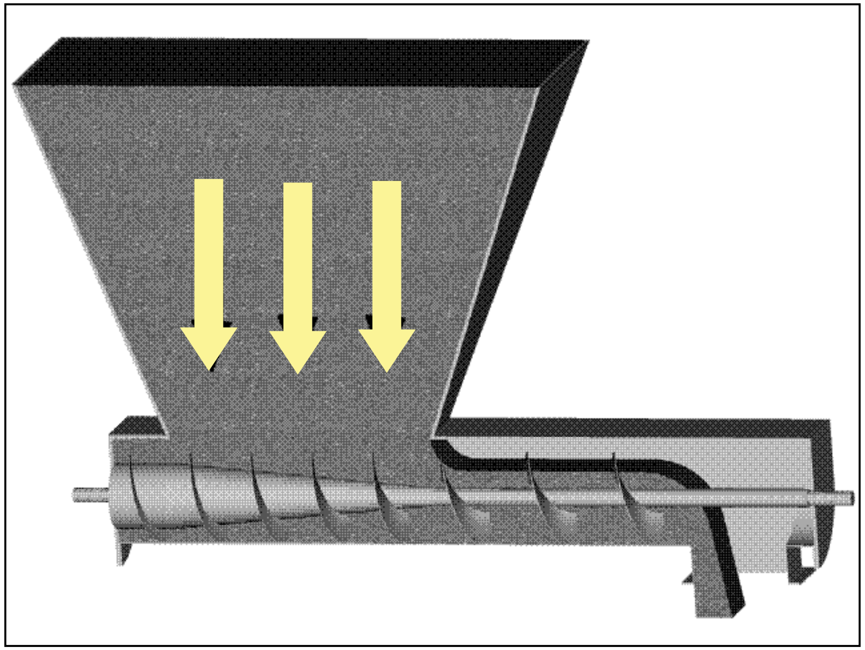
Rotary valves

- Typical speed: 15-25 rpm
- Maximum speed: 35-40 rpm

Screw feeders



Constant diameter, constant pitch



Tapered shaft diameter, increasing pitch

Constant pitch and shaft diameter

Jenike & Johanson

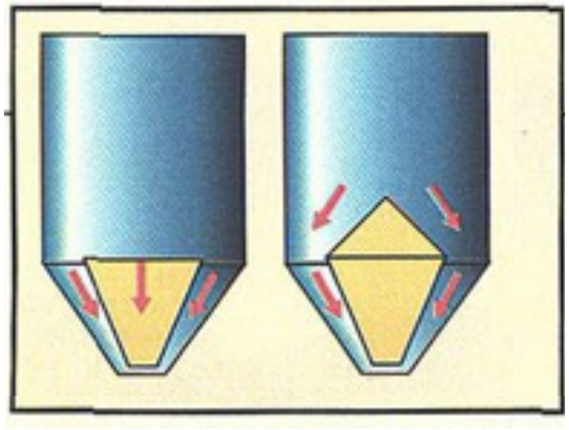
Tapered shaft and increasing pitch

Jenike & Johanson

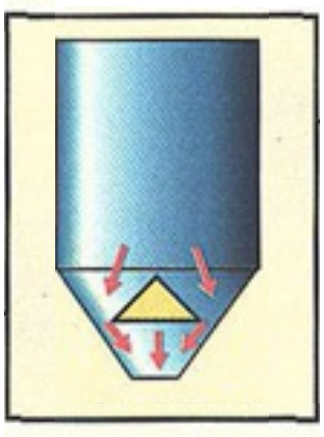
Tricks for handling neurotic powders

- Inserts
- Converging/Diverging walls
- Agitation
- Air assistance

Inserts



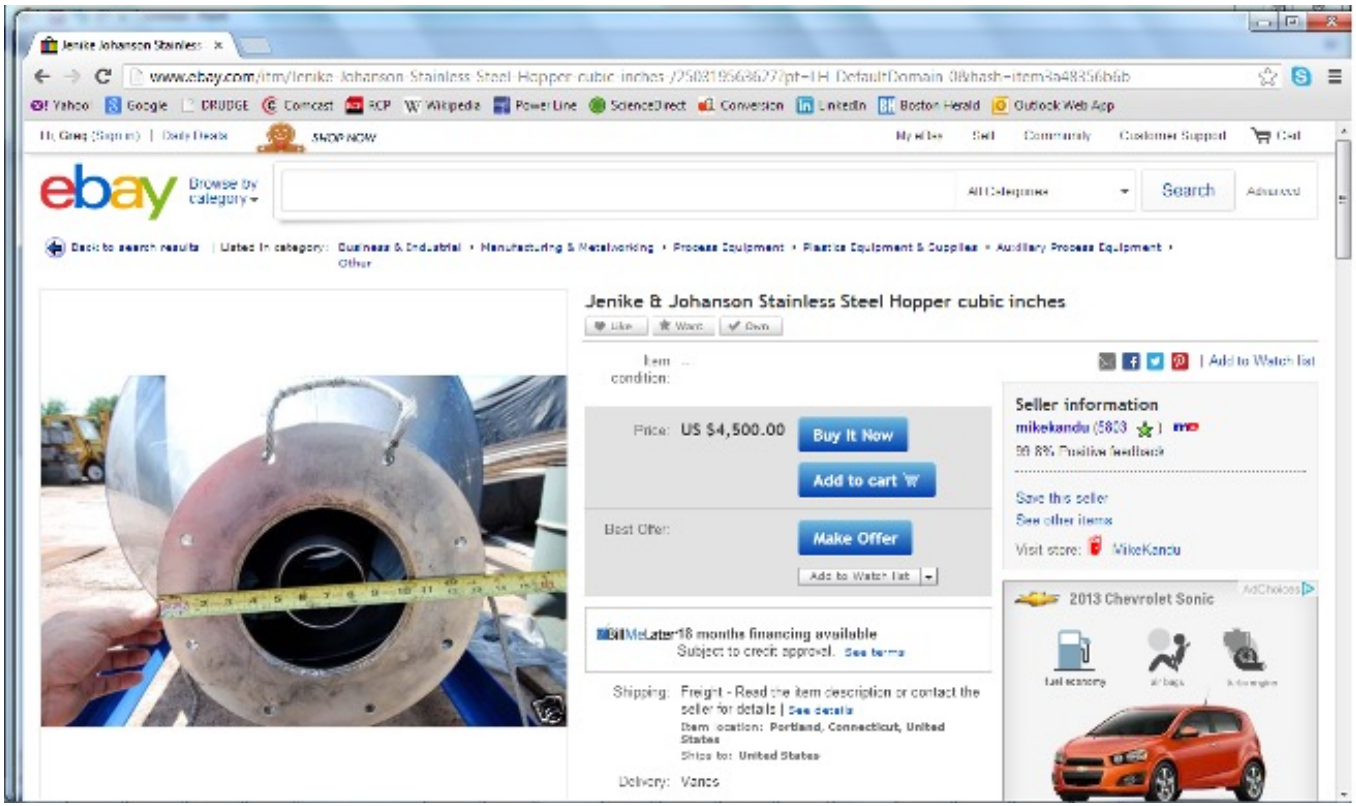
Cone-in-cone



Inverted cone

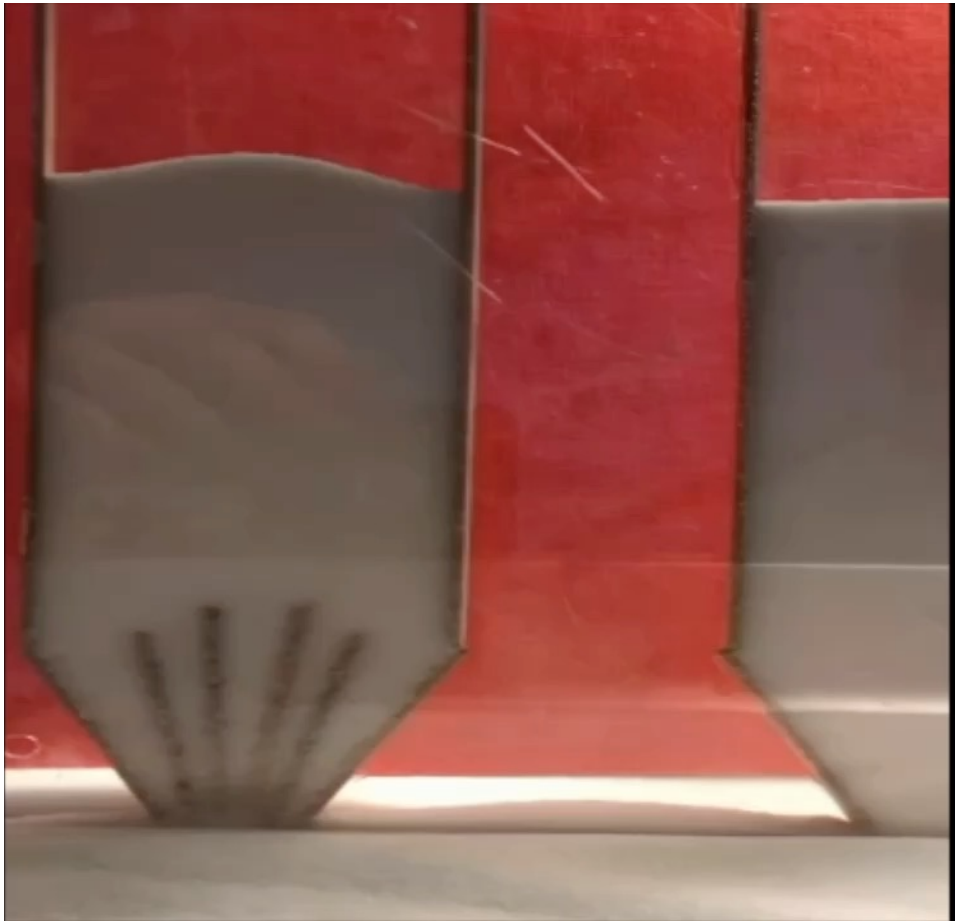
Greg Mehos & Associates LLC • www.mehos.net • greg@mehos.net • 978-799-7311

Inserts


Jenike Johanson Stainless
Yahoo
Google
DRUDGE
Comcast
RCP
Wikipedia
Power Line
ScienceDirect
Conversion
LinkedIn
Boston Herald
Outlook Web App
SHOP NOW
ebay
Browse by category
Search
Advanced
Back to search results
Listed in category: Business & Industrial • Manufacturing & Metalworking • Process Equipment • Plastics Equipment & Supplies • Auxiliary Process Equipment • Other
Jenike & Johanson Stainless Steel Hopper cubic inches
Like
Want
Own
Add to Watch list
Item condition:
Seller information
mikekandu
Price: US $4,500.00
Buy It Now
Add to cart
Save this seller
See other items
Best Offer:
Make Offer
Visit store: MikeKandu
Add to Watch list
2013 Chevrolet Sonic
AdChoices
BillMeLater 18 months financing available
Subject to credit approval. See terms
Shipping: Freight - Read the item description or contact the seller for details | See details
Item location: Portland, Connecticut, United States
Ships to: United States
Delivery: Varies

GM&A

Inserts^2



Converging/diverging

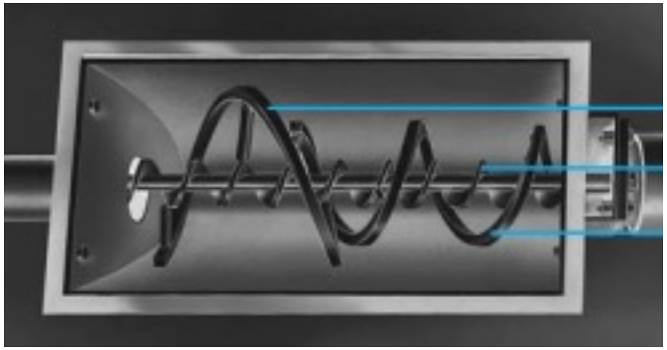
Diamondback

Stacked wedges
a.k.a. LynFlow

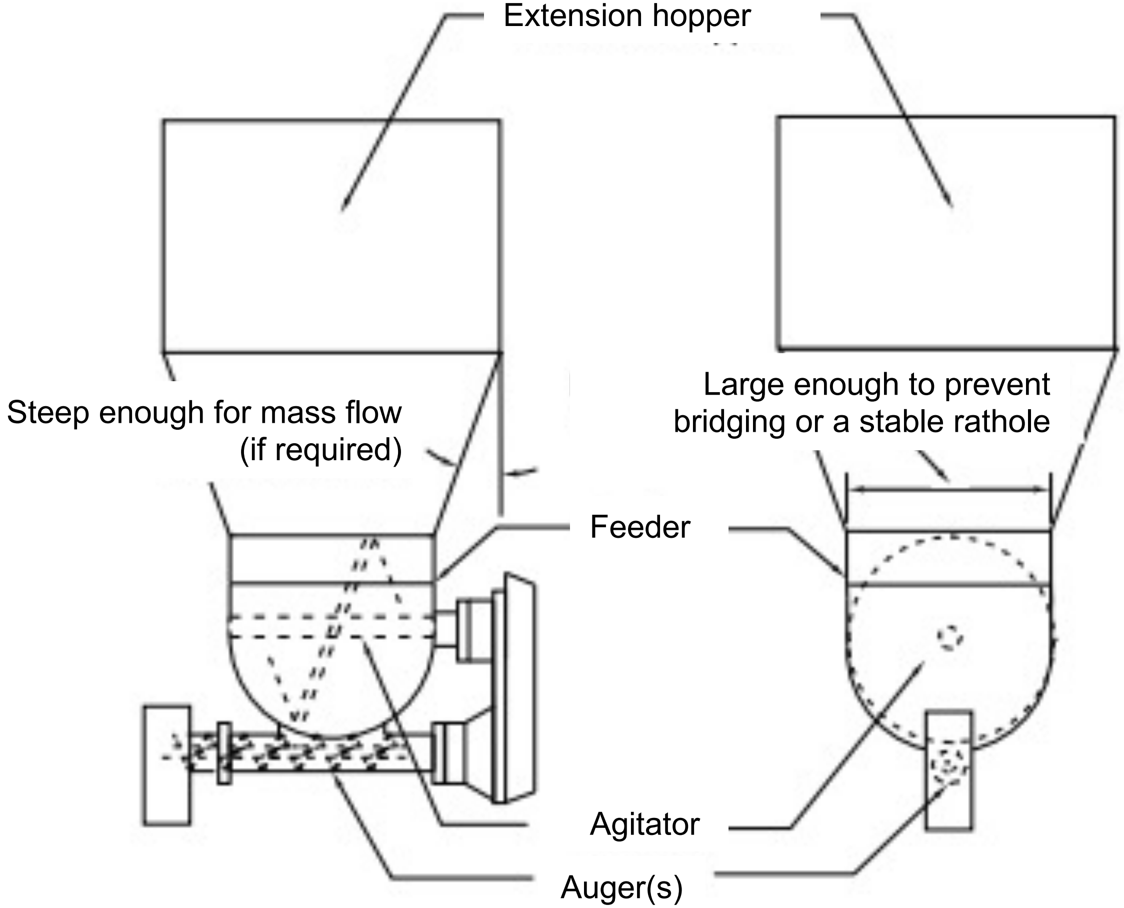
Converging/diverging

"D-tron"

Agitated feeders

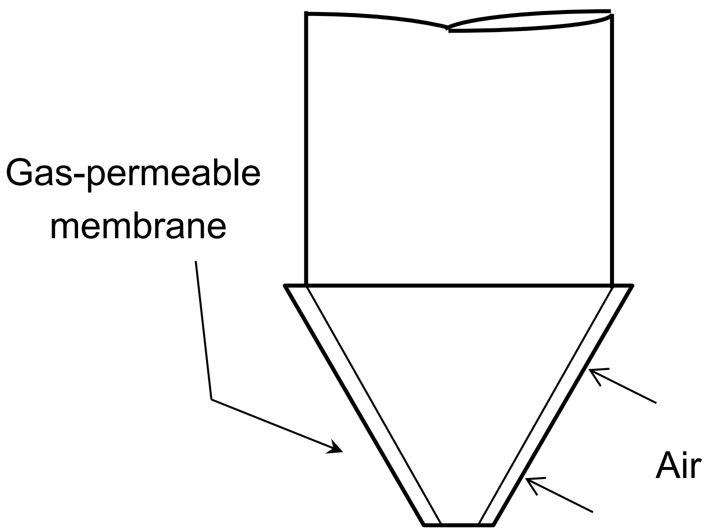


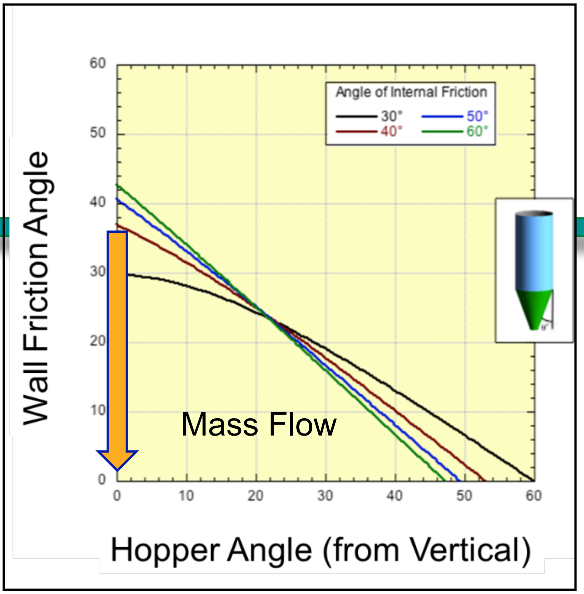
Agitated feeders

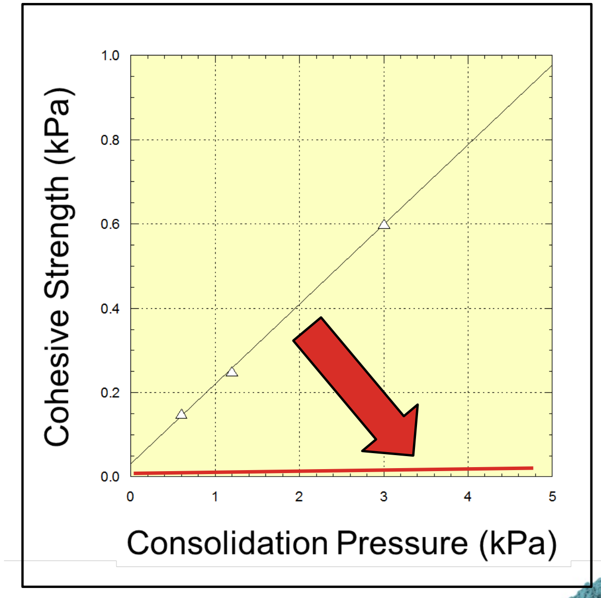


Air assistance

Air assistance



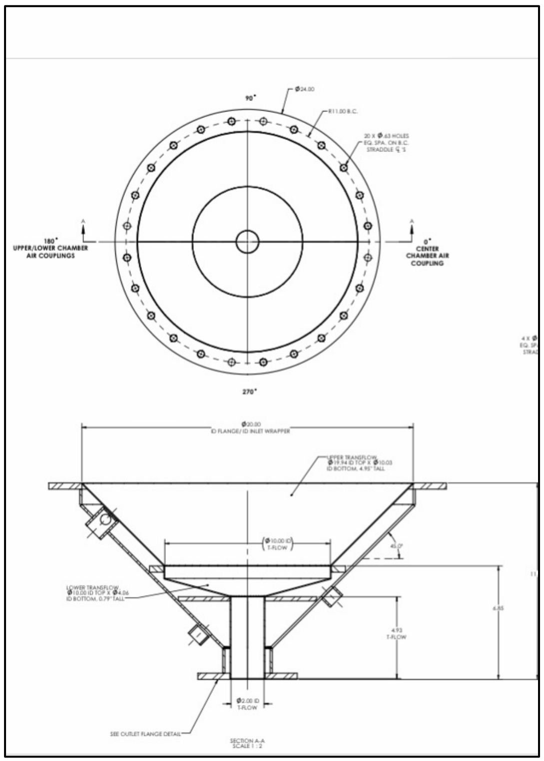




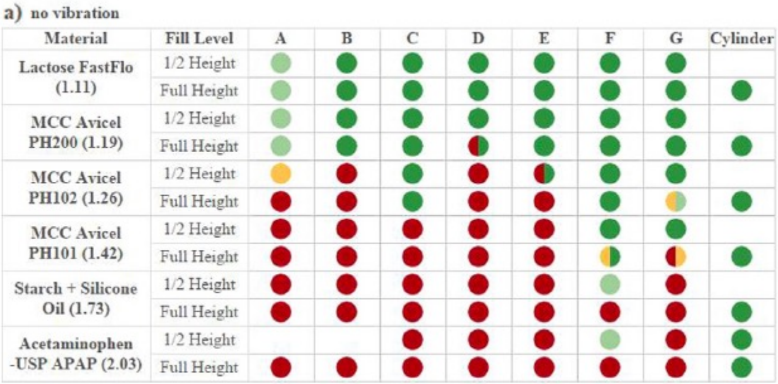
Air assistance

Air assistance

Air assistance



Vibrators


a) no vibration
Material
Fill Level
A
B
C
D
E
F
G
Cylinder
Lactose FastFlo (1.11)
MCC Avicel PH200 (1.19)
MCC Avicel PH102 (1.26)
MCC Avicel PH101 (1.42)
Starch + Silicone Oil (1.73)
Acetaminophen -USP APAP (2.03)
1/2 Height
Full Height

Vibrators

a) no vibration

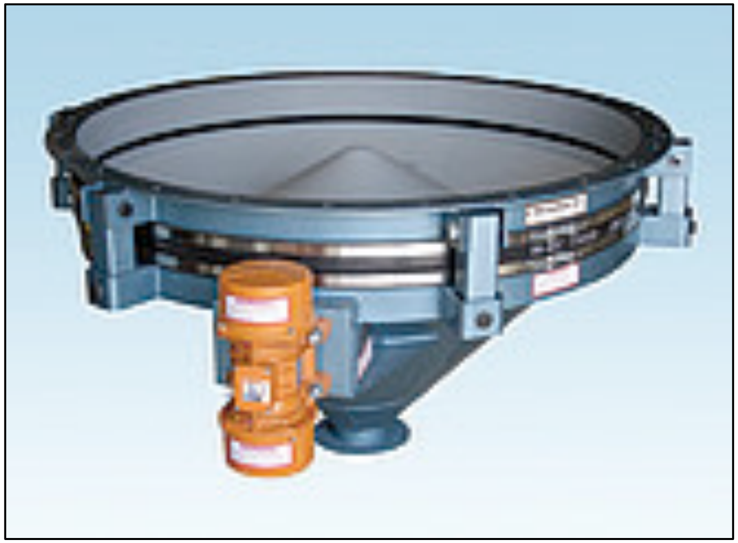
Material	Fill Level	A	B	C	D	E	F	G	Cylinder
Lactose FastFlo (1.11)	1/2 Height	Funnel Flow	Mass Flow	Mass Flow	Mass Flow	Mass Flow	Mass Flow	Mass Flow	
	Full Height	Funnel Flow	Mass Flow	Mass Flow	Mass Flow	Mass Flow	Mass Flow	Mass Flow	Mass Flow
MCC Avicel PH200 (1.19)	1/2 Height	Funnel Flow	Mass Flow	Mass Flow	Mass Flow	Mass Flow	Mass Flow	Mass Flow	
	Full Height	Funnel Flow	Mass Flow	Mass Flow	Bridging / Mass Flow	Mass Flow	Mass Flow	Mass Flow	Mass Flow
MCC Avicel PH102 (1.26)	1/2 Height	Rathole	Bridging	Mass Flow	Bridging	Bridging / Mass Flow	Mass Flow	Mass Flow	
	Full Height	Bridging	Bridging	Mass Flow	Bridging	Bridging	Mass Flow	Rathole / Funnel Flow	Mass Flow
MCC Avicel PH101 (1.42)	1/2 Height	Bridging	Bridging	Bridging	Bridging	Bridging	Mass Flow	Mass Flow	
	Full Height	Bridging	Bridging	Bridging	Bridging	Bridging	Rathole / Mass Flow	Bridging / Rathole	Mass Flow
Starch + Silicone Oil (1.73)	1/2 Height	Bridging	Bridging	Bridging	Bridging	Bridging	Funnel Flow	Bridging	
	Full Height	Bridging	Bridging	Bridging	Bridging	Bridging	Bridging	Bridging	Mass Flow
Acetaminophen -USP APAP (2.03)	1/2 Height			Bridging	Bridging	Bridging	Funnel Flow	Bridging	Mass Flow
	Full Height	Bridging	Bridging	Bridging	Bridging	Bridging	Bridging	Bridging	Mass Flow

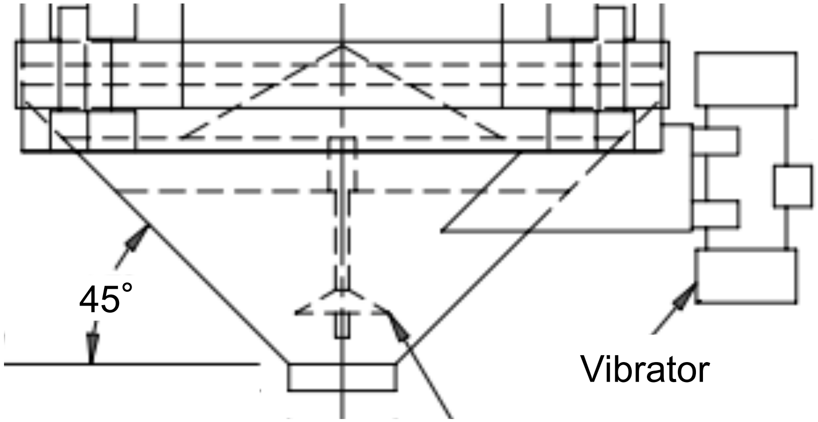
b) with vibration

Material	Fill Level	A	B	C	D	E	F	G	Cylinder
Lactose FastFlo (1.11)	1/2 Height	Rathole / Bridging	Mass Flow / Bridging	Bridging	Bridging	Bridging	Funnel Flow	Funnel Flow	
	Full Height	Rathole / Bridging	Bridging	Bridging	Mass Flow / Bridging	Bridging	Funnel Flow	Funnel Flow	Mass Flow
MCC Avicel PH200 (1.19)	1/2 Height	Bridging	Bridging	Bridging	Bridging	Bridging	Funnel Flow	Funnel Flow	
	Full Height	Bridging	Bridging	Bridging	Bridging	Bridging	Bridging	Bridging	Mass Flow
MCC Avicel PH102 (1.26)	1/2 Height	Bridging		Bridging		Bridging	Bridging	Bridging	
	Full Height	Bridging	Bridging	Bridging	Bridging	Bridging	Bridging	Bridging	Bridging
MCC Avicel PH101 (1.42)	1/2 Height	Bridging	Bridging	Bridging	Bridging		Bridging	Bridging	
	Full Height	Bridging	Bridging	Bridging	Bridging	Bridging	Bridging	Bridging	Bridging
Starch + Silicone Oil (1.73)	1/2 Height	Bridging	Bridging	Bridging	Bridging		Bridging		
	Full Height	Bridging	Bridging	Bridging	Bridging	Bridging	Bridging	Bridging	Mass Flow
Acetaminophen -USP APAP (2.03)	1/2 Height	Bridging					Bridging	Bridging	
	Full Height	Bridging	Bridging	Bridging	Bridging	Bridging	Bridging	Bridging	Bridging

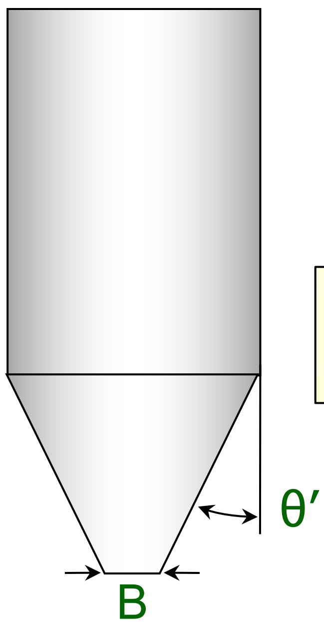
Mass Flow   Funnel Flow   Rathole   Bridging

Bin activators





Solids discharge rates



$$\frac{2(m+1)\tan\theta'}{Bg} v_o^2 = 1 - \frac{2(m+1)\cos\theta'\sin(\beta+\theta')f_c}{\rho_b g B} + \frac{1}{\rho_{bo} g}\frac{dP}{dz}\bigg|_o$$

$$\left[\frac{2(m+1)\tan\theta'}{Bg}\right]v_o^2 + \left[\frac{1}{K_o}\left(1-\frac{\rho_{bo}}{\rho_{bmp}}\right)\right]v_o + \frac{2(m+1)\cos\theta'\sin(\beta+\theta')f_c}{\rho_b g B} - 1 = 0$$

Permeability

Mehos, G., "Maximum Solids Discharge Rates from Hoppers", *Chem. Engr. Res. Des.*, 191, 564 (2023).

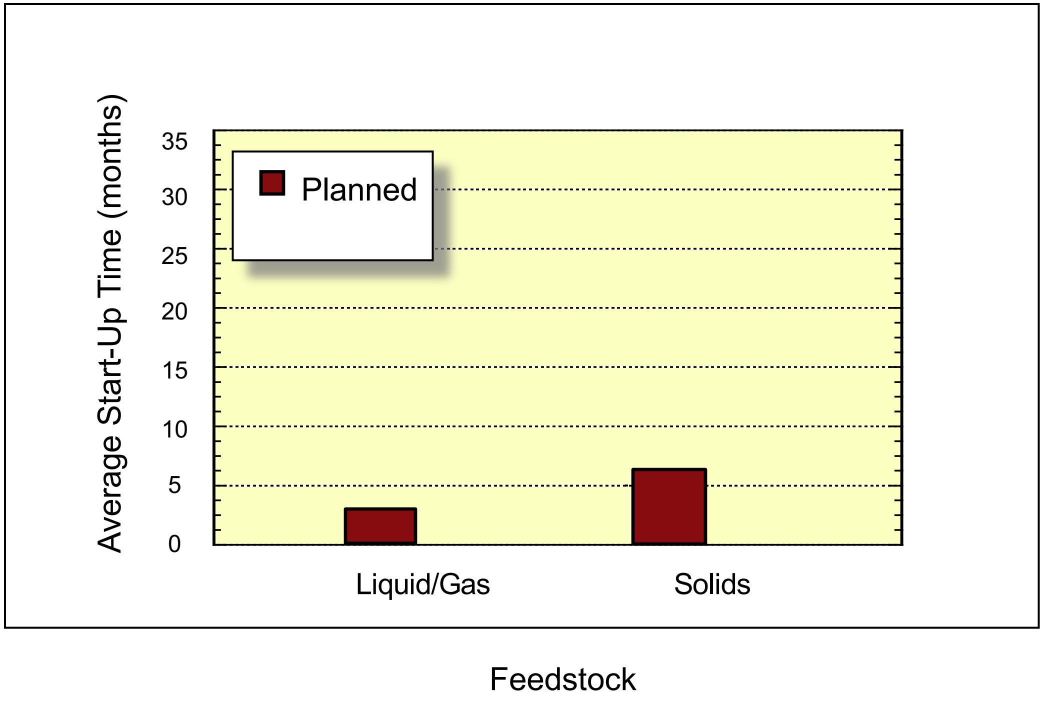
Summary

- Flow obstructions
  - Arching and ratholing
  - Erratic discharge
- Flow properties
  - Cohesive strength
  - Compressibility
  - Wall friction
- Design
  - Outlet
  - Hopper angle

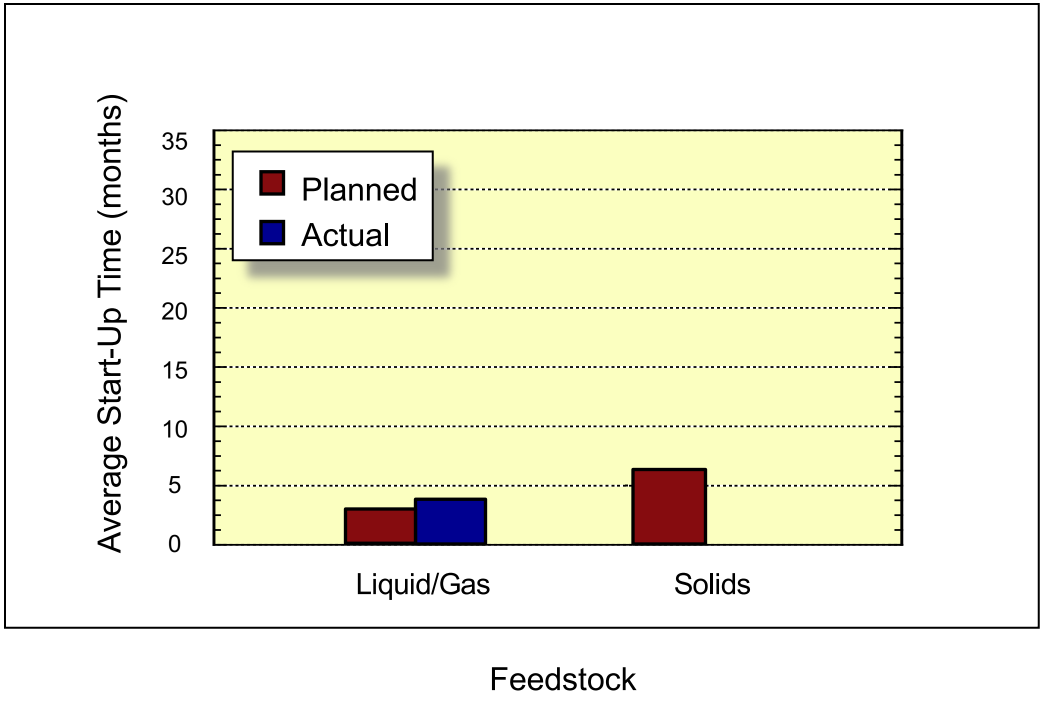
Rand Corporation Study

- Study by independent organization
- 40 solids processing plants in U.S. and Canada
- Six-year duration

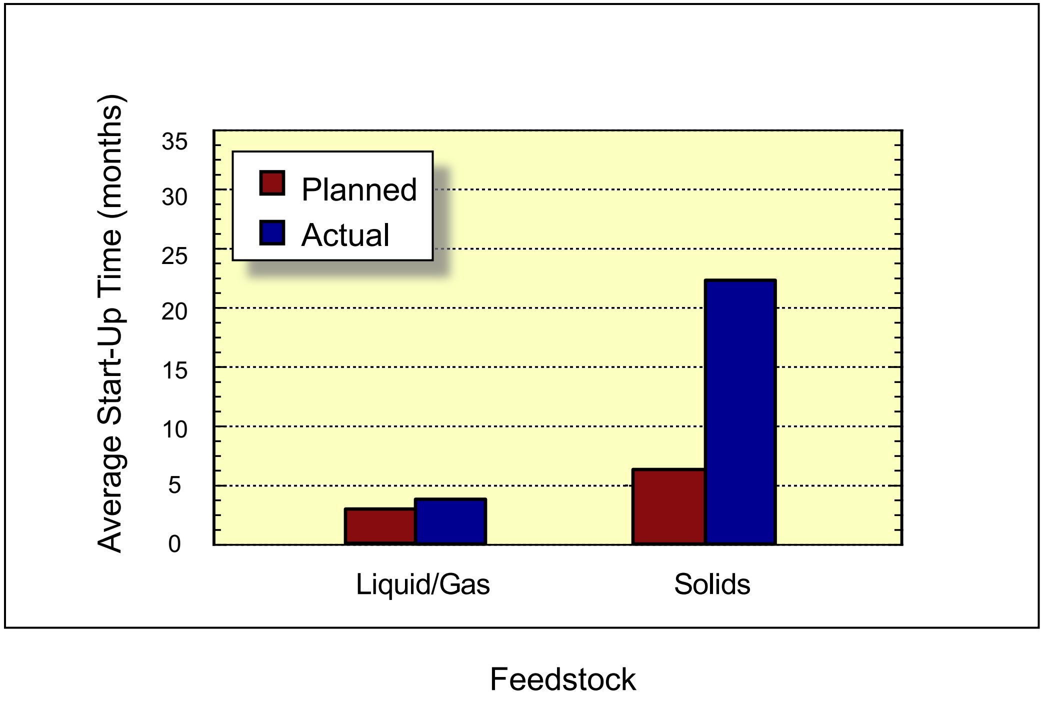
Planned vs. actual start-up



Planned vs. actual start-up

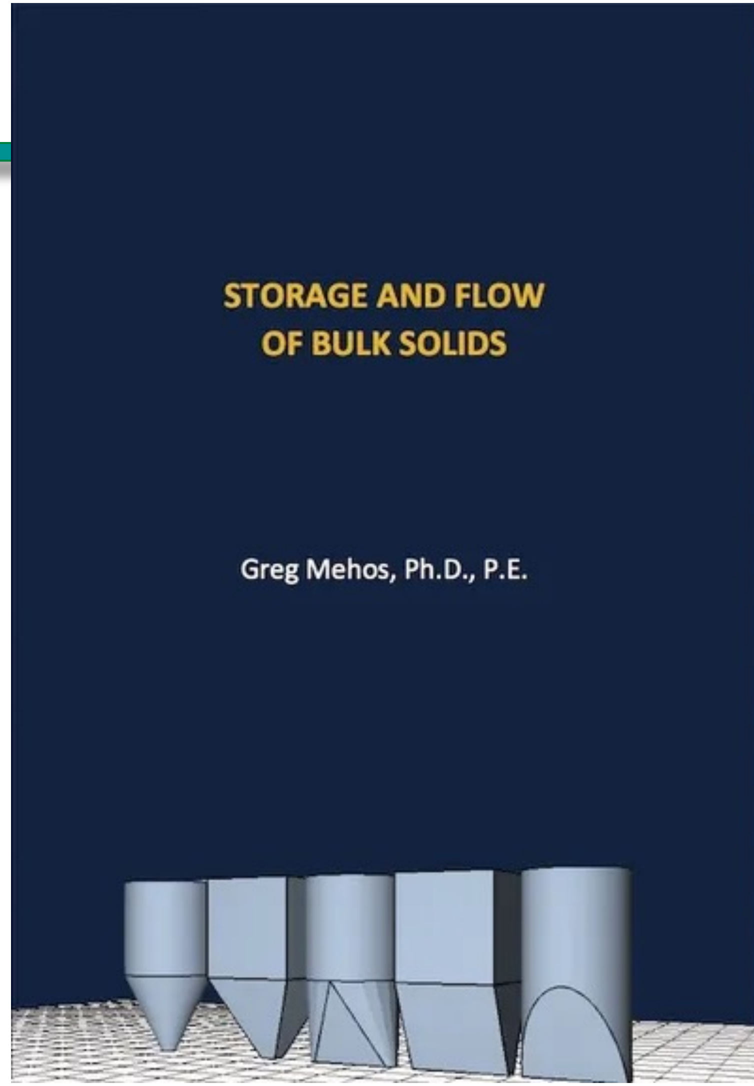


Planned vs. actual start-up



Rand conclusions

- 80% experienced solids handling problems
- Average startup time *ca.* 20 months (*vs.* 4 mo. for fluids)
- Typical performance 40 to 50% of design


STORAGE AND FLOW
OF BULK SOLIDS
Greg Mehos, Ph.D., P.E.

8. BETTER REFERENCES THAN THIS ONE

1. Arnold, P., A. Roberts, and A. McLean, Bulk Solids: Storage, Flow, and Handling, TUNRA, Newcastle, Australia, 1978.
2. Bates, L., User Guide to Segregation, British Materials Handling Board, Marlow, England, 1997.
3. Bates, L., Guide to the Design, Selection, and Application of Screw Feeders, Cromwell Press, Trowbridge, England, 2000.
4. Fayed, M. and L. Otten, Handbook of Powder Science and Technology, Van Nostrand Reinhold Company, New York, 1997.
5. Jenike, A., Storage and Flow of Solids – Bulletin 123, University of Utah, Salt Lake City, Utah, 1964.
6. Kulwiec, R., Materials Handling Handbook, John Wiley and Sons, Hoboken, NJ, 1985.
7. McGlinchey, Bulk Solids Handling – Equipment Selection and Operation, Blackwell Publishing Company, Ames, IA, 2008.
8. Rhodes, M. Introduction to Particle Technology, John Wiley and Sons, Hoboken, NJ, 2008.
9. Schulze, D., Powders and Bulk Solids: Behavior, Characterization, Storage and Flow, Springer, Berlin, 2008.
10. Shamiou, P., Handling of Bulk Solids – Theory and Practice, Butterworths, London, 1990.
11. Woodcock, C. and J. Mason, Bulk Solids Handling: An Introduction to the Practice and Technology, Springer Science, New York, 1987.

Flow and Storage of Powders

Greg Mehos, Ph.D., P.E.
gmehos@uri.edu
greg@mehos.net
www.mehos.net
https://www.linkedin.com/in/gmehos/
978-799-7311