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BY

Flow and Storage of Powders

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Flow and Storage of Powders

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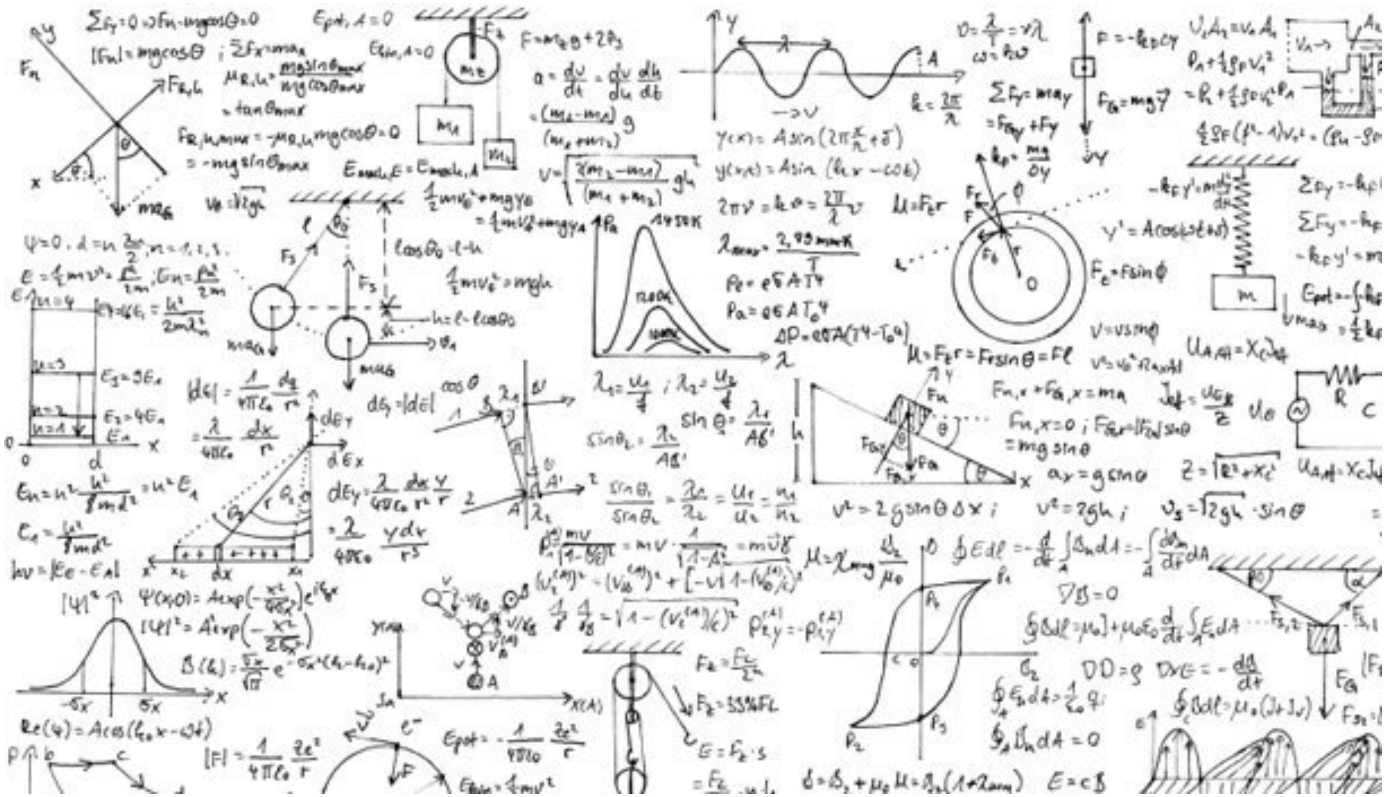
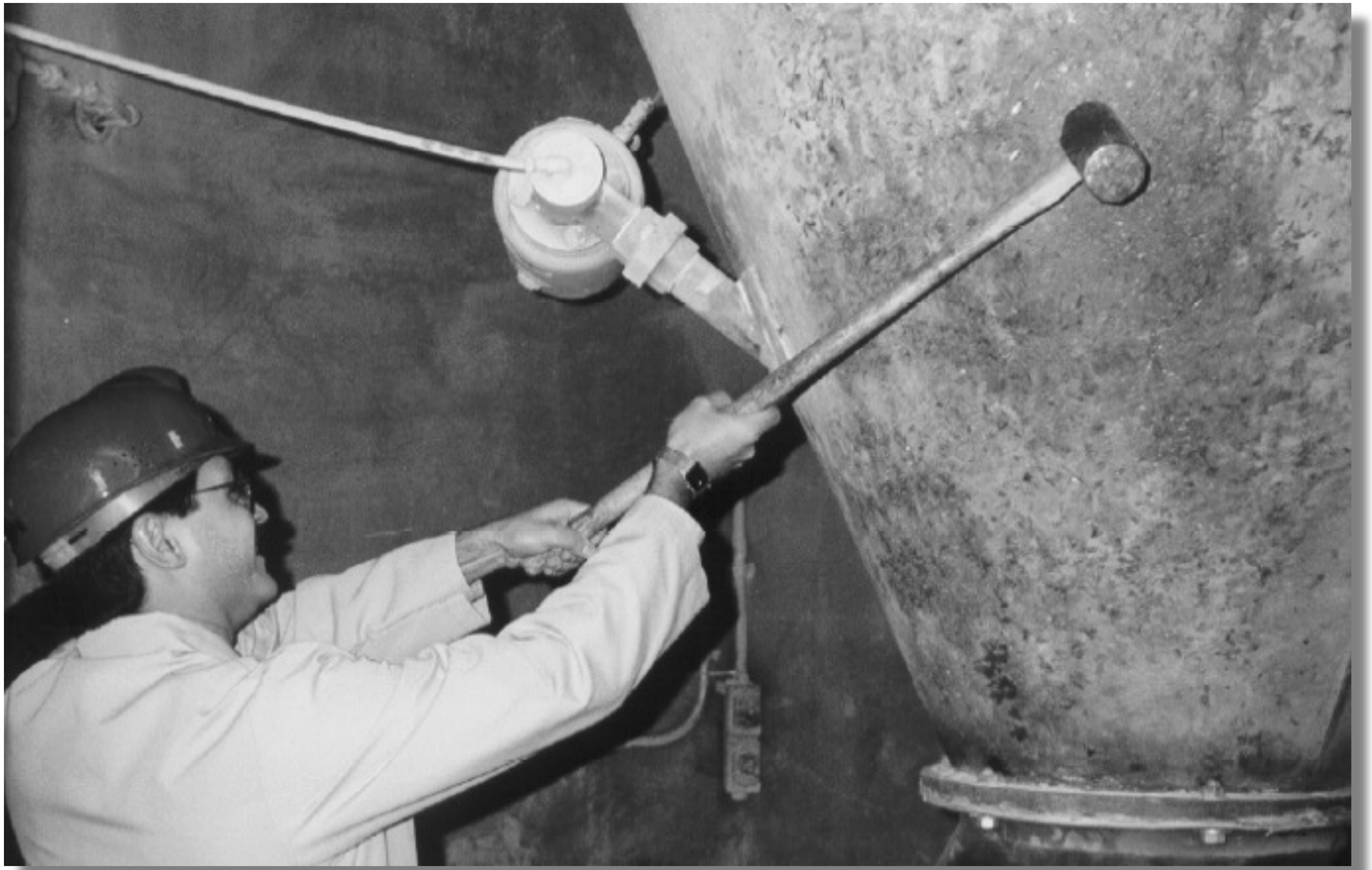


Flow and Storage of Powders



Flow and Storage of Powders

Agenda

- Definitions
- Powder flow behavior
- Fundamental powder flow properties

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- Stresses in solids
- Testers

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- Definitions
- Powder flow behavior
- Fundamental powder flow properties
- Stresses in solids
- Testers
- Predicting flow behavior and designing powder handling equipment
- Feeder selection
- Tricks for challenging materials
- Special topics

Goals

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

Goals

Goals

Definitions

Bulk solid

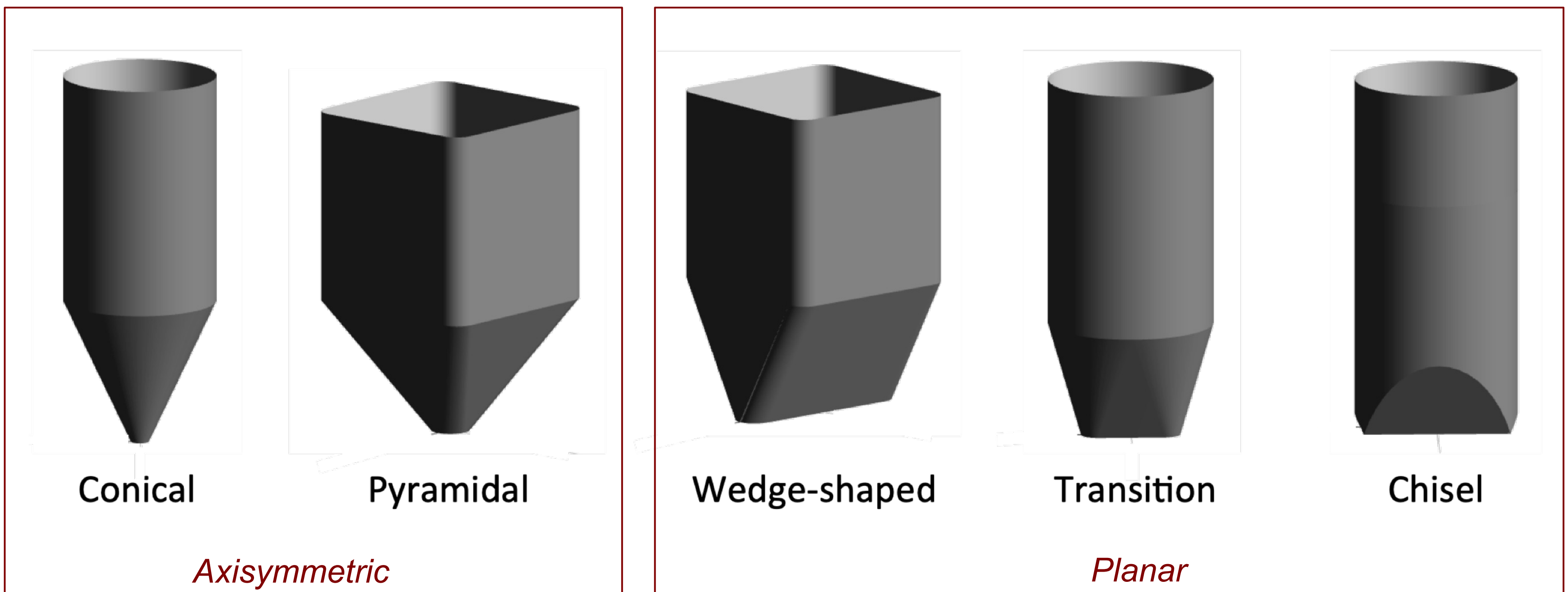
“Powder”

Definitions

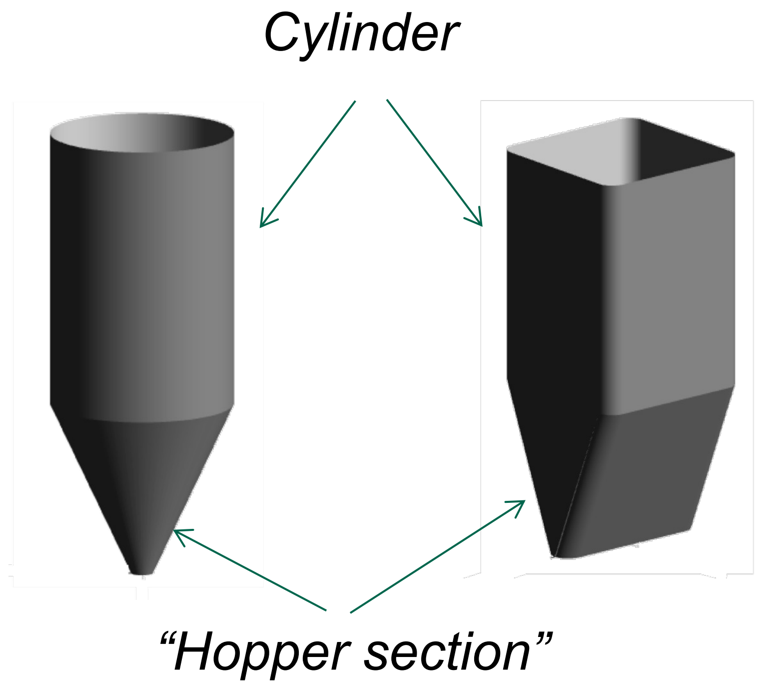
Biomass

Definitions

Hopper, bin, or silo

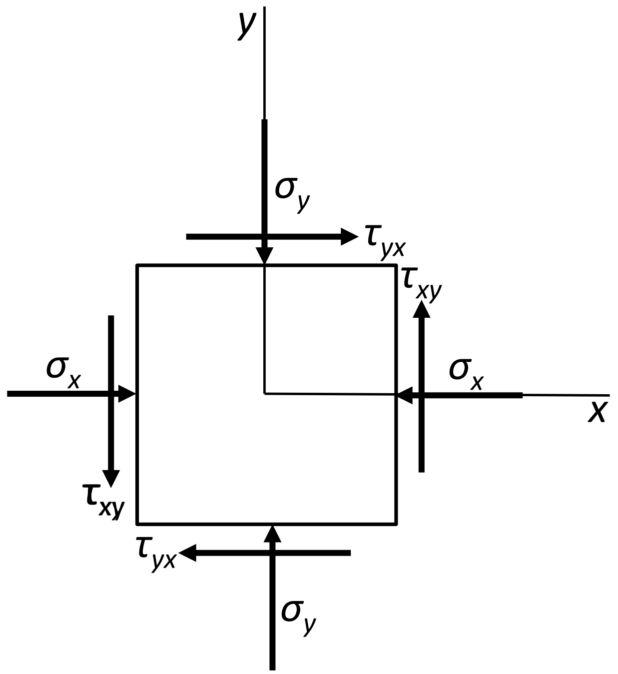


Definitions



Definitions

- Stress
  - Normal stress
  - Shear stress
- Pressure
- Major principal stress



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

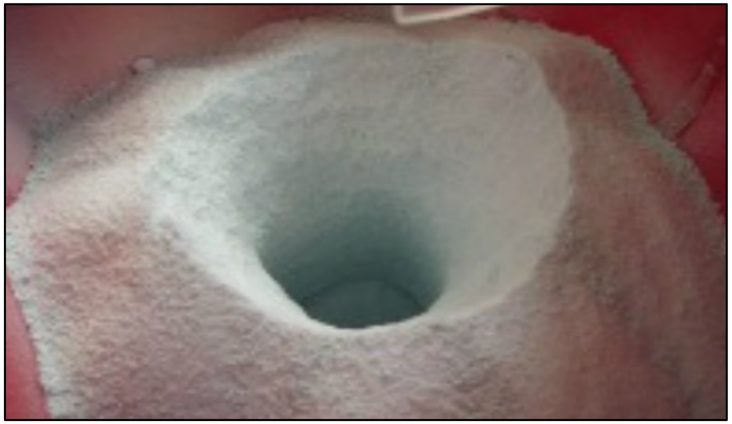
Classification of bulk solids

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

Flow problems

- Ratholing



Flow problems

- Ratholing
- Arching/bridging

Flow problems

- Ratholing
- Arching/bridging

Flow problems

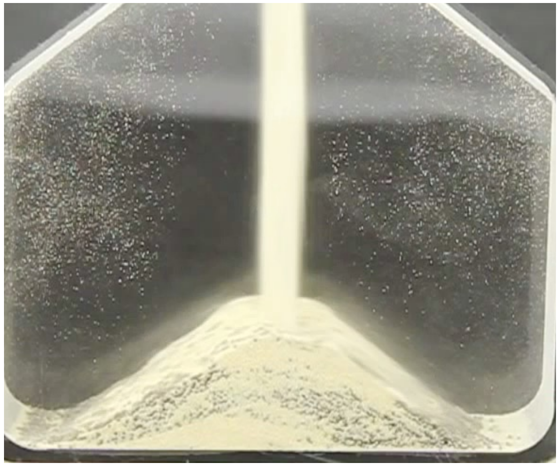
- Ratholing
- Arching/bridging
- Caking

Flow problems

- Ratholing
- Arching/bridging
- Caking
- Flooding

Flow problems

- Ratholing
- Arching/bridging
- Caking
- Flooding
- Segregation



Flow problems

- Ratholing
- Arching/bridging
- Caking
- Flooding
- Segregation

Lyn Bates: Christmas tree segregation

Flow problems

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

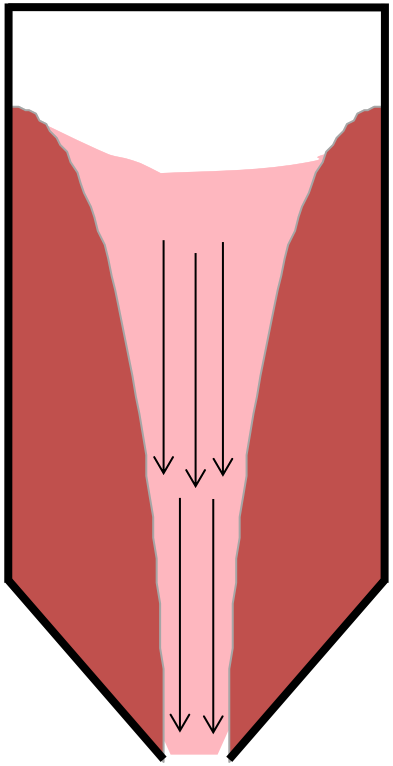
Flow problems

- Ratholing
- Arching/bridging
- Caking
- Flooding
- Segregation
- Limiting discharge rate
- Structural

Solids flow patterns

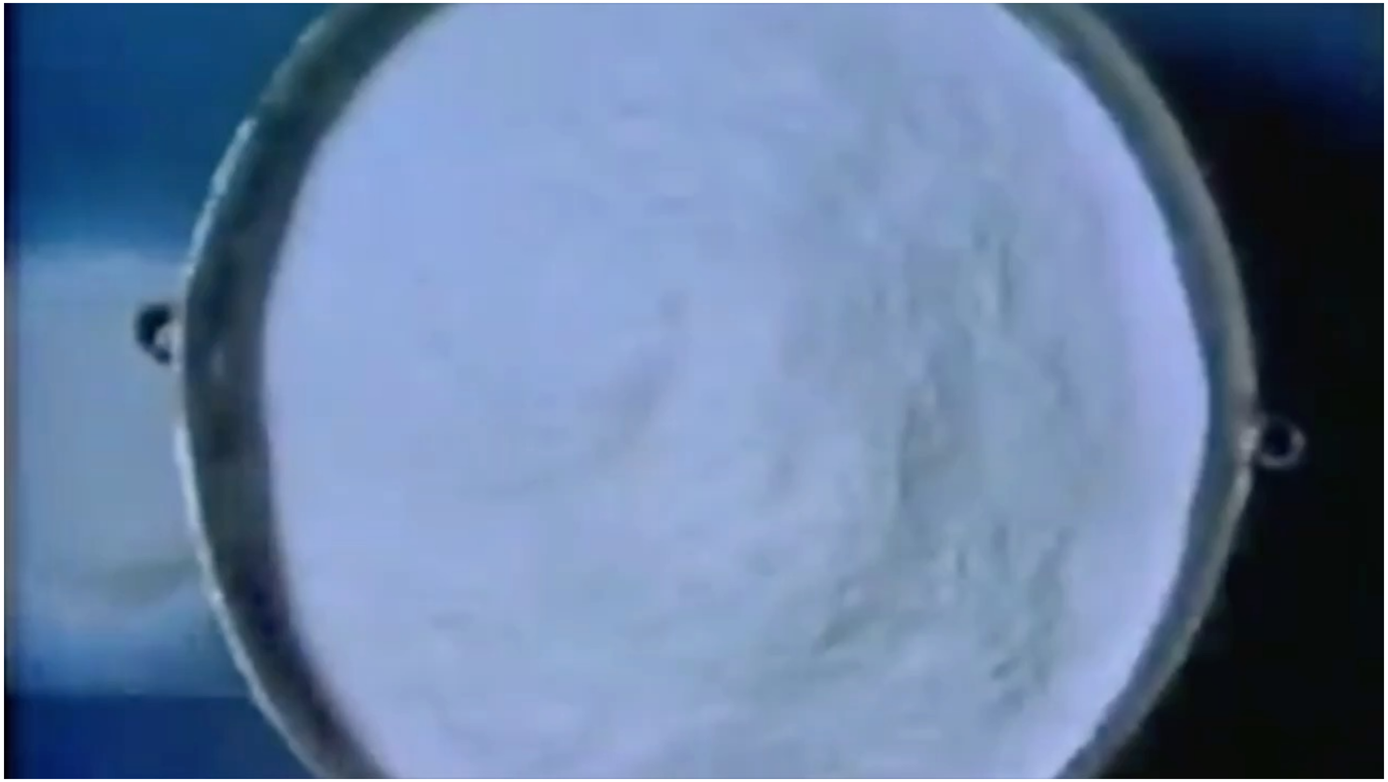
- Funnel flow
- Mass flow

Funnel flow

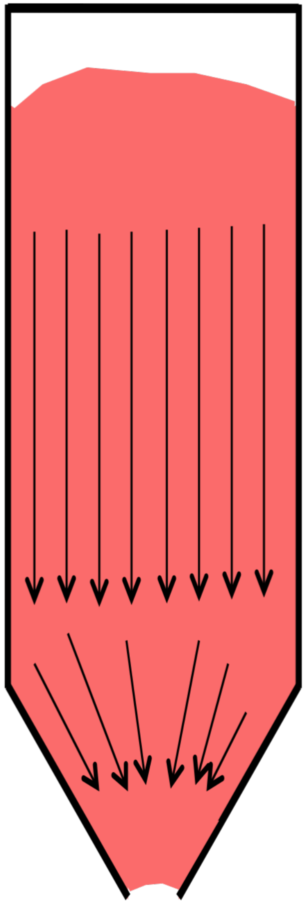


Funnel flow

Funnel flow



Mass flow



Mass flow

Flow patterns

Funnel flow

- First in, last out
- Ratholes may be stable
- Fine powders will flood
- Segregation made worse
- Caking more likely
- Low headroom

Mass flow

- First in, first out
- No ratholes
- Fine powders de-aerate
- Segregation minimized
- Steady discharge
- Steep/low friction walls
- Taller for same capacity
- Higher wall stresses

Mass flow

Funnel flow

No flow

Preventing flow problems

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

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

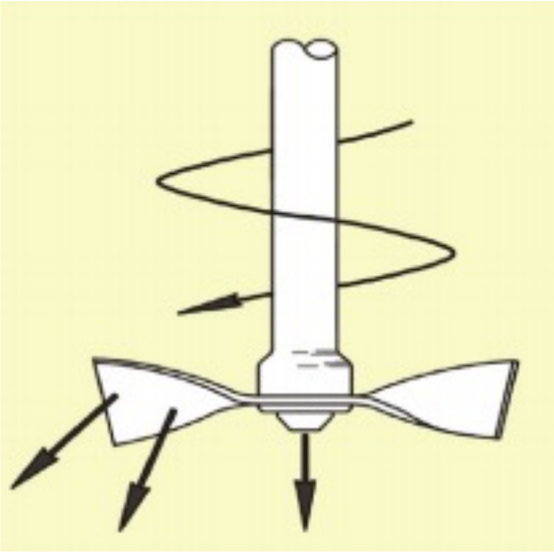
Hosokawa Tester

Tribocharge Tester

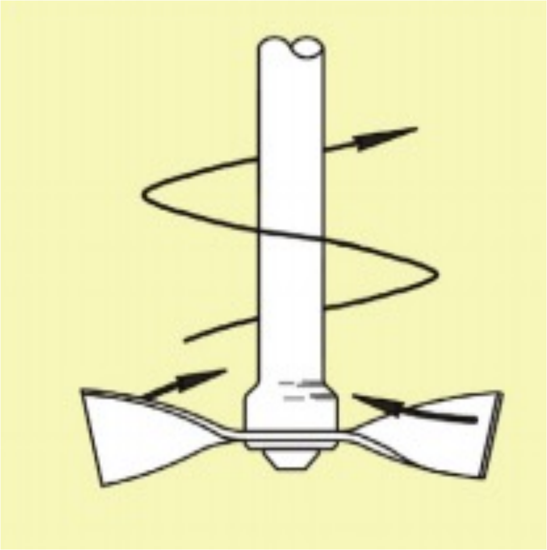
Score	Flowability and Performance
90-100	Excellent
80-89	Good
70-79	Fair
60-69	Passable
40-59	Poor
20-39	Very Poor
0-19	Very, Very Poor

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

Flow energies



Basic Flow Energy



Specific Energy

Flowability

- Angle of repose
- Carr and Hausner ratios
- Carr Index
- Flow energy
- Flowdex
- FFC (often erroneously called flow function)

Flowability

- Angle of repose
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Do not predict flow behavior!

So how should we define flowability?

So how should we define flowability?

Good flowability:

So how should we define flowability?

Poor flowability:

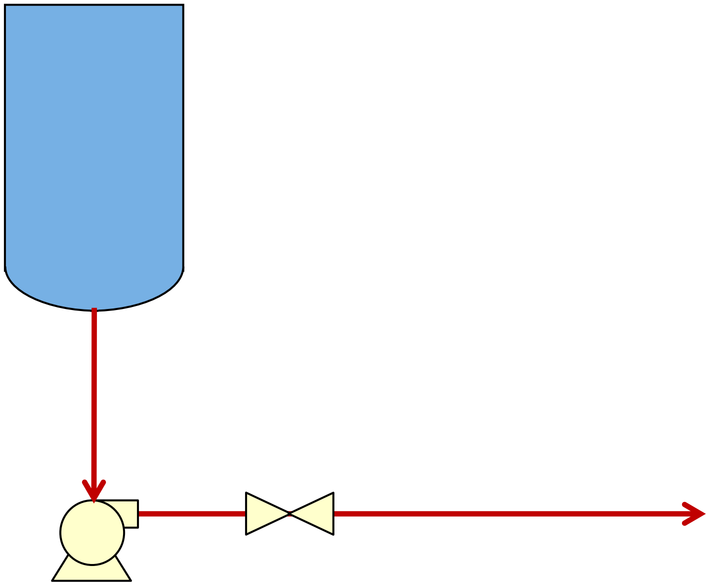
Fundamental properties

- <u>*Predict*</u> flow behavior
  - Will powder flow reliably from bin or hopper?
  - Are walls steep enough to prevent ratholes from forming?
  - Is solids discharge rate steady enough for downstream process?
- <u>*Design*</u> bins and hoppers
  - Minimum outlet dimension to prevent obstructions to flow
  - Recommended mass flow hopper angles
  - Outlet dimension that allows desired solids discharge rate

GM&A

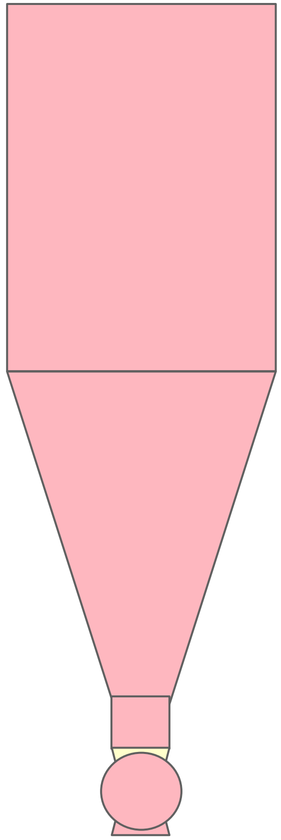
Fundamental properties

- Viscosity
- Density
- Vapor pressure



Fundamental properties

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



Andrew Jenike

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

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

Fundamental properties

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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

Used to calculate solids discharge rates

CHEMICAL ENGINEERS' HANDBOOK
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McGRAW-HILL
PERRY'S CHEMICAL ENGINEERS' HANDBOOK
PERRY CHILTON KIRKPATRICK
CHEMICAL ENGINEERS' HANDBOOK
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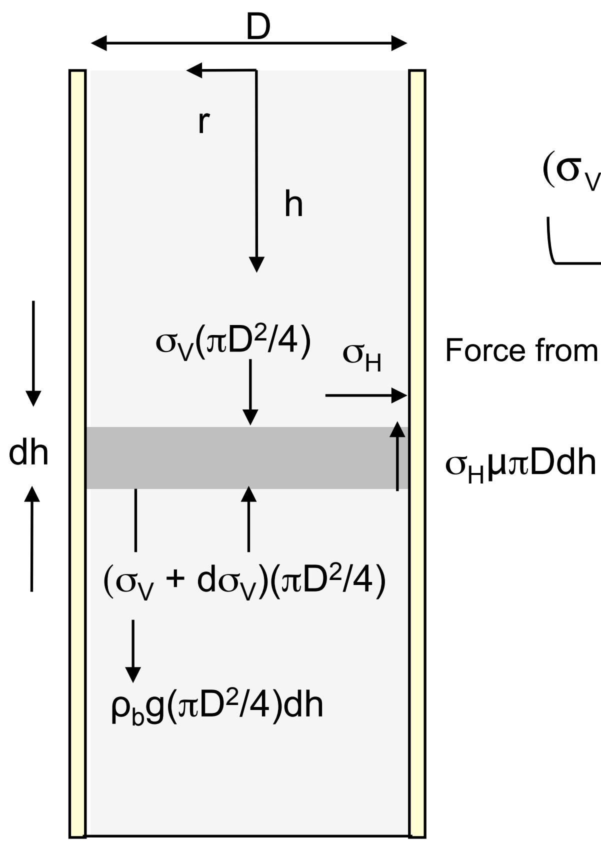
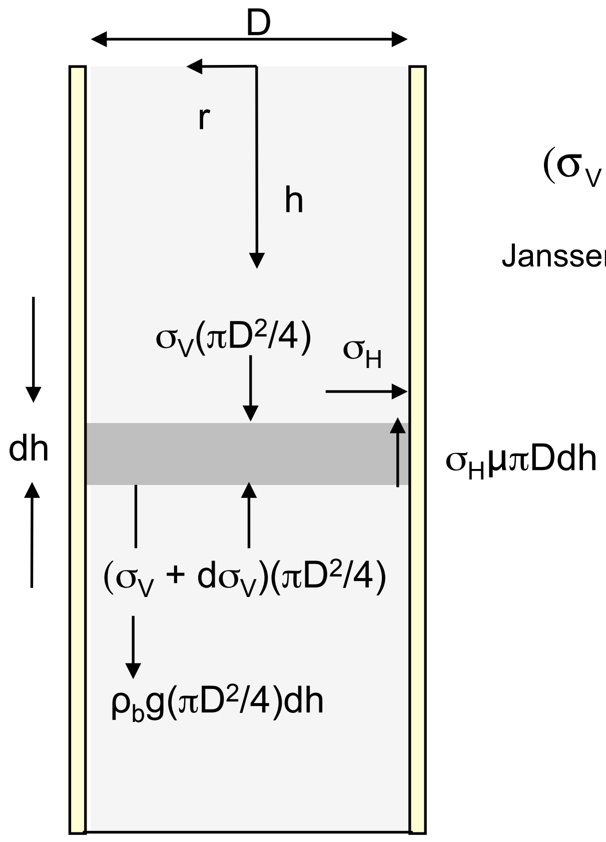
Pressure distribution



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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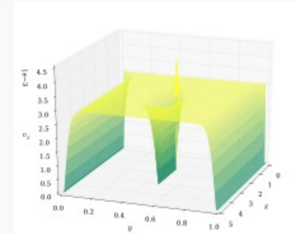
Integrating factor

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.

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

Contents [hide]

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

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

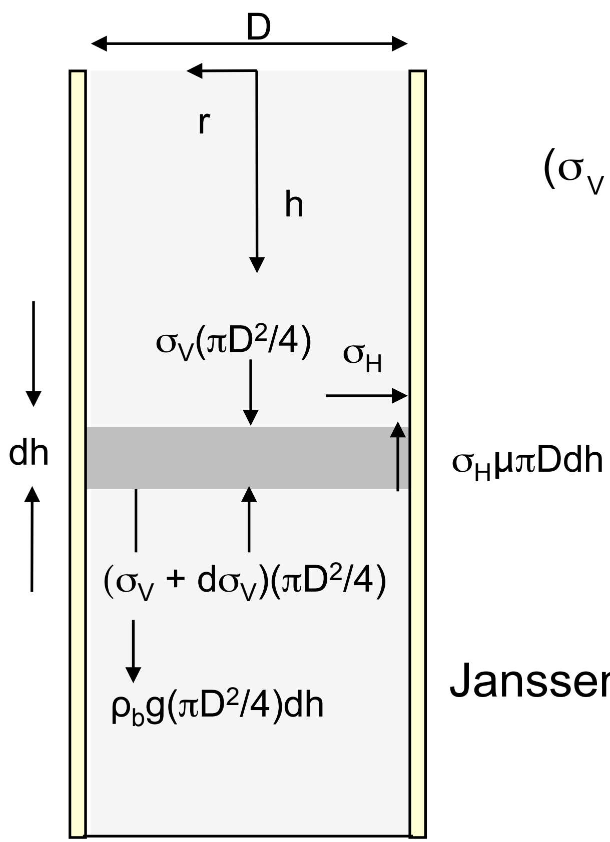
The basic idea is to find some function $M(x)$, called the "integrating factor," which we can multiply through our DE in order to bring the left-hand side under a common derivative. For the canonical first-order, linear differential equation shown above, our integrating factor is chosen to be

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

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

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

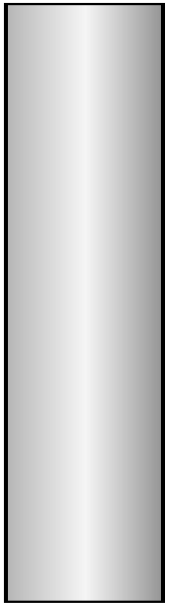
$$k = \frac{\sigma_H}{\sigma_V} \cong 0.4$$

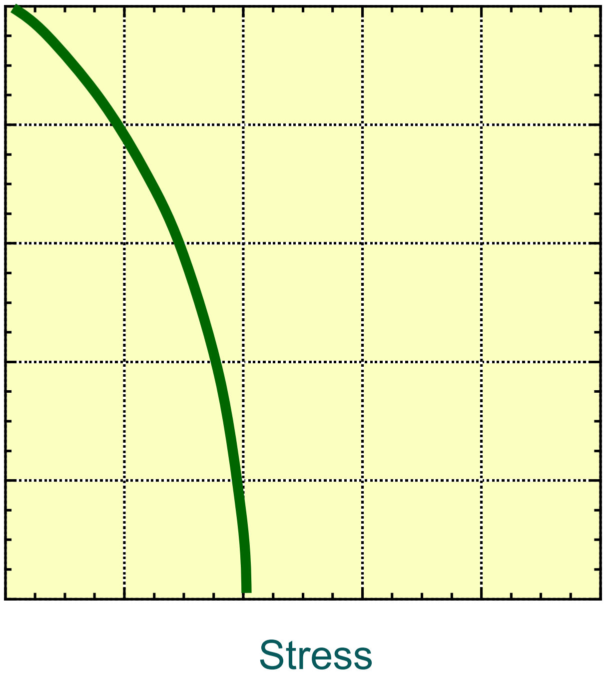
$$\frac{D}{4}\frac{d\sigma_V}{dh} + k\mu\sigma_V \quad \frac{D}{4}\rho_b g$$

Janssen Equation:

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

Pressure distribution





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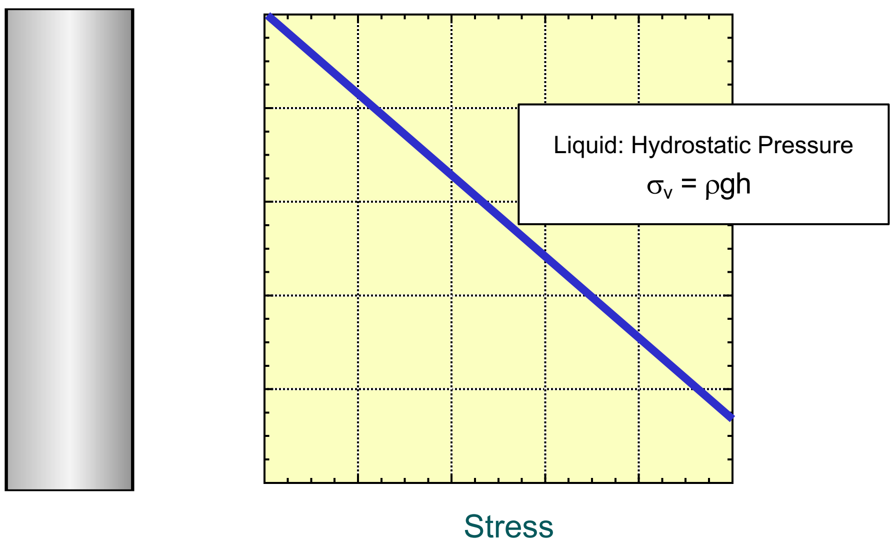
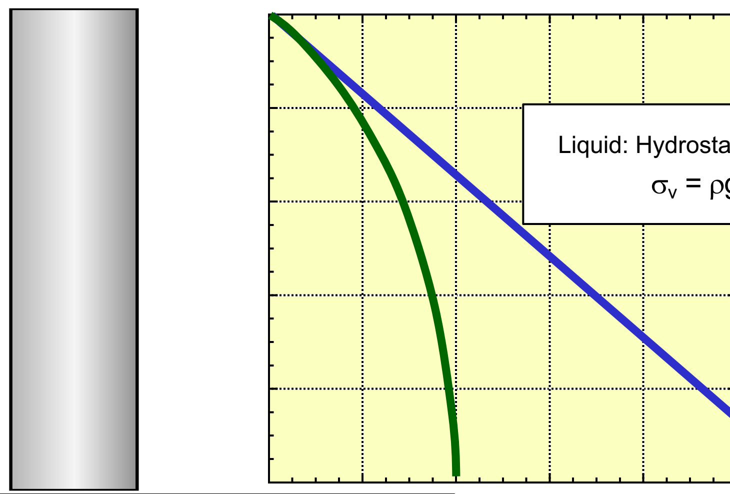


Pressure distribution



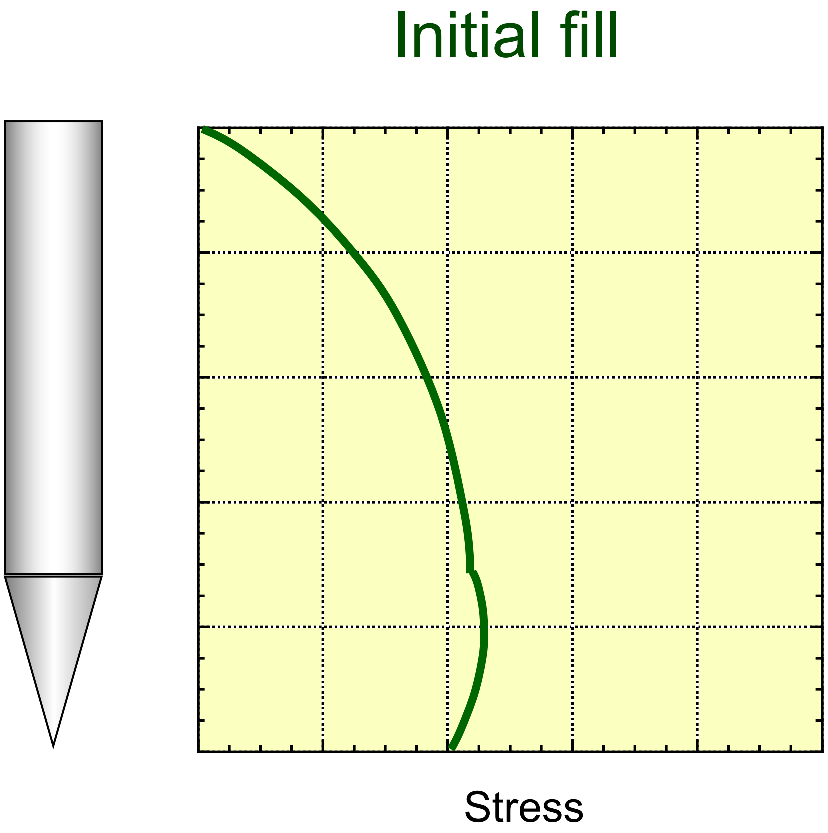
Liquid: Hydrostatic Pressure

$$\sigma_v = \rho g h$$

Janssen Equation:

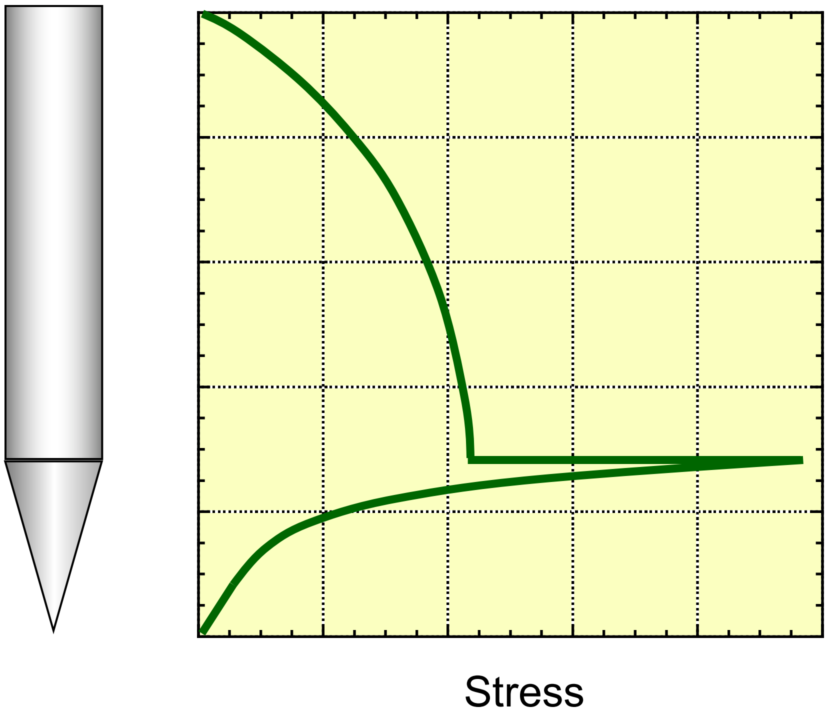
$$\sigma_v = \frac{\rho_b g D}{4k\mu}\left[1 - \exp\left(\frac{-4k\mu h}{D}\right)\right]$$

Pressure distribution



Pressure distribution

After discharge (mass flow)



Pressure distribution

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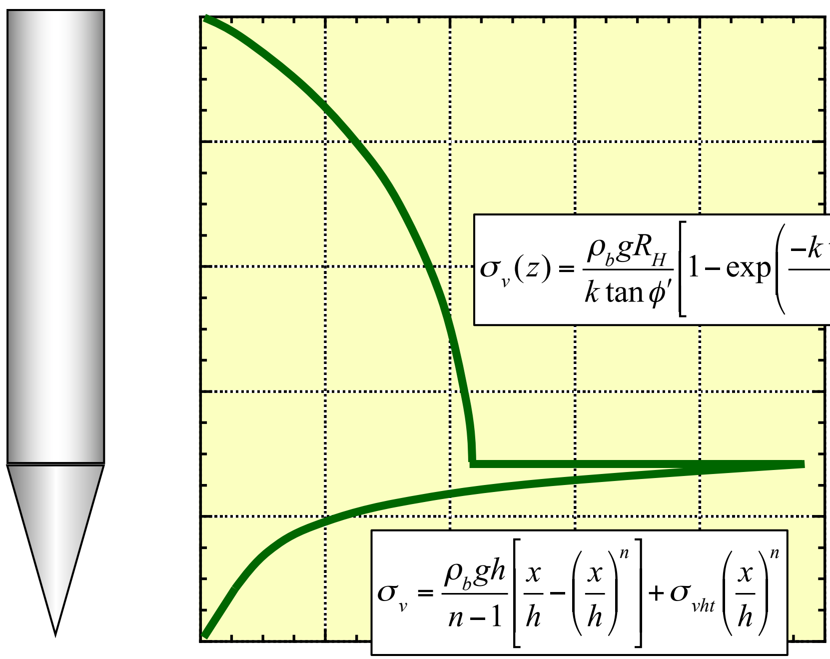
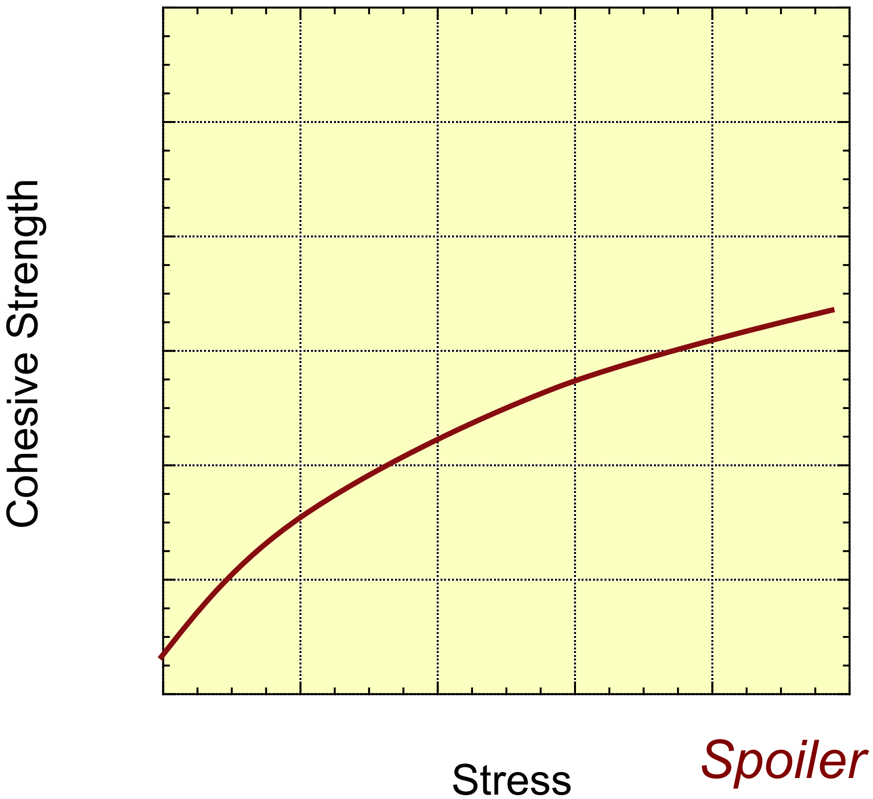


$$\sigma_v(z) = \frac{\rho_b g R_H}{k \tan\phi'}\left[1 - \exp\left(\frac{-k\tan\phi' z}{R_H}\right)\right]$$

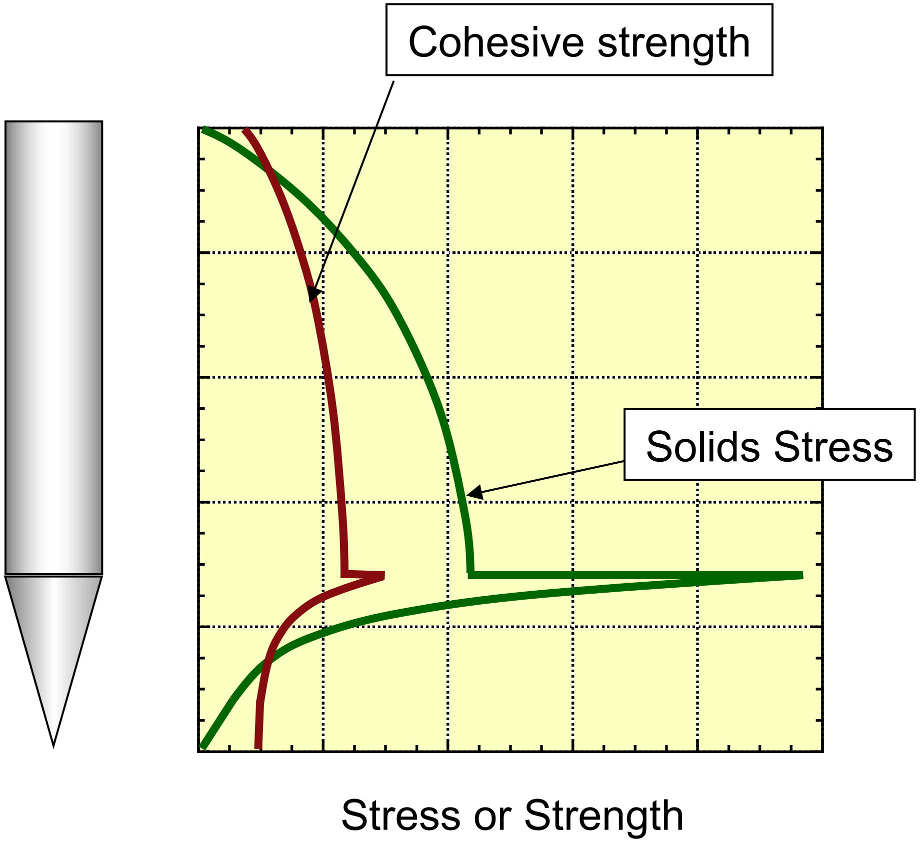
$$\sigma_v = \frac{\rho_b g h}{n-1}\left[\frac{x}{h} - \left(\frac{x}{h}\right)^n\right] + \sigma_{vht}\left(\frac{x}{h}\right)^n$$

Cohesive strength

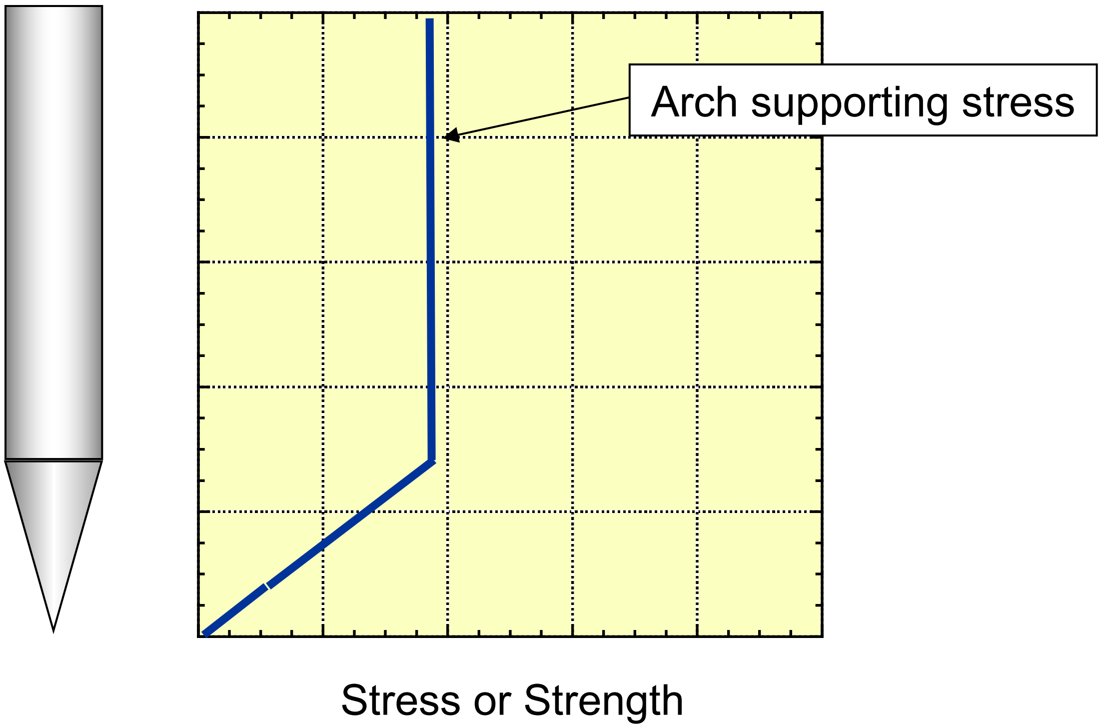


Spoiler alert: shear cell tester!

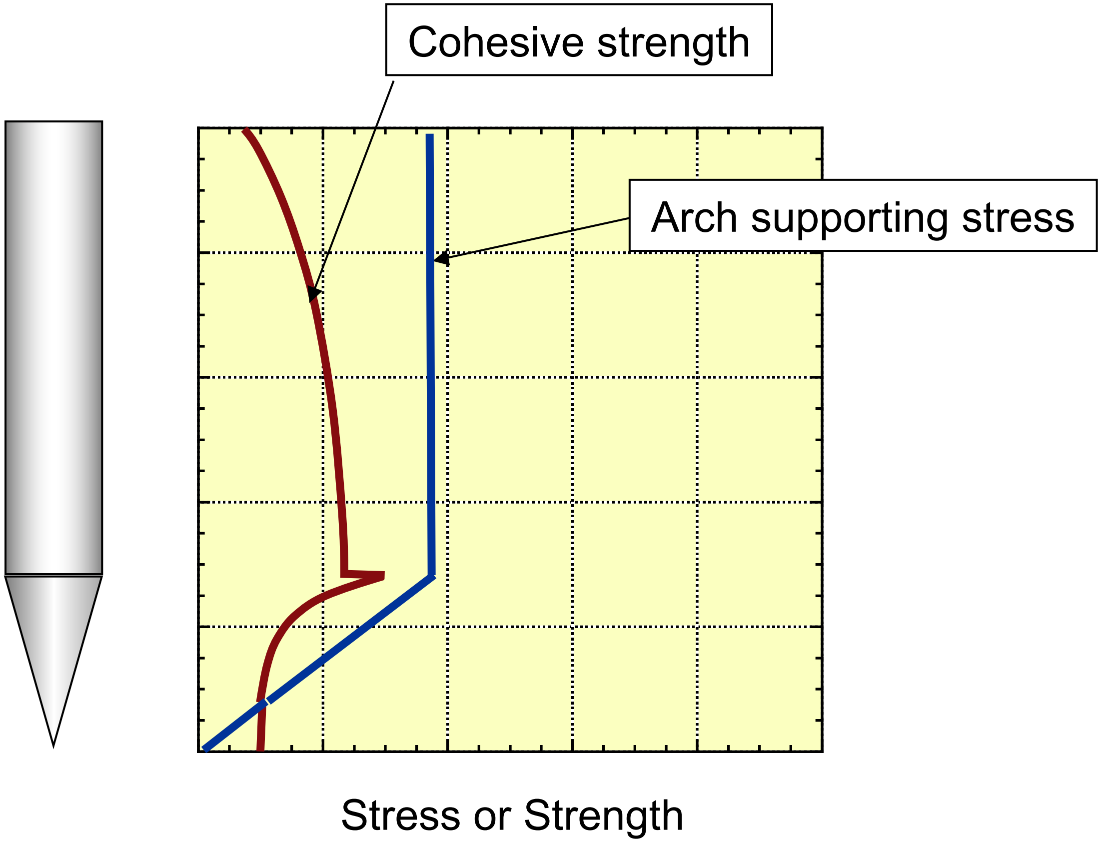
Cohesive strength



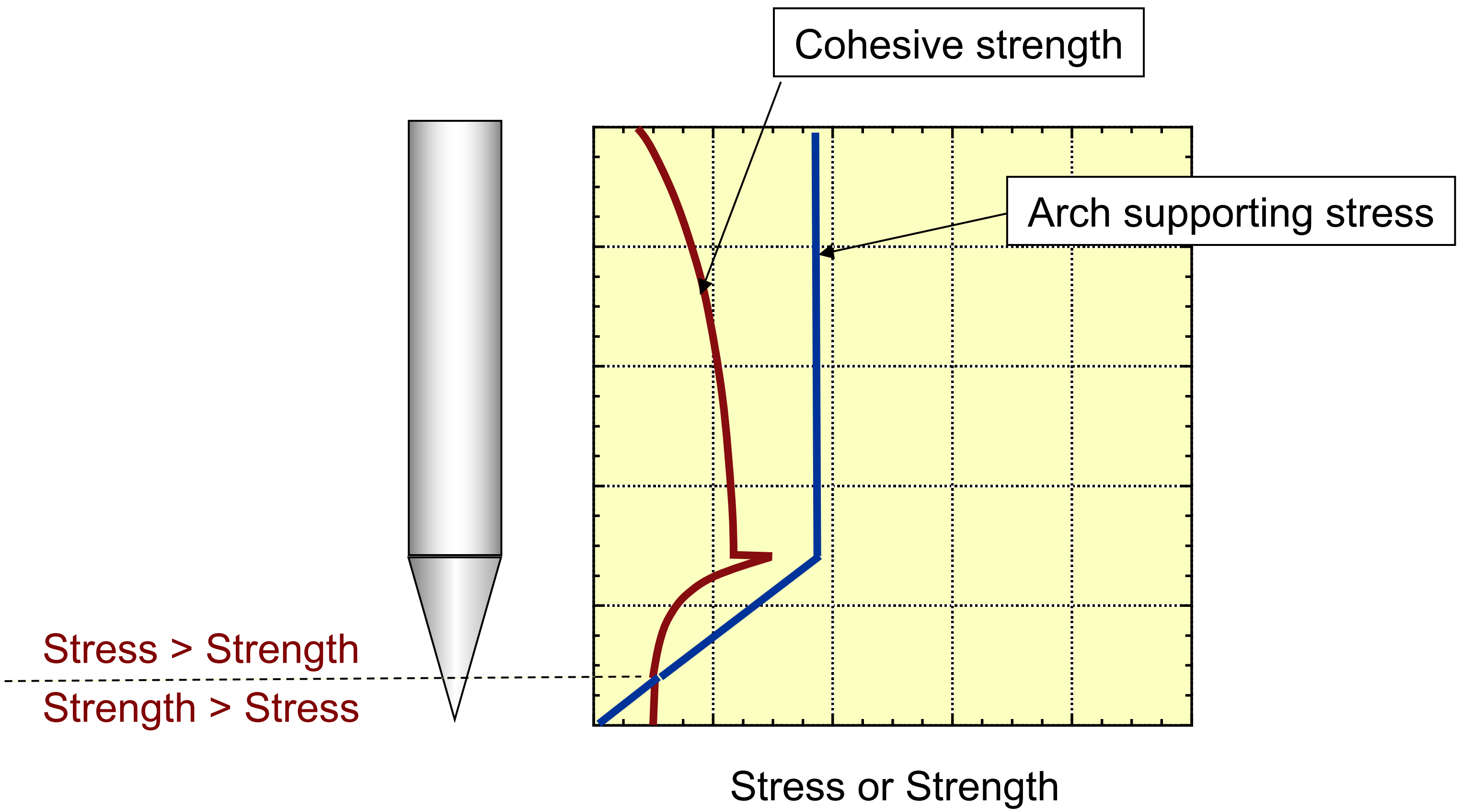
Arch stress



Arch stress


Cohesive strength
Arch supporting stress
Stress or Strength

Arch stress


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

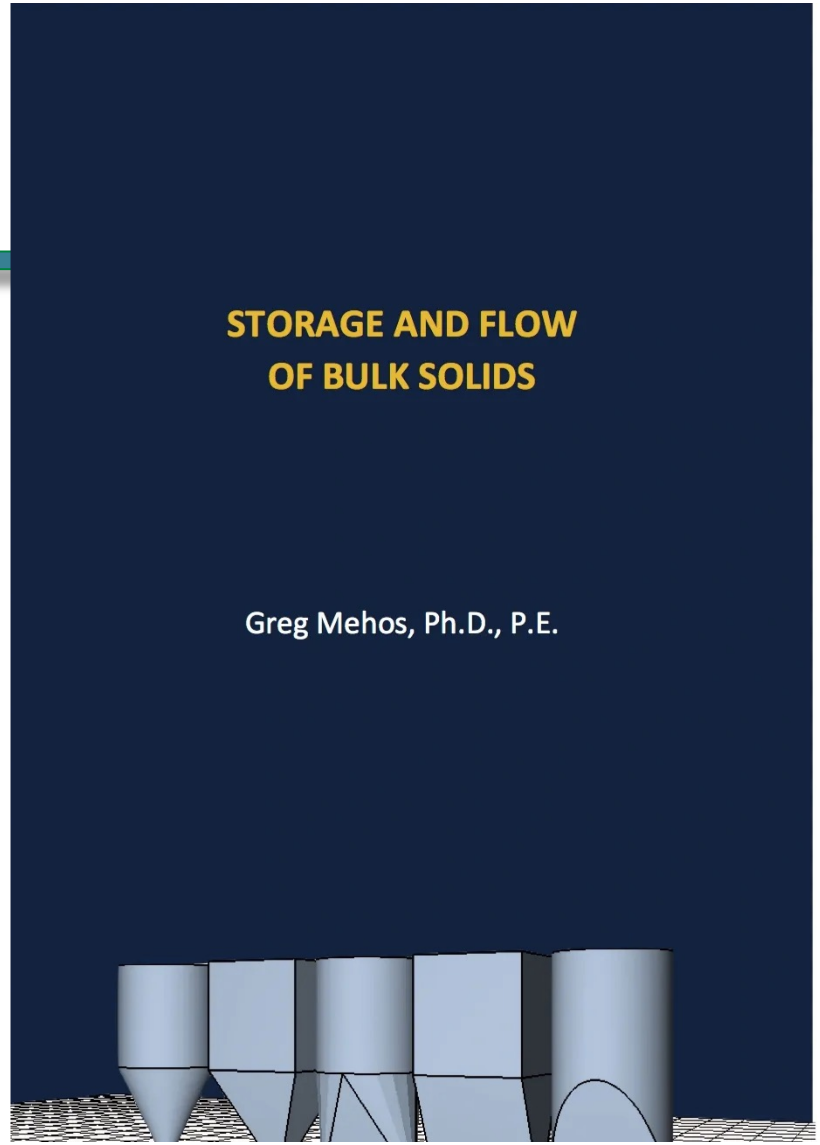
Keys to reliable flow

Designer

- Size hopper outlet to ensure flow of powder with known cohesive strength
- Specify hopper angle and wall material to allow mass flow
- Size outlet to allow desired discharge rate

Formulator

- Reduce cohesive strength by increasing particle size, reducing moisture content, adding flow aid.
- Add lubricant or granulate to ensure low wall friction
- Formulate blend to allow desired discharge rate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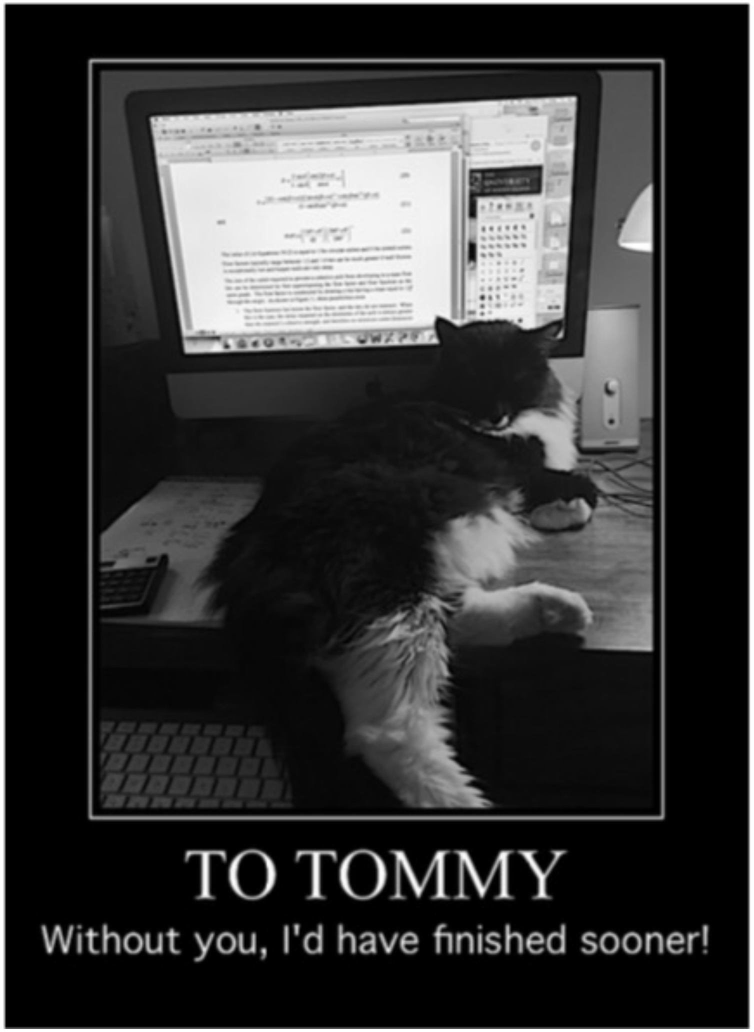

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