# CHBE 344: Unit Operations 1

# How is it made?

Tortilla chips

Paper towels

Canned tomatoes

Sugar

Chocolate

# CHBE 344: Course Overview

Unit 1: Characterization and Creation of Particles

Unit 2: Mechanical Separations

Unit 3: Thermal Separations and Other Unit Operations

# Objectives

By the end of this course students should be able to do the following:

**Apply** computer programming for solving engineering problems and presenting solutions

**Explain and Apply** the basic methods of characterization of particles, droplets and bulk solids

**Calculate** various physical quantities (including efficiency and energy requirements) related to the design and performance of various unit operations (mechanical and thermal) frequently encountered in process engineering

**Design** appropriate and efficient physical separation processes using empirical correlations and theoretical concepts

**Analyze** separation processes with energy and environmental considerations

# How to get an A in CHBE 344

- Come to all classes and participate
  - Read the syllabus carefully
- Complete all homework assignments
  - Work though the assignment by yourself first
  - Triple check your answers and compare with classmates
  - Make sure you understand how to get the correct answer
- Get help when you need it
  - Use the discussion board
  - Come to tutorials and office hours
  - Email the instructor

# Getting Full Credit on Participation and Homework

Participation

- Participate in Kahoot questions during class (sign in with student number)
  - Two Kahoot questions will be chosen at random for each lecture
  - Giving an answer to at least one of the two questions will be counted as participating

Homework assignments (no partial credit)

- Points will only be given if both of these are true (**no partial credit**)
  - You have provided the correct answer with the correct number of significant figures
  - You clearly show your work (print out code)
- When the answer requires a plot (**no partial credit**)
  - Everything must be appropriately labelled (axes, legend, etc.)
  - Font size and data points must be large enough to be easily read
- You must use Matlab or Python to perform your calculations and create plots
  - Use of Excel, graphing calculator, or other method will result in 20% penalty
  - Use of Python will gain 10% bonus points

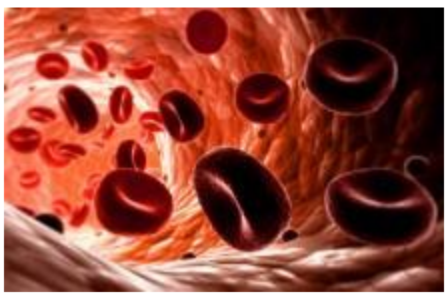
# Unit 1: Characterization and Creation of Particles

Objectives:

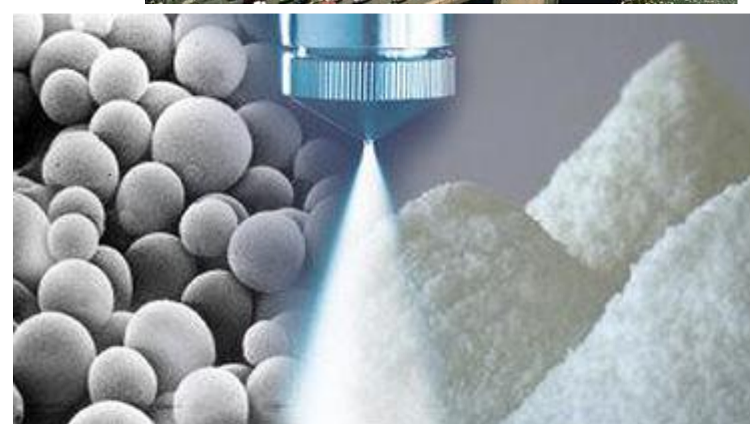
- **Plot** distribution functions of various kinds and **calculate** various moments of the distributions using Matlab or Python
- **Name** several methods for generating particles of various materials and **describe** the general operating principles of each method
- **Calculate** the effect of some process parameters related to particle generation

# Examples of Particles





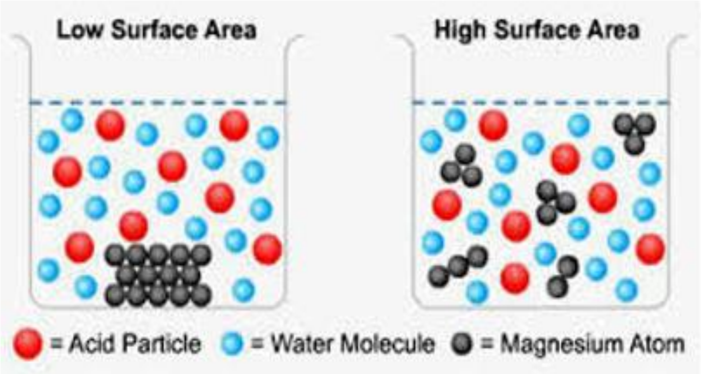




# Particles in Industrial Processes

Cleaning up oil spills (larger droplets contain more oil)

Catalysts in chemical reactions (smaller particles have more surface area per unit mass)




Wood chips in pulp manufacturing (uniform cooking requires uniform particle size)

# Scale of Particles

μm

$10^5$

Pellet products
Crystalline industrial chemicals

$10^4$

Granular fertilisers, herbicides, fungicides
Detergents

$10^3$

Granulated sugars
Spray dried products

$10^2$

Powdered chemicals
Powdered sugar
Flour

$10^1$

Toners
Powder metals

$10^0$

Electronic materials
Photographic emulsions
smoke

$10^{-1}$

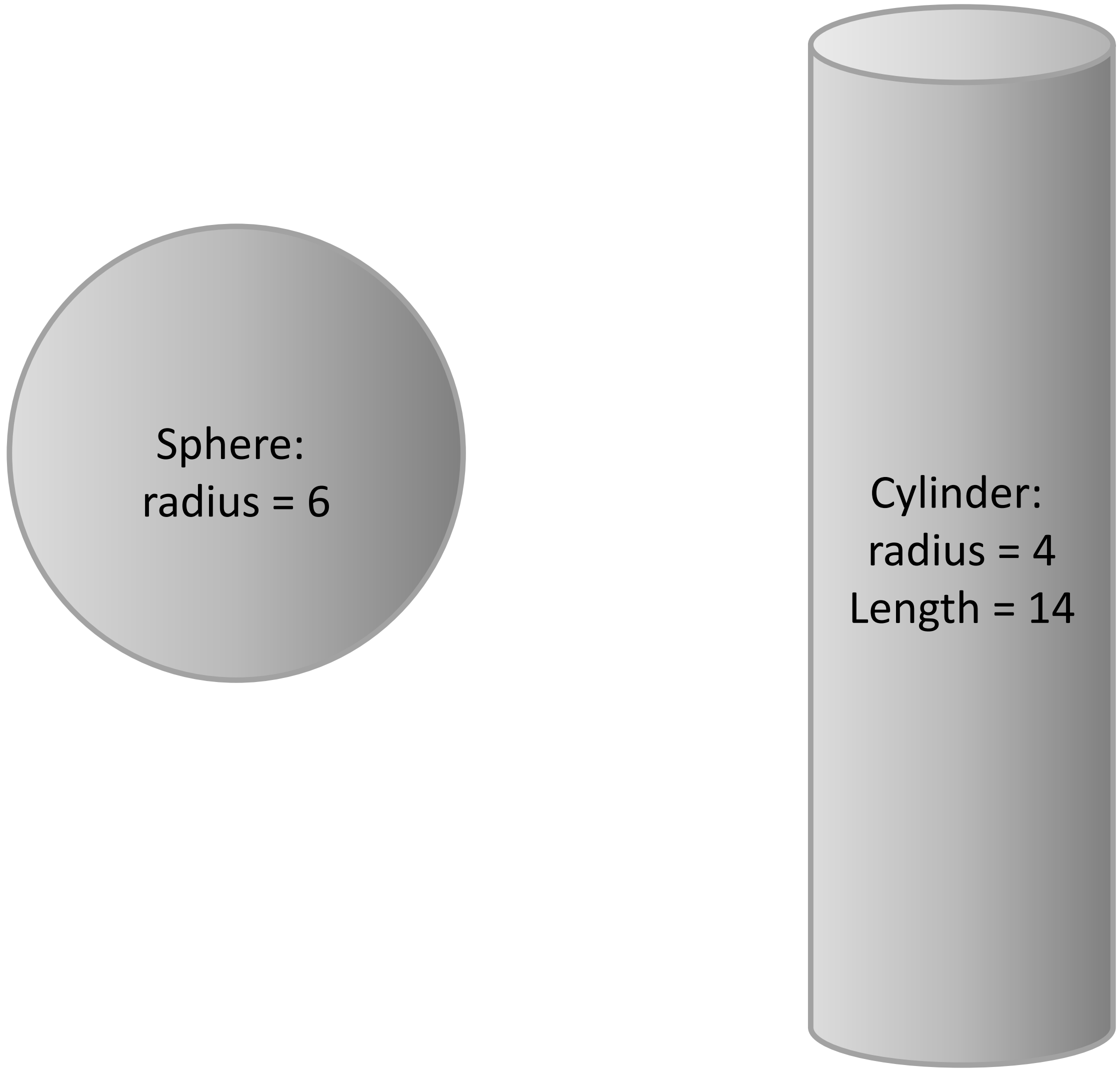
pigments
Fumed silica

$10^{-2}$

Metal catalysts
Carbon blacks

By Antipoff - 28.11.2012 (Wikipedia)

# Which is bigger?




Python

# Particle Size Analysis

- **Equivalent volume diameter** is the diameter of a sphere having the same volume as the particle.

$$\boxed{d_\upsilon = (6V/\pi)^{1/3}}$$

- **Equivalent surface diameter** is the diameter of a sphere having the same surface area as the particle.

$$\boxed{d_s = (S/\pi)^{1/2}}$$

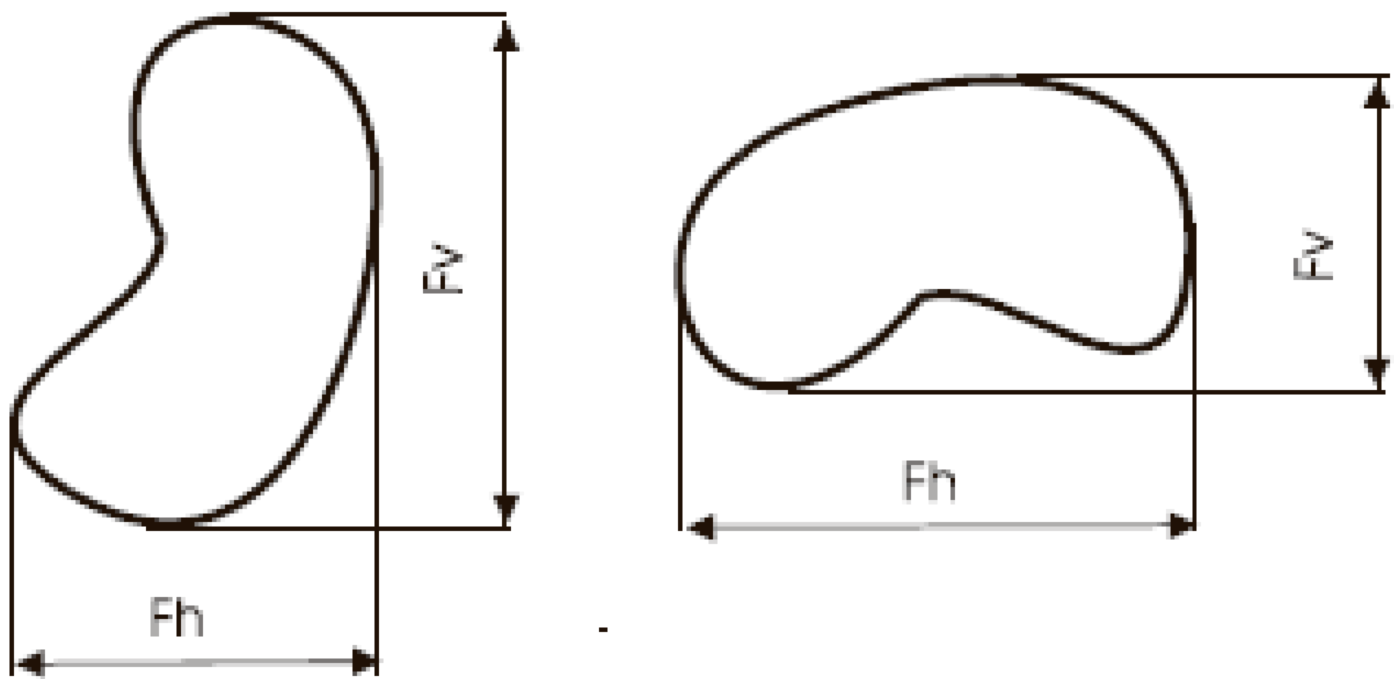
- **The equivalent surface-volume diameter** is the diameter of a sphere having the same surface to volume ratio as the particle. (also known as **Sauter diameter**)

$$\boxed{d_{sv} = 6V/S}$$

# Definitions of Particle Diameters

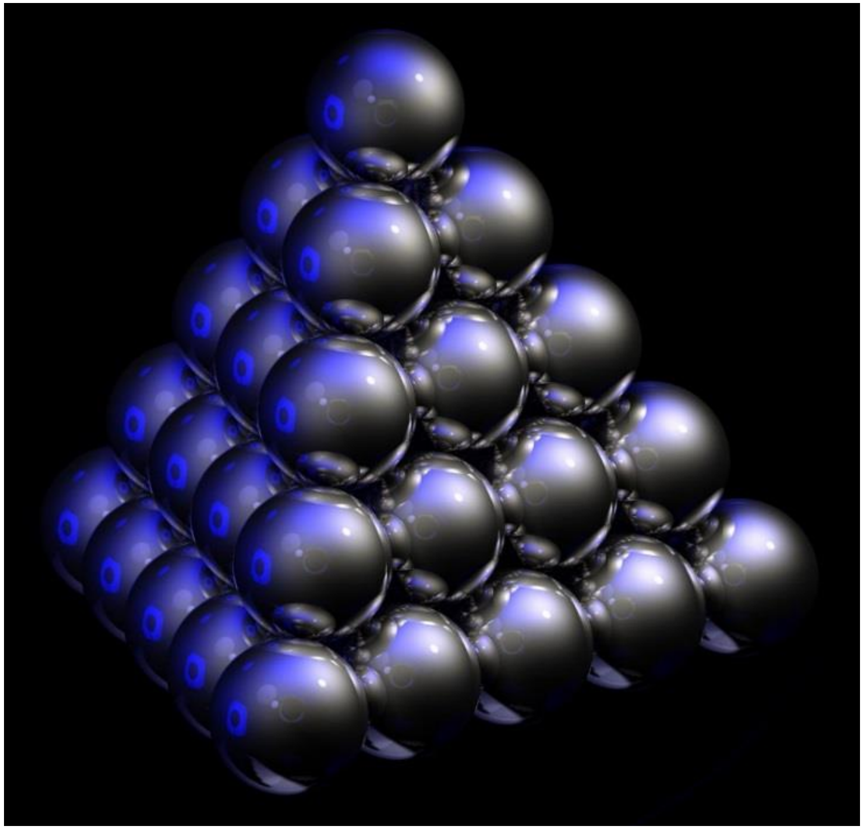
| Symbol | Name | Definition |
|---|---|---|
| $d_{\upsilon}$ | Volume diameter | Diameter of a sphere having the same volume ( ) as the particle |
| $d_S$ | Surface diameter | Diameter of a sphere having the same surface as the particle |
| $d_{S\upsilon}$ | Surface-volume diameter | Diameter of a sphere having the same external surface to volume ratio as a sphere |
| $d_d$ | Drag diameter | Diameter of a sphere having the same resistance to motion as the particle in a fluid of the same viscosity and at the same velocity ($d_{\upsilon}$ approximates $d_s$ when Re is small) |
| $d_f$ | Free-falling diameter | Diameter of a sphere having the same density and the same free-falling speed as the particle in a fluid of the same density and viscosity |
| $d_{stk}$ | Stoke’s diameter | The free-falling diameter of a particle in the laminar flow region (Re<0.2) |
| $d_{\alpha}$ | Projected area diameter | Diameter of a circle having the same area as the projected area of the particle in random orientation |
| $d_{AR}$ | Projected area diameter | Diameter of a circle having the same area as the projected area of the particle in random orientation |
| $d_C$ | Perimeter diameter | Diameter of a circle having the same perimeter as the projected outline of the particle |
| $d_A$ | Sieve diameter | The width of the minimum square aperture through which the particle will pass |
| $d_F$ | Feret’s diameter | The mean value of the distance between pairs of parallel tangents to the projected outline of the particle |
| $d_M$ | Martin’s diameter | The mean chord length of the projected outline of the particle |
| $d_R$ | Unrolled diameter | The mean chord length through the center of gravity of the particle |

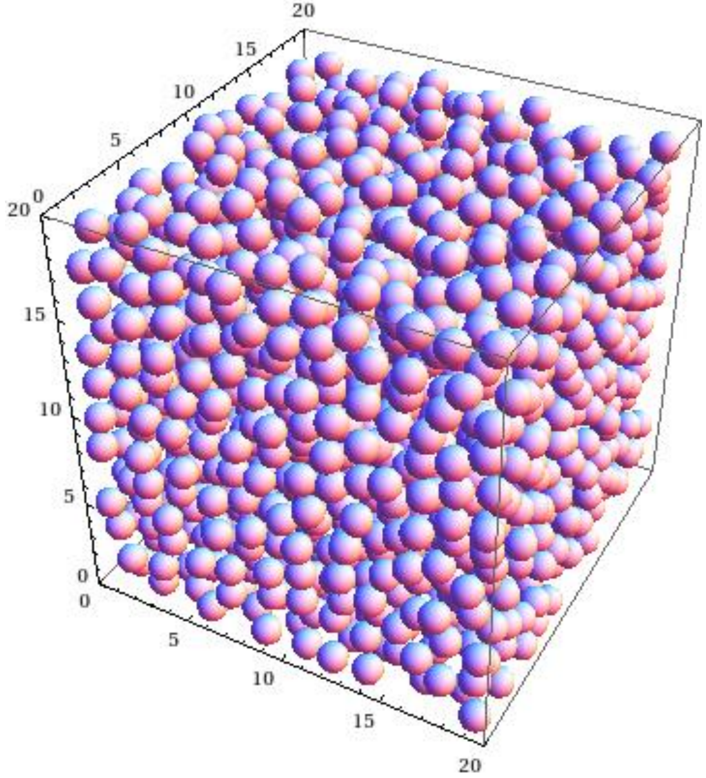
# Feret Diameter




By Unknown (Wikipedia)

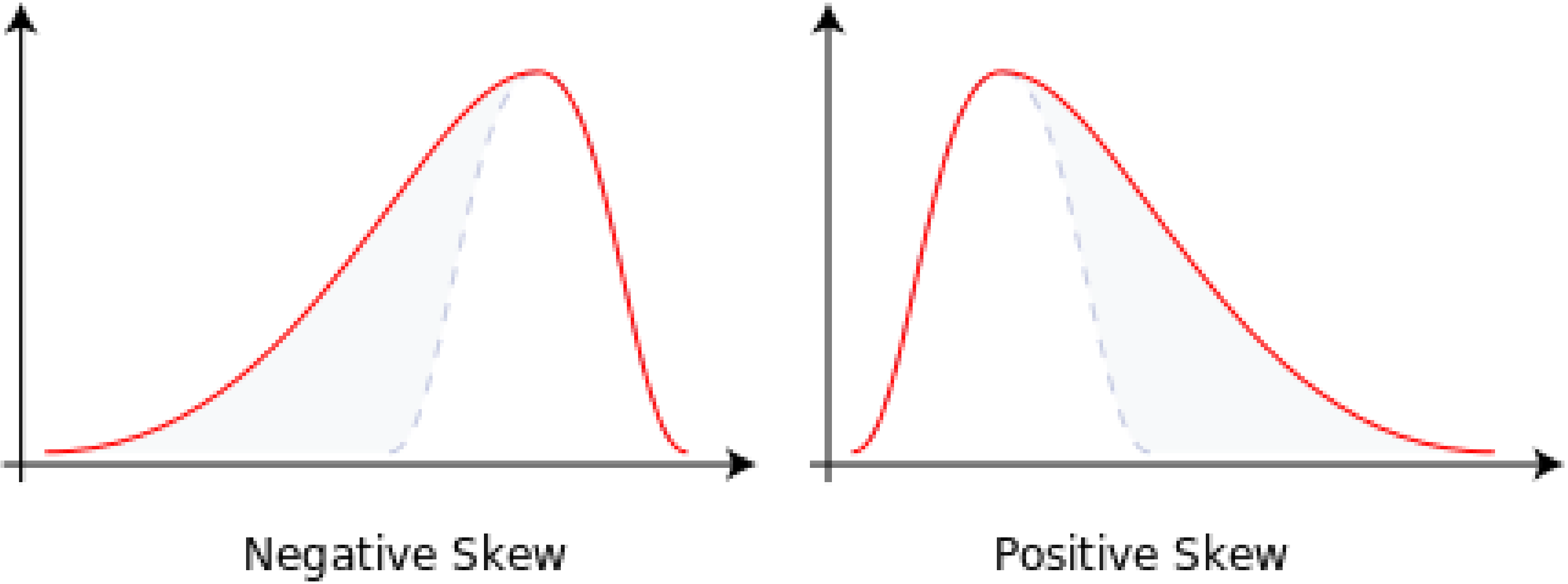
# Packing Density





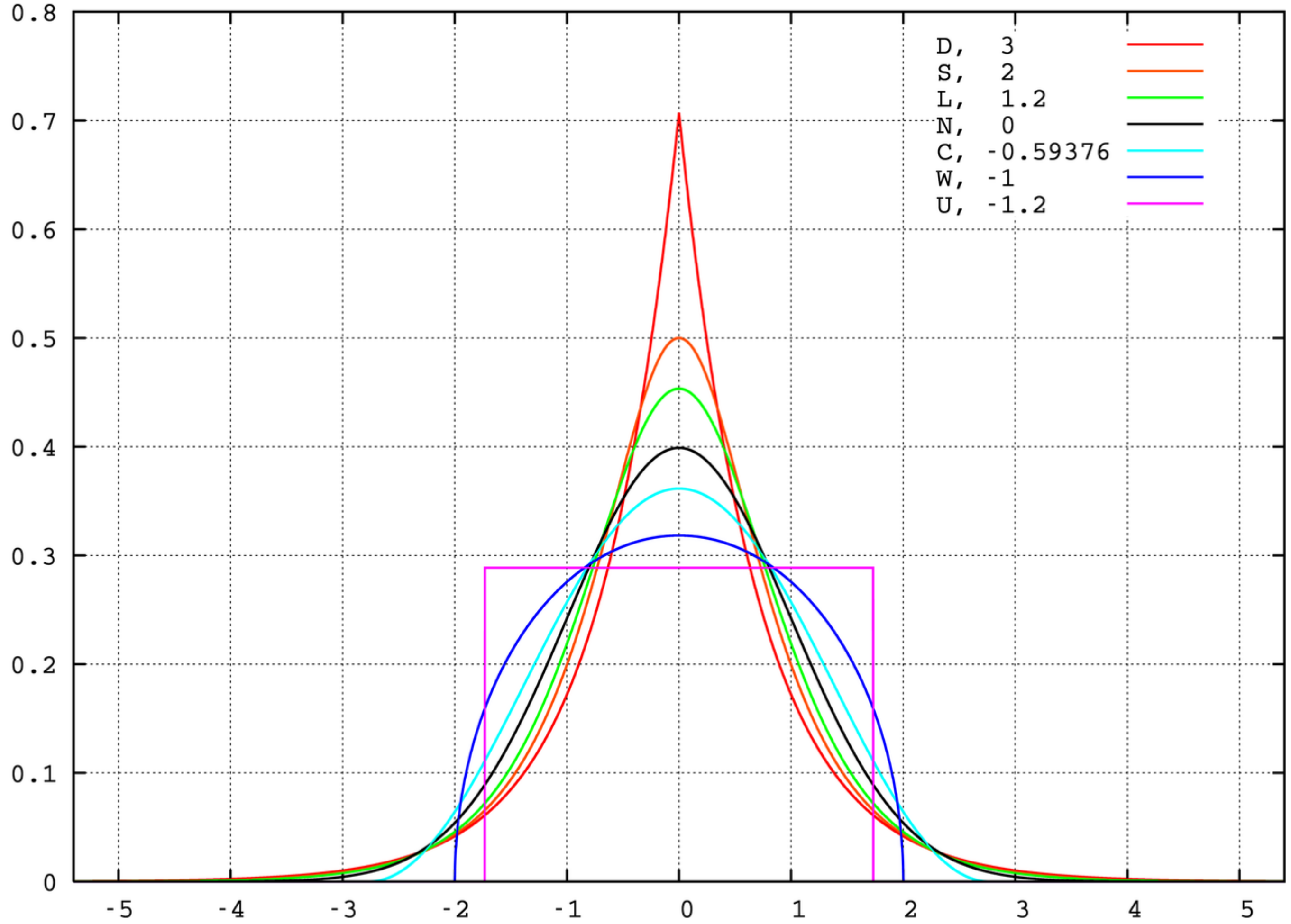
# Distributions of Particles

# Skewness




By Rodolfo Hermans (Godot) at en.wikipedia. - Own work;
https://commons.wikimedia.org/w/index.php?curid=4567445

# Kurtosis or Peakedness



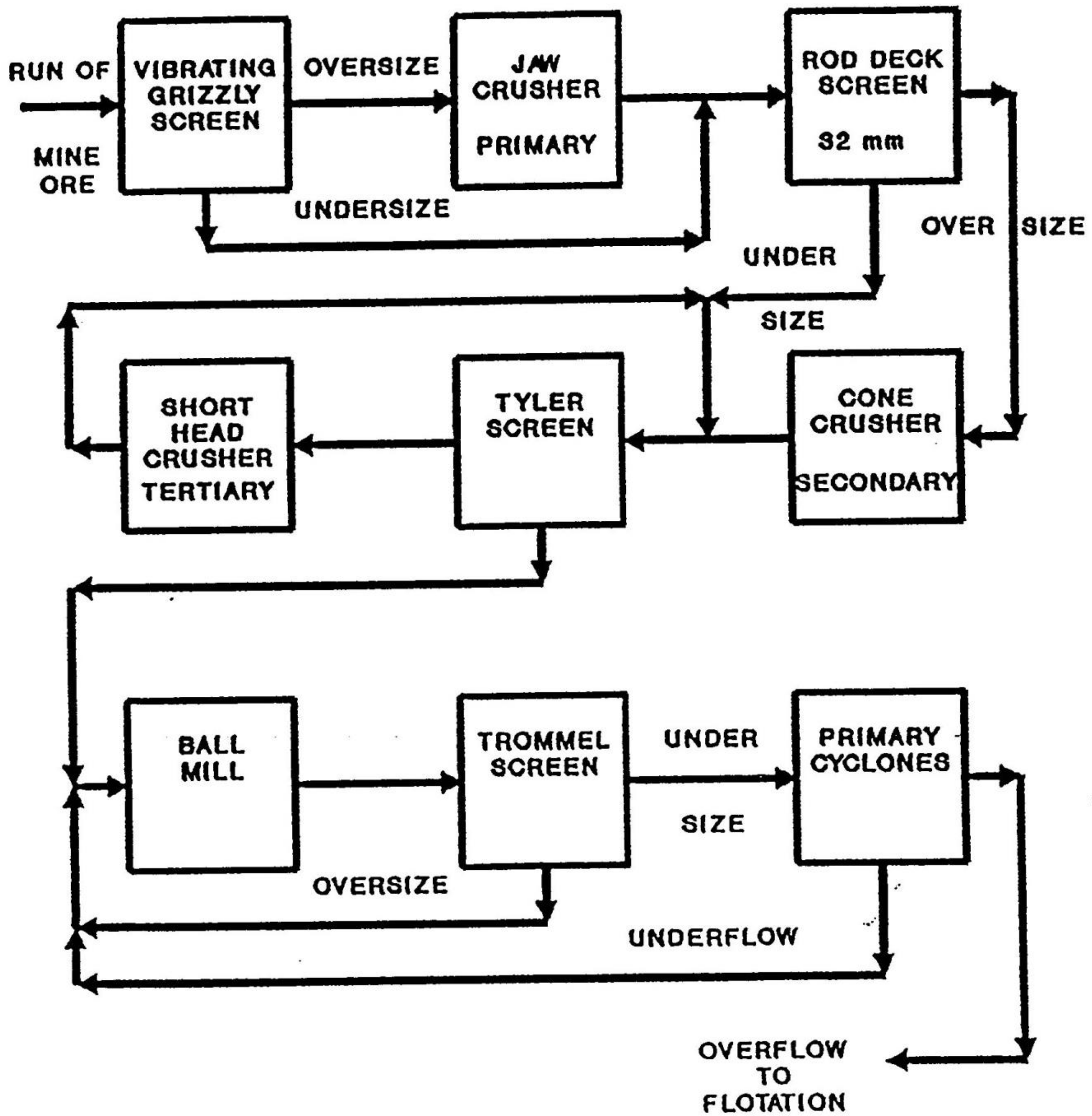

These distributions have the same mean and variance

By MarkSweep - Own work, Public Domain, https://commons.wikimedia.org/w/index.php?curid=1436041

# Size Reduction of Solids: Comminution

Cement (0 – 4:00 min)

# Typical Mineral Processing Flow Sheet



# Equipment for Crushing and Grinding

| **Coarse Material**<br>**(>500 mm)** | **Intermediate Material**<br>**(6mm – 500 mm)** | **Fine Material**<br>**(325 mesh – 6 mm)** |
|---|---|---|
| Stag Jaw Crushers | Crushing Rolls | Buhrstone Mills |
| Dodge Jaw Crushers | Disc Crushers | Roller Mills |
| Gyratory Crushers | Edge Runner Mills | Ball Mills |
| | Conical Crushers | Tube Mills |
| | Stamp Batteries | |
| | Hammer Mills | |
| | Pin Mills | |

# Equipment for Crushing and Grinding

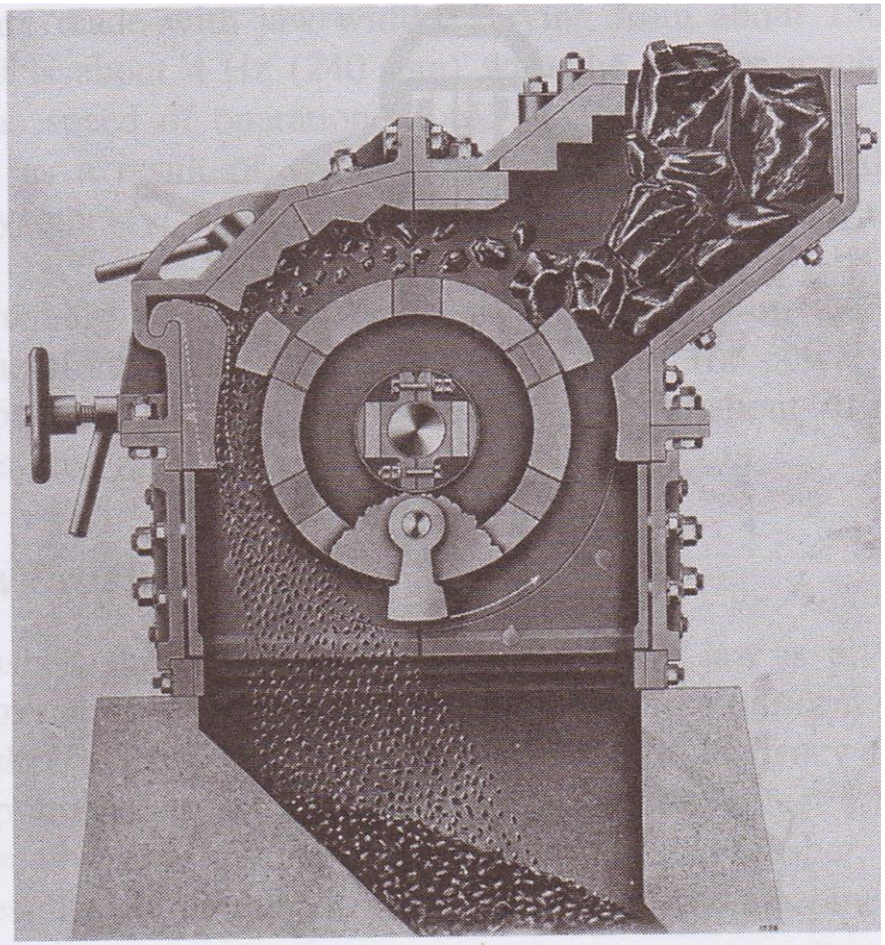
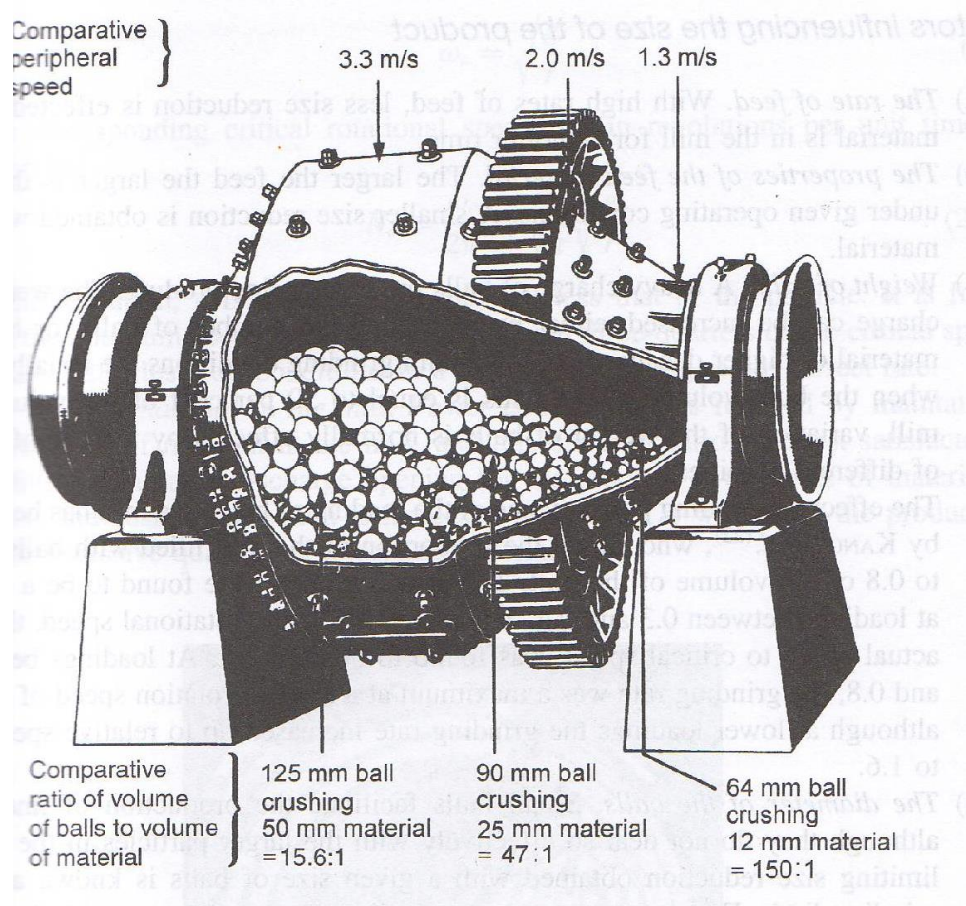


Figure 2.7. Rotary coal breaker




Cut-away view of the Hardinge conical ball mill showing how energy is proportioned to work required

# Bond work index values

| Material | Specific gravity | *Work index $E_i$* (kWh/ton) |
|---|---|---|
| Bauxite | 2.20 | 8.78 |
| Cement clinker | 3.15 | 13.45 |
| Cement raw material | 2.67 | 10.51 |
| Clay | 2.51 | 6.30 |
| Coal | 1.4 | 13.00 |
| Coke | 1.31 | 15.13 |
| Granite | 2.66 | 15.13 |
| Gravel | 2.66 | 16.06 |
| Gypsum rock | 2.69 | 6.73 |
| Iron ore (hematite) | 3.53 | 12.84 |
| Limestone | 2.66 | 12.74 |
| Phosphate rock | 2.74 | 9.92 |
| Quartz | 2.65 | 13.57 |
| Shale | 2.63 | 15.87 |
| Slate | 2.57 | 14.30 |
| Trap rock | 2.87 | 19.32 |

# Bosley Wood Flour Mills - 2015

# Top Down: Liquid Particles

Fuel Injectors (0 – 2:30 min)

# Top Down: Gas Particles

**pH control of Bioreactor**


**Cappuccino Foam**

**Overrun in Ice Cream**

<u>Water Oxygenation</u> (0 – 2:30 min)

# Bottom Up: Gas Particles

**Bread**

**Beverages**

**Cushions**

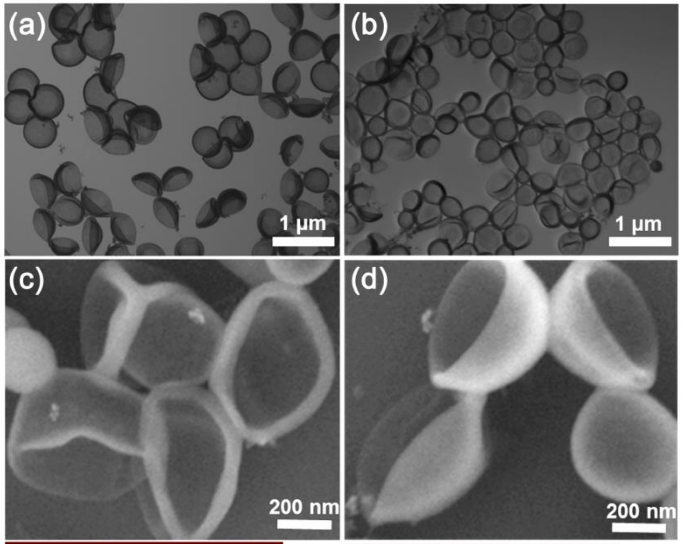
Polyurethane Foam

# Bottom Up: Liquid and Solid Particles

## Condensation

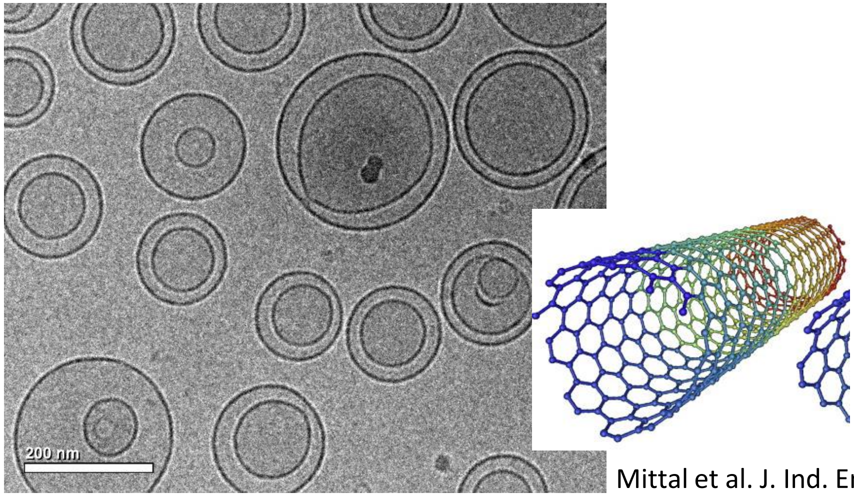
## Precipitation


## Emulsion Precipitation




Bian et al. Chemistry of Materials 2015

## Self Assembly




Mittal et al. J. Ind. Eng. Chem. 2015

## Crystallization