JMBC course : Particle Technology
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Liquid-Solid Filtration

UNIVERSITY of GREENWICH

JMBC course 2019
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Outline

Liquid-Solid Filtration

- Theory of filtration
- Total resistance
- Specific resistance of filter cake

Two case studies:

- Constant rate
- Constant pressure

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Solid-Liquid separation

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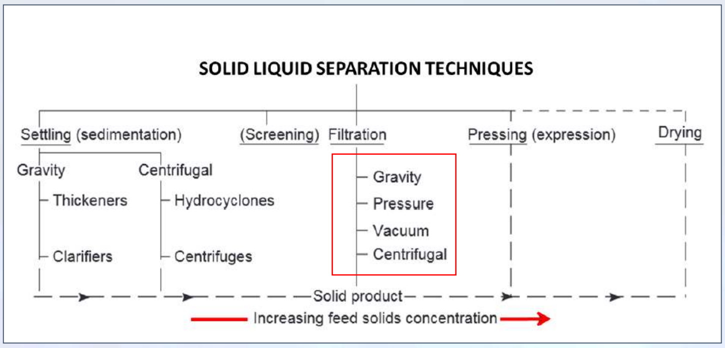
Solid-Liquid separation



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Why filter?

- For separation of:
  - Solids (as product) from liquid waste (e.g. slurry dewatering via filtration in TiO_2 manufacturing)
  - Solids (as waste) from liquid product (e.g. broth filtration for penicillin recovery)
  - Solids (as product) from liquid product (e.g. sugar mud from sugar solution. Precipitated chalk is filtered, washed and pressed (limeX)
  - Solids (as waste) from liquid (waste) (e.g. effluent treatment)

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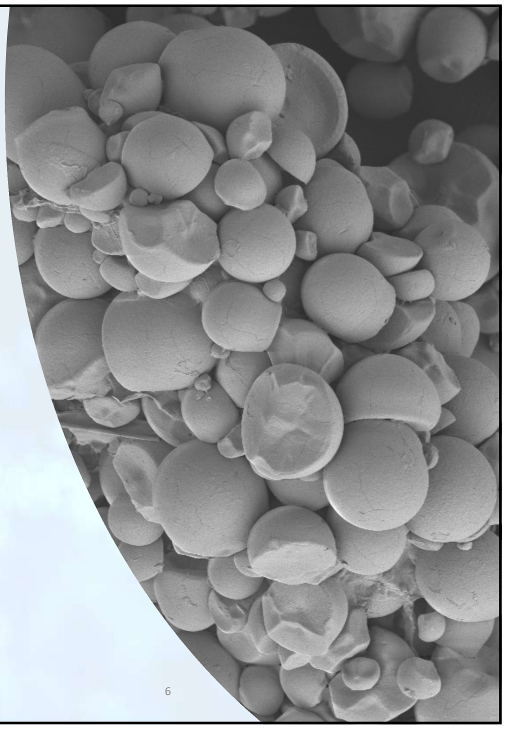
The key particle characteristics

- Particle size
  - Particle size distribution (mass or volume; surface; number)
- Particle shape
  - Shape distribution
- Particle nature
  - Compressible?
  - Sticky?
- Particle chemical properties



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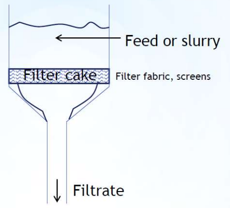
Solid-Liquid separation

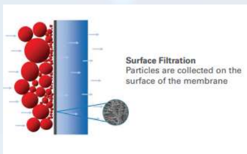
Filtration



Flow of filtrate by:

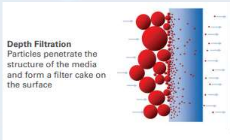
a) Gravity
b) Pressure > atmospheric or upstream of medium
c) Applying vacuum downstream of medium
d) Centrifugal force

Solid-Liquid separation



Surface filtration is a process where the filtrate passes across the thickness of a porous sheet while the suspended solids are retained on the surface of the sheet. A sheet with large pores has low resistance to flow therefore filtrate flow is rapid, however, small particles may pass through resulting in a cloudy filtrate.
Surface filtration allows no cake accumulation. Flow stops when solids cover the pores.
Example: Filtration sterilization of beer using microporous filters.

Solid-Liquid separation



Depth filtration is a process where the filter medium is thick, and solids penetrate the depth of the filter. Eventually, solids block the pores and stop filtrate flow, or solids may break through the filter and contaminate the filtrate.

Once filtrate flow stops or slows down considerably, the filter must be replaced.

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Theory of filtration

Theory of Filtration

1st stage

Particles enmeshed in filter
Reduced surface area
Increased resistance to flow of filtrate

2nd stage

Cake build up
Filtrate encounters 3 types of resistance:
a) Channels and pores of filter
b) Filter medium
c) Filter cake

Fluid flow influenced by pressure differential across the filter

$$Rate\ of\ filtration = \frac{Driving\ force}{Resistance}$$

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Theory of filtration

Total resistance

$$R = \mu \cdot r \cdot (L_c + L)$$

μ - viscosity
r - specific resistance of filter cake
L_c - thickness of filter cake
L - thickness of filter medium

$$L_c = \frac{w \cdot V_c}{A}$$

w - solid content per unit volume of liquid
V_c - volume of liquid passed through filter
A - area of filter surface

$$R = \mu \cdot r \cdot \left[\frac{w \cdot V_c}{A} + L\right]$$

Theory of filtration

Specific resistance of filter cake

$$r = \frac{k(1-\varepsilon)S^2}{x^3 \rho_s}$$

k- constant
ε - Porosity of the cake (void volume)
S – specific area of solid particles
ρ- density of solids
x- size of the particles

Equation for flow through the filter under the driving force of the pressure drop

$$Rate\ of\ filtration = \frac{Driving\ force}{Resistance}$$

$$\frac{dV_c}{dt} = \frac{\Delta P \cdot A}{\mu \cdot r \cdot \left[\frac{w \cdot V_c}{A} + L\right]} \quad \textbf{Eq. 1}$$

Theory of filtration

Typical Values of Specific Resistance, **r**

Material	Upstream filtration pressure (kN/m^2)	**r** m^{-2}
Carboraffin charcoal	110	4×10^{13}
	170	8×10^{13}
Calcium carbonate (precipitated)	270	3.5×10^{14}
	780	4.0×10^{14}
Ferric oxide (pigment)	270	2.5×10^{15}
	780	4.2×10^{15}
Mica clay	270	7.5×10^{14}
	780	13×10^{14}
Colloidal clay	270	8×10^{15}
	780	10×10^{15}
Gelatinous magnesium hydroxide	270	5×10^{15}
	780	11×10^{15}
Gelatinous aluminium hydroxide	270	3.5×10^{16}
	780	6.0×10^{16}
Gelatinous ferric hydroxide	270	3.0×10^{16}
	780	9.0×10^{16}
Thixotropic mud	650	2.3×10^{17}

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1. Filtration at constant rate

Important in early stages
Resistance to flow is constant → rate is constant

$$\int \frac{dV}{Adt} = \frac{V}{A \cdot t} = \frac{\Delta P}{\mu \cdot r \cdot \left[\frac{w \cdot V_c}{A} + L\right]} \quad \textbf{Eq. 2}$$

$$\Delta P = \frac{V}{A \cdot t} \cdot \mu \cdot r \cdot \left[\frac{w \cdot V_c}{A} + L\right] \quad \textbf{Eq. 3}$$

APPLICATIONS

1. Eq. 2 gives quantity of liquid passing through filter in a given time.
2. Pressure drop required for any desired flow rate can be found from Eq. 3.
3. Resistance of filter cake can be determined.

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2. Constant pressure filtration

Important once cake built up
Flow occurs under constant pressure differential

i.e. ΔP in Eq. 1 is constant

$$\mu \cdot r \cdot \left[\frac{w \cdot V}{A} + \mathrm{L}\right] dV = \Delta P \cdot A \cdot dt$$

$$\int_{V=0}^{V=V} \mu \cdot r \cdot \left[\frac{w \cdot V}{A} + \mathrm{L}\right] dV = \int_{t=0}^{t} \Delta P \cdot A \cdot dt$$

$$\mu \cdot r \cdot \left[\frac{w \cdot V^2}{2A} + \mathrm{LV}\right] = \Delta P \cdot A \cdot t$$

Rewriting: $$\frac{t \cdot A}{V} = \frac{\mu \cdot r \cdot w}{2\Delta P\left(\frac{V}{A}\right)} + \frac{\mu \cdot r \cdot L}{\Delta P}$$

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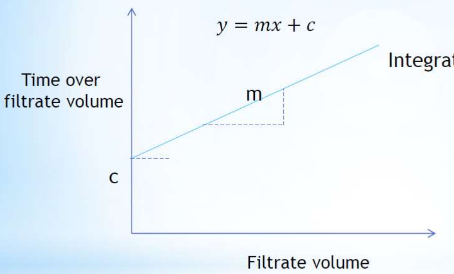
CONSTANT PRESSURE FILTRATION
Example



Integrate general equation at constant ΔP

$$\frac{dt}{dV} = \frac{\mu r c}{\Delta P A^2} V + \frac{\mu R}{A \Delta P}$$

To give:

$$\frac{t}{V} = \frac{\mu r c}{2\Delta P A^2} V + \frac{\mu R}{A \Delta P}$$

$$\frac{t}{V} = mV + c$$

Need to know:

-Viscosity (μ)
- Density
-Pressure (ΔP)
-Filter area (A)
-Slurry mass fraction
-Cake moisture

We can calculate:

Mass of dry cake deposited (c)
Specific resistance (α)
Filter medium resistance (R_m)

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Equipment selection

FACTORS TO CONSIDER

-The properties of the fluid, particularly its viscosity, density and corrosive properties.
-The nature of the solids—its particle size and shape, size distribution, and packing characteristics.
-The concentration of solids in suspension.
-The quantity of material to be handled, and its value.
-Whether the valuable product is the solid, the fluid, or both.
-Whether it is necessary to wash the filtered solids.
-Whether very slight contamination caused by contact of the suspension or filtrate with the various components of the equipment is detrimental to the product.
-Whether the feed liquor may be heated.
-Whether any form of pretreatment might be helpful.
-Equipment maintenance.
-Product value.

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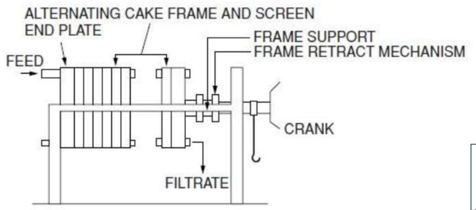
Equipment

Plate and frame filters



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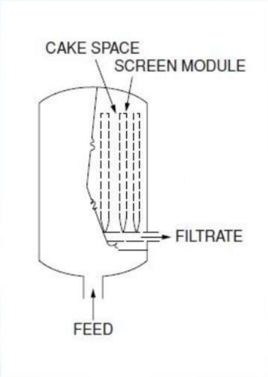
Equipment

Vertical leaf filters



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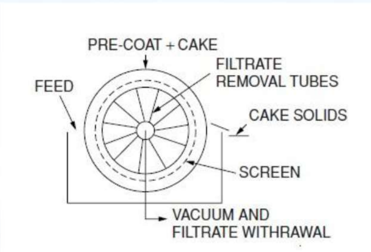
Equipment

Rotary vacuum drum filters



Scrapper discharge
Precoat discharge

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Cross-flow filtration

- An alternative method of reducing the resistance to filtration is to recirculate the slurry and thereby maintain a high velocity of flow parallel to the surface of the filter medium.
- In cross- flow filtration the suspension flows with high speed tangentially to the filter surface, preventing the formation of a cake.
- Typical recirculation rates may be 10–20 times the filtration rate.

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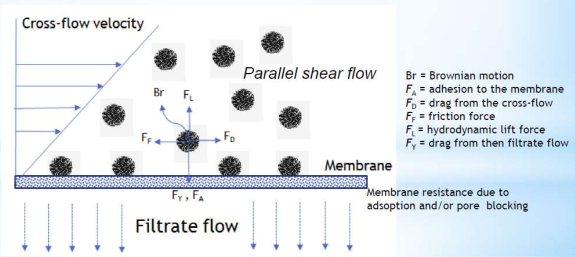
Cross-flow filtration

-Only a small flow of liquid passes through the filter medium.

-A certain layer of solids accumulates in the boundary layer on the filter surface, and reduces the flow of filtrate.

-After an initial period, a dynamic equilibrium is established between **convective** transport of solids to the filter surface and removal of solids by turbulence and by **diffusion**.



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