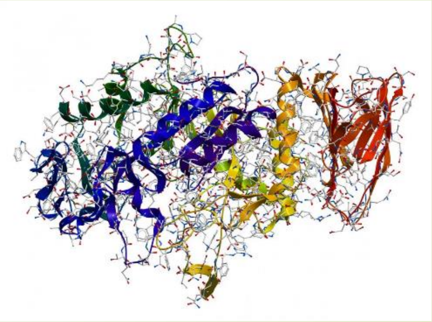
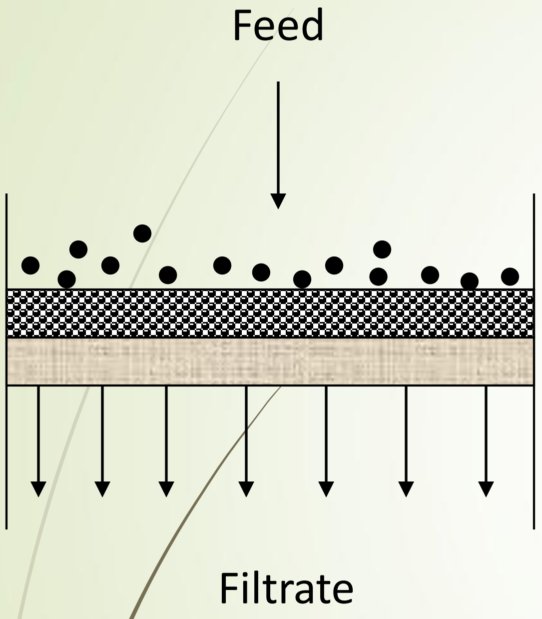


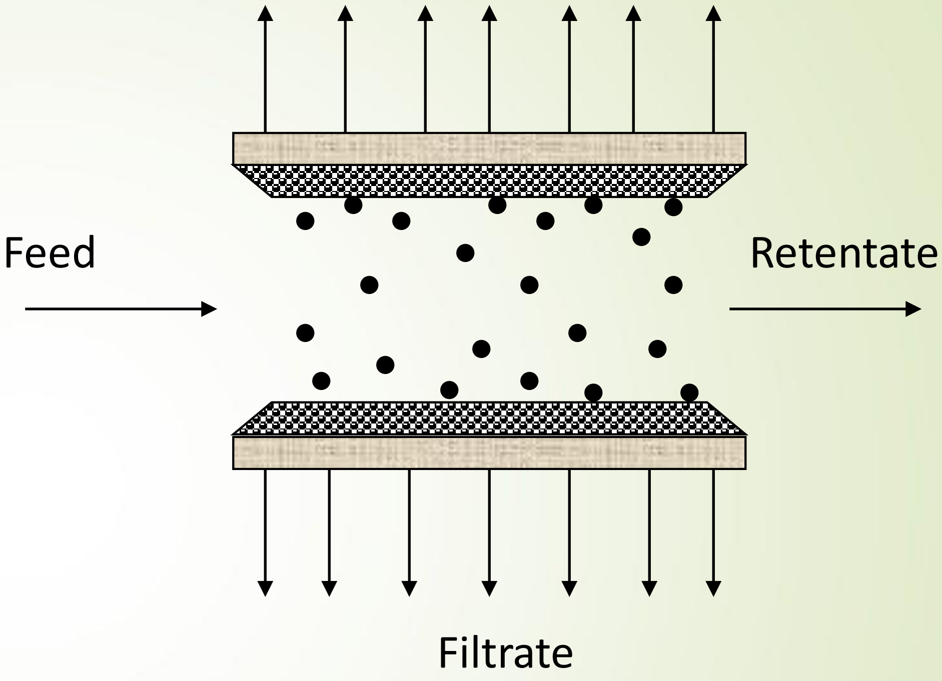
CEN-CHE 422
ENZYME ENGINEERING

Enzyme Separation and Purification Methods-2

FILTRATION



Dead-end Filtration



Cross-flow Filtration

Used for separation of cell and large molecules from fermentation medium

The driving force is the pressure difference (ΔP).

Carried out in a positive pressure difference or vacuum.

The filtration rate depends on the properties of the solid and fluid.

- Crystal structure, low viscosity.
- Incompressible fluids are easy to filter.
- The fermentation medium is non-Newtonian due to the cells and makes filtration difficult.

A cake is formed by the accumulation of solid on the filter surface.

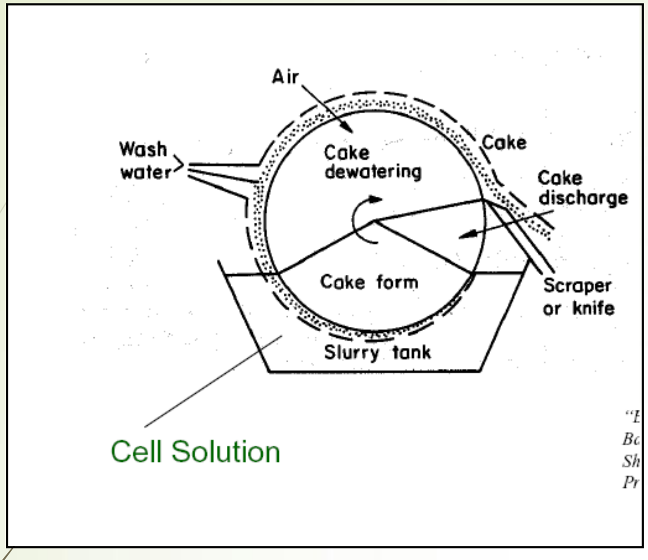
- Many microbial cakes are compressible; that is, as the pressure drop increases during filtration, the porosity of the cake decreases. This reduces the filtration rate.

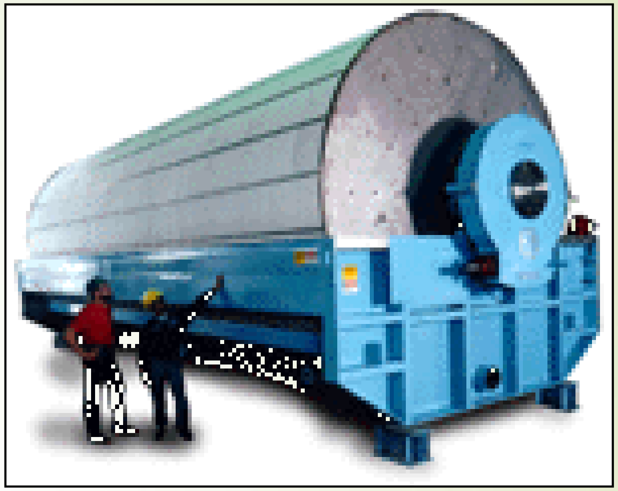
Filter aids

- Substances with high porosity (eg diatomaceous earth $\varepsilon = 85\%$).
- They are added to the medium to increase the porosity, which decreases as the cake forms.
- However, they also absorb the liquid and reduce the clarity of the filtrate.

No contamination during filtration

Rotary Vacuum Filters





- As the drum rotates under vacuum, the cells adhere to the surface as a thin plate.
- The cell layer thickness thickens with cake formation.
- The solid layer is washed with water on its way to the exit point and the air and water are removed.
- At the exit, the cake is cut with a knife.
- The vacuum in the body creates the driving force for the fluid and air flows.

- Particle size > 10 μm
- Yeast, animal and plant cells
- In antibiotic (penicillin) production, wastewater cleaning

https://www.youtube.com/watch?v=m2d-Ov9RIM4

The rate of filtration: (driving force)/(resistance)
(Poiseuille Law)

$$\frac{1}{A}\frac{dV}{dt}=\frac{\Delta P g_C}{(r_m+r_c)\mu}$$

ΔP	**pressure drop through the cake and filter medium (N/m² = kg/m² s)**
V	**the volume of filtrate (m³)**
A	**the surface area of the filter (m²)**
μ	**filtrate viscosity (kg/m s)**
r_m	**the resistance of the filter medium (m^{-1})**
r_c	**the resistance of the cake (m^{-1})**
g_c	**1 kg m/s² N**

r_m characteristic of the filter medium
As cake resistance increases during filtration r_c is higher than r_m

$$r_c >> r_m$$

Cake resistance r_c :

$$r_c=\alpha\frac{W}{A}=\alpha\frac{CV}{A}$$

$$W=CV$$

W	**total weight of the cake on filter**
C	**the weight of the cake deposited per unit volume of filtrate**
α	**average specific resistance of the cake**

$$\alpha=\alpha^{'}(\Delta P)^{s}$$

s=cake compressibility (s=1 easy compressible solids, s=0 incompressible solids)

α' = a constant depending on the mophology and size of particles in the cake

or

$$\alpha=\frac{K_v a^2(1-\varepsilon)}{\varepsilon^3\rho_p}$$

Kv	**The shape factor of the particle**
a	**The specific surface area of the particle**
ε	**The porosity of the cake**
ρ_p	**the density of the particle**

$$a=\frac{\text{surface area of a particle}}{\text{volume of a particle}}$$

$$a=\frac{\text{total volume of the cake}-\text{volume of the particles}}{\text{total volume of the cate}}$$

$$\frac{d(V/A)}{dt}=\frac{\Delta P}{(r_m+\alpha\frac{CV}{A})\mu}$$

t = 0 V = 0
t = t V= V

Integration with the BCs yields:

$$\boxed{V^2+2VVo=Kt}$$

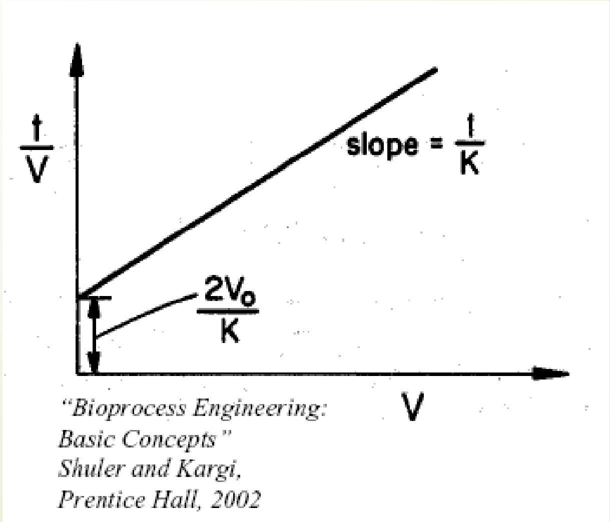
Ruth Equation *for constant pressure filtration*

$$Vo=\frac{r_m}{\alpha C}A \qquad K=(\frac{2A^2}{\alpha C\mu})\Delta P$$

$$\frac{t}{V}=\frac{1}{K}(V+2Vo)$$

✓A plot of (t/V) versus V yields a straigth line with a slope of 1/K ve intercept of 2Vo/K.

✓The values for r_m ve α are calculated from experimentally determined values of K and Vo.



"Bioprocess Engineering: Basic Concepts" Shuler and Kargi, Prentice Hall, 2002

How to increase the filtration rate:

$$\frac{d(V/A)}{dt} = \frac{\Delta P}{(r_m + \alpha \frac{CV}{A})\mu}$$

- Increase the filter area A: larger filtration equipment and greater capital cost.
- Increase the filtration pressure drop (ΔP):
  - For compressible cakes, α increases with ΔP. However, this lowers filtration rate. In practice, $\Delta P<0.5$
  - ΔP can only be increased by reducing s (addition of filter aid in the broth can reduce *s* to some extent.)
- Reduce the cake mass (W=CV): This is achieved by reducing the thickness of cake deposited per revolution of the drum (in continuous equipment)
- Reduce the fluid viscosity: Material to be filtered is diluted.
- Reduce the specific cake resistance (α):

$$\boxed{\alpha = \frac{K_v a^2 (1-\varepsilon)}{\varepsilon^3 \rho_p}}$$

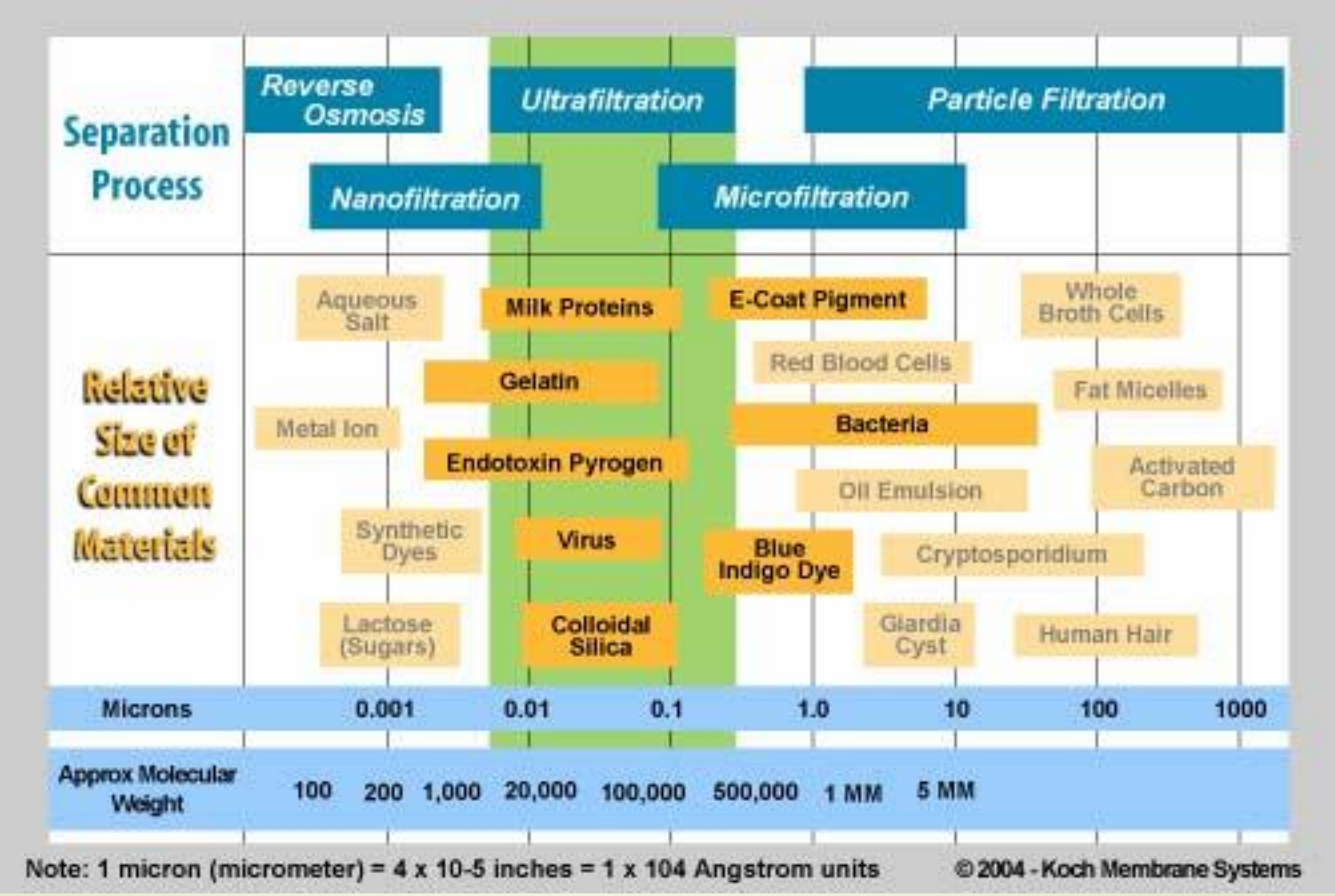
How to decrease α?

- Increase the porosity (ε): Cake porosity usually decreases as cells filtered. Using filter aid reduces this effect.

- Reduce the shape factor (Kv): It may be possible to change the cell morphology by manupulating fermentation conditions.

- Reduce the specific area of the particles (a): Achieved by changing the conditions of fermentation and broth pretreatment.

Ultrafiltration, Microfiltration



Note: 1 micron (micrometer) = 4 x 10-5 inches = 1 x 104 Angstrom units

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Membranes

- **Ultrafiltration (UF) membranes :**

  Pore size = 0.001-0.1 μm

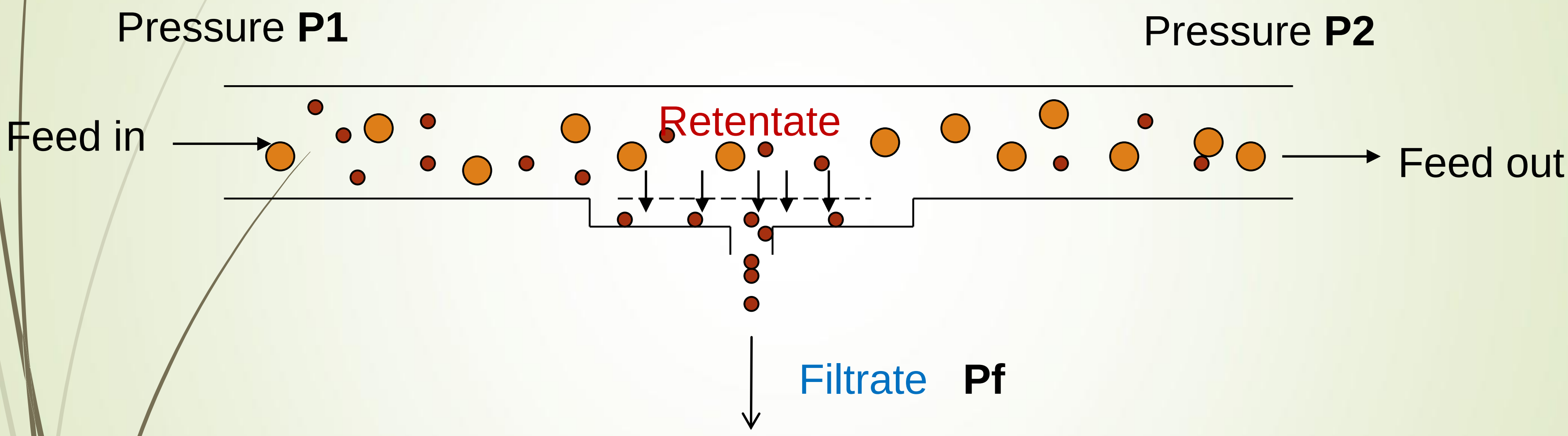
  Molecular weight cutoff (MWCO) = 1000 Dalton – 1,000,000 Da

- **Microfiltation (MF) membranes**

- **0.1 μm or larger pores**

Membrane materials:
Cellulose acetate (CA),
polysulfone (PS),
polyethersulfone (PES),
polyamide, polyimide, ..

Cross-flow UF



Pressure **P1**

Pressure **P2**

Feed in

Retentate

Feed out

Filtrate **Pf**

Filtrate: Filtered part
Retentate: Remaining part on the membrane

The pressure that makes the liquid flow

$$\Delta P = P_i - P_o$$

For laminar flow (Hagen-Poiseuille Equation).

$$-\Delta P = \frac{C_1 \mu L V}{d^2} = \frac{C_2 \mu L Q}{d^4}$$

Here:
L = pipe lenght
μ = fluid viscosity
Q = volumetric flow rate
D = pipe diameter

For turbulent flow::

$$-\Delta P = \frac{C_3 f L V^2}{d} = \frac{C_4 f L Q^2}{d^5}$$

Here:
f = friction factor depending on Re number

Transmembrane Pressure (TMP, ΔP_M):

The driving force that allows the liquid to pass through the membrane

$$\Delta P_M = \frac{P_i + P_o}{2} - P_f$$

Here:
P_f= filtrate pressure; about atm pressure
$P_f = P_{atm}$

$$\Delta P_M = P_i - \frac{1}{2}\Delta P$$

For high ΔP_M;
high inlet pressure (Pi) and low flow rate (Q) is required!

Filtrate Flux Rate: (J: mol/m² s): is function of TMP

$$J = \frac{\Delta P_M}{(r_G + r_M)}$$

Here:
r_G and r_M are cake resistance and membrane resistance, respectively,
r_M is constant
r_G changes with solid mass and cross-flow rate

The filtration flux J also depends on the liquid flow rate !
There is usually an optimum fluid flow rate that maximizes the filtration rate

At low speeds, the mass transfer coefficient k is low;
this results in high gel resistance and low filtration flux.

At high speeds, ΔP is high; this results in low ΔP_M
and hence low filtrate flux.