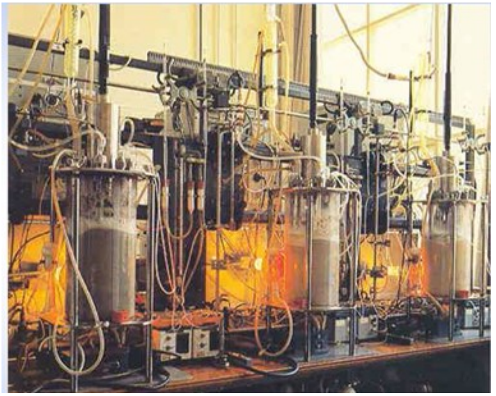
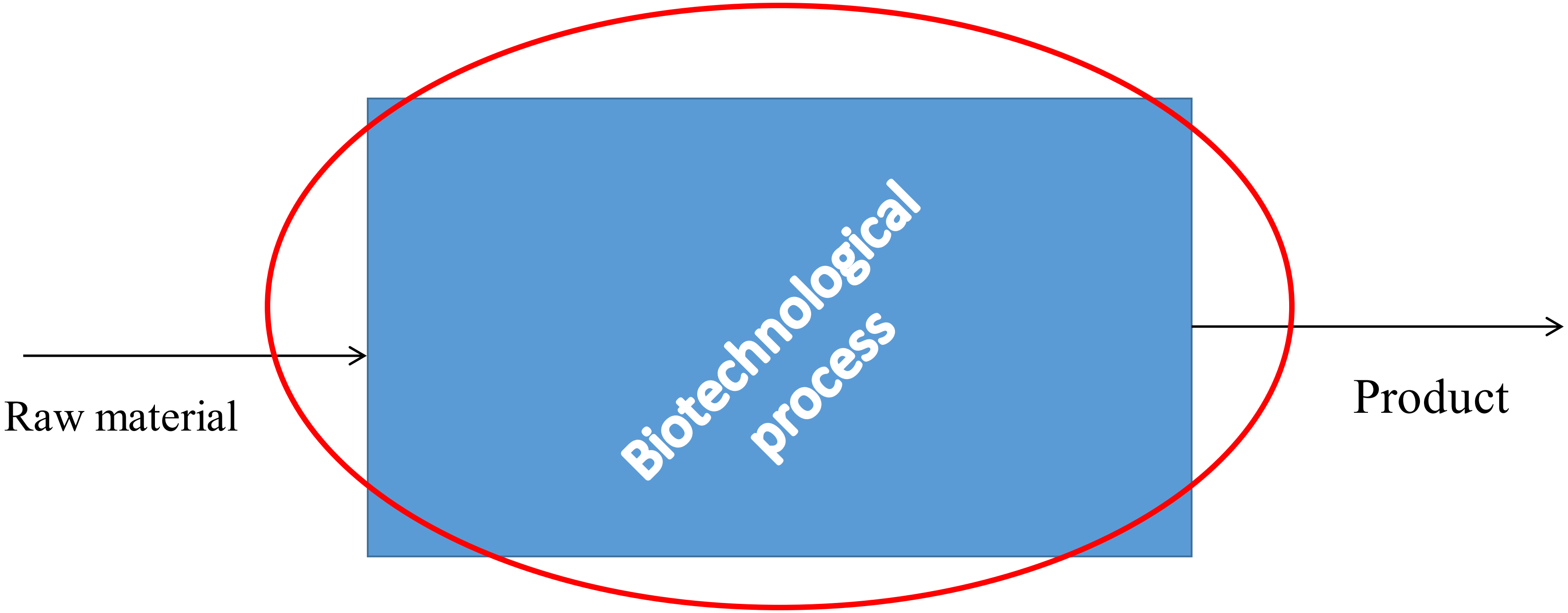
ADDIS ABABA UNIVERSITY
ADDIS ABABA INSTITUTE OF TECHNOLOGY SCHOOL OF CHEMICAL AND BIOENGINEERING

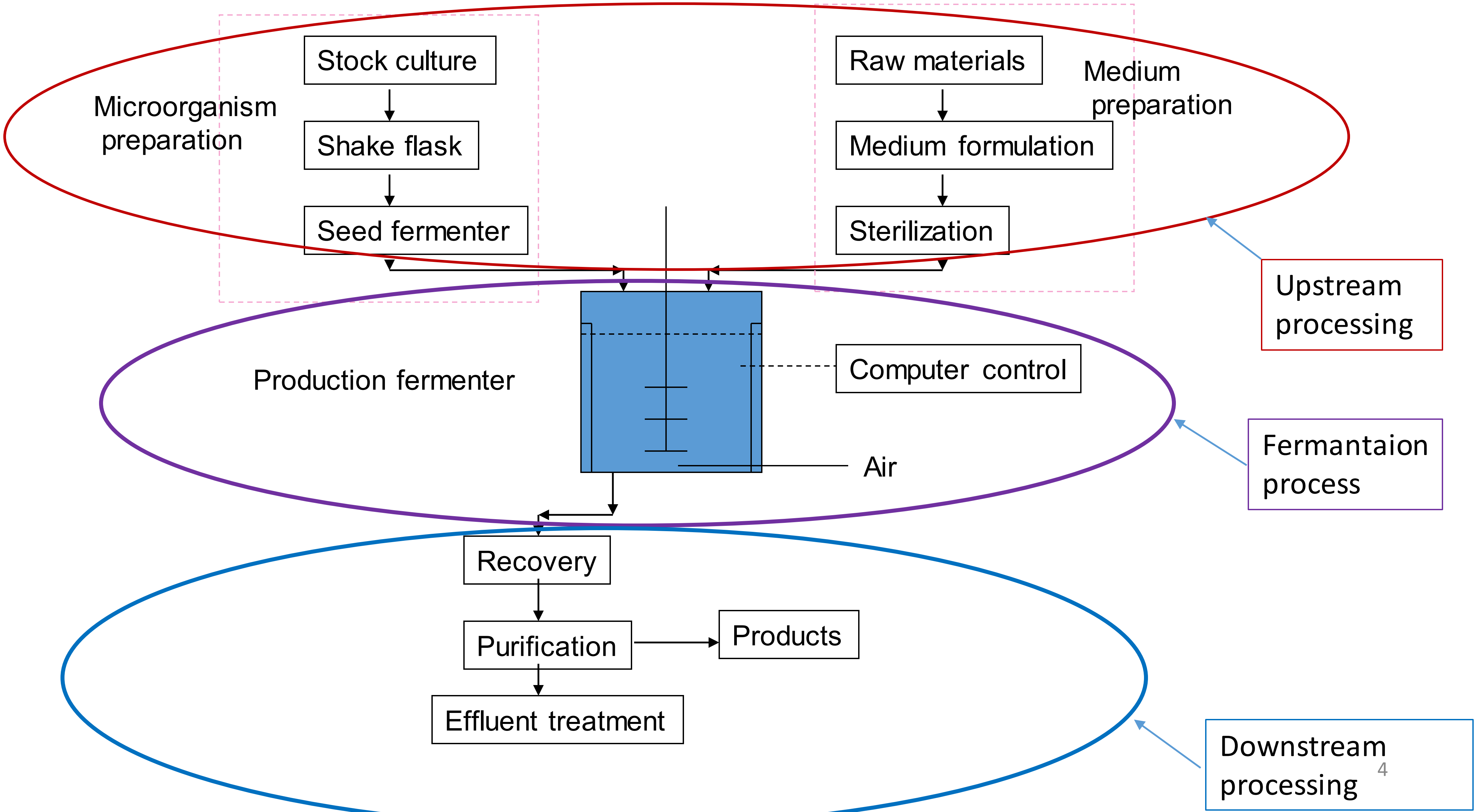
Course: Design and Development of Food Products and Equipment

EQUIPMENT DESIGN: FERMENTER



BACKGROUND



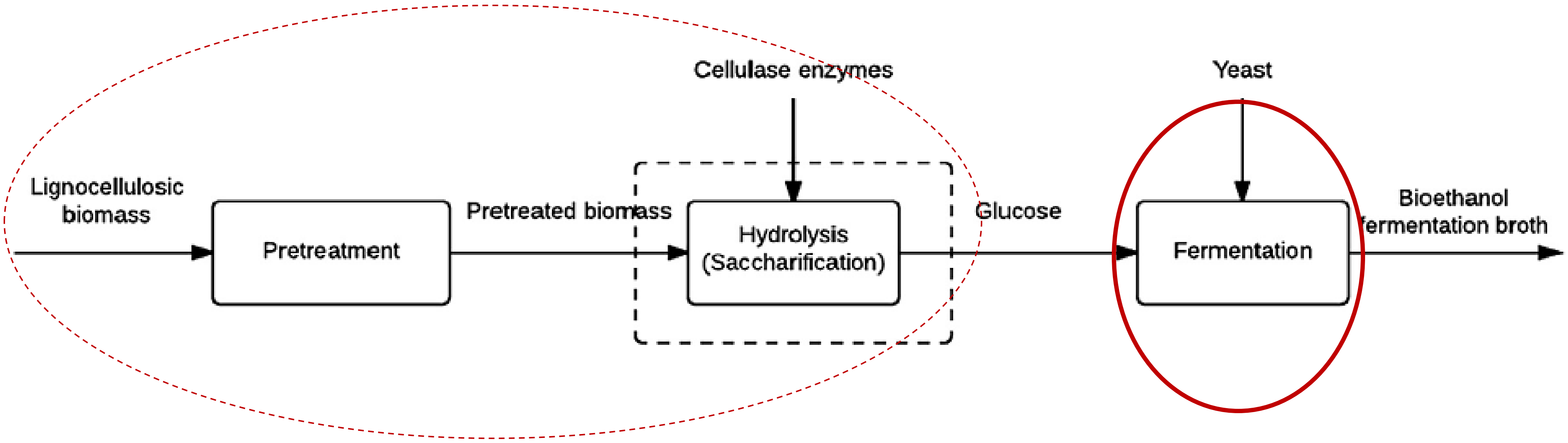

Stock culture
Microorganism preparation
Shake flask
Seed fermenter
Raw materials
Medium preparation
Medium formulation
Sterilization
Upstream processing
Production fermenter
Computer control
Air
Fermantaion process
Recovery
Purification
Products
Effluent treatment
Downstream processing

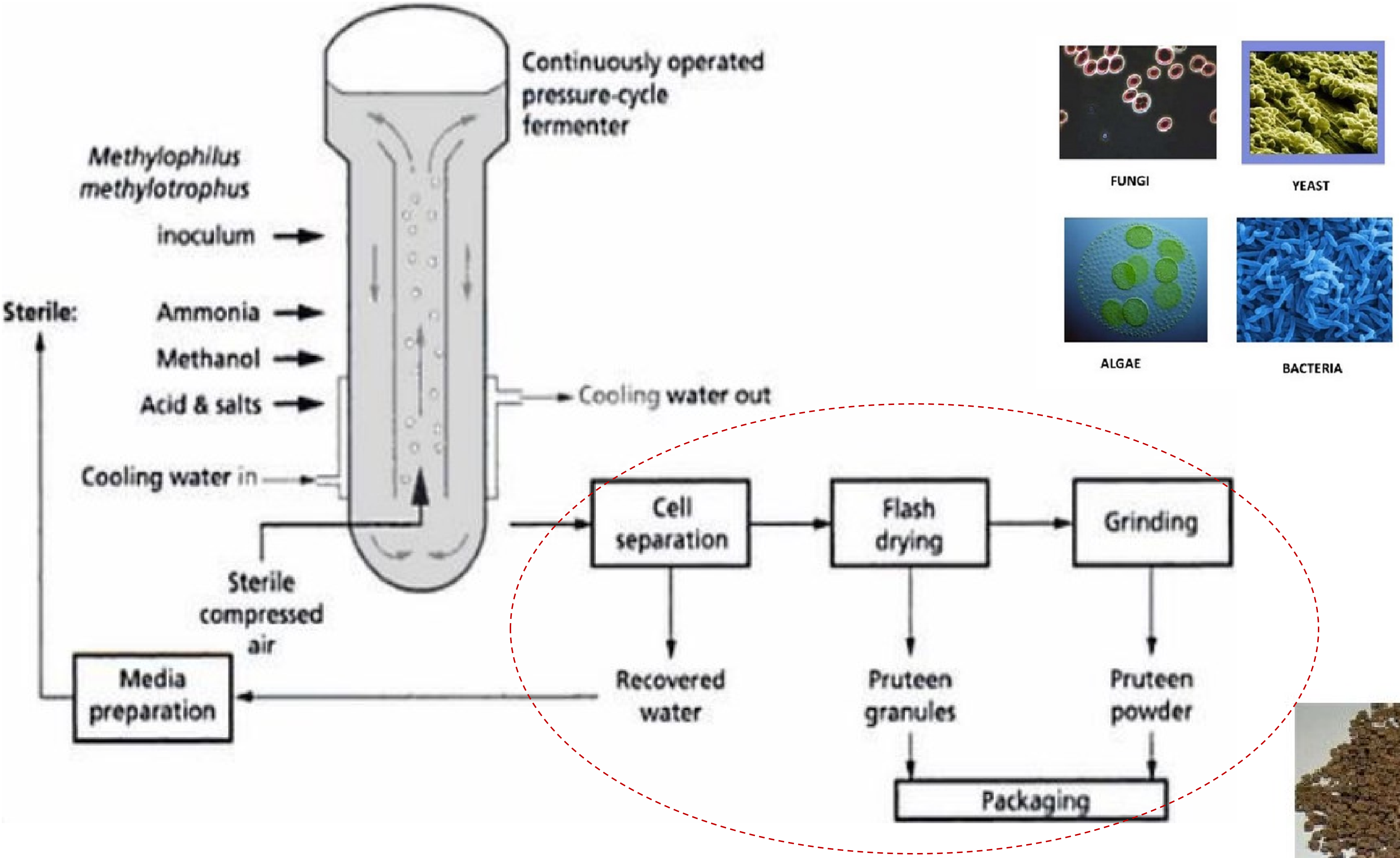
Fermentation process

- The entire process of biotechnology can be divided in to three stages
  - ✓ Upstream processing which involves preparation of liquid medium, separation of particulate and inhibitory chemicals from the medium, sterilization, air purification etc.
  - ✓ Fermentation which involves the conversion of substrates to desired product with the help of biological agents such as microorganisms; and

Cont.

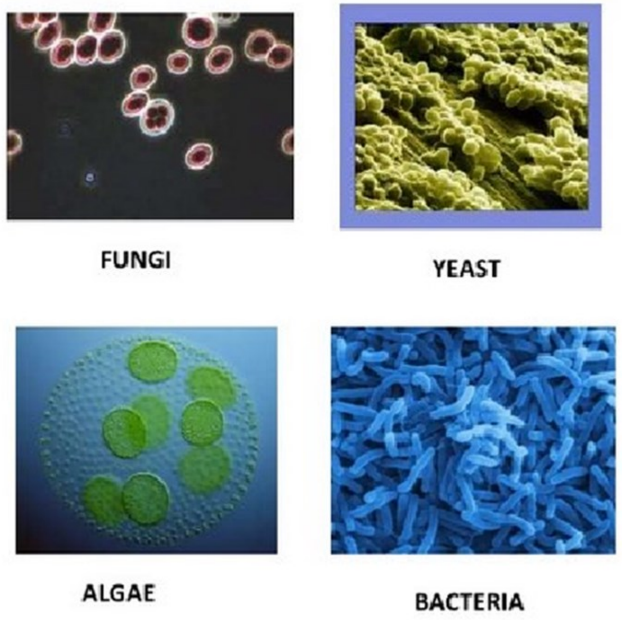
- ✓ Downstream processing which involves separation of cells from the fermentation broth, purification and concentration of desired product and waste disposal or recycle

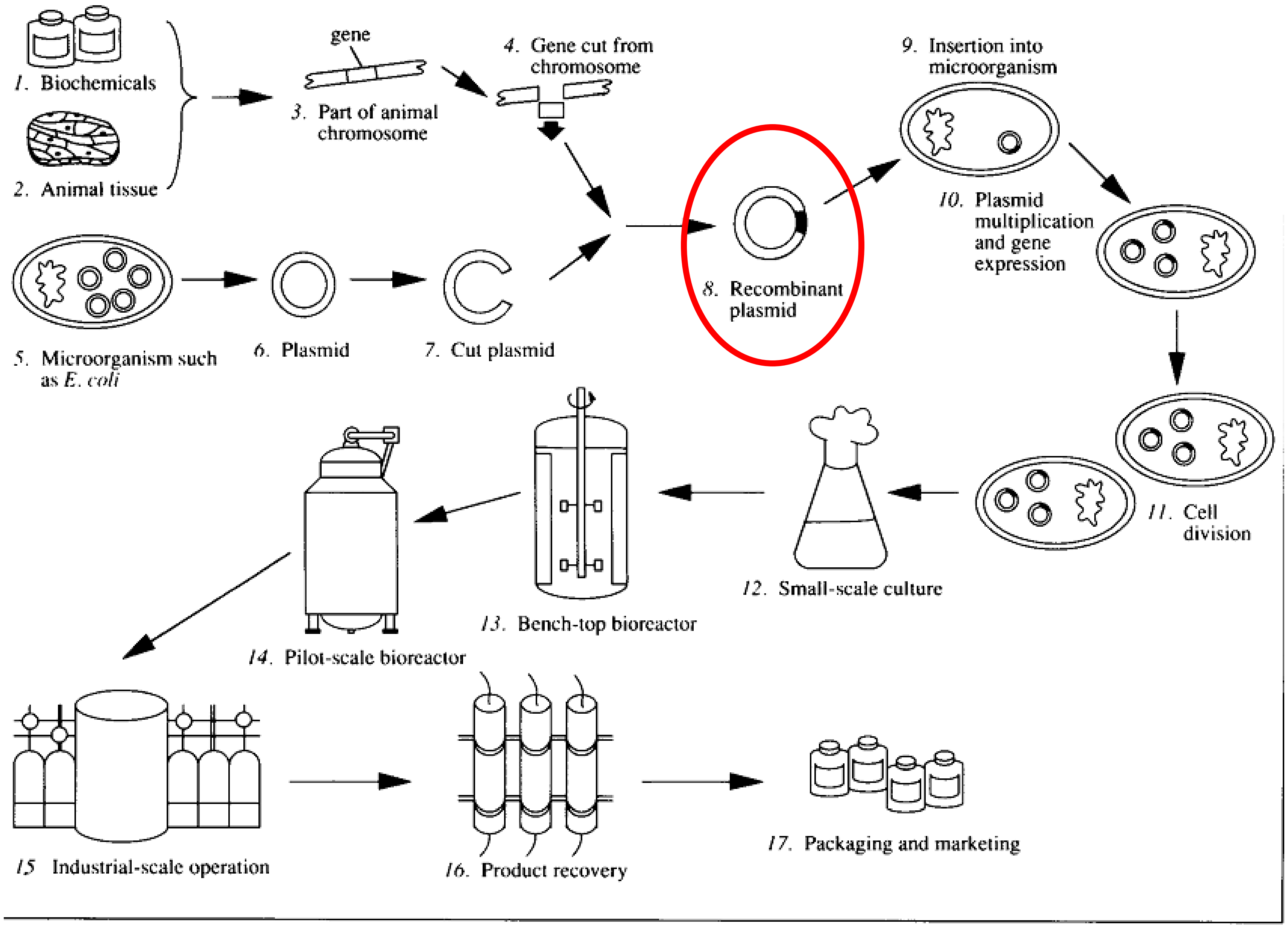



Continuously operated pressure-cycle fermenter
Methylophilus methylotrophus
inoculum
Sterile:
Ammonia
Methanol
Acid & salts
Cooling water in
Cooling water out
Sterile compressed air
Media preparation
Cell separation
Flash drying
Grinding
Recovered water
Pruteen granules
Pruteen powder
Packaging
FUNGI
YEAST
ALGAE
BACTERIA

Bioprocess

- Bioprocess operations make use of microbial, animal and plant cells and components of cells such as enzymes to manufacture new products and destroy harmful waste





1. Biochemicals
2. Animal tissue
gene
3. Part of animal chromosome
4. Gene cut from chromosome
5. Microorganism such as E. coli
6. Plasmid
7. Cut plasmid
8. Recombinant plasmid
9. Insertion into microorganism
10. Plasmid multiplication and gene expression
11. Cell division
12. Small-scale culture
13. Bench-top bioreactor
14. Pilot-scale bioreactor
15 Industrial-scale operation
16. Product recovery
17. Packaging and marketing

Cont.

- For fermenter design, therefore the knowledge of the following concepts are required
  - ✓ Reaction kinetics ;
  - ✓ Mass and energy balance, and
  - ✓ Mass transfer rate
- Besides, the advantage and disadvantage of one reactor configuration over the other ,under certain fermentation condition, is needed to be known

Reaction kinetics

- Enzymes

$$E + S \underset{k_{-1}}{\overset{k_1}{\rightleftharpoons}} ES \xrightarrow{k_2} E + P$$

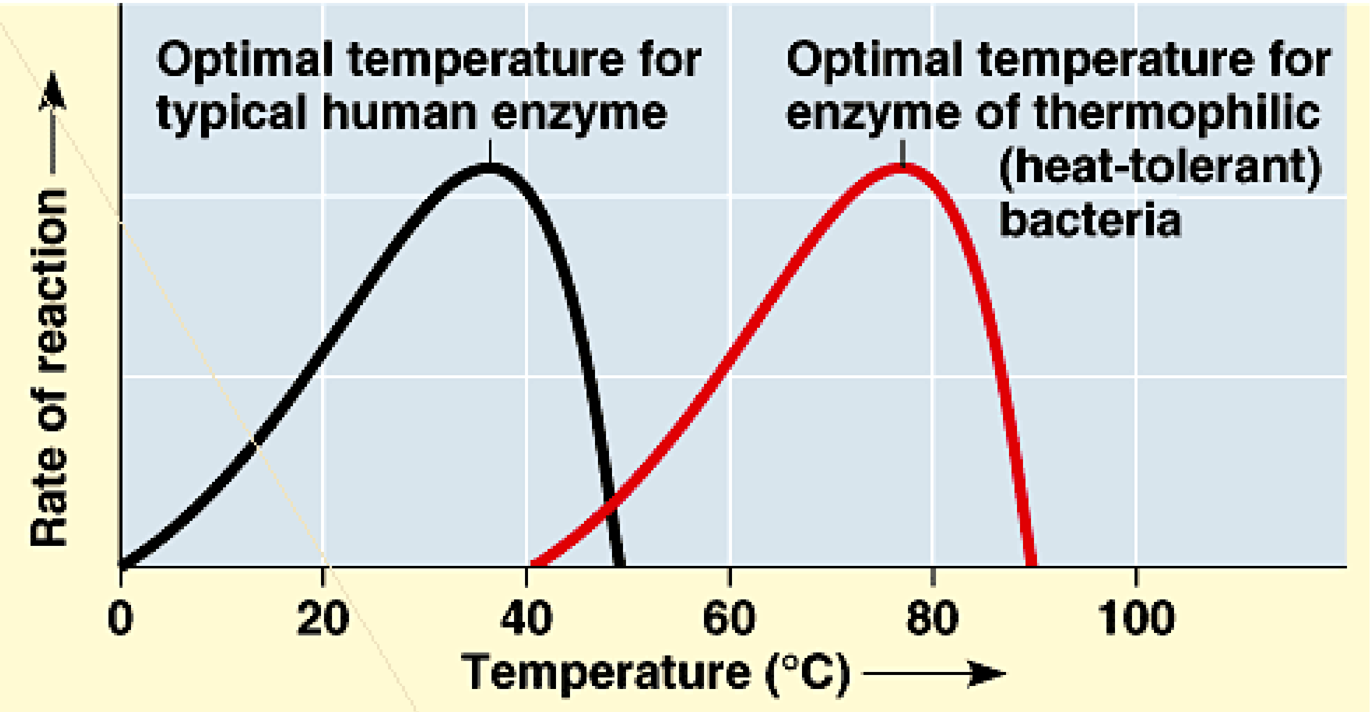
$$v = \frac{v_{max}\, s}{K_m + s}$$

Leonor Michaelis,
1875–1949

Maud Menten,
1879–1960

Cont.

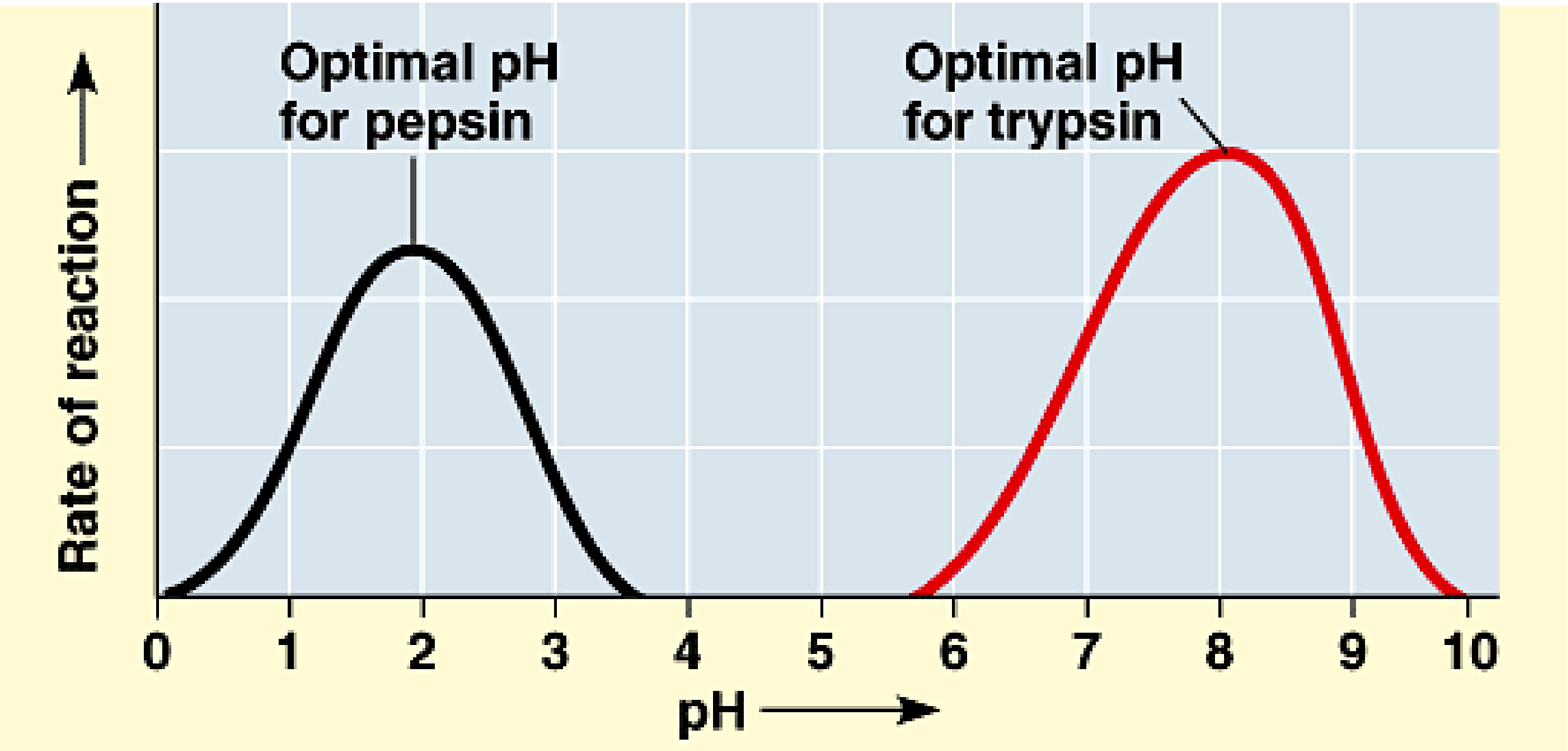
- Factors affecting enzyme activity
  - ✓Temperature



(a) Optimal temperature for two enzymes

Cont.

- ✓ pH

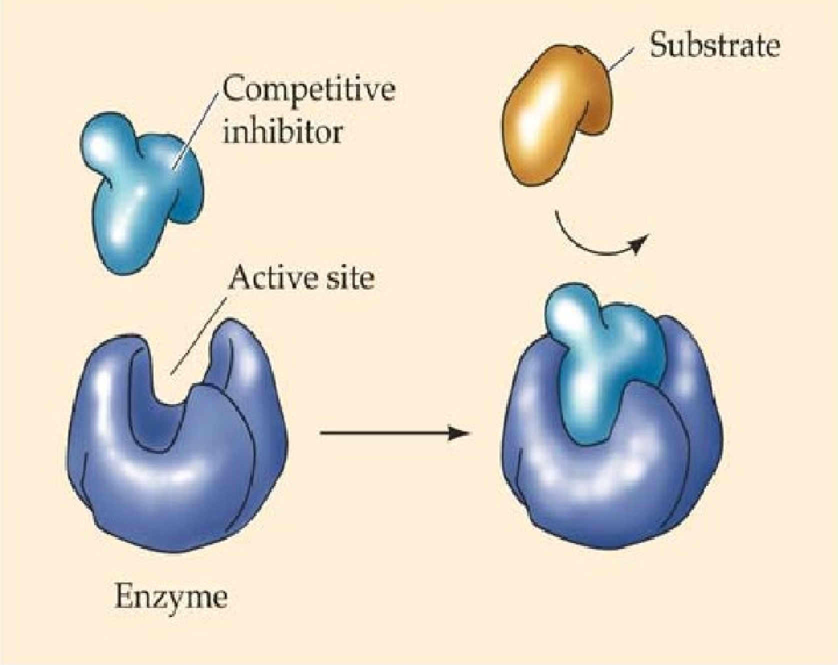


(b) Optimal pH for two enzymes

Cont.

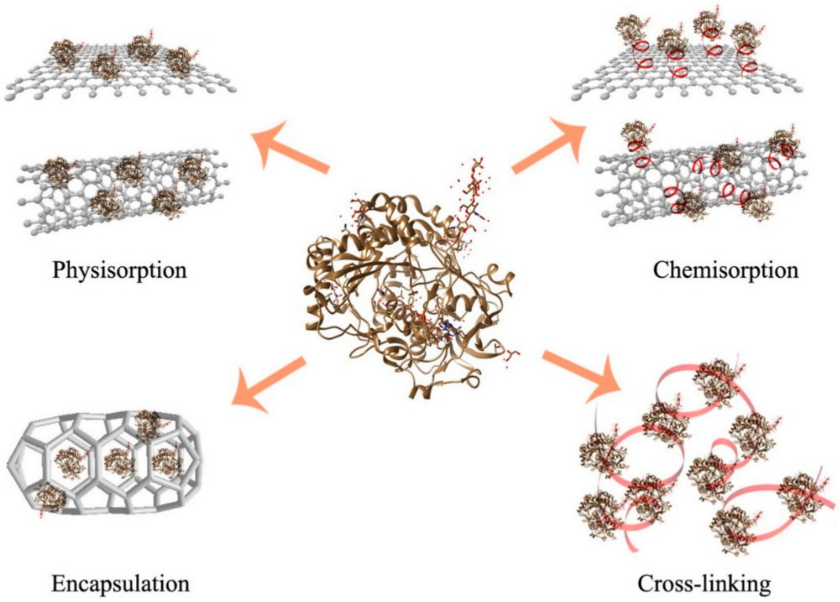
✓Inhibitors

- Competitive inhibitors: are chemicals that resemble an enzyme's normal substrate and compete with it for the active site



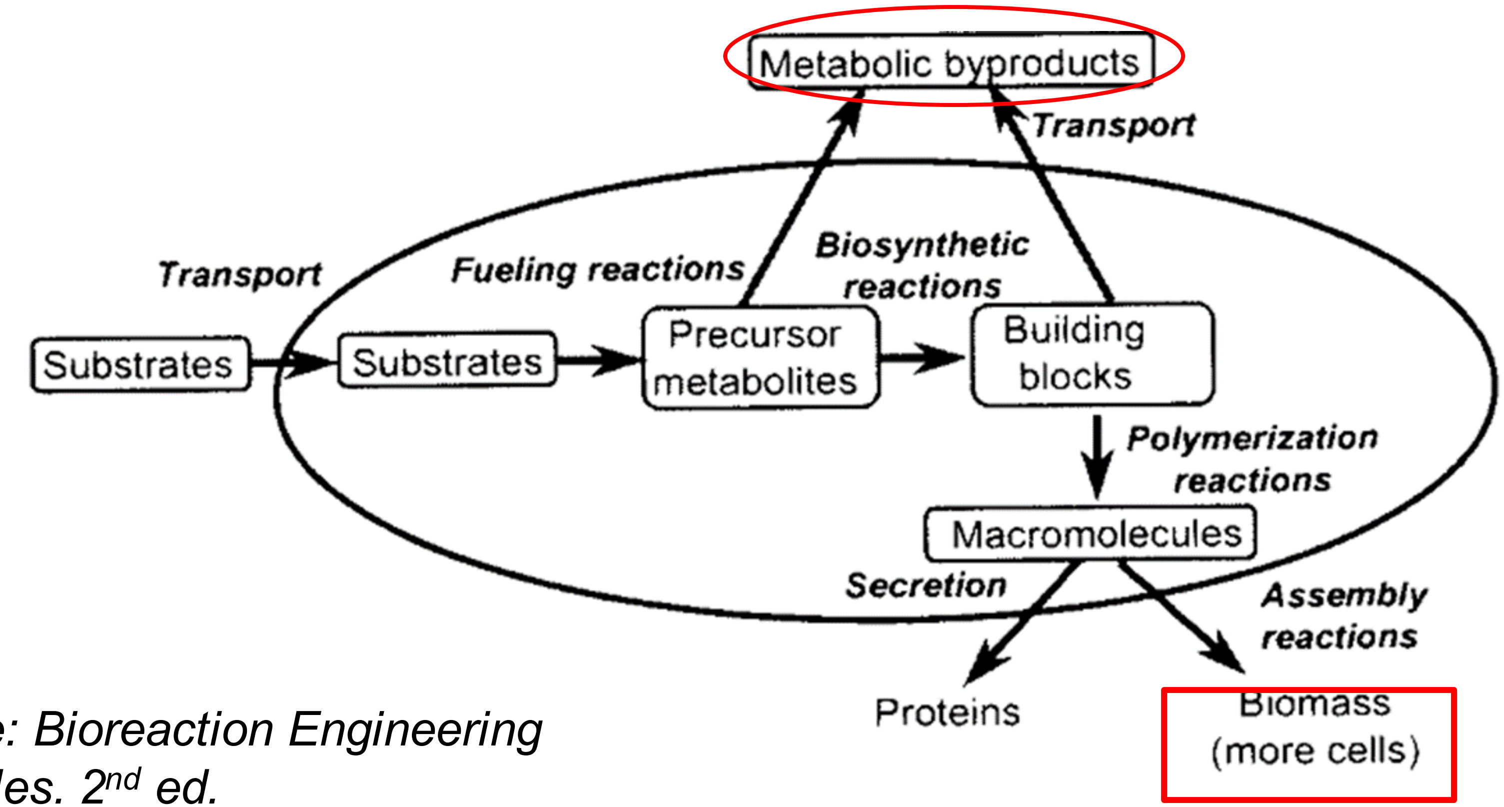
Enzymes

- Deciding the type of enzyme to be used is also important
  - ✓ Free enzyme
    - more sensetive to environmental conditions
    - Separation problem
  - ✓ Immobilized enzyme
    - Reduction in performance



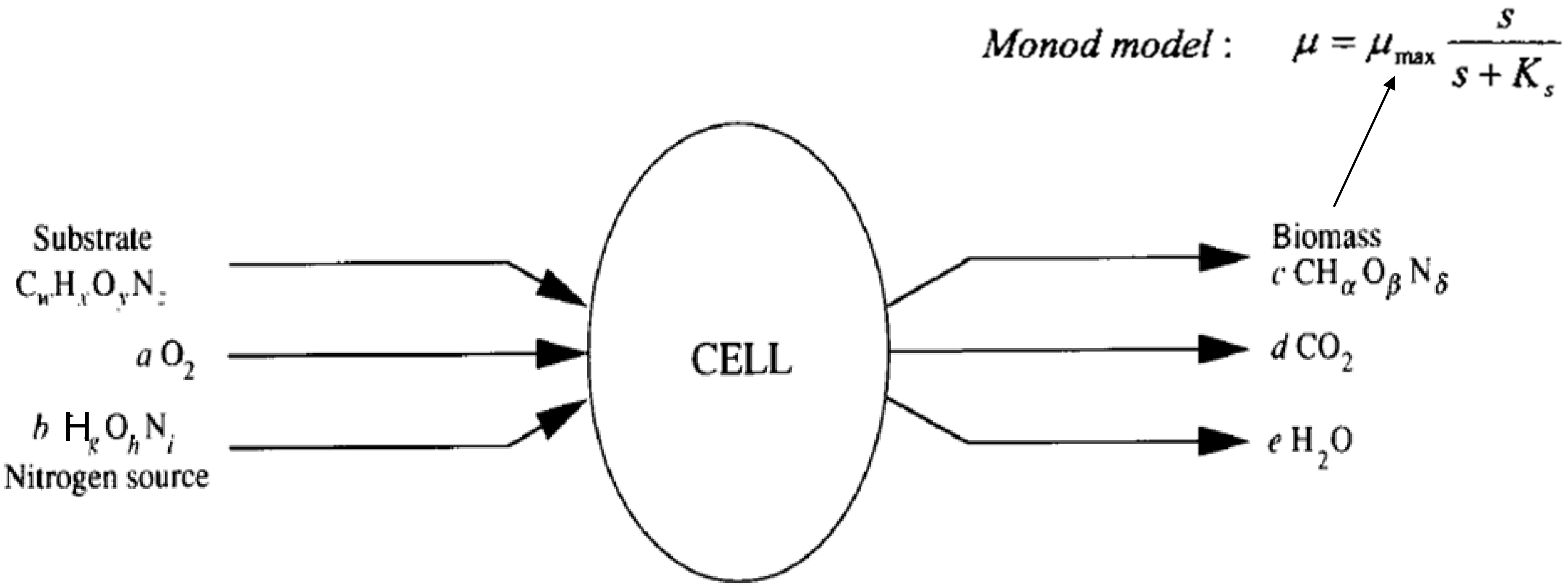
Cell growth

Reactions and processes involved in cell growth and product formation.



Source: Bioreaction Engineering Princples. 2nd ed.

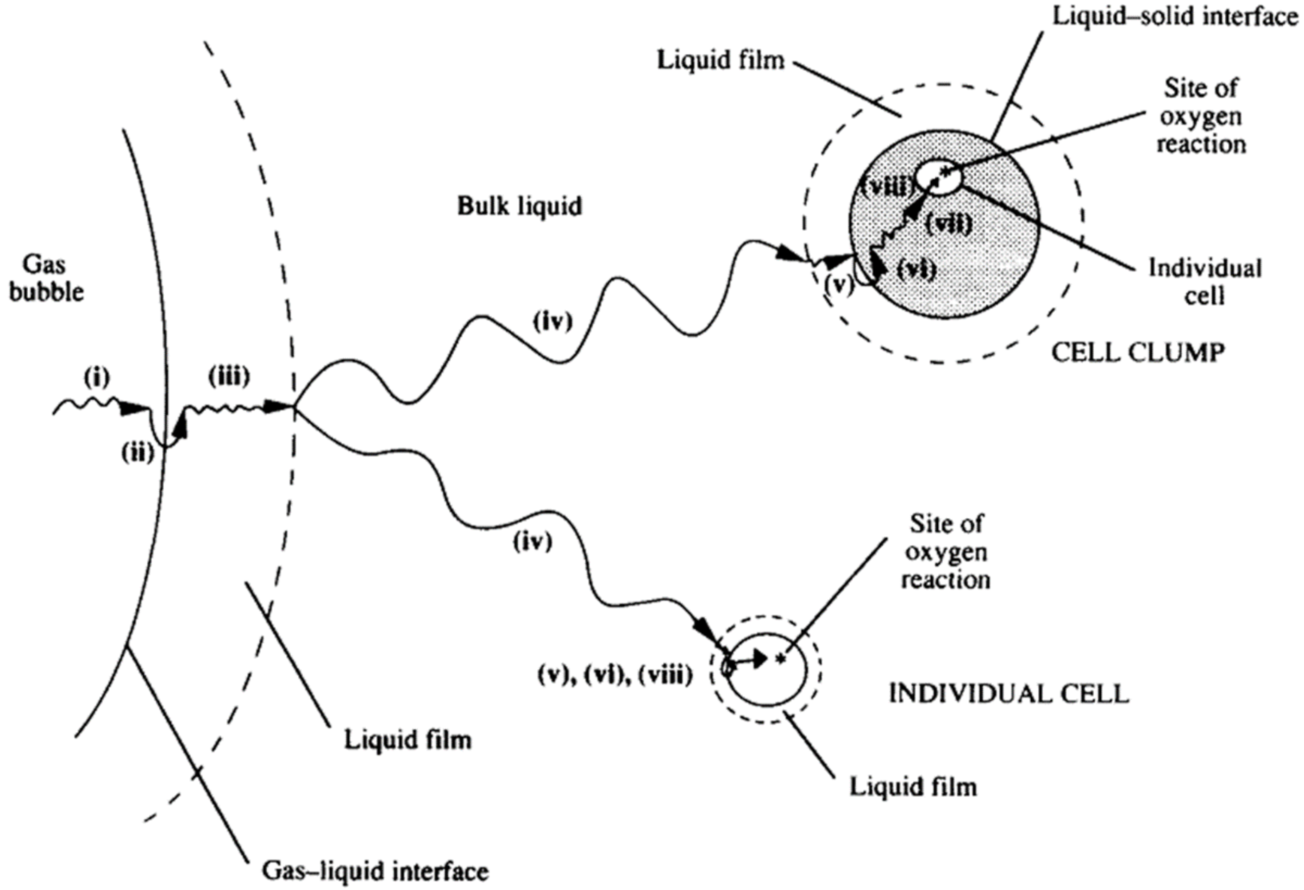
Mass balance (cont'd)



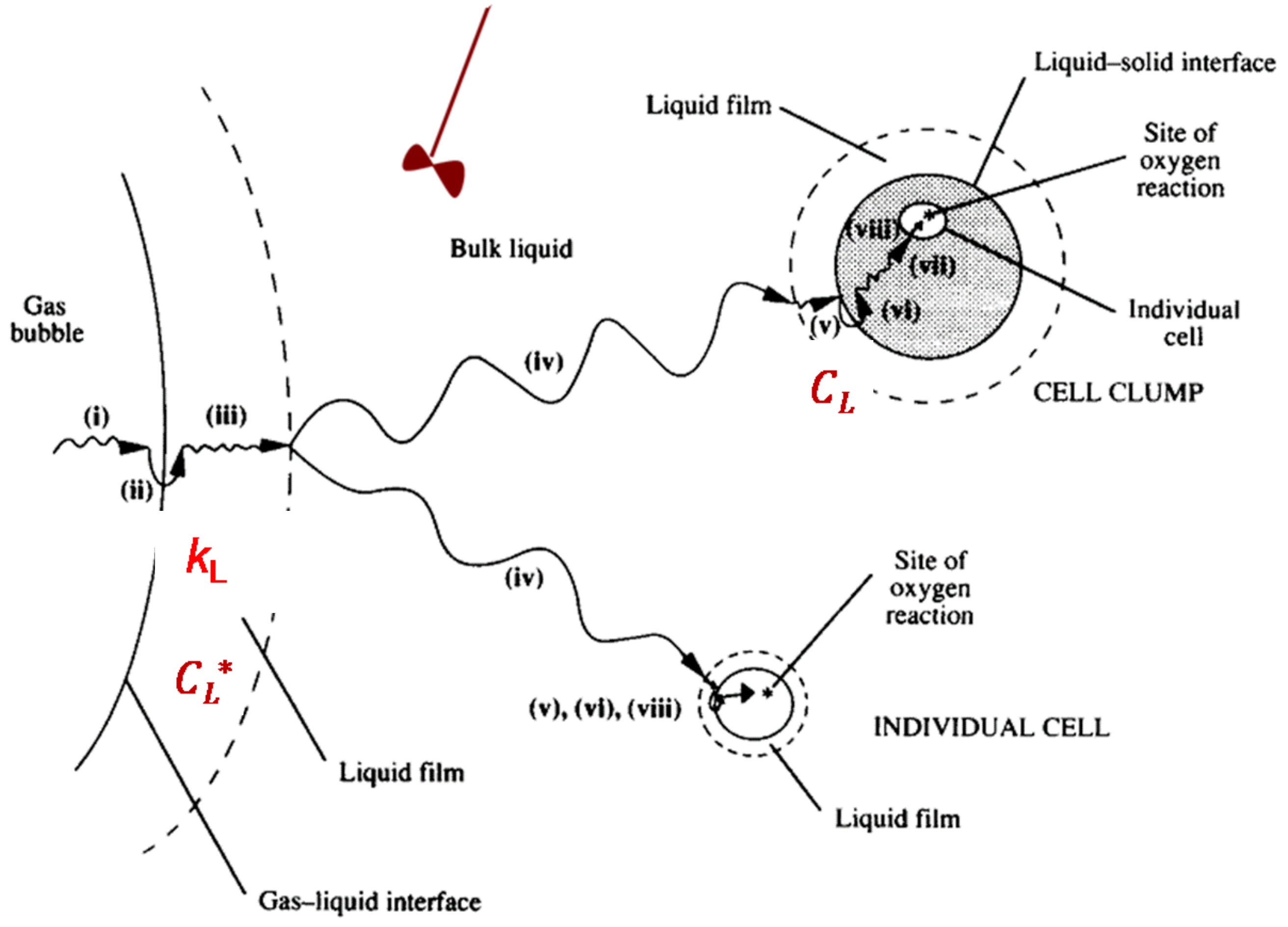
(From J.A. Roels, 1980, Application of macroscopic principles to microbial metabolism, Biotechnol. Bioeng. 22, *2457–2514)*

Organism	*Elemental formula*	*Degree of reduction γ (relative to NH_3)*
Escherichia coli	$CH_{1.77}O_{0.49}N_{0.24}$	4.07
Klebsiella aerogenes	$CH_{1.75}O_{0.43}N_{0.22}$	4.23
Kl. aerogenes	$CH_{1.73}O_{0.43}N_{0.24}$	4.15
Kl. aerogenes	$CH_{1.75}O_{0.47}N_{0.17}$	4.30
Kl. aerogenes	$CH_{1.73}O_{0.43}N_{0.24}$	4.15
Pseudomonas $C_{12}B$	$CH_{2.00}O_{0.52}N_{0.23}$	4.27
Aerobacter aerogenes	$CH_{1.83}O_{0.55}N_{0.25}$	3.98
Paracoccus denitrificans	$CH_{1.81}O_{0.51}N_{0.20}$	4.19
P. denitrificans	$CH_{1.51}O_{0.46}N_{0.19}$	3.96
Saccharomyces cerevisiae	$CH_{1.64}O_{0.52}N_{0.16}$	4.12
S. cerevisiae	$CH_{1.83}O_{0.56}N_{0.17}$	4.20
S. cerevisiae	$CH_{1.81}O_{0.51}N_{0.17}$	4.28
Candida utilis	$CH_{1.83}O_{0.54}N_{0.10}$	4.45
C. utilis	$CH_{1.87}O_{0.56}N_{0.20}$	4.15
C. utilis	$CH_{1.83}O_{0.46}N_{0.19}$	4.34
C. utilis	$CH_{1.87}O_{0.56}N_{0.20}$	4.15
Average	$CH_{1.79}O_{0.50}N_{0.20}$	4.19

Mass transfer



The oxygen transport path to the microorganism. Generalized path of oxygen from the gas bubble to the microorganism suspended in a liquid is shown. The various regions where a transport resistance may be encountered are as indicated



$$\frac{dC_L}{dt} = k_L a(C_L^* - C_L)$$

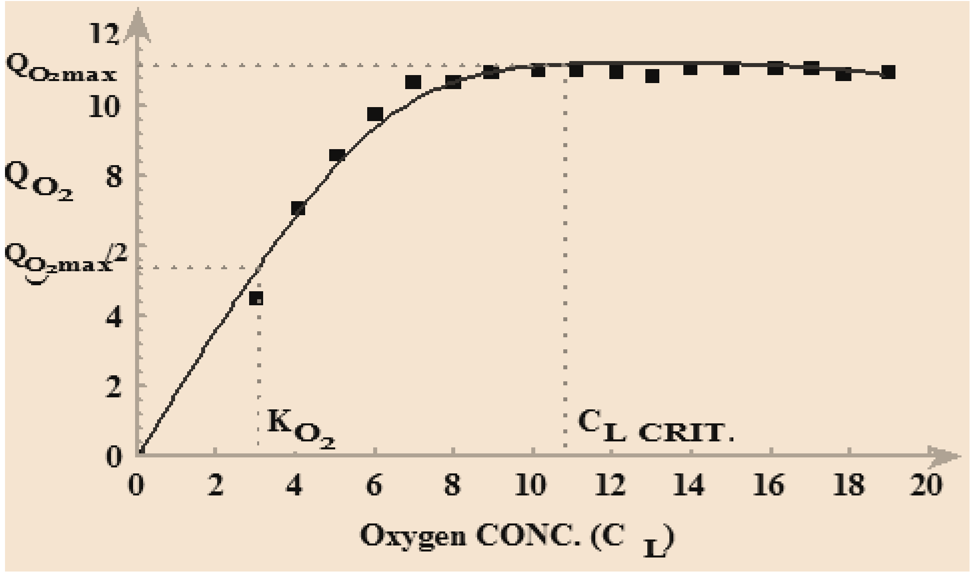
k_L is the liquid phase mass-transfer coefficient
a is area for mass transfer
C is concentration

Oxygen transfer (cont.)

- At Steady-state with no O_2 accumulation in the liquid phase:
  - ✓ Rate of oxygen transfer = Rate of oxygen uptake
- In general:
  - ✓ Q_{O2} = *f*(microbial species and type of cell, age of cell, dissolved O_2 conc., temperature, pH, etc.)
    - Q_{O2} = Respiration rate

Oxygen transfer (cont.)

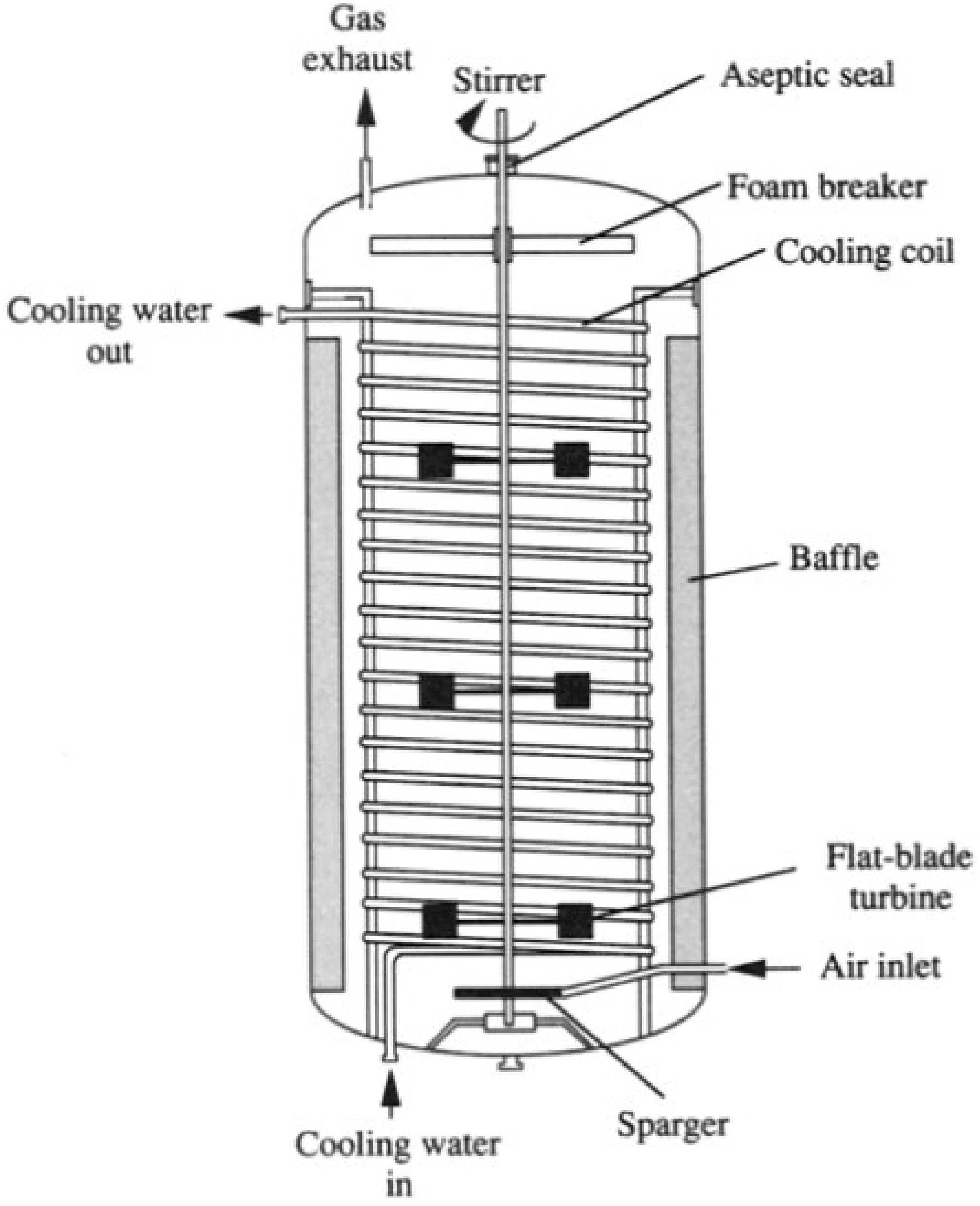
- If O_2 concentration, C_L, is the limiting factor in cell growth, then Q_{O2} is a strong function of dissolved O_2 concentration C_L (= mg O_2/L). The relationship between Q_{O2} and C_L is of the Monod type

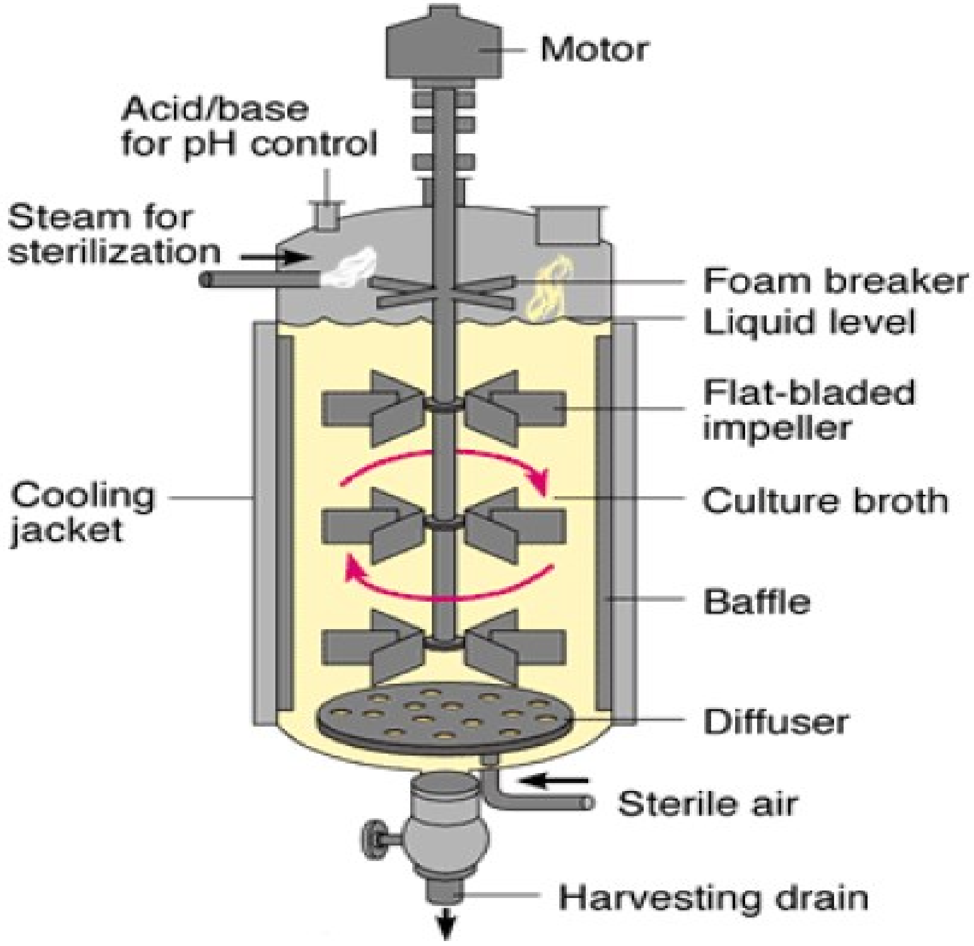


$$Q_{O2} = \frac{Q_{O2max} \cdot C_L}{K_{O2} + C_L}$$

Basic Features of Fermenation Equipement

- An agitator system
- An oxygen delivery system
- A foam control system
- A temperature control system
- A pH control system
- Sampling ports
- A cleaning and sterilization system


Gas exhaust
Stirrer
Aseptic seal
Foam breaker
Cooling coil
Cooling water out
Baffle
Flat-blade turbine
Air inlet
Sparger
Cooling water in


Motor
Acid/base for pH control
Steam for sterilization
Foam breaker
Liquid level
Flat-bladed impeller
Cooling jacket
Culture broth
Baffle
Diffuser
Sterile air
Harvesting drain

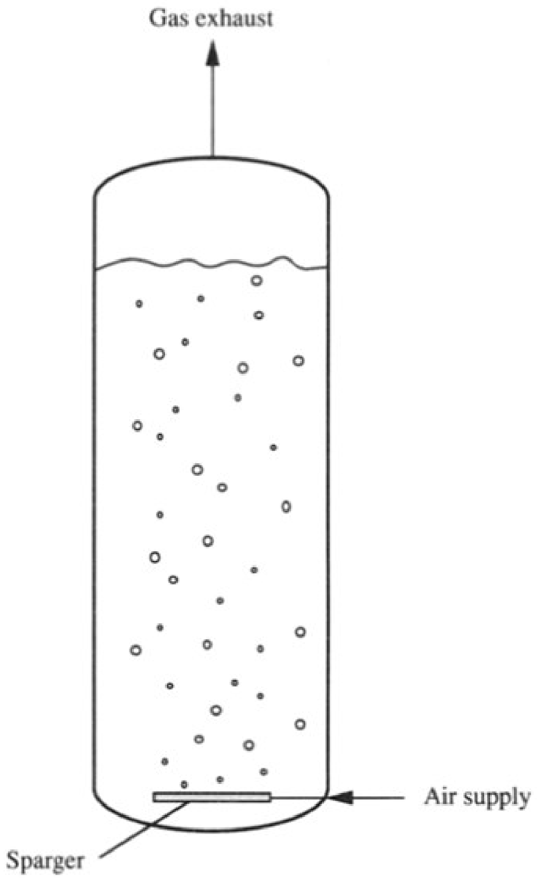
Fermenter configuration

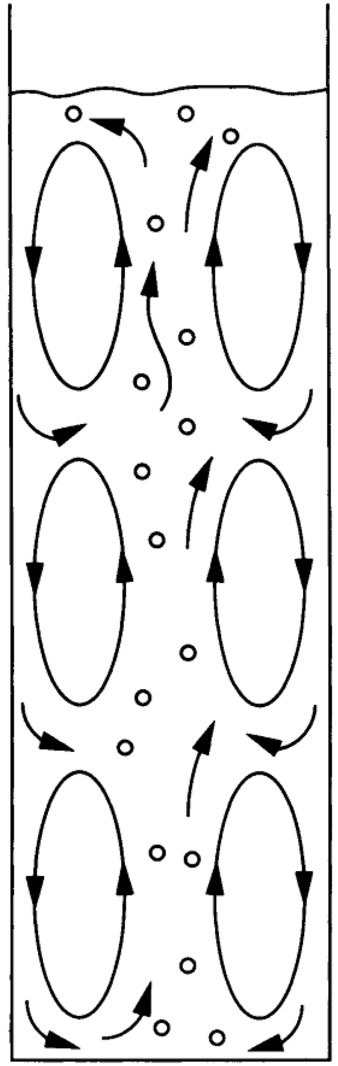
- Stirred aerobic reactor
  - ✓ Agitation
    - Provides mixing
    - Facilitates oxygen and heat transfer
    - Maintains uniform environment through out the vessel
  - ✓ Baffles (on the walls of vessels)
    - Prevent vortex formation in the fermentation broth
    - There should be enough gap between wall and baffle so that scouring action around vessel is facilitated

Configuration (Con.)

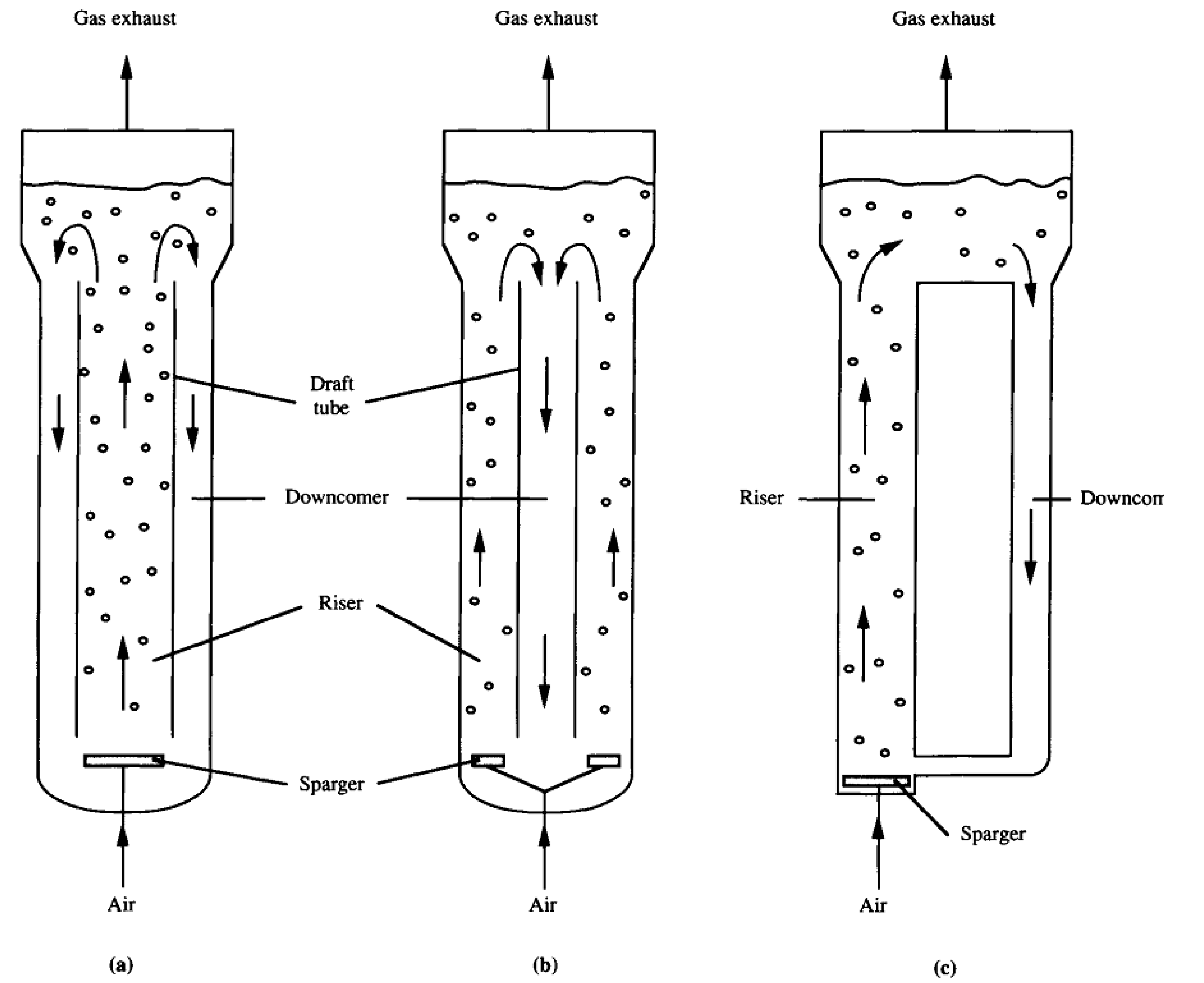
✓Bubble column

- Bubble columns are applied industrially for production of bakers' yeast, beer and vinegar, and for treatment of waste water



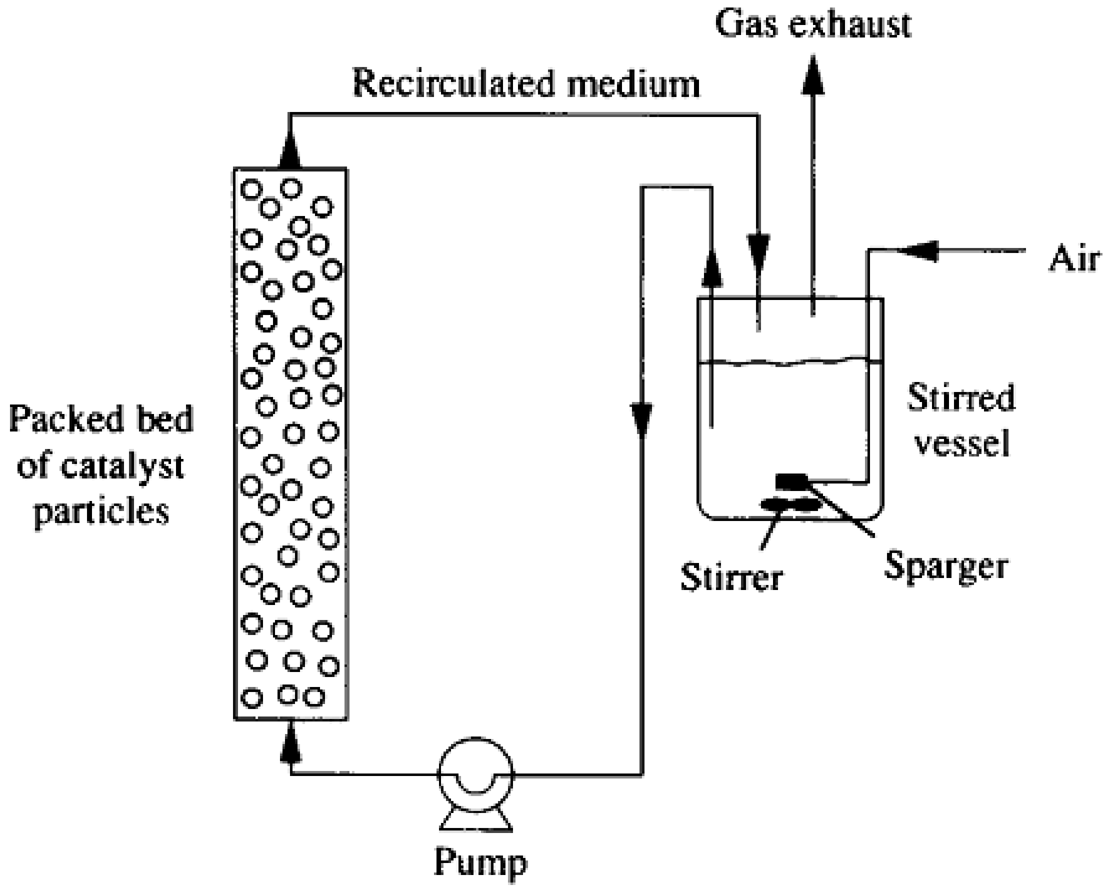


✓Airlift reactor



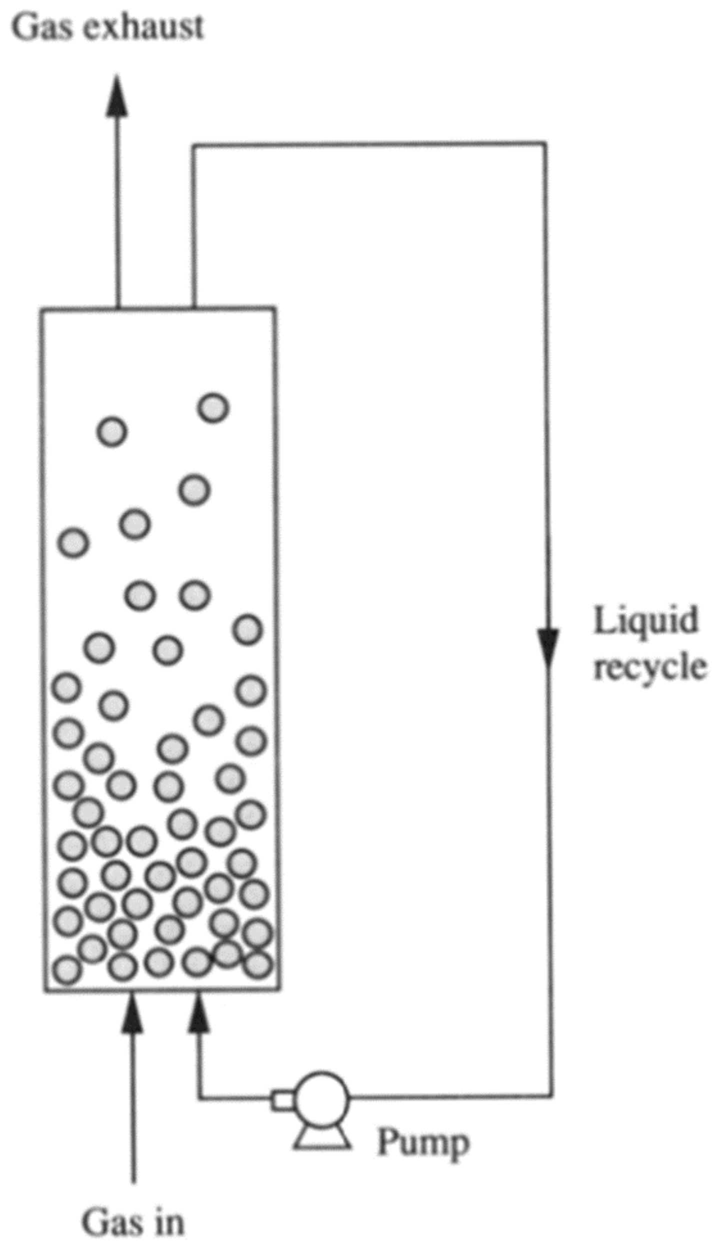
Confugration (cont'd)

✓Packed bed



- Packed bed fermenter
  - ✓ The particles should be relatively incompressible and able to withstand their own weight in the column without deforming and occluding liquid flow
  - ✓ Recirculating medium must also be clean and free of debris to avoid clogging the bed
  - ✓ Packed beds are unsuitable for processes which produce large quantities of carbon dioxide or other gases which can be come trapped in the packing

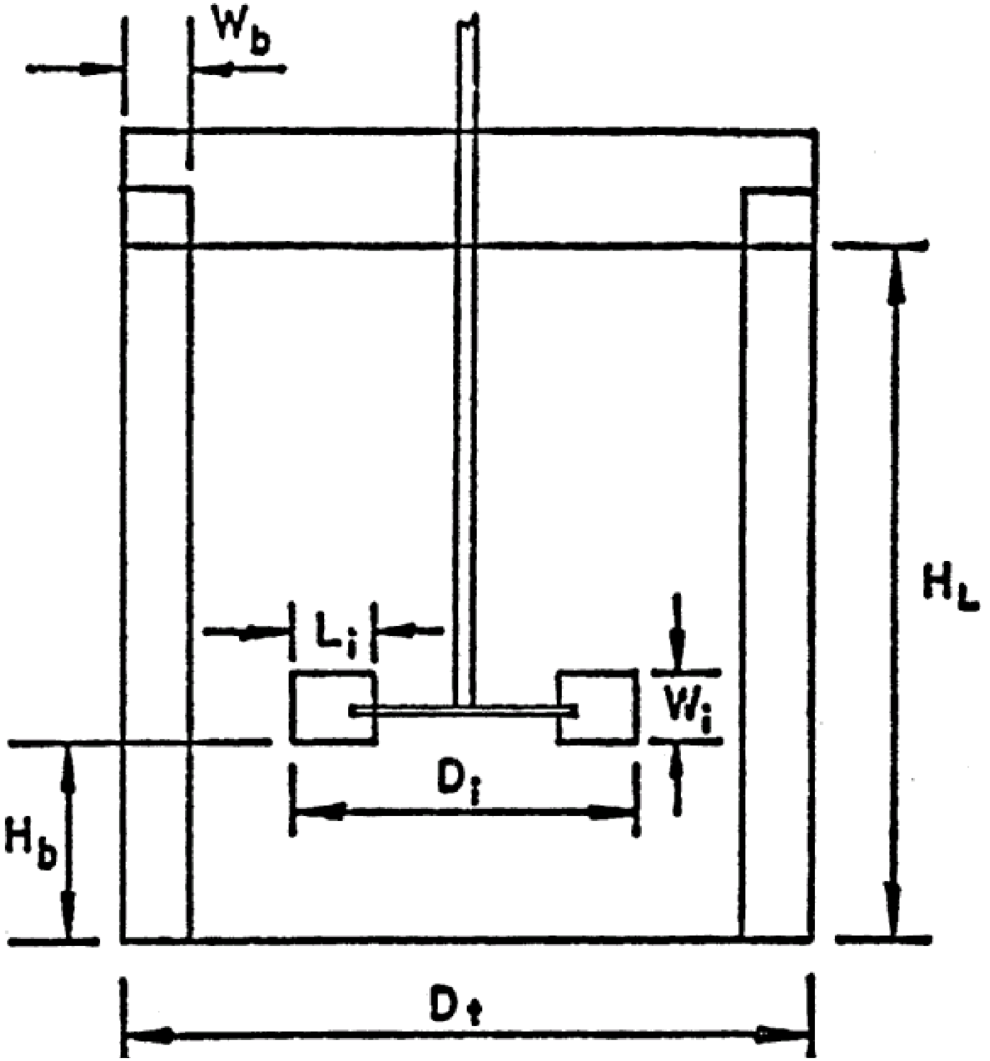
✓Fluidized bed reactor



Reactor performance

- Configuration
- Aspect of construction
- Mode of operation

The dimensions of a "standard" stirred tank bioreactor vessel with Baffles



Geometric Ratios for a Standard Bioreactor Vessel

Impeller Type	D_i/D_t	H_L/D_t	L_i/D_i	W_i/D_i	H_b/D_i	W_b/D_t	No. Baffles
Flat-Blade turbine	0.33	1.0	0.25	0.2	1.0	0.1	4

Where:

D_t = tank diameter,

H_L = liquid height

D_i = impeller diameter

H_b = impeller distance from bottom of vessel

W_b = baffle width

L_i = impeller blade length

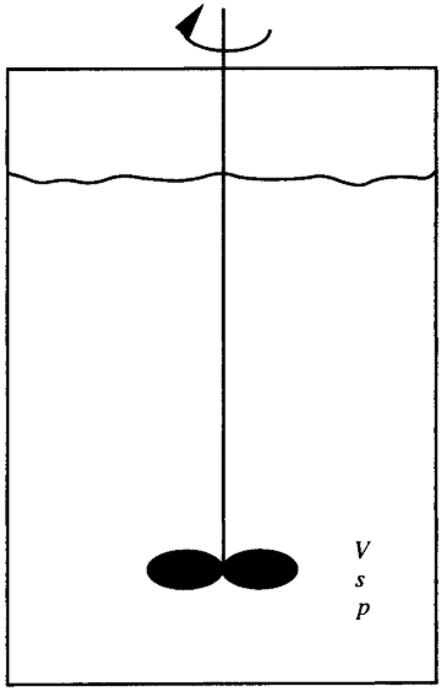
W_i = impeller blade height

Source : Catapano et.al (2009), Bioreactor design and scale up, Cell Tissue React. Eng. 173–259

- ✓ Head space for disengagement (20-30 % of aerobic reactor)
  - Minimum entrainment of droplets in exhaust gas

Fermenter Operation Modes

- Batch operation
  - ✓ A batch bioreactor is normally equipped with
    - An agitator to mix the reactant
    - pH controller
    - Foam breaker
    - Temperture controller
    - etc



- Estimate the batch reaction time required to reduce the substrate concentration from s_o to s_f

$$\frac{d(sV)}{dt} = \frac{-v_{max}\, s}{K_m + s} V$$

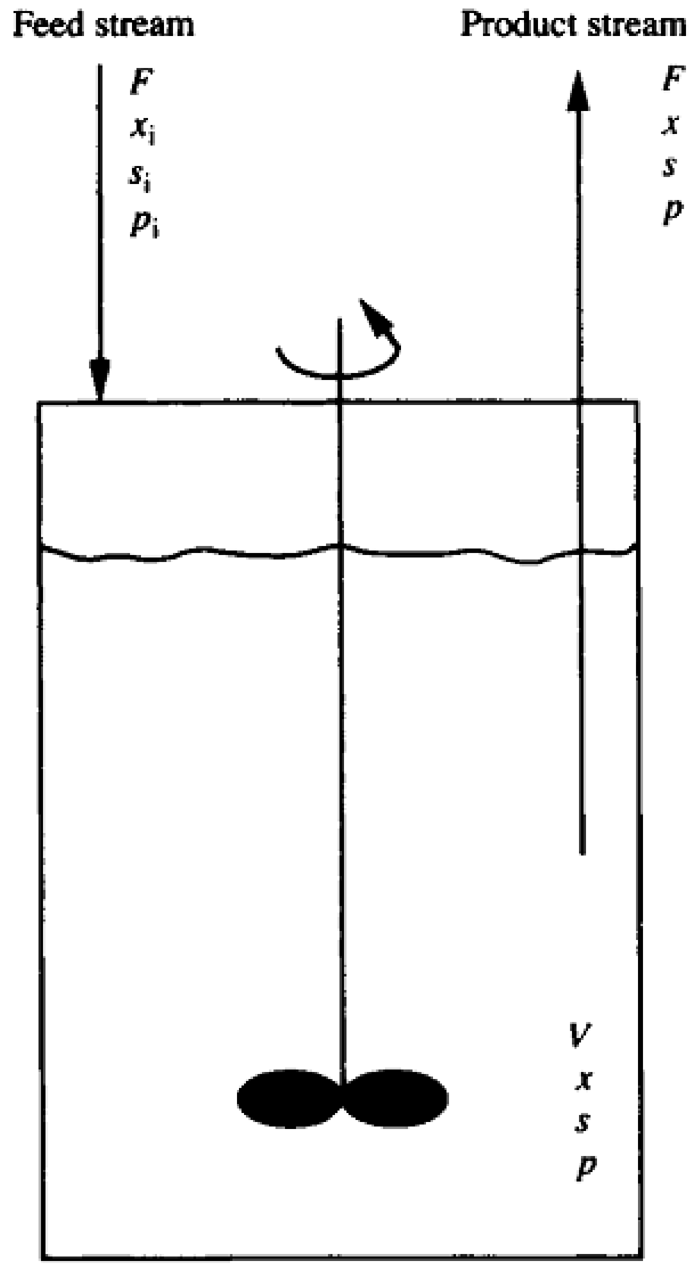
$$-\int dt = \int \frac{K_m + s}{v_{max}\, s} ds$$

$$t_b = \frac{K_m}{v_{max}} \ln \frac{s_0}{s_f} + \frac{s_0 - s_f}{v_{max}}$$

- Continous stirred tank reactor

A continuous stirred-tank reactor (CSTR) is an ideal reactor which is based on the assumption that the reactants are well mixed.

$$Fs_i - Fs - \frac{v_{max} s}{K_m + s} V = 0$$



Thank you