Biological Treatment Processes

1.Introduction

- Why biological treatment
  - Reduce BOD
  - Reduce SS
  - Oxidize ammonia, remove nitrogen and phosphorous
  - Oxidize sulphide
  - Remove possibly harmful organics
  - Substances which have negative impact on water quality have to be converted by simple biological processes into harmless substances.
- What is biological treatment
  - Treatment of the wastewater with adapted biomass

Importance

- Largely responsible for reduction of organic material in wastewater
- Use organic matter as a food supply to support the growth of biomass
- Also use organic material to provide energy for growth resulting in production of CO_2 and other metabolic byproducts thereby reducing total BOD

Types of Microbial Communities

- Aerobic
  - utilize oxygen
- Anaerobic
  - grow in absence of oxygen
- Facultative
  - can grow either with or without oxygen
  - metabolism changes as environment changes from aerobic to anaerobic

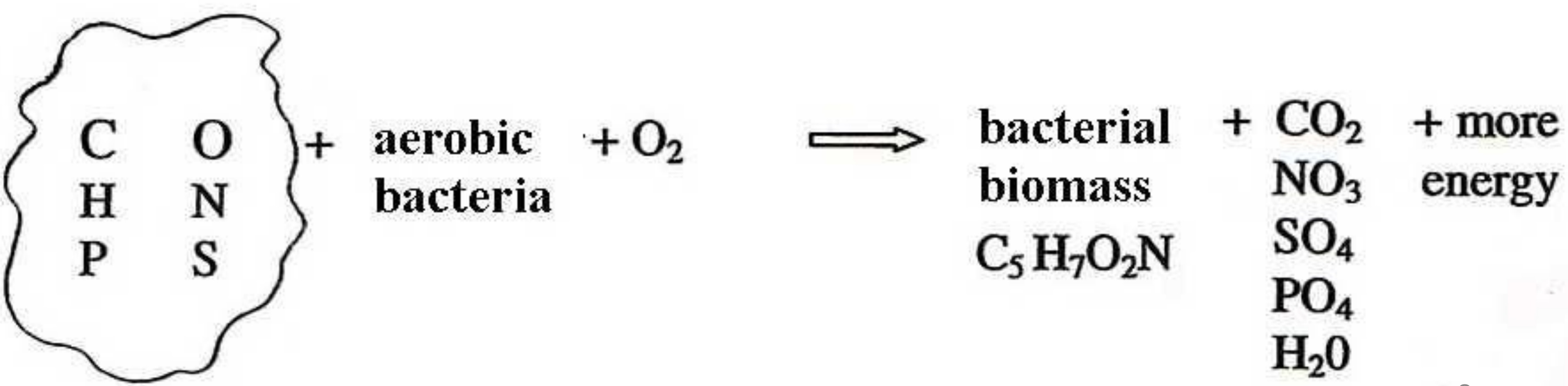
Aerobic Organisms

- Perform best when waters are well aerated and contain relatively high concentrations of dissolved molecular oxygen
- Require high rates of oxygen supply for wastewater treatment processes

Diffused Aeration

Aerobic Processes

- presence of oxygen
- rapid conversion
- release lots of energy



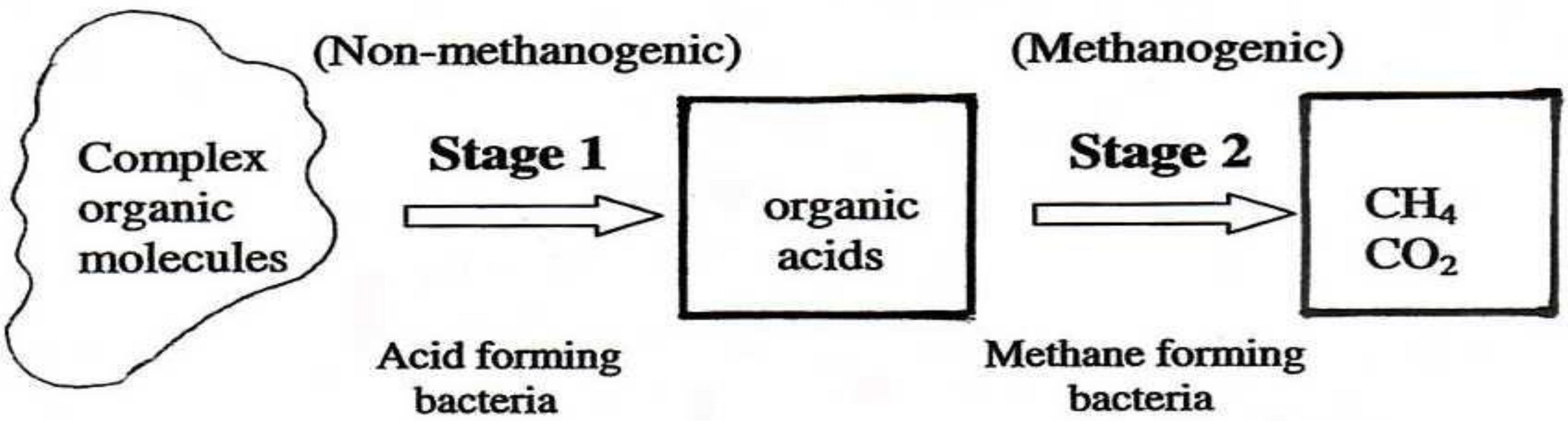
Anaerobic Organisms

- Perform best in conditions with little or no molecular oxygen
- Obtain needed oxygen from molecules that contain oxygen

Anaerobic Processes

- Complex two stage process that takes place in the absence of oxygen
  - acid-forming phase
    - acid forming bacteria hydrolyze the complex organic molecules and convert them into organic acids, lowering the pH
  - methanogenic phase
    - methane forming bacteria metabolize the acids to CH_4 and CO_2
    - amino acids are broken down, forming ammonia which tends to raise the pH

Anaerobic Processes



1.) Hydrolize complex organic molecules

starches ⟹ sugars
proteins ⟹ amino acids
fats ⟹ intact

2. Organic acids formed; pH depressed; may retard further growth

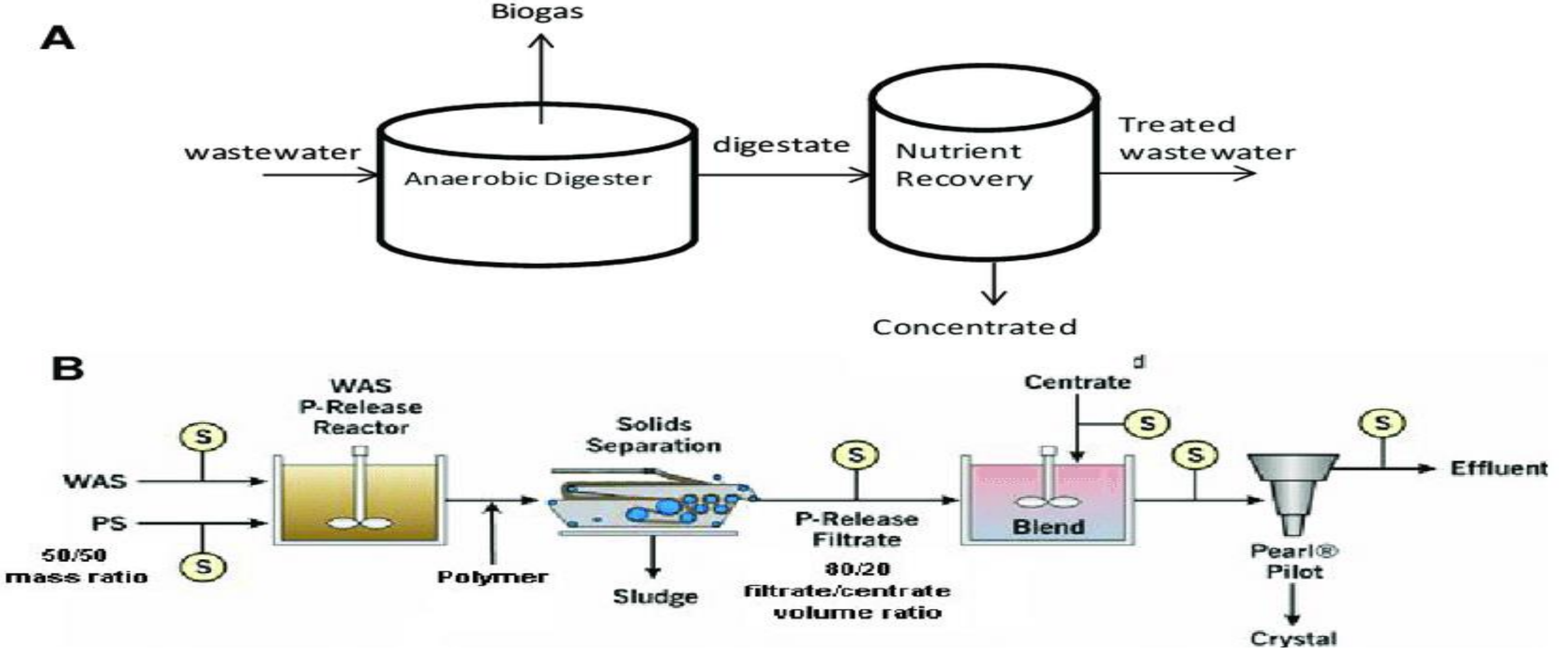
1.) Metabolize organic acids to CH_4 and CO_2

2.) Amino acids ⟹ NH_3 raises pH

3.) Fats ⟹ CH_4 and CO_2

Anaerobic Processes

- Reduction of organic matter generates H_2S and other foul smelling compounds



Facultative Organisms

- Prefer aerobic conditions but easily adapt to low oxygen circumstances
- Produce alcohols, organic acids and other organic chemicals when growing anaerobically

Temperature and Growth

- Growth rates increase with increasing temperature (0 to 55 ºC)
  - Mesophilic organisms prefer 20-45 °C
  - Thermophilic organisms prefer 45-60 °C
- Growth rates approximately double for a 10 ºC rise in temperature
- Temperature extremes may interfere with metabolic processes or harm the organisms

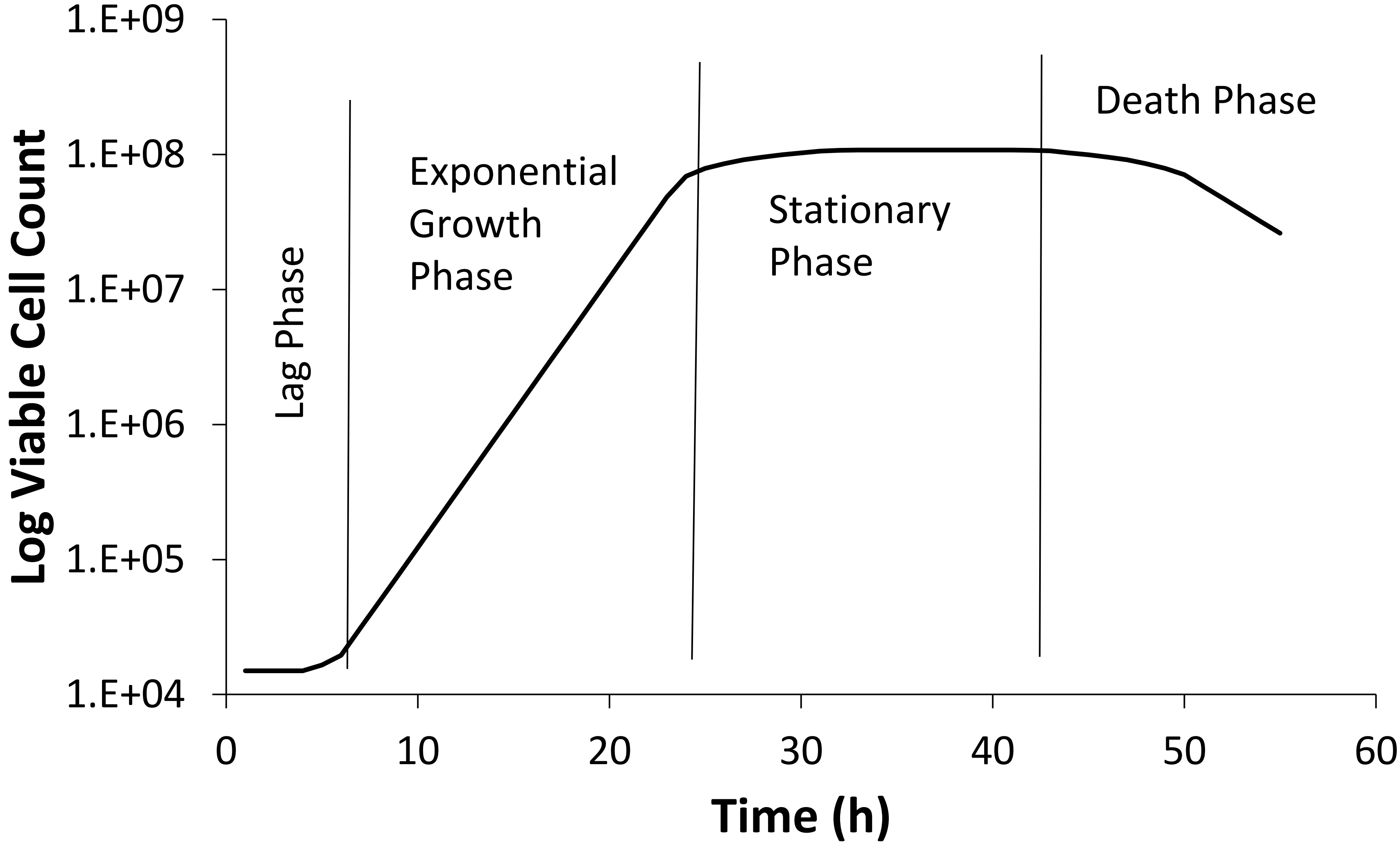
Toxicity

- Many microbial organisms are able to adapt to changes in their environment – if changes are gradual
- Sudden changes or introduction of toxic materials may be harmful or lethal to the biological community

Microbial Growth

- How do microorganisms grow when inoculated into a batch of growth medium?

Microbial Growth Phases



Lag Phase

- Period for cells to adapt to their new environment

Exponential Growth Phase

- Cells have abundant food and grow without limit during this phase

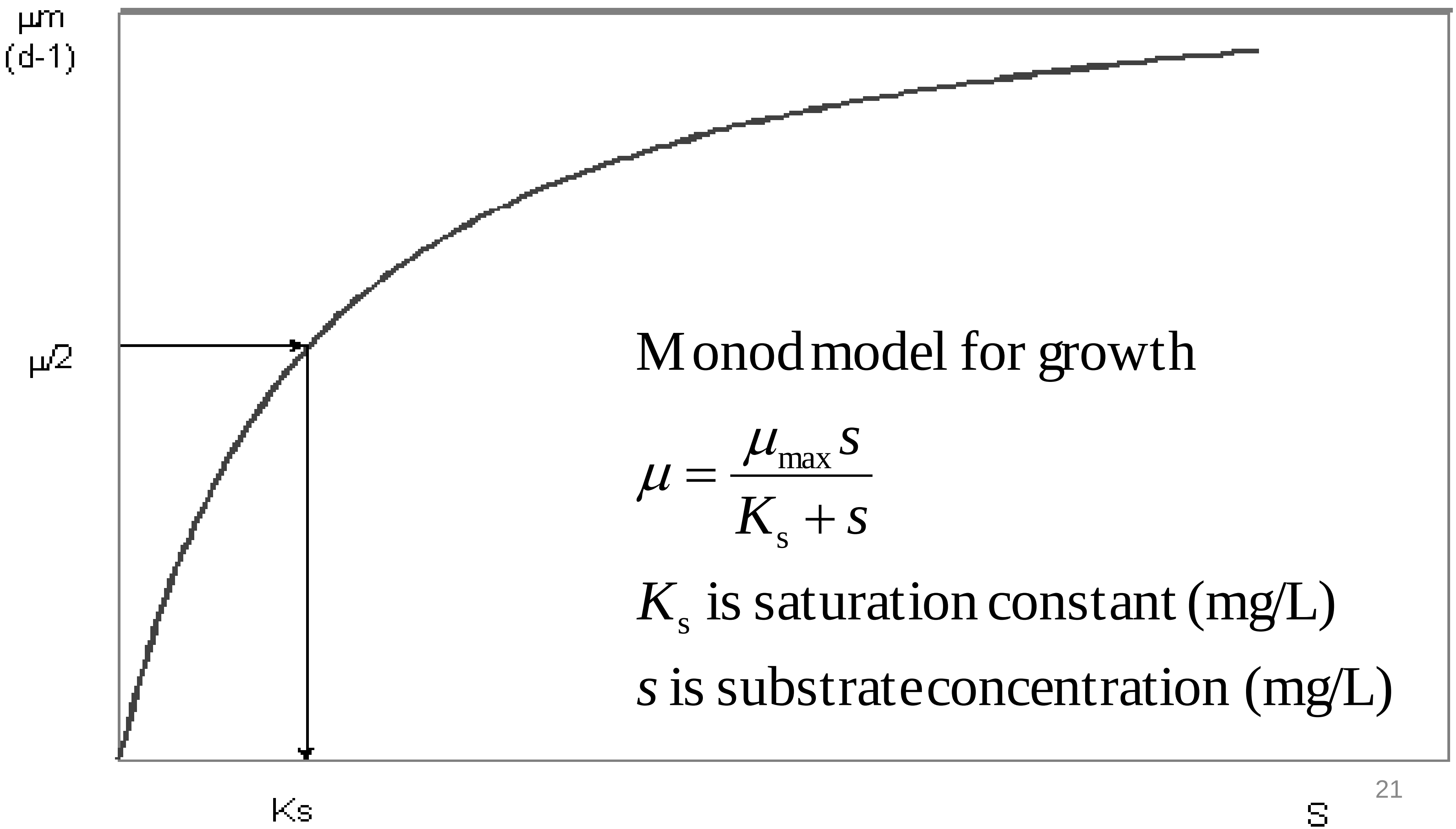
$$x = x_0 e^{\mu t}$$

  - x is cell concentration (mass dry wt/vol)
  - x_0 is cell concentration at start of exponential phase
  - μ is the specific growth rate (time^{-1})
  - t is time

Specific Growth Rate

- specific growth rate is a function of environmental conditions for the organism, including substrate (food) concentration
- there is a maximum rate at which organisms can grow even with plenty of nutrients available ($\mu_{\max}$)
- as substrate becomes limited, growth slows down
- a simple equation describing this behavior is called the Monod model

Specific Growth Rate



Monod model for growth

$$\mu = \frac{\mu_{\max} s}{K_s + s}$$

K_s is saturation constant (mg/L)

s is substrate concentration (mg/L)

Stationary Phase

- Food supply becomes limiting
- Some cells die while others continue to grow – these processes balance one another so there is no net change in number of viable cells

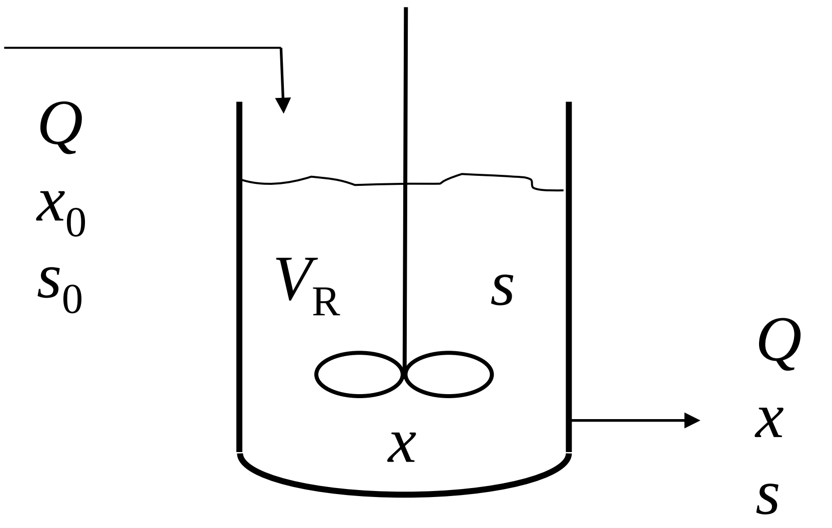
Death Phase

- Death processes dominate growth so the number of viable cells begins to decline

Bioreactors

- Typical reactor for the activated sludge process is the continuous stirred tank reactor (CSTR)
  - the tank is fed continuously with a steady flow rate
  - the tank is thoroughly mixed so contents are uniform throughout
  - effluent from the tank has the same composition as the contents of the tank
  - concentrations in the tank remain constant over time

CSTR



Mass balance on cells:

$$Qx_0 \quad - \quad Qx \quad + \quad V_R \mu x \qquad = 0$$

Input – Output + Generation = Accumulation

CSTR Analysis

- Number of organisms in the feed for the activated sludge process is normally very small so feed can be considered sterile:

$$x_0 = 0$$

$$Qx_0 - Qx + V_R \mu x = 0$$

$$Qx = V_R \mu x$$

$$\mu = Q / V_R = D = 1/\theta$$

- D is the dilution rate (1/time)
- θ is the residence time

CSTR Analysis

- substitute the Monod equation for μ:

$$D = \mu = \frac{\mu_{\max} s}{K_{\mathrm{s}} + s}$$

- this can be solved for s if given the dilution rate:

$$s = \frac{DK_{\mathrm{s}}}{\mu_{\max} - D}$$

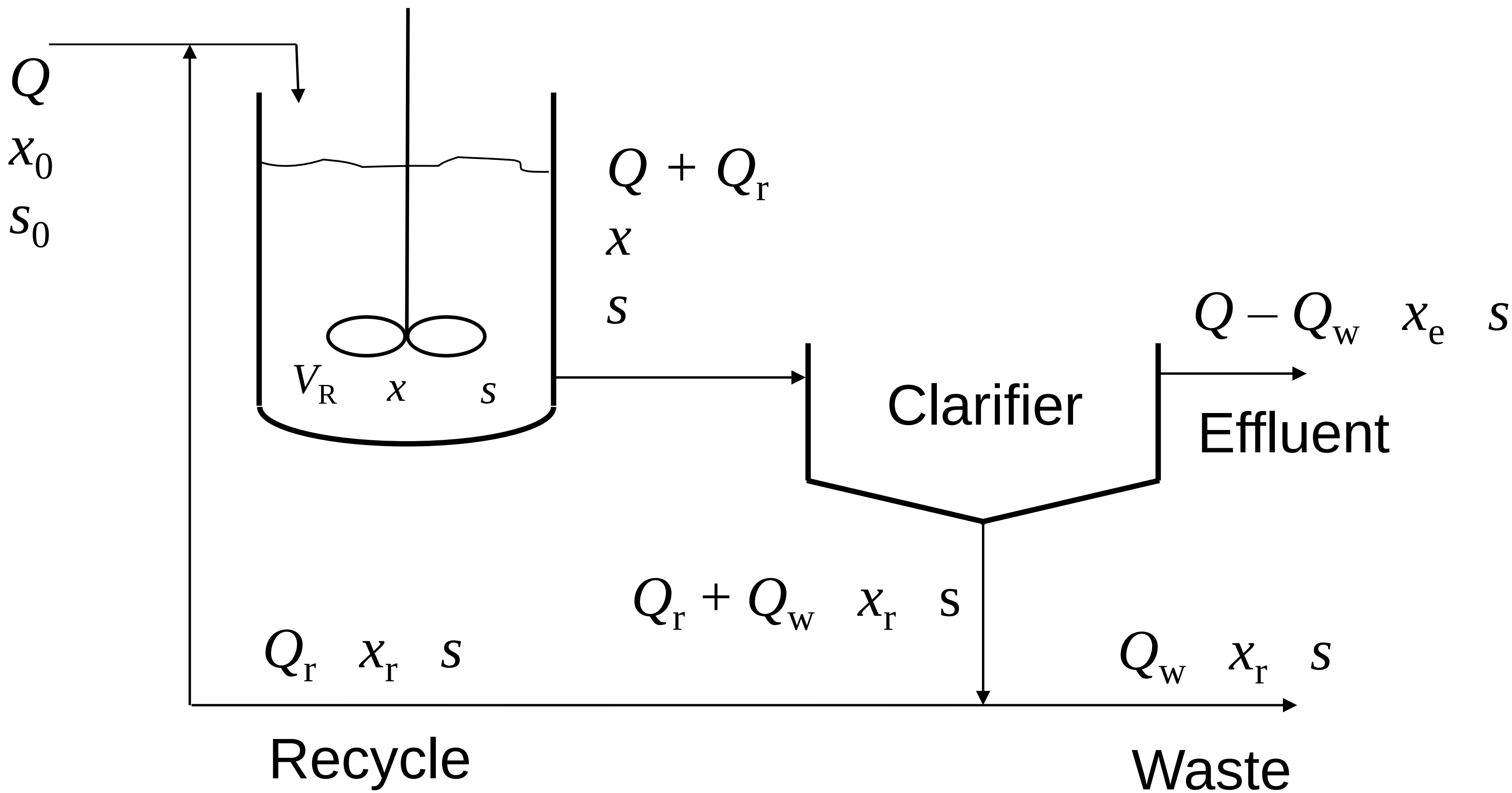
CSTR Analysis

- Organisms have a limit as to how fast they can grow, which is the maximum specific growth rate, $\mu_{\max}$
- If D exceeds $\mu_{\max}$ (approximate), the flow will be faster than cells can divide and ultimately all cells will disappear from the reactor – called washout

CSTR with Recycle

- If cells are continuously added to the CSTR, then D can exceed $\mu_{\max}$ and higher feed flow rates can be used
- Typically used for activated sludge processes

Activated Sludge Process



Important Parameters

- Hydraulic residence time:

$$\theta = V_\mathrm{r}/Q$$

- Cell residence time:

$$\theta_\mathrm{c} = \frac{V_\mathrm{r} x}{Q_\mathrm{w} x_\mathrm{w}}$$

- Yield coefficient:

$$Y = \frac{x_\mathrm{w}}{s_0 - s} = \frac{\text{mass cells produced}}{\text{mass substrate consumed}}$$

- cell death (decay) coefficient, k_d

Activated Sludge Process

- Food for the process is generally considered the soluble BOD_5 present in the influent (s_0)
- Biomass (x) is considered to be the mixed liquor (contents of the reactor) volatile suspended solids (MLVSS)
- Biomass in influent stream (x_0) is considered to be the volatile suspended solids in the influent (VSS)

Activated Sludge Process

- Assumptions made in analyzing activated sludge process:
  - cell concentration in influent is negligible compared to that in the reactor:

    $$x_0 = 0$$

  - cell concentration in clarifier overflow is negligible compared to that in the reactor:

    $$x_e = 0$$

Activated Sludge Design Equations

- Using the parameters and assumptions defined previously, the cell concentration in the reactor is given by

$$x = \frac{\theta_c Y (s_0 - s)}{\theta (1 + k_d \theta_c)}$$

Activated Sludge Design Equations

- Similarly, assuming the Monod growth model applies and using the parameters and assumptions defined previously, the substrate (soluble BOD_5) concentration in the reactor is given by

$$s = \frac{K_{\mathrm{s}}\left(1 + k_{\mathrm{d}}\theta_{\mathrm{c}}\right)}{\theta_{\mathrm{c}}\left(\mu_{\mathrm{max}} - k_{\mathrm{d}}\right) - 1}$$

Typical Parameter Values for Activated Sludge Processes

Parameter	Units	Value	
		Range	Typical
K_s	mg BOD_5/L	25 – 100	60
k_d	d^{-1}	0 – 0.30	0.10
μ_{max}	d^{-1}	1 – 8	3
Y	mg VSS/mg BOD_5	0.4 – 0.8	0.6

Effluent BOD_5

- For process analysis, we considered the cell concentration in the effluent stream to be negligible; however, there is a fraction of the suspended solids that do not settle in the clarifier which contributes to the BOD_5 load to the receiving body of water.
- This BOD_5 in the suspended solids must be subtracted from the total BOD_5 allowed in the discharge to get the allowable soluble BOD_5 which is the substrate concentration (s) in the effluent

Nitrogen Removal

- Nitrogen can be removed from wastewater using a two-stage biological process
  - Nitrification – aerobic process

    Ammonia is oxidized to nitrate, consuming O_2
  - Denitrification – anoxic process

    Nitrate is used as an oxygen source for respiration producing N_2 gas

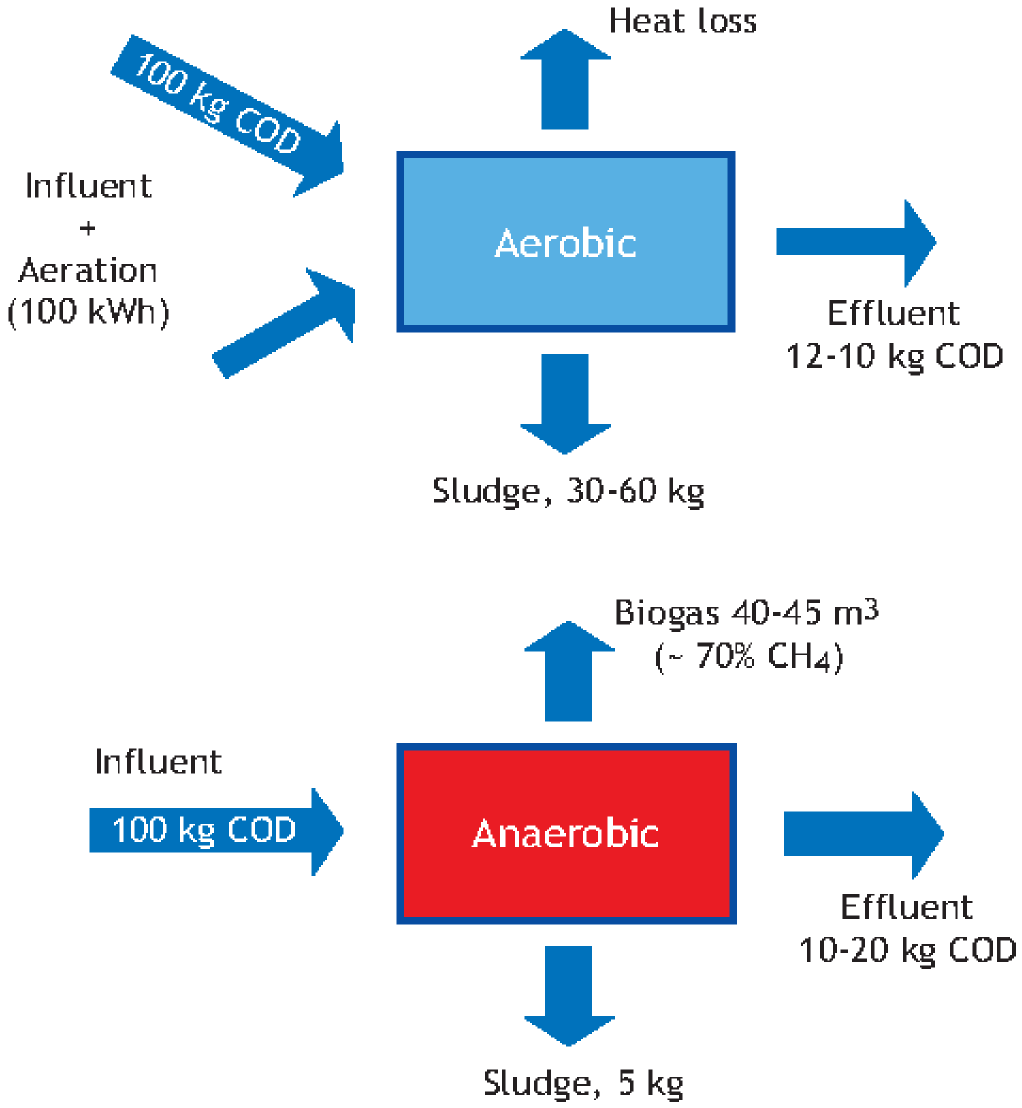
Phosphorus Removal

- Chemical phosphorus removal
  - Ferric chloride ($FeCl_3$)
  - Alum ($Al_2(SO_4)_3$)
  - Lime ($Ca(OH)_2$)

Phosphorus Removal

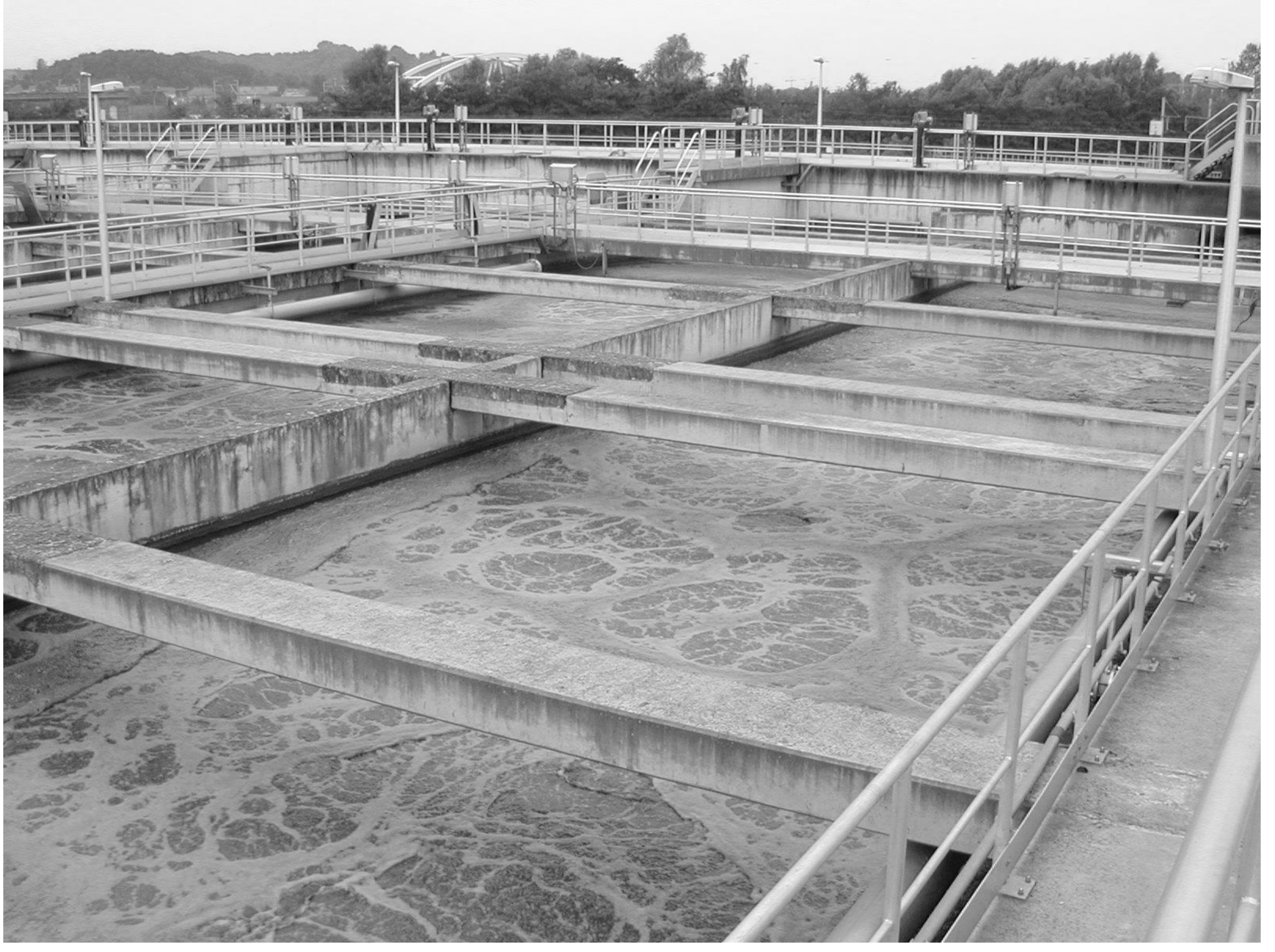
- Biological phosphorus removal
  - Anoxic step converts organic phosphorus to orthophosphate
  - During aerobic growth, orthophosphate is taken up by organisms during growth and additional phosphate is converted to polyphosphate which accumulates in the biomass

Activated Sludge Plant


Heat loss
100 kg COD
Influent
+
Aeration
(100 kWh)
Aerobic
Effluent
12-10 kg COD
Sludge, 30-60 kg
Biogas 40-45 m^3
(~ 70% CH_4)
Influent
100 kg COD
Anaerobic
Effluent
10-20 kg COD
Sludge, 5 kg

Return sludge (on right) mixing with incoming wastewater (on left)

Anoxic treatment at start of activated sludge process for organisms to convert organic phosphorus to orthophosphate.



Aeration basin for activated sludge process

Clarifier for activated sludge process

Augurs lifting sludge coming from clarifier outlet to be returned to activated sludge treatment process.