CE 356: Fundamentals of Environmental Engineering

Environmental Microbiology & Engineering Design

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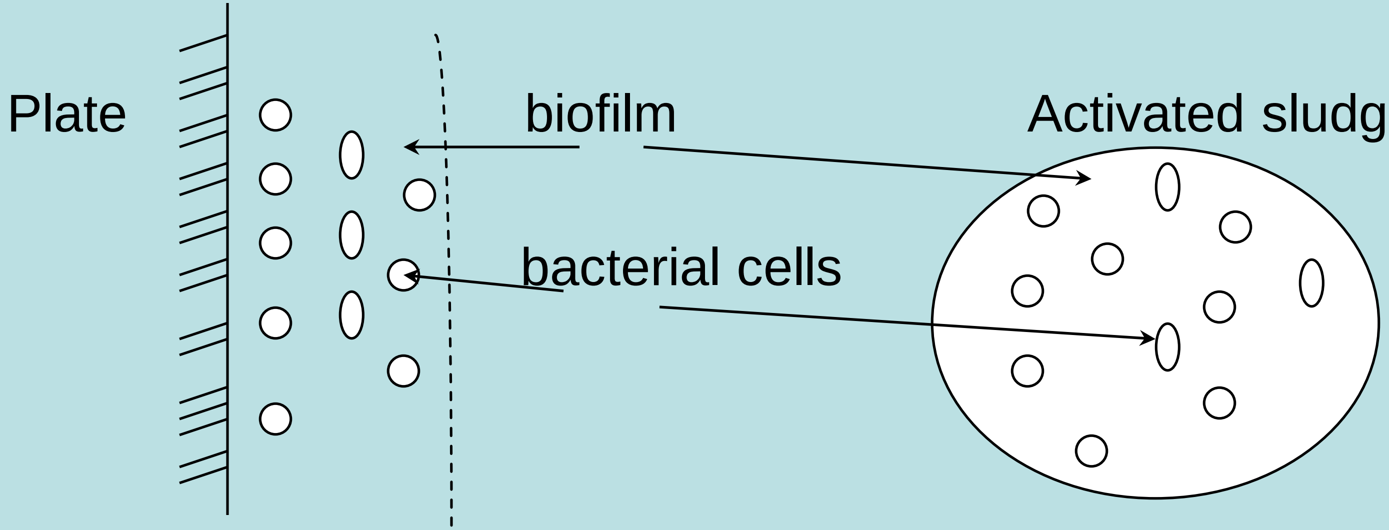
Learning Objectives

- Comprehend the concepts of:
  - Distribution of energy from BOD under aerobic and anaerobic growth of bacteria,
  - "Nutritional" value of domestic wastewater for bacteria,
  - Batch growth of bacteria,
  - Design equation for continuous growth of bacteria,
  - Sludge age,
  - Food to microorganism (F/M) ratio.

Significant Microorganisms

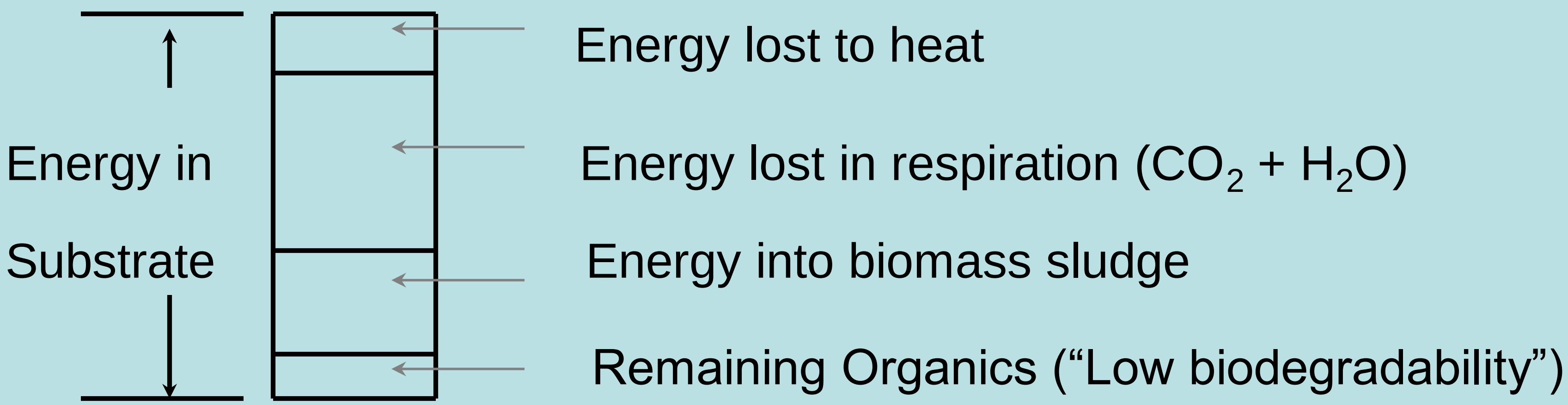
- Bacteria – single cell microorganisms that reproduce by binary fission.
- Fungi – yeasts and molds.
- Protozoa – Single cell animals
  - Bacteria consume soluble (dissolved) BOD (organic substrate) and are aggregated into biofilm and floc to which suspended solids attach.



Aerobic Metabolism

$$\begin{array}{l} Biodegradable + Bacteria + O_2 \rightarrow CO_2 + H_2O + Bacteria \\ Organics \qquad\qquad\qquad\qquad\qquad\qquad + remaining \ organics \end{array}$$

- Efficient conversion of energy

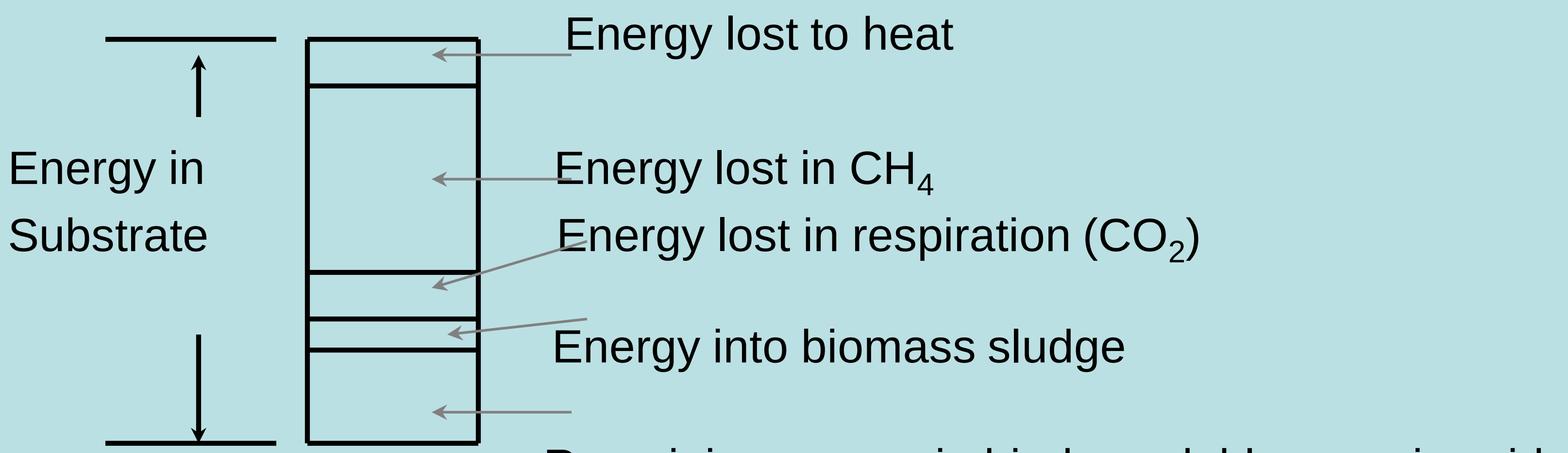


- Good for the receiving stream, high biomass yield and low BOD in final effluent

Anaerobic Metabolism

$$\underset{Organics}{Biodegradable} + Bacteria \rightarrow CH_4 + CO_2 + Bacteria + Organic\ \ Acids\ \ (Biodegradable)$$

- Inefficient conversion of energy



- Low biomass yield and high BOD in final effluent

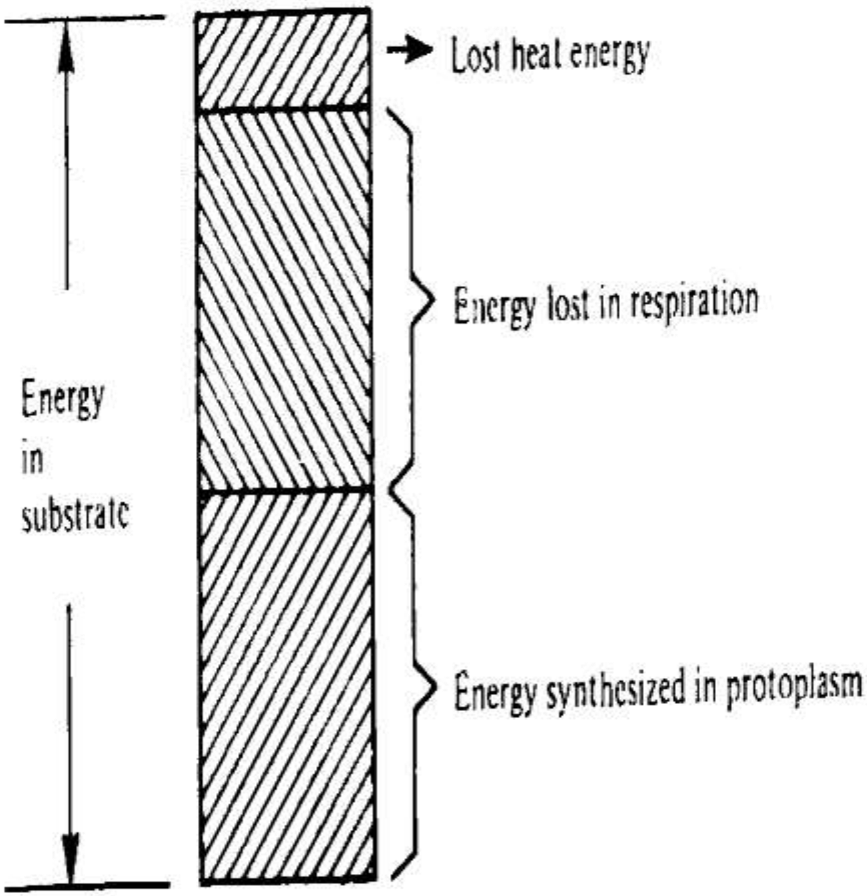


Figure 12.3 Energy conversions in aerobic metabolism.

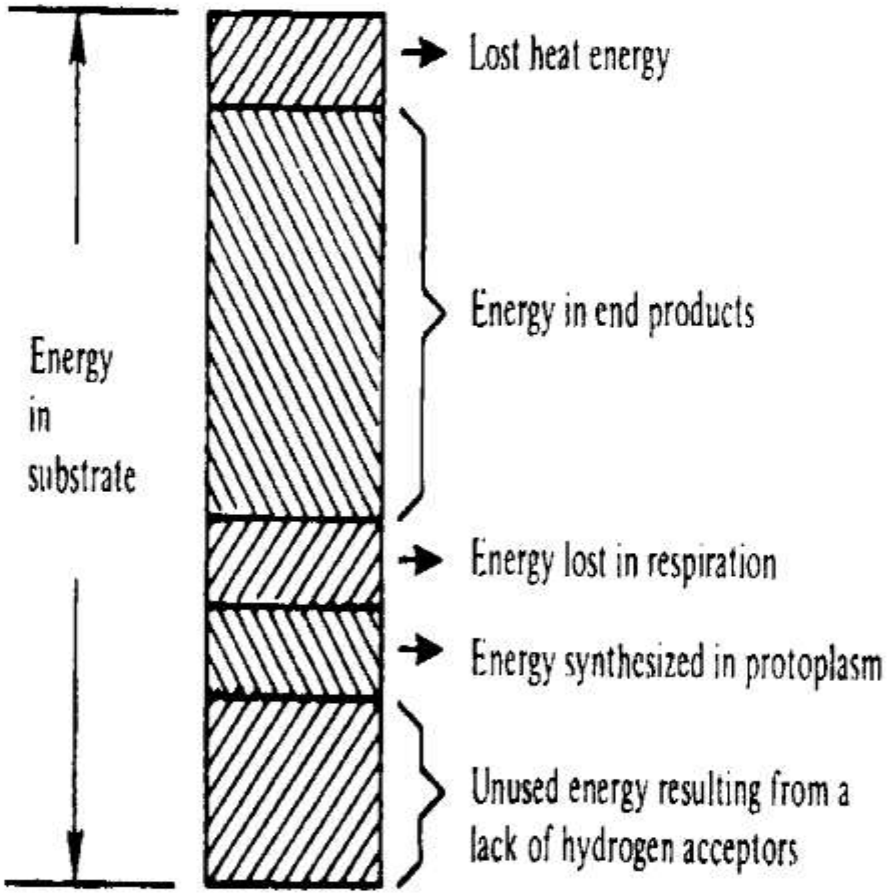


Figure 12.2 Energy conversions in anaerobic metabolism.

(from Viessman, Jr. and Hammer, 1998, pp. 521-522)

Aerobic vs Anaerobic Treatment

- Compare the segments of energy distribution in the waste material for each treatment type.
- Match the segment of each energy bar with the appropriate component of each biochemical equation.
- How does the design engineer decide which form of treatment to use for a given waste source?

Biomass General Formulas

- $C_{60}H_{87}O_{23}N_{12}P$
- $C_5H_7O_2N_2$

C = 50%
O = 20%
N = 14%
H = 8%
P = 3%

Total = 95%

How does this information relate to the characteristics of wastewater?

Growth of Heterotrophic Cultures

- Cultures:

  - Continuous Growth: substrate (BOD) fed continuously

  - Batch Growth:
    - Single dose of substrate (BOD)
    - Single inoculation of biomass (mixed liquor suspended solids, MLSS)
    - Growth not limited by O_2, N, or P
    - Monitor change of substrate level (COD or BOD) and MLSS with time

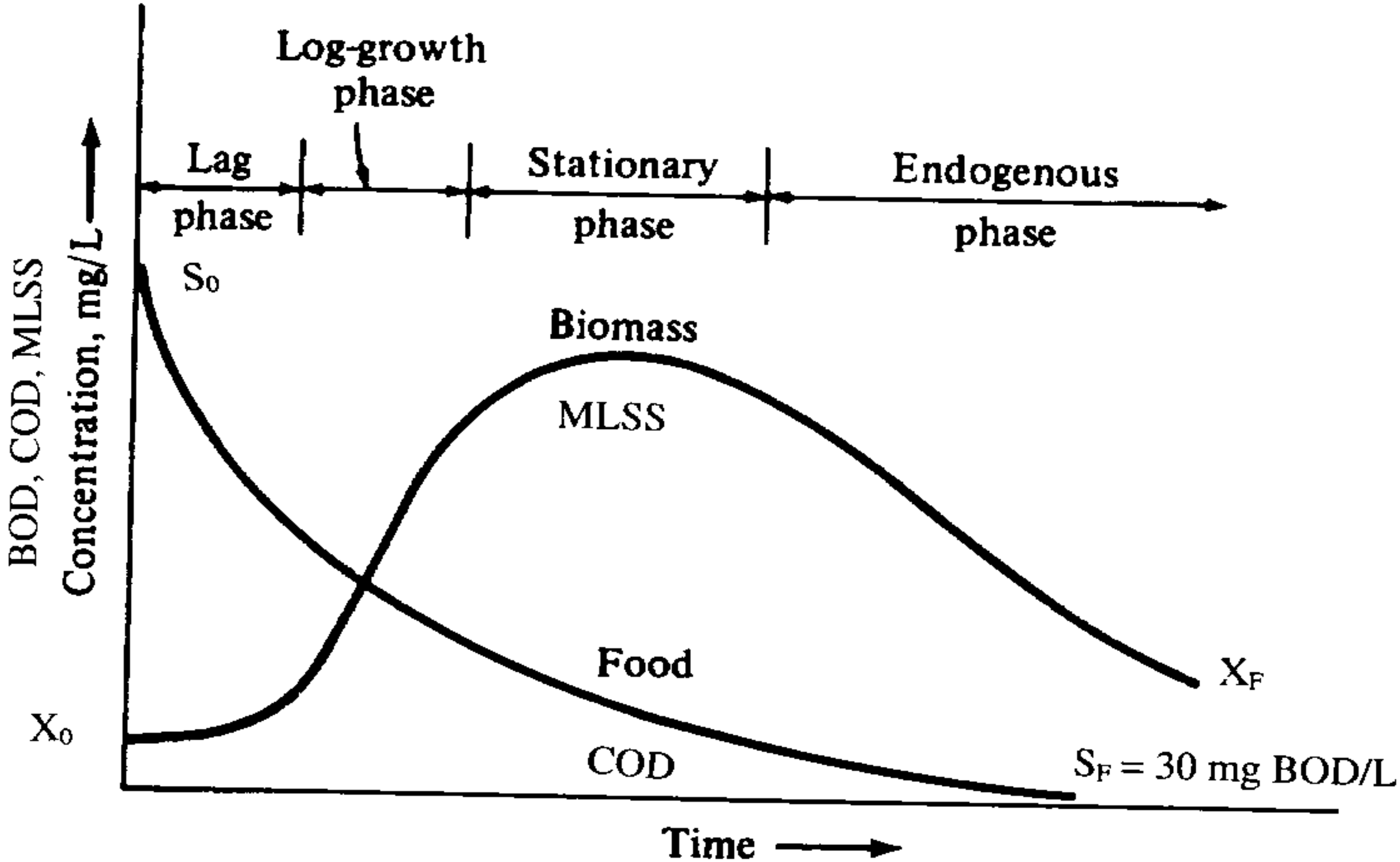


Figure 5-14 Biomass growth and food utilization.

$$X_F - X_O = Sludge\ Production$$

$$S_0 - S_F = Substrate\ removal\ (BOD\ reduction)$$

(from Peavy, Rowe, and Tchobanoglous, 1985, p.231)

Growth of Heterotrophic Cultures

- Lag phase: acclimation to new substrate, could be short lived
- Log Growth: active reproduction by binary fission
- Stationary: Growth = Death
- Endogenous: Death > Growth
- In lag and log growth phases sufficient substrate is available
- In stationary and endogenous phases substrate is limited

$$\frac{X_F - X_0}{S_0 - S_e} = Y = biomass\ \ yield = \frac{mg\ \ MLSS\ \ produced}{mg\ \ BOD\ or\ COD\ removed}$$

Secondary Treatment Models

- Models for secondary treatment are developed around:
  - BOD (substrate) reduction
  - Sludge (biomass) production
  - Retention time (activated sludge only)

- Log Growth Phase:

$$\frac{dX}{dt} = Y\frac{dS}{dt} \qquad where\ Y = yield\ coefficient$$

$$\frac{dS}{dt} = substrate\ removal\ rate$$

$$\frac{dX}{dt} = biomass\ growth\ rate$$

Secondary Treatment Models

- Endogenous Phase (starvation/death phase):

$$\frac{dX}{dt} = -k_d X \qquad where\ k_d = decay\ coefficient$$

- Net Growth:

$$\frac{dX}{dt} = Y\frac{dS}{dt} - k_d X \qquad where\ Y = yield\ coefficient$$

$$\frac{dS}{dt} = substrate\ utilization\ rate$$

$$\frac{dX}{dt} = biomass\ growth\ rate$$

Secondary Treatment Models

- Specific Growth Rate & Specific Substrate Utilization Rate

$$\frac{dX}{dt} = Y \frac{dS}{dt} - k_d X$$

$$\frac{dX \ / dt}{X} = Y \frac{dS \ / dt}{X} - k_d$$

$$\frac{dX \ / dt}{X} = \frac{1}{\theta_c} \qquad where \;\; Y = yield \;\; coefficien \; t$$

$$\frac{dS}{dt} = substrate \;\; utilizatio \; n \;\; rate$$

$$\frac{dX}{dt} = biomass \;\; growth \;\; rate$$

$$\theta_c = sludge \;\; age$$

Sludge Age

- Sludge age is the length of time (days) the sludge (bacteria) is retained within the secondary treatment process.
  - Activated sludge: 10 days $Y_{net} = 0.4 - 0.6$
  - Trickling filter: 100 days $Y_{net} = 0.1 - 0.3$

$$Y_{net} = \frac{lb\ sludge\ produced}{lb\ BOD\ removed}$$

- Trickling filters also produce a more dense (thicker) sludge:
  - TF = 1.5% solids
  - AS= 0.8% solids

Quantify in Engineering Design Terms

$$\frac{1}{\theta_c} = Y \frac{dS / dt}{X} - k_d \qquad (1)$$

$$dS = (S_0 - S_e) \qquad (2)$$

$$dt = \frac{V}{Q} \qquad (3)$$

Combine Equation (1), (2), *and* (3)

$$\frac{1}{\theta_c} = Y \frac{(S_0 - S_e)Q}{XV} - k_d$$

Design Equation: Identify, define (units), and describe the "design parameters" vs "typical known" conditions. Which parameter(s) does the design engineer control?

$$\frac{1}{\theta_c} = Y\frac{(S_0 - S_e)Q}{XV} - k_d$$

Food:Microorganism (F/M) Ratio

$$\frac{F}{M} = \frac{Substrate\ Applied\ (lb)}{Mass\ of\ Microorganisms\ (lb)\ in\ the\ treatment\ system}$$

$$\frac{F}{M} = \frac{Q\ S_0}{V\ X} \quad units\ of\ [day^{-1}]$$

- As F/M changes, the phase of growth shifts:
  - – High F/M, log growth phase, more sludge
  - – Low F/M, endogenous growth phase, less sludge
  - – Trickling filter is a low F/M process (less sludge).
  - – Activated sludge is a higher F/M process (compared to trickling filter, more sludge)

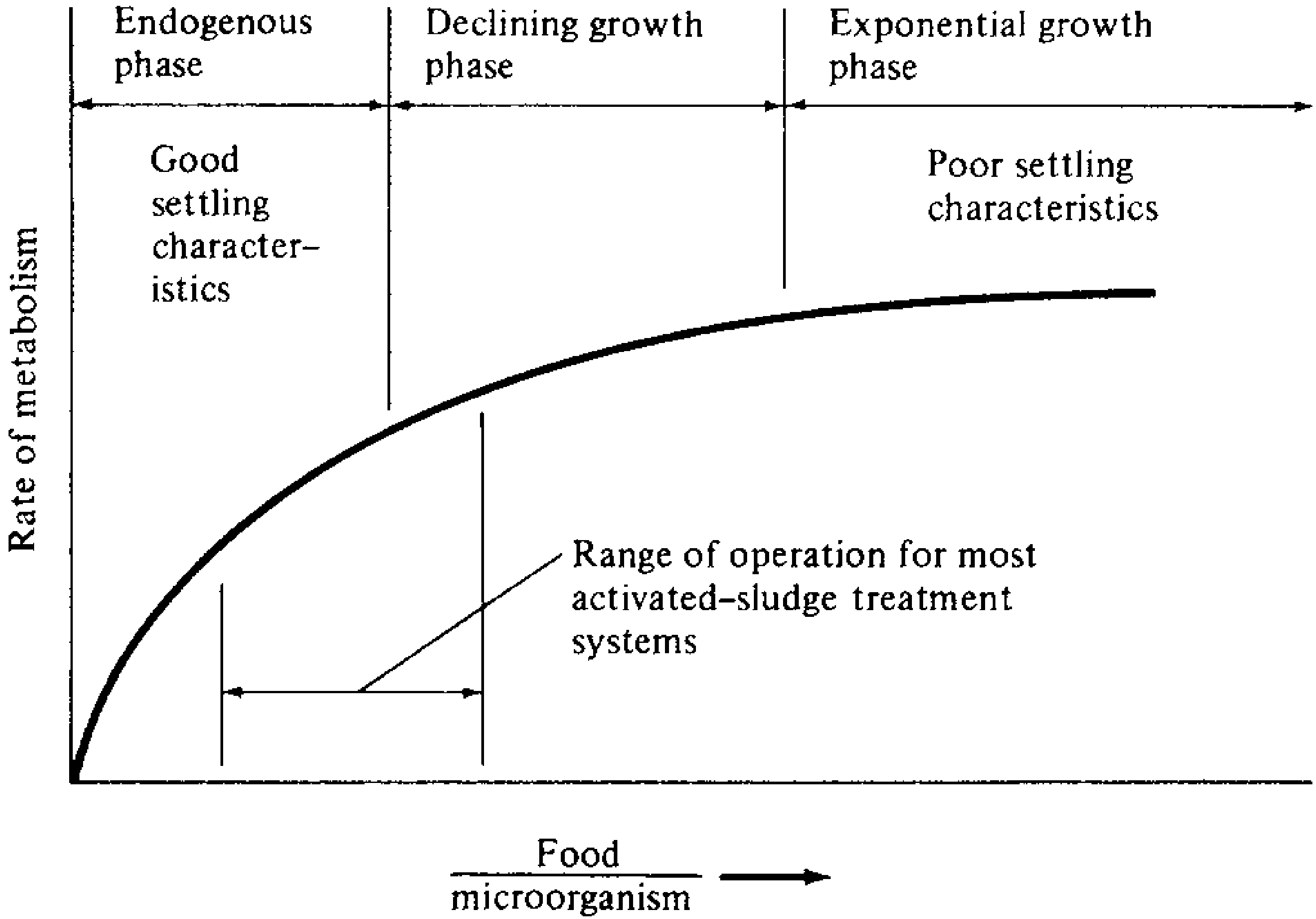


Figure 12.9 Rate of metabolism versus increasing food/microorganism ratio.

(From Viessman, Jr. and Hammer, 1998, p. 529)

References

- Peavy, Howard S., Rowe, Donald R., and Tchobanoglous, George. (1985). Environmental Engineering. New York. McGraw-Hill.
- Viessman Jr., Warren and Hammer, Mark J. (1998) Water Supply and Pollution Control. Menlo Park. Addison Wesley Longman.