ENVE 302

Environmental Engineering Unit Processes

CHAPTER: 3

Bacterial Growth Kinetics

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Microbial Growth Kinetics

Rate of growth of bacterial cells can be defined as

$$r_g = \mu . X$$

rate of increase in bacterial pop. is proportional to the number of bacteria present

Autocatalytic rxn
aA → bB r=k[B]

r_g = net biomass production rate (g VSS/m^3.d)

μ = specific biomass growth rate $\left(\frac{g\,VSS}{g\,VSS.d}\right)$

X = biomass concentration $\left(\frac{g\,VSS}{m^3}\right)$

Growth rate of bacteria → can be defined by Monod eqn $\frac{g\,new\,cells}{g\,cells.d}$

$$\mu = \mu_m \frac{S}{K_S + S}$$

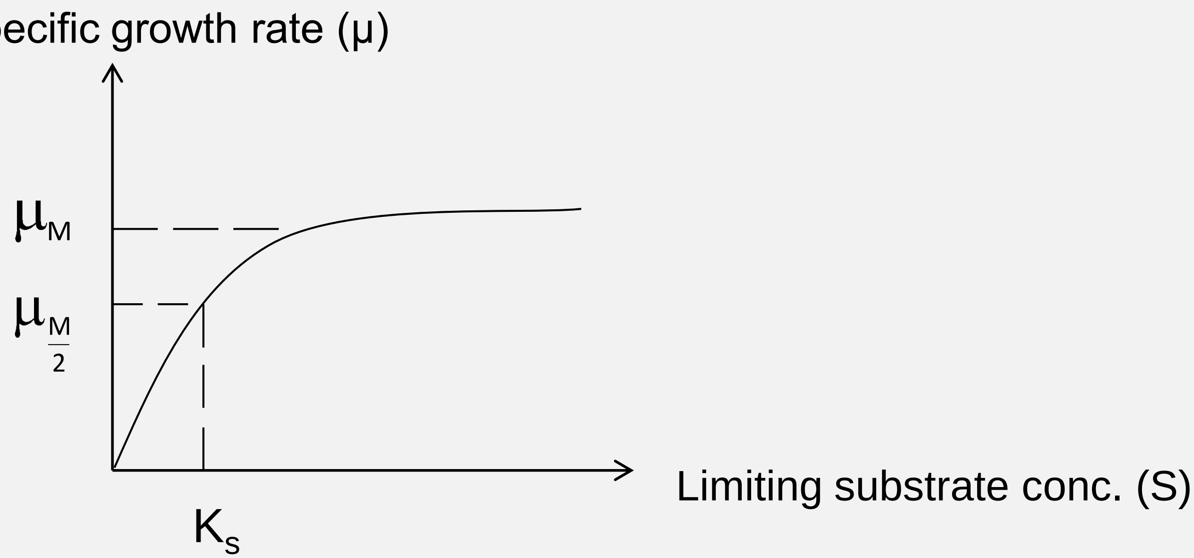
where

μ = specific biomass growth rate

μ_M = max specific biomass growth rate (g VSS/g VSS.d)

The growth limiting substrate can be any of the essential (i.e e$^-$ donor, e$^-$ acceptor or nutrients) but often it is the e$^-$ donor that is limiting, as other requirements are usually available in excess. ← S = growth limiting substrate conc in solution (g/m^3)

K_s = half velocity constant (substrate conc at one half the max specific biomass growth rate (g/m^3)

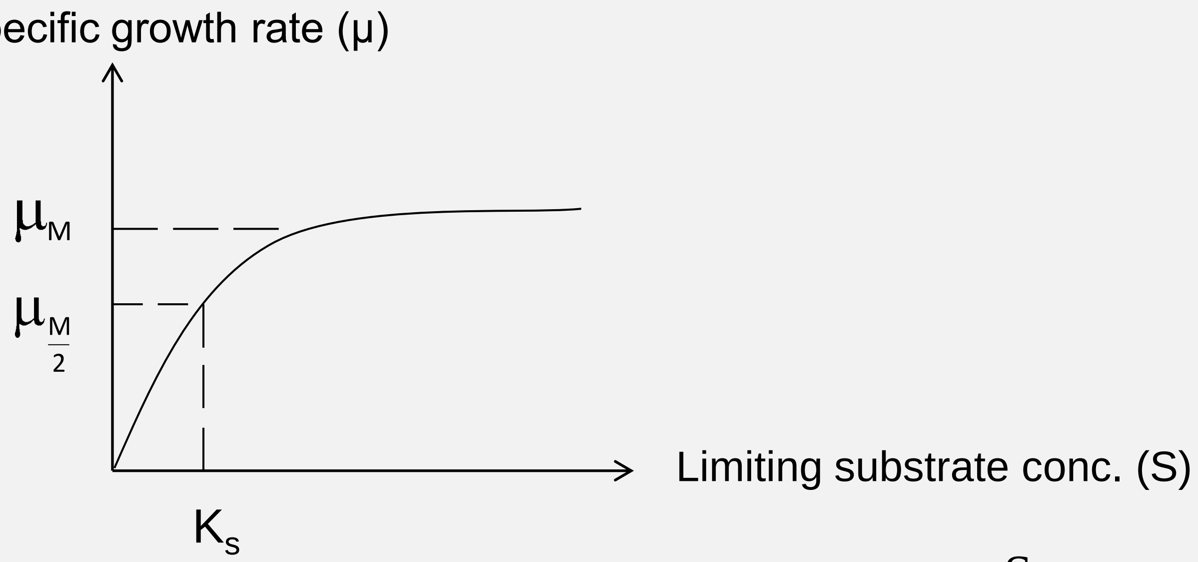


For high substrate conc ($S >> K_s$) → $\mu = \mu_m \dfrac{S}{K_S + S}$

↓ (K_S) negligible with respect to S

→ $\mu = \mu_M$

Bacteria grow at their max. rates } Growth rate is independent from substrate conc. → Zero order kinetics



For low substrate conc ($S \ll K_s$) → $\mu = \mu m \dfrac{S}{K_S + S}$

S ↓ Negligible with respect to Ks

→ $\mu = (\mu_M / Ks)S$ ⟶ First order kinetics

Growth rate is dependent on subs conc

$r_g = \mu . x$

$\mu = \mu M \dfrac{S}{K_S + S}$

$\dfrac{r_g}{x} = \mu m \dfrac{S}{K_s + S}$ ⟶ $r_g = \dfrac{\mu_m XS}{K_S + S}$

$$Y = \text{biomass yield coeff} = \frac{\text{g biomass produced}}{\text{g substrate utilized}}$$

$$r_g = \text{biomass production rate (g VSS/m}^3\text{d)}$$

$$r_{su} = \text{substrate utilization rate (g subst/m}^3\text{d)}$$

$$Y = \frac{r_g}{-r_{su}}$$

$$r_g = -Y r_{su}$$

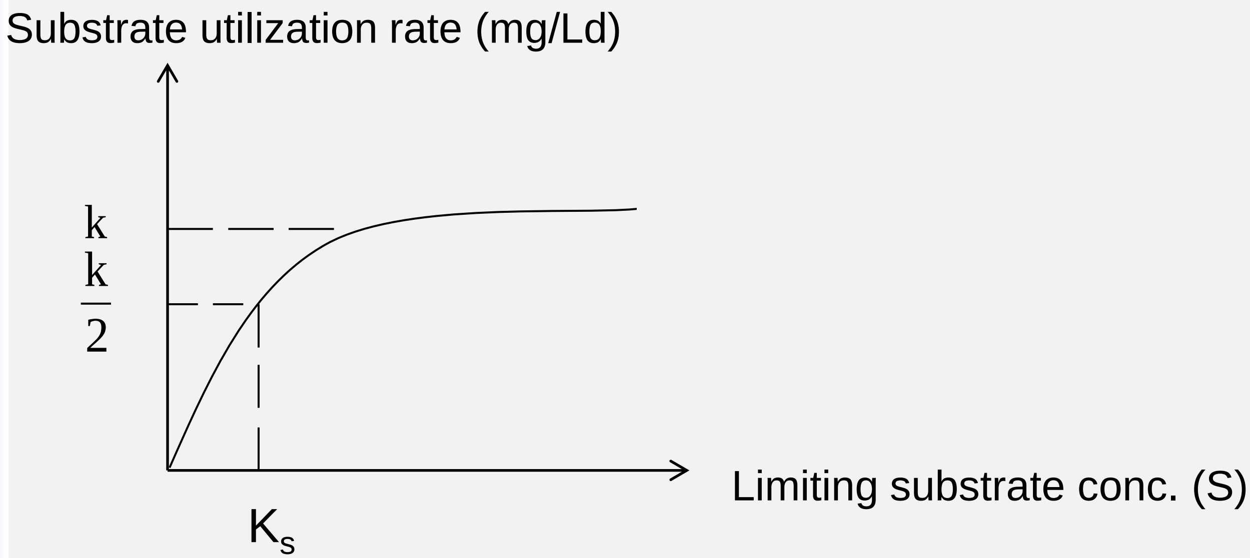
(-) → substrate is decreasing with time due to substrate utilization

$$r_g = \frac{\mu_m XS}{K_s + S}$$

$$r_g = -Y r_{su}$$

$$r_{su} = \frac{-\mu m}{Y} \frac{XS}{K_s + S}$$

k= max specific substrate utilization rate

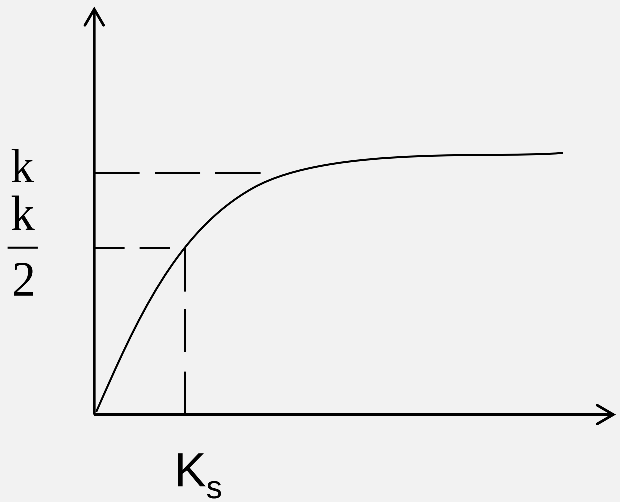


For high substrate conc ($S >> K_s$) → $r_{su} = -\frac{kXS}{K_s + S}$ = -k.X

↓ (K_s) Negligible with respect to S

Subst. utilization → zero order → independent from subst conc.

Substrate utilization rate (mg/Ld)



Limiting substrate conc. (S)

For low substrate conc ($S \ll K_s$) → $r_{su} = -\frac{kXS}{K_s+S} = \frac{-kXS}{K_s}$

(S in K_s+S:) negligible with respect to Ks

Subst.utilization → 1st order → subst utilization rate → dependent on subst. conc.

Rate of growth & rate of substrate utilization expressions must be corrected to account for

1.the energy required for cell maintenance

2.cell death

→ m.o in all growth phases require energy for cell maintenance

→ in bacterial systems used for ww treatment not all the cells in the system are in log growth phase

Endogenous decay coeff rate (time^{-1}) → accounts for the cell mass due to oxidation of internal storage products for energy for cell maintenance, cell death

The decrease in cell mass caused by energy requirement for cell maintenance and cell death is proportional to the concentration of m.o present

The endogenous decay term can be formulated as follows:

$$r_d = -k_d X$$

Kd=endogenous decay coeff. $\left(\frac{gVSS}{gVSSd}\right)$

$$r_g = \frac{\mu_m XS}{K_s + S}$$

$$r_d = -k_d X$$

$$r_g' = \frac{\mu_m XS}{K_s + S} - k_d X$$

net rate of bacterial growth (g VSS/m^3d)

$$r_g = -Yr_{su} \rightarrow r_g' = -Yr_{su} - k_d X$$

$$r_g' = \frac{\mu_m X S}{K_s + S} - k_d X \qquad \frac{r_g'}{X} = \frac{\frac{\mu_m X S}{K_s + S} - k_d X}{X} \Rightarrow \mu' = \frac{\mu_m S}{K_s + S} - k_d$$

not specific growth rate, time^{-1}

$$(r_g = \mu X)$$

$$Y = -\frac{r_g}{r_{su}} \Rightarrow Y_{obs} = -\frac{r_g'}{r_{su}}$$

Effect of Temperature

Effect of temperature on the rxn rate of a biological process is expressed as follows

$$k_T = k_{20}\phi^{(T-20)}$$

k_T = rxn rate coeff at temp T

k_{20} = rxn rate coeff at 20^0 C

ϕ = temp – activity coeff (1.02-1.25)

T = temperature, ^{0} C

Total Volatile Suspended Solids and Active Biomass

X in kinetic expressions used to describe biological kinetics } Active biomass

VSS in a reactor consist of

→ nonbiodegradable VSS (nbVSS) in the influent ww fed to the biological reactor

→ active biomass

→ cell debris following endogenous decay

During cell death → cell lysis occurs

→ release of cellular material into liquid for consumption by other bacteria

→ a portion of cell mass (cell wall) is not dissolved and remains as nonbiodegreadable material

→ cell debris = 10-15 % original cell weight

→ cell debris is also measured as VSS contributes to total VSS conc measured in the reactor mixed liquor

The rate of production of cell debris α endogenous decay rate

r_{xd}= rate of cell debris production $\left(\frac{g\,VSS}{m^3 d}\right)$

$$r_{xd}=F_d(k_d)X$$

F_d=fraction of biomass that remains as cell debris (0.10 - 0.15 g VSS/gVSS)

Total VSS production rate in the aeration tank can be defined as follows

$$r_{XT,VSS} = \underbrace{-Y r_{su} - k_d X}_{\text{active biomass from soluble biodegradable COD}} + \underbrace{f_d (k_d) X}_{\text{nbVSS from cell debris}} + \underbrace{\frac{Q X_{0,i}}{\forall}}_{\text{nbVSS in influent}}$$

active biomass from soluble biodegradable COD

nbVSS from cell debris

nbVSS in influent

$r_{XT,VSS}$ = total VSS production rate g/m^{3}d

Q = influent flowrate, m^3/d

$X_{0,i}$ = influent bVSS conc., g/m^3

$\forall$ = volume of reactor

$$Y_{obs} = \frac{\text{g VSS produced}}{\text{g substrate utilized}} = \frac{-r_{XT,VSS}}{r_{su}}$$

Example: For an industrial ww activated sludge process

influent ww → bsCOD=300 g/m^3

nbVSS=50 g/m^3

Q=1000 m^3/d

in the reactor → X=2000 mg/L

bsCOD=15 g/m^3

$\forall$=105 m^3

cell debris fraction (F_d)=0.10

Determine ;

1.net biomass yield

2.observed solids yield

3.Biomass fraction in mass

Table 7-9

Typical kinetic coefficient for the activated sludge process for the **removal of organic matter** from domestic wastewater at 20°C

Coefficient	Unit	Value	
		Range	Typical
k	g bsCOD / g VSS.d	2-10	5
K_s	mg/L BOD mg/L bsCOD	25-100 10-60	60 40
Y	mg VSS/ mg BOD mg VSS/ mg bsCOD	0,4-0,8 0,3-0,6	0,6 0,4
k_d	g VSS/ g VSS.d	0,06-0,15	0,10

Ref: Metcalf & Eddy

Table 8-10

Activated-sludge kinetic coefficients for **heterotrophic bacteria** at 20 C*

Coefficient	Unit	Range	Typical value
μ_m	*g VSS/ g VSS.d*	3,0-13,2	6,00
K_s	$g\ bCOD/\ m^3$	5,0-40,0	20,0
Y	*g VSS / g bCOD*	0,30-0,50	0,40
k_d	*g VSS / g VSS.d*	0,06-0,20	0,12
f_d	Unitless	0,08-0,20	0,15
Θ values			
μ_m	Unitless	1,03-1,08	1,07
k_d	Unitless	1,03-1,08	1,04
K_s	Unitless	1,00	1,00

* Adapted from Henze et al. (1987a); Barker and Dold (1997); and Grady et al. (1999)