Water pollution control

- Conventional disinfectant: Cl, Ozone, UV.
- Filtration Granular Media filtration most common. Involved backwash. A clean bed is filtered to waste till the media "ripens" and the particle capturing capabilities are restored.
- **Coagulation&flocculation**-> disinfection destroys/inactivates pathogens.
- Coagulants overcome repulsion(coagulant addition);Flocculation->floc growth
- High particle/floc reduce filter runs between backwash& reduce production.
- High alum dose->available alkalinity, sludge production. Add more particle as 'aid', recirculate small portion of sludge to mixer.
- Flocculation Mixing system: 1.**mechanical**(vertical shaft turbine/horizontal paddle). 2.**baffled channel basins**. 3.**reactor clarifier proprietary system**. 4.**contact flocculation**. 5.**diffused air/water jet agitation**. Criteria for system: detention time, velocity gradient/G value.
- filtration can improve subsequent process because removal of **Removal of particulates that protect microbes and inhibit disinfection.**
- Granular media filtration is not only physical b/c **particles too small**, **-e charge inhibit media-particle attachment**.
- 2 mechanism involved in coagulation using coagulants such as alum&ferric: 1. **Absorption and charge neutralization**. 2. **Enmeshment(sweep floc)**
- low-turbidity -> low collision frequency -> hard to treat by chemical coagulation
- treat low turbidity water: 1. **Add high dose of alum for sweep flo**c. 2. **Increase collisions by adding coagulant aid or recirculating a portion of floc sludge**
- negative consequences (sweep flocculation treat low turbidity): **high chemical cost**; **high sludge production&removal cost**; **high alkalinity consumption**/might need to +chemicals to increase alkalinity
- Ferric is better @ph=8: has lower solubility @8, AlOH4 dominates @8-> ineffective at charge neutralization
- Jar test, pilot testing, adjustment at full scale -> **determine optimal dose of coagulant**
- Polyaluminum (PACl) better b/c: more efficient absorption&charge neutralization->lower dose->lower sludge; less sensitive to ph fluctuation, lower temp
- use of clarification before filtration: reduce solids loading, reduce frequency of backwashes, increase filtration rate
- chemical coagulation removed Natural Organic Matter(NOM)&phosphorus.
  - Originates from terrestrial&aquatic. Humic&fulvic acids large fraction. Amber color to water. React with Cl to form chlorinated byproduct.
  - Enhanced Coagulation; Removed by absorption n complexation with Al3+&Fe3+. Might need sweep flocculation (high doses)
  - Al(PO4) precipitate.

Sedimentation type:

- Type1: discreet particle settling->low concentration, negligible flocculation n inter particle effects; Type2: flocculant particle settling->aggregation leads to differential settling; Type3: Hindered/Zone settling->Concentrated suspension with high rate of particle collisions with interactions; Type4:Compression Settling->High concentrations of particles in region beneath zone settling, rearrangement of particle structure occurs.
  - **Type1**:**S**tokes **L**aw(Cd=24/Re,Re<1) $v_p = g(\rho_p - \rho_w)d_n^2/18\mu$. Sedimentation in winter->cold water viscosity increase, less efficient.Hydraulic loading rate$Q/(L\times W) = Q/A = v_c$. $v_p < v_c$will be removed.Fraction of removal:v_p/v_c. **Type2**:floc v&size change w/ time. irregular shape->increased drag->modified **S.L**. Open structure of floc->effective ρ decreased.
  - Sedimentation->drinking water. Types: horizontal flow sedimentation(conventional in N.A)->separate floc. stage; narrow particle size range; loading rate=0.5~1.5m/h; low ρ sludge 0.2-0.5% by volume. **Improvements**: hydraulic loading rate effect efficiency; larger basin A, remove smaller particles; increase surface A by trays, tubes,plates. Eg.lamella plate settlers:shorter settling distance;increased drag->more hydraulic stability; smaller footprint&higher hydraulic loading rate.
  - Solids contact clarifiers(coag,flocc,sedim all in one reactor). 1. **solids recirculation clarifiers**:mixed&flocculated mass into zone@higher concentration->fine floc captured.2.**sludge blanket clarifiers**:fluidized bed of floc; no prior flocculation; smaller particles will flocc.3.**pulsator**.

Waterborne Pathogens Size: Virus(0.02-0.3μm);bacteria(0.5-10);Cryptosporidium oocysts(4-5);Giardia cyst(6-10x10-15). Log removal objectives:每个 10 次方->1 log->90%.99%.99.9%...CFU(colony forming unit). **Rapid Sand Filtration**:3 length scales(bed,media,particle size). Turbidity: NTU("Nephelometric Turbidity Unites), Measure of light scattered by particles. Coagulants->destabilized particle: Hydrolyzed metal salts, alum (Al2(SO4)3·14H2O)&ferric chloride (FeCl3·6H2O); Prehydrolyzed metal salts-polyaluminum chloride(PACl);Organic cationic polymers(inter particle bridging; reduce required alum dose, not consume alka.)->rapidly mixed to disperse in the water. Alum&ferric chloride r acid. Alkalinity=HCO3(-)+CO3(2-)+OH(-).units: mg/L as CaCO3.

Problems caused by increasing consumption of water: environmental side (places stress on river, lake and groundwater aquifers, require dams and flooding with serious ecological impacts) and economic side(increasing and expensive investments in water system infrastructure needed to gather, deliver and dispose of water).

Water pollution: the contamination of water bodies like rivers and lakes caused by human activities, which is harmful for organisms and plants on earth.

When is water polluted: for drinking, microbial, metals, and organics are present. for aquatic, less oxygen and high metal content. for agriculture, high salinity.

Classification of pollutants: aggregation state (particulate; dissolved solids, liquids or gases)

Water treatment: technology to reduce and eliminate harmful substance for environment.

Water quality: the ability of aqueous environment to support normal range of biological species.

Dissolved oxygen: DO decreases as T increase; less DO at higher altitude and used up by aerobic bacteria.

Total solids (TS): the amount of matter less volatile than water (103 C)

$$TS = \frac{m_{cf} - m_{ci}}{V}$$

TS = total solids [mg/L]
m_{ci} = initial crucible mass [mg]
m_{cf} = crucible mass after drying at 103 ºC [mg]
V = sample volume [L]

Volatile solids : the amount of matter volatize when heated to 550C   FS= TS-VS $TVS = \frac{m_{cf} - m_{cx}}{V}$

TVS = total volatile solids [mg/L]
m_{cx} = crucible mass after ignition at 550 ºC [mg]

Total suspendid solids: $TSS = \frac{m_{ff} - m_{fi}}{V}$

Total dissolved solids: the amount of matter dissolved in water. **TDS= TS-TSS**

Volatile suspendid solids: VSS = total solids [mg/L] $VSS = \frac{m_{ff} - m_{fx}}{V}$

Fixed suspendid solids: m_{fx} = filter mass after heating at 550 ºC [mg]

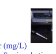
FSS=TSS-VSS

TSS = total suspended solids [mg/L]
m_{fi} = initial filter mass [mg]
m_{ff} = filter mass after drying at 103ºC [mg]

Dissolved organic carbon: dissolved faction of TOC (total organic carbon)

Biochemical oxygen demand:

$$BOD\ (mg/L) = \frac{D_1 - D_2}{P}$$



D_1: initial DO of the diluted wastewater (mg/L)
D_2: final DO of the diluted wastewater after incubation (usually for 5 days) (mg/L)
P: decimal fraction of the wastewater sample use (mL of WW used per mL volume of the BOD bottle)

$$BOD\ (mg/L) = \frac{(D_1 - D_2) - (B_1 - B_2)f}{P}$$

D_1: initial DO of the diluted wastewater - mg/L
D_2: final DO of the diluted wastewater after incubation - mg/L
B_1: initial DO of the seed sample (control) – mg/L
B_2: final DO of the seed sample (control) after incubation– mg/L
f: ratio of seed in sample to seed in control (seed in D_1 to seed in B_1)
P: decimal fraction of the wastewater sample use

Alkalinity: the ability of water to neutralize acid. $BOD\ (at\ any\ time, t) = BOD_u(1 - 10^{-Kt})$

Hardness: measure of concentration of Ca2+, Mg2+, Fe3+

Nitrification: ammonium ions->nitrite by Nitrosomonas bacteria; nitrite->nitrate by nitrobacter bacteria

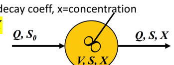
$NH_4^+ + 2O_2 \rightarrow NO_3^- + 2H^+ + H_2O$

Toxicity: LC_{50}- percentage of wastewater that 50% organism are killed. **Factors affect toxicity:** species chosen, test organism density, temperature, physical factor(salinity..).

Pathogen: microorganisms cause disease. **Water Pathogen**: pathogens transmitted by water, transmitted via fecal-oral route and often a zoonosis. **How to Prevent waterborne illness:** 1. filtration: physical removal, dependent on organism charge & water condition. 2. chlorination: damage cell membrane, proteins, nucleic acid ->organism cannot duplicate, dependent on organic load. 3. UV disinfection: damage DNA & RNA-> cells cannot duplicate, dependent on turbidity, organic and microbial load. **Indicator organisms**: organism presence indicate pathogen presence. **Two approach to regulation:** 1. environmental quality based regulations: based on ecosystem approach, environmental quality objectives in ecosystem are determined, permissible total loading of substance are identified to prevent ecosystem exceeding objective, all contributing sources are assigned discharge limit so the sum inputs less than permissible environmental loading. 2. technology based regulation: no environmental quality consideration, regulatory limits for source dependent on nature of source. **The guidelines for Canadian drinking water quality (GCDWQ) sets maximum concentration for:** 1. microbial characteristic 2. chemical and radiological characteristics 3. aesthetic quality. **Drinking water standard in BC:** 4 log removal of viruses; 3 log removal of Giardia & Cryptosporidium; 2 barriers; 1 NTU; 0 E-Coli.

Biological wastewater treatment

- Important growth parameter
  - Temperature: ideal range25-37C, T drop-> removal eff. Drops. $r_T = r_{20}\theta^{(T-20)}$ r: rate at T &20.θ=temp.activ.coeff.
  - pH: 6~9. 'self-buffer'. High pH-> part system ineffective
  - Nutrients: Acti.Sludge **BOD_5:N:P=100:5:1**. Longer HRT->less critical nutrient control
  - Toxicity: presence of toxic mtrl->bacterial activity inhibited
- Endogenous Metabolism(Decay)
  - 2 process: 1.bacterial cells remove BOD&produce new cellular mtrl 2.Bacteria undergo self-destructive endo~respiration
  - cell mass drop due to decay, proportional to concentration$r_d = -k_d x$. r_d=decay rate, k_d=decay coeff, x=concentration
  - Net biomass growth $r_g' = dX/dt = \mu_{max}XS/(S+K_s) - k_d X = -Y\,dS/dt - k_d X$
  - Net specific growth rate$\mu' = (1/X)(dX/dt) = \frac{\mu_{max} \cdot S}{S+K_s} - k_d$.
  - Effect of endogenous decay on r_g ->$Y_{obs} = r_g'/r_s$



- ASB: mean retention time(V/Q) of at least 5d. Aeration by either diffused air or mechanical surface aerator.
  - O_2 for BOD removal and endog~resp. biological solids in suspen. Accu=in+out+new growth

$$\frac{dS}{dt}V = QS_0 - QS - V r_s = QS_0 - QS - V\left(\frac{1}{Y}\frac{\mu_{max} X S}{S+K_s}\right)$$

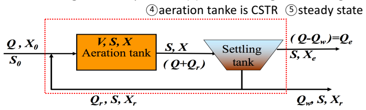
$$S_0 - S_e = \frac{V}{Q}\left(\frac{1}{Y}\frac{\mu_{max} X S}{S+K_s}\right) = \frac{V}{Q}\frac{\mu X}{Y} = \theta\frac{\mu X}{Y}$$

$$X = Y\frac{(S_0 - S_e)}{\mu\theta} = Y\frac{(S_0 - S_e)}{1 + k_d\theta}$$

$$\mu = \frac{1}{\theta} + k_d$$

$\frac{X}{(S_0 - S_e)} = Y_{obs} = \frac{Y}{1 + k_d\theta}$ relates Y_{obs} to Y, Y_{obs} depends on mean retention time, largerθ, smaller Y_{obs}

Activated Sludge ->Assump:①.BOD(S)is rate limiting②.X_0&$X_e$negli.~=0③subtrate consumption in aeration tank ④aeration tanke is CSTR ⑤steady state (Accu=in-out+new. Overall biomass balance)



$$\theta_c = \frac{cell\ in\ reactor}{rate\ cells\ leave\ the\ system} = \frac{VX}{Q_w X_r}$$

Q_wX_r=net flow of biomass VX=biomass in reactor

- Overall substrate balance: $QS_0 - (Q - Q_w)S - Q_w S - V\frac{\mu X}{Y} = 0 \Rightarrow Q(S_0 - S) - V\frac{\mu X}{Y} = 0$ $\mu = \frac{\mu_{max}S}{S+K_s} = \frac{YQ(S_0 - S)}{VX}$

Q(S0-S)=BOD

$$\frac{Q_w X_r}{VX} = \frac{YQ(S_0 - S)}{VX} - k_d$$

left=net specific rate of biomass growth, red circle=rate of production of biomass(must >=0)

- Design parameter: $\frac{S_0 - S}{S_0} \times 100$ (target eff.) $V/Q = \theta\ (hydraulic\ retention\ time)$

$$\frac{1}{\theta_c} = \frac{QS_0}{VX} \cdot Y \cdot \frac{(S_0 - S)}{S_0} - k_d$$

θ_c =mean biomass retention time/sludge age $\frac{1}{\theta_c} = \mu - k_d$

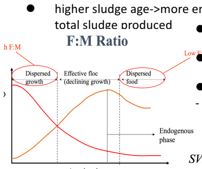
$$\frac{1}{\theta_c} = \left(\frac{F}{M}\right)\left(\frac{efficiency}{100}\right) \cdot Y - k_d$$

$$\frac{F}{M} = \frac{rate\ of\ BOD\ fed}{biomass\ in\ the\ reactor} = \frac{QS_0}{VX} = \frac{S_0}{\theta X}$$

sludge age relate toF:M – F/M: degree of starvation of microorganism –sludge age: residence time of sludge

- higher sludge age->more endogenous decay. These 2 affect performance of activated sludge, settleability of sludge, total sludge produced

F:M Ratio

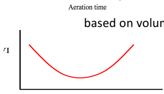


- high F/M(~>0.8)->filamenous(丝状)organism dominate->poor settleability in clarifier
- high carbohydrate content, low DO, lack of N and P-> growth of filamenous organisms
- flocculating capacity of activated sludge is lowest @log growth phase(high F/M)
- Sludge Settleability:

efficiency depend on solid/liquid separation step in 2nd clarifier. Settling quality measured by Sludge Volume Index (SVI)

$$SVI = \frac{Volume\ occuplied\ by\ settled\ sludge}{Initial\ suspended\ solids\ concentration\ of\ usettled\ sludge} = \frac{mL/L}{mg/L}\left(1000\frac{mg}{g}\right)$$

based on volume of sludge settled by 30 mins in 1L. Good settle->low SVI(<100-150)

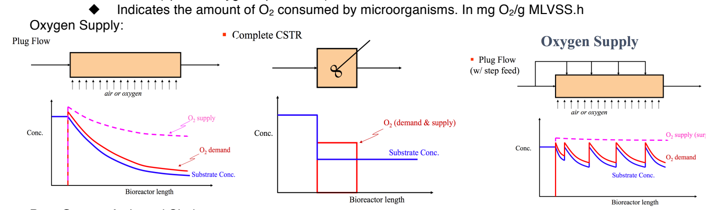


- min SVI -> optimum solid/liquid separation occur, when the activated sludge system has a well population which produces large flocculent particles.
- low F/M ratio -> endogenous decay predominates & cell debris forms a dispersed floc/pinpoint floc->doesn't settle well

Sludge quality problem -> one main problem for activated sludge reactor is poor floc formation. Two main part->1. Filamentous, 2. Non-filamentous

- Filamentous grow & outcompete floc formers ->sludge bulking or excessive foaming. Bulking Sludge{SVI >150}
  - Promote the formation of a stable and viscous brown foam -> hard to break mechanically.
  - Foaming can be a nuisance or can lead to serious operational problems
    - Foam layers can inhibit aeration and mixing)
    - In cold climates, foam layers can freeze
    - In warm weather, foam can be odorous
- Non-Filamentous Sludge Quality
  - Pin point floc: small weak flocs which are easily sheared or are subject to hydraulic surge flotation in the final clarifier.
    - associated with extended aeration (and result in turbid effluent)
  - Dispersed Growth: the selection of single celled bacteria over floc formers.
    - caused by high F:M ratio and possibly high H2S (>20 mg/L) concentration, results in very turbid effluent.
  - Nutrient (N,P)deficiency: the production of a viscous foam, the sludge to have a jelly-like consistency>interfere w/ compaction
  - Floating sludge: caused by denitrification producing N_2 gas bubbles->become entrapped and increase sludge buoyancy
  - Toxic shocks: lead to upset conditions which eventually allow filaments to proliferate
- Aeration (O_2 supply): provide O_2 for BOD&COD consumption
  - DO concentration should maintain @1.5-4 (2 is commonly used)
  - Mechanical aeration: specific to large &open bioreactor
  - Diffused aeration: most bioreactor & activated sludge systems
- Oxygen Uptake Rate (OUR) (mg O_2/L.min)
  - microorganisms use oxygen, and can be taken as a measure of the biological activity
  - determined by taking a sample of mixed liquor, saturated with DO, and with a DO probe measuring the decrease in DO with time.
  - Most valuable in combination w/VSS
    - SOUR (specific oxygen uptake rate)
    - Indicates the amount of O_2 consumed by microorganisms. In mg O_2/g MLVSS.h

Oxygen Supply:



Pure Oxygen Activated Sludge:

- Conventional active.sludge is oxygenated with air, some designs utilize pure O_2 instead of air
  - Pure oxygen systems have become economical with the development of the pressure swing adsorption system for the production of molecular oxygen
  - In the pure O_2 process, the activated sludge aeration tanks are covered and oxygen gas is introduced into the headspace of the tank as required
  - Carbon dioxide is the major gaseous end product which accumulates in the system.
  - One pure oxygen plant reported 250-400 ppm of CO2 in the system effluent, >> the toxic levels for fish (pH adjustment and air stripping may be required prior to effluent discharge)

Dissolved air flotation Process: wastewater treatment, air dissolved in water particles under pressure-> produce supersaturated gas solution->release air on liquid under P_{atm} -> bubbles form. ($V_{bp} >> V_p$) **Air Saturator**: produce superheated solution of air in water. **DAF ideal for**: reservoir water; algae blooms; low turbidity; cold waters. DAF thicken waste activated sludge. DAF thickener sized by solids loading rate. **DAF thickening Pros&Cons**: thickening dilute sludge, work well without polymer, simple equipment; high power consumption, lower max solids concentration, odor issue, require space. **Water flow equalization principal application:** dry weather flows reduce peak flow, wet-weather flows in sanitary collection system experiences inflow&infiltration, combined stormwater and system flows. **Equalization Pros&Cons**: shock loads eliminated, toxic substance diluted, pH stabilization, sedimentation & filter performance improved, chemical feed control improved; large area needed, offensive odour, additional operation&maintenance, increased capital cost. **Basin design elements:** location, inline&offline choice, required basin volume, basin configuration, control of odour. **When is chemical oxidation used**: wastewater with low BOD/COD, coupled with biological oxidation process, water with chemical contaminants. Ozone for water treatment: photolysis of oxygen, first used as disinfectant. Ozonation process design depends: O_3 in feed, pH, T, P, bubble size, water composition. **Ozone needed:** pilot plant studies, previous experience, extrapolated models. **Disinfection:** process to inactivate microbe growth. **Inactive process includes denaturation of**: proteins, lipids, nucleic acids. **Ideal Disinfectant**: broad spectrum, fast acting, effective with organic matter, nontoxic, provides residual. **Disinfectants:** free chlorine (strong oxidant, alters membrane permeability&oxidize DNA); ozone & chlorine dioxide& electrochemically generated mixed oxidant (strong oxidant); combined chlorine (weak); UV (DNA damage) **Microbe Resistance to disinfectant**: vegetative bacteria->enteric viruses->protozoancyst->acid fast bacteria. **Effect of water quality on disinfection:**particulate(protect microbes); dissolved organics(consume disinfectant); inorganic compounds;pH;T. **Disinfection activity:** C*t. **Free chlorine disinfectant (Cl_2):** greater inactivation at low pH(HOCl) than high pH(OCl-), greater reactivity for neutral chemical. **Resistance of Cryptosporidium to free chlorine**. **Chlorine Disinfection Pros&Cons**: well established, effective, has residual, inexpensive; toxic, low doses ineffective, release volatile organic compound, toxic by-product. **ClO_2 Pros&Cons**: effective, low DBP, long lasting residual formed; high chemical hazard, unstable, expensive, sensitive to organic&inorganic loads. Ozone Pros&Cons: adequate disinfection, less chlorine dosage, less DBP, small THM formation; brominated DBP, increased biodegradable organic matter, no residual. **UV disinfection**: UV light penetrates through bacteria, inactivates through DNA damage& thymidine dimer formation. **Minimum UV dose depends**: UV lamp type, water quality, target organism, reactor geometry. **Microbes resistance to UV**: Cyst&oocysts ->bacteria->viruses->spores.

UV dose= intensity*exposure time. **UV disinfection pros&cons:** no DBP&toxic residuals, effective, easy operation; no residual disinfection for water, lamp fouling, hard to monitor, high turbidity water. **Natural organic matter(NOM):** reduce disinfection efficacy, form DBP, membrane fouling, bacteria regrowth, aesthetic&taste&odor issue. **IEX process**->exchange of ions in resin structure with ions in solution. **Resin type:**Remove hardness/alkalinity: weakly acidic cation exchange resin(-COOH)&strongly acidic cation ~(-HSO_3^-) 2. Remove anions (NO_3^-, $SO4^{-2}$, $HCO3^-$)and organics: weakly basic anion exchange resin(N(CH3)2)& strongly ~(N(CH3)3OH). **Water softening:** use strong acidic cation exchange resin in Na^+ to remove Ca^{+2}&Mg^{+2}. **Water de-alkalization:** remove bicarbonate by weakly acidic~, apply for soft drinks. **Water demineralization:** remove all the ions from water CIX(H+)-AlX(OH-). **IEX pros&cons**: simultaneous ion removal, effective, easy operation; regeneration, preferential removal of ions. **Langmuir Eqn**:

$$q_e = \frac{q_{\max}.b.C_e}{1+b.C_e} \quad q = \frac{(C_0 - C_e) \times V}{M}$$

C_0: Initial concentration, V: Volume, M: Resin mass
q_e : substance adsorbed (mg/g) at equilibrium
C_e : equilibrium concentration of substance in the solution (mg/L)
Q_{max} : maximum sorption capacity
b : Langmuir constant (related to heat of adsorption)

Freundlich Eqn: $q_e=K_fC_e^n$ K_f: constant; n: measure of sorption intensity

Equivalent weight=atomic weight/ valence charge **Equilibrium constant (K_{a-b})=** $(q_A/C_A)^m*(C_B/q_B)^n$

Q= total exchange capacity of the IEX resin (eq/L)
C= total ionic concentration in the solution (eq/L)
X= fraction of species in solution
Y= fraction of species in solid phase

$q_A=Y_A*Q$
$c_A=X_A*C$
$X_A+X_B=1$
$Y_A+Y_B=1$

Separation factor: $\alpha_B^A = \frac{Y_A/X_A}{Y_B/X_B}$ **Purpose of biological ww treatment:** meet environment regulations, protect receiving streams, control pollution. **Types of secondary treatment:** suspended growth systems&fixed film system. **Stabilization Ponds Pros&Cons**: minimal operation requirements, low operation cost; large area required, poor solid removal, limited operation control. **Aerated Lagoons Pros&Cons:** less land required, improved BOD/TSS removal,HRT reduced; require operator skilled, increased utility cost, limited solids removal. **Activated sludge system Pros&Cons:** require limited space, handle shock load, excellent solids removal; require trained operator&monitoring; high operating cost. **Specific growth rate:** $\mu = \frac{1}{x}\frac{dx}{dt} = \frac{\mu_{\max} S}{S+K_s}$

dx/dt: rate of change in concentration of bacteria
K_S: substrate conc. at half the maximum growth rate
x: concentration of bacterial
S: concentration of limiting substrate

$$\frac{dS}{dt} = -\frac{x}{Y}\frac{\mu_{\max} S}{S+K_s}$$

$$\frac{dS}{dt} = -\frac{k\,S\,x}{S+K_s}$$

Determine Kinetic constant: $\frac{1}{\mu} = \frac{S+K_s}{\mu_{\max} S} = \frac{1}{\mu_{\max}} + \frac{K_s}{\mu_{\max}}\frac{1}{S}$