Urban Environmental Engineering 5

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Lecture in the Last time

- Turbulent Diffusion
  - Time smoothing of diffusion equation
- Concentration (Mass density, ….)
- Exercise

Today's Lecture

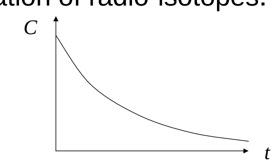
- Reaction Kinetics
  - First order reaction
  - Zero order reaction
  - Monod Equation
  - Streeter Phelps equation
  - First order reactions in series

First order reaction

- This type of reaction is often seen in environments. First order reaction is a reaction whose rate is in proportional to its concentration. One of the famous examples is deformation of radio-isotopes.

$$\frac{dC}{dt} = -k_1 C$$

$$C = C_0 \exp(-k_1 t)$$



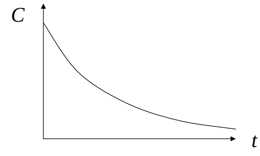
The concept of half life

- Half life time can be defined in the case of first order reaction.

$$t_{1/2} = \frac{1}{k_1} \ln 2$$

$$\frac{dC}{dt} = -k_1 C$$

$$C = C_0 \exp(-k_1 t)$$

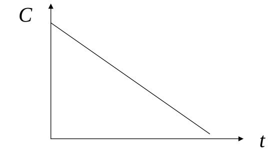


Zero order reaction

- This type of reaction is also seen in environments where the concentration of target compounds is not the limiting factor. Zero order reaction is a reaction whose rate is independent from its concentration.

$$\frac{dC}{dt} = -k_1$$

$$C = C_0 - k_1 t$$

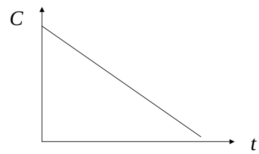


Half life time in zero order reaction

- Half life time concept is not frequently used in the case of zero order reaction, because half life time is dependent on initial concentration in the case of zero order reaction.

$$\frac{dC}{dt} = -k_1$$

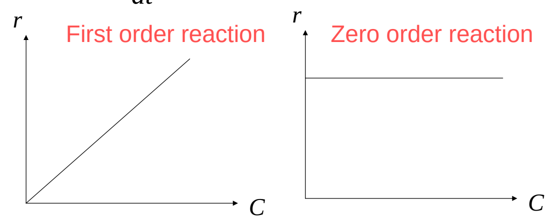
$$C = C_0 - k_1 t$$



Reaction rate

- Reaction rate is defined as

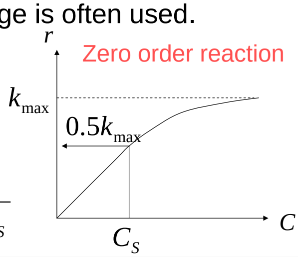
$$r = -\frac{dC}{dt}$$



Monod-type rate constant

- Monod-type rate constant, which follow first order reaction in low concentration range and zero order reaction in high concentration range is often used.

$$r = -\frac{dC}{dt} = k_{\max}\frac{C}{C + C_S}$$



Growth of algae in lake and in sea

- The growth of phytoplankton is often modeled by using triple-monod-rate equation.

$$r = \frac{dX}{dt} = k_{\max}\frac{[N]}{[N] + C_{S,N}} \bullet \frac{[P]}{[P] + C_{S,P}} \bullet \frac{[I]}{[I] + C_{S,I}} X$$

X: Mass density of Phytoplankton

N: Nitrogen concentration

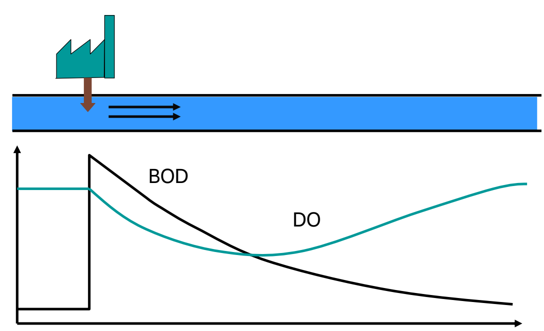
P: Phosphorous concentration

I : Irradiation

Streeter Phelps's Equation

- A set of differential equations describing changes in DO and BOD.
- This equation is used for assessing the point where minimum DO will be observed.

Change in DO and BOD



Streeter Phelps's equation

$$\frac{d[BOD]}{dt} = -k_1[BOD]$$

$$\frac{d[DO]}{dt} = -k_1[BOD] + k_2([DO]_{sat} - [DO])$$

Reduction of BOD and Consumption of DO

First order Reaction Constant

$$\frac{d[BOD]}{dt} = -k_1[BOD]$$

$$\frac{d[DO]}{dt} = -k_1[BOD] + k_2([DO]_{sat} - [DO])$$

DO recovery

$$\frac{d[BOD]}{dt} = -k_1[BOD]$$

$$\frac{d[DO]}{dt} = -k_1[BOD] + k_2([DO]_{sat} - [DO])$$

DO recovery constant

Saturated DO conc.

Reduction in BOD

$$\frac{d[BOD]}{dt} = -k_1[BOD]$$

is a first order linear differential equation and this can easily be solved into exponential form.

$$[BOD] = [BOD]_{t=0} \exp(-k_1 t)$$

Change in DO

$$\frac{d[DO]}{dt} = -k_1[BOD] + k_2([DO]_{sat} - [DO])$$

Here, we define y as $y=([DO]_{sat} - [DO])$.

$$\frac{dy}{dt} = -\frac{d[DO]}{dt}$$

$$\frac{dy}{dt} = k_1 L_0 \exp(-k_1 t) - k_2 y$$

where $L_0 = [BOD]_{t=0}$.

How can we solve the DO equation

$$\frac{dy}{dt} = k_1 L_0 \exp(-k_1 t) - k_2 y$$

We call this equation linear non-homogeneous first order differential equation. This equation can be solved by constant variation method.

How can we solve the DO equation

$$\frac{dy}{dt} = k_1 L_0 \exp(-k_1 t) - k_2 y$$

Non-homogeneous part

Homogeneous parts

We call this equation linear non-homogeneous first order differential equation. This equation can be solved by constant variation method.

Constant variation method

This type of differential equations has following solution.

$$y = C(t)\exp(-k_2 t)$$

By substituting this solution to the original differential equation, following equations will be obtained.

$$\frac{dy}{dt} = C(t)(-k_2)\exp(-k_2 t) + \frac{dC(t)}{dt}\exp(-k_2 t)$$
$$= k_1 L_0 \exp(-k_1 t) - k_2 C(t)\exp(-k_2 t)$$

Detailed modifications

$$\frac{dy}{dt} = C(t)(-k_2)\exp(-k_2 t) + \frac{dC(t)}{dt}\exp(-k_2 t)$$
$$= k_1 L_0 \exp(-k_1 t) - k_2 C(t)\exp(-k_2 t)$$

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$$\frac{dC(t)}{dt}\exp(-k_2 t) = k_1 L_0 \exp(-k_1 t)$$

Detailed modification (Contd.)

$$C(t) = \frac{k_1 L_0}{k_2 - k_1}\exp[(k_2 - k_1)t] + C_0$$

Integral constant

Going back to the oridinal equation, we obtain

$$y = \left(\frac{k_1 L_0}{k_2 - k_1}\exp[(k_2 - k_1)t] + C_0\right)\exp(-k_2 t)$$

Final solution which satisfies the initial condition

If we assume initial condition of $y=y_0$ at $t=0$,

$$y_0 = \frac{k_1 L_0}{k_2 - k_1} + C_0$$

By solving this equation for Co and by substituting this into the original equation, we obtain the final solution

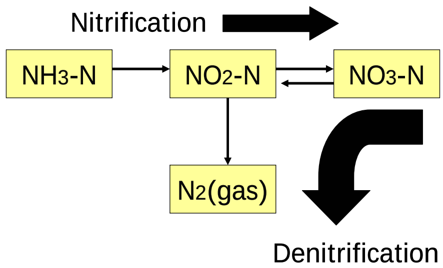
$$y = \frac{k_1 L_0}{k_2 - k_1}\left(\exp(-k_1 t) - \exp(-k_2 t)\right) + D_0 \exp(-k_2 t)$$

where D_0 is $DO_{sat}-[DO]_{t=0}$

Nitrogen

- TN (total nitrogen)
- DTN (Dissolved TN) and PTN (Particulate TN)
- NH3-N (Ammonia Nitrogen), NO2-N (Nitrite), NO3-N(Nitrate)

Nitrification and Denitrification



Nitrification takes place in the case of sufficient DO condition.

Denitrification takes place in the case of anoxic condition.

Equation of change in Nitrification

First order reactions in series

$$\frac{d[NH3-N]}{dt} = -k_1[NH3-N]$$

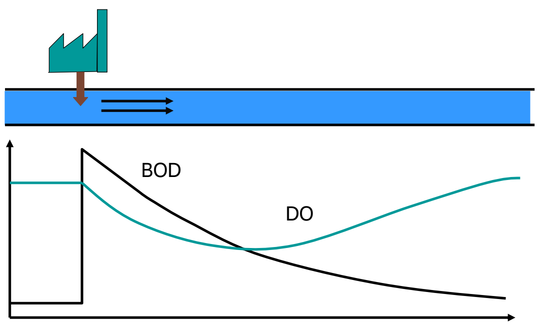
$$\frac{d[NO2-N]}{dt} = k_1[NH3-N] - k_2[NO2-N]$$

$$\frac{d[NO3-N]}{dt} = k_2[NO2-N]$$

All Units are (mgN/L) or (mol/L)

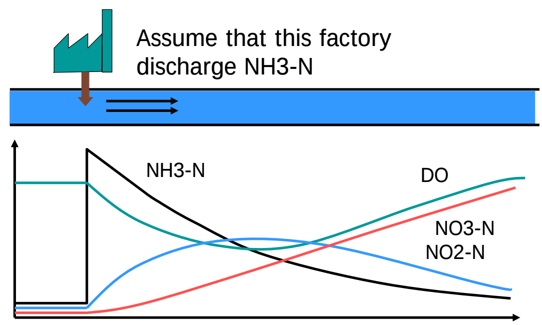
If we use mgNH3/L, mgNO2/L, and mgNO3/L, the inclusion of conversion factor is necessary.

Change in DO and BOD



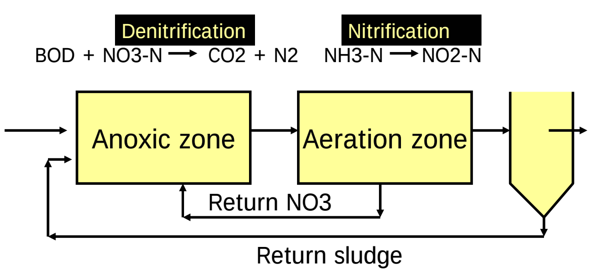
Change in Nitrogen

Assume that this factory discharge NH3-N

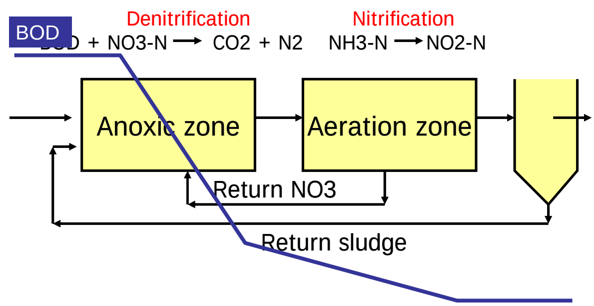


If DO is sufficient, NH_3-N is converted into NO_3-N

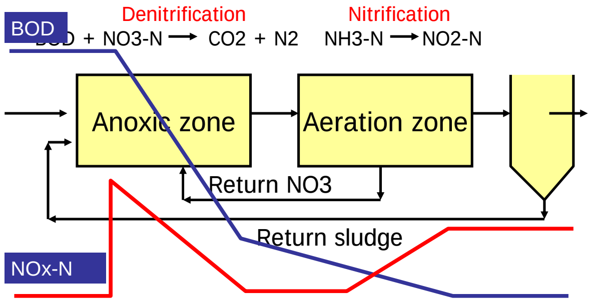
Nitrogen Removal Process using nitrification and denitrification



Nitrogen Removal Process using nitrification and denitrification

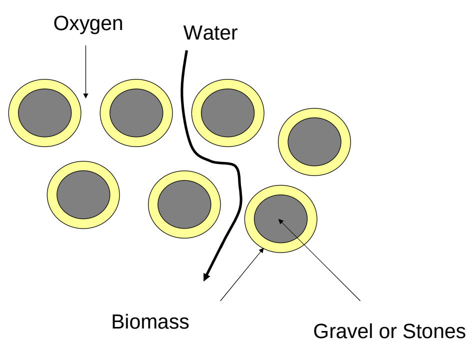


Nitrogen Removal Process using nitrification and denitrification

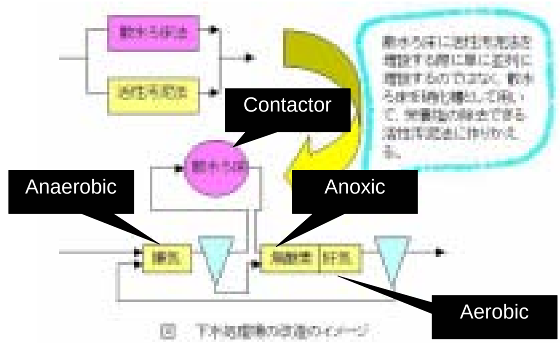


Wastewater treatment plant in South Africa

Contact media filtration



Improvement of N, P removal by combining contact media filtration and activated sludge.



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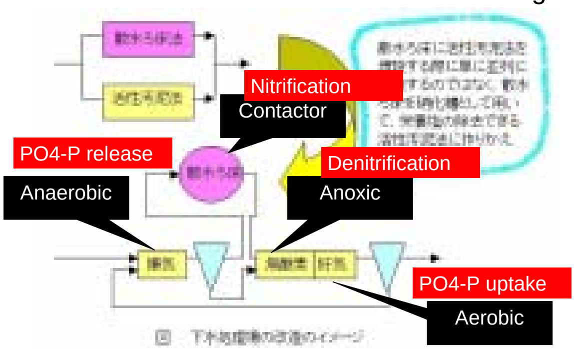
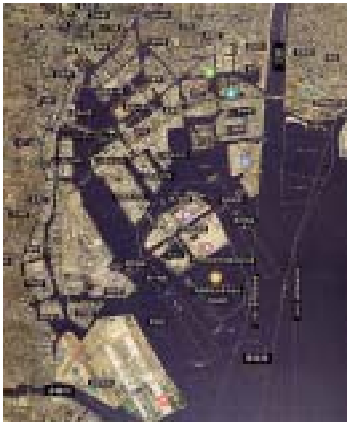


Leachate from solid waste disposal site



Solid waste disposal in Tokyo

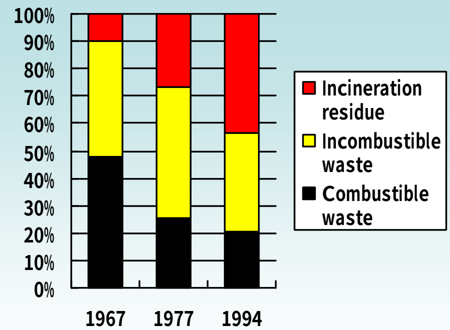


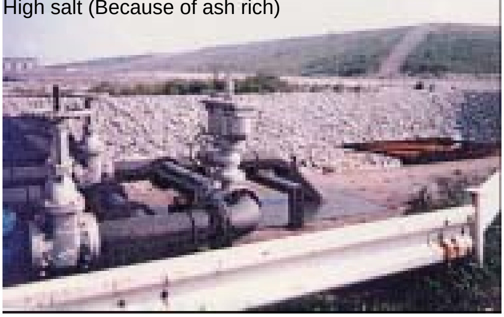
Figure 1. Weight composition of solid waste derived from domestic waste and received at landfill sites for final disposal in Japan. (Matsufuji, 1998)

Leachate contains

1) High COD but low BOD (Because of ash rich)

2) High N but low P

3) High salt (Because of ash rich)



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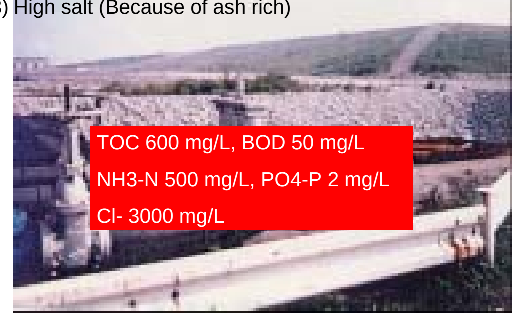


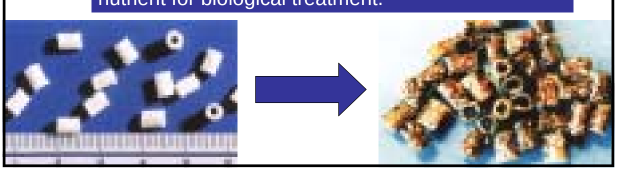
Leachate contains

1) High COD but low BOD (Because of ash rich)

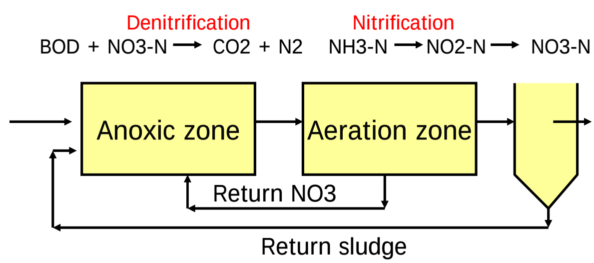
Not only biological treatment but chemical precipitation is applied.

2) High N but low P

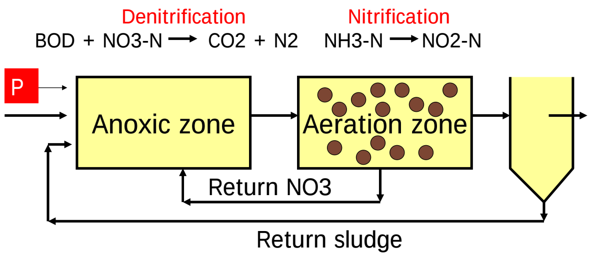
Attached media were introduced to retain nitrifiers. Phosphorous is added to make a good balance of nutrient for biological treatment.



Nitrogen Removal Process using nitrification and denitrification



1) Contact media (Polypropylene cube) was introduced in the areobic zone to retain nitrobactor
2) Phosphorous is added to activate biological process.



Sanitation in Japan

Approximate population ratio in service in Japan

65% Public Sewerage System

10% Community Plants

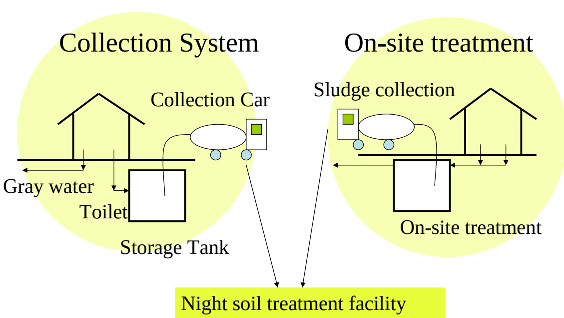
Urban Cities

20% On-site Domestic wastewater treatment

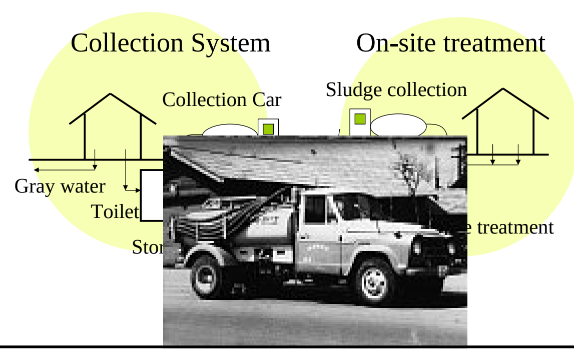
5% Storage and Collection

Rural area

Sanitation in rural area in Japan



Sanitation in rural area in Japan



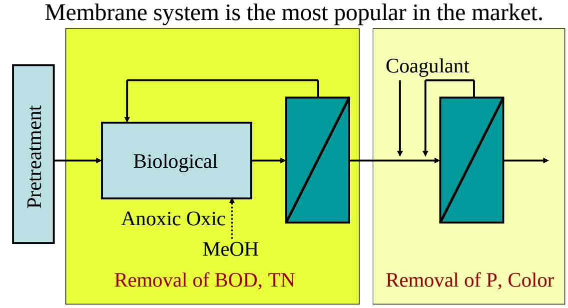
Collected night soil contains

1)High COD, high BOD, high N, and high P.

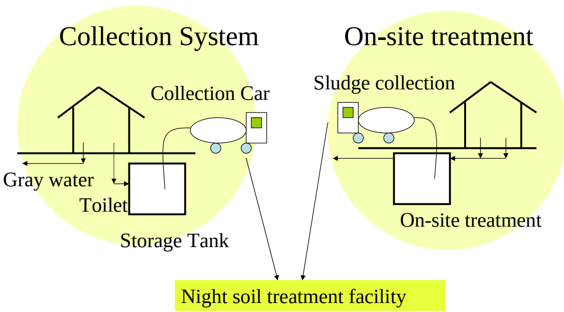
2)However, if we consider the balance between C and N, Carbon is not sufficient for the removal of Nitrogen. Methanol is added for denitrification.

Night Soil Treatment

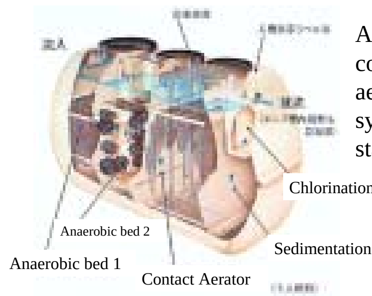
Membrane system is the most popular in the market.



Sanitation in rural area in Japan



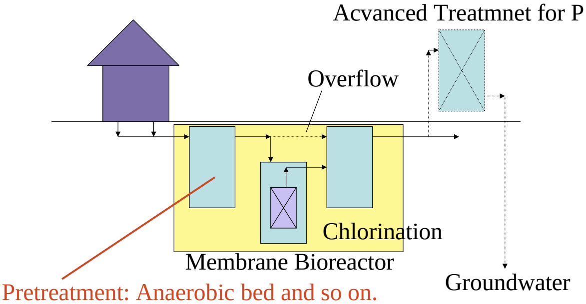
On-site domestic wastewater treatment



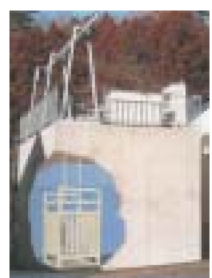
Anaerobic contactor - aerobic contactor system is the standard.

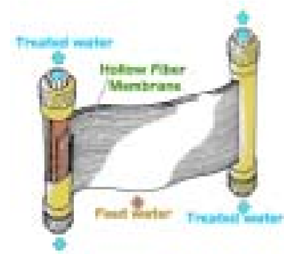
From Kubota catalog

On-site membrane wastewater treatment (Developing)



Mitsubishi Rayon Hollow Fiber

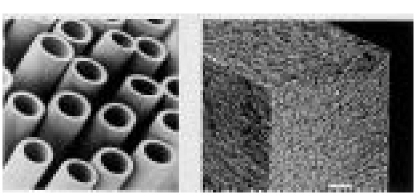




Applications can be seen in food industries.

From Mitsubishi Rayon Catalog

Mitsubishi Rayon Hollow Fiber



Pore size 0.4µm   Cross section

From Mitsubishi Rayon Catalog