EWCE 333
Wastewater Engineering and Sanitation

Lecture 15

Instructor

Lt Col Kazi Shamima Akter, Ph.D., Engrs

Associate Professor

Department of EWCE, MIST

Lecture Outline

Topics	Reference
• Waste stabilization ponds – process involved, advantages, disadvantages • Types of stabilization ponds	Water Supply and Sanitation - Feroz Ahmed and Mujibur Rahman ITN -BUET

Waste Stabilization Ponds

- Large shallow rectangular basins enclosed by earthen embankments.
- Open to atmosphere.
- Treatment by natural processes involving both algae and bacteria.
- As unaided by man, the rate of oxidation is rather slow.
- Longer hydraulic retention time: 30-50 days not being uncommon.

Process involved in Waste Stabilization Ponds

- Sedimentation
- Oxidation
- Digestion
- Synthesis
- Photosynthesis
- Endogenous Gas Respiration
- Gas Exchange
- Aeration
- Evaporation
- Thermal Currents
- Seepage

Advantages of Waste Stabilization Ponds

- Cheapest and simplest of all treatment technologies.
- Produce high quality effluent.
- Reduce the level of pathogens much lower than other methods
- Absorb variable organic and hydraulic loading with less adverse effect on the effluent quality

Advantages of Waste Stabilization Ponds

- No mechanical or external energy (except atmosphere) input
- Minimum control
- Skilled operators are not required
- Lower capital, operation and maintenance cost

Disadvantages of Waste Stabilization Ponds

- Large land area is required
- Odor problem in anaerobic condition
- Excessive accumulation of algae and bacteria cells may overload the receiving water bodies

Types of Waste Stabilization Ponds

(a) Anaerobic Ponds

- A digester requiring no oxygen supply
- Anaerobic bacteria break down the complex organic wastes

(b) Facultative Ponds

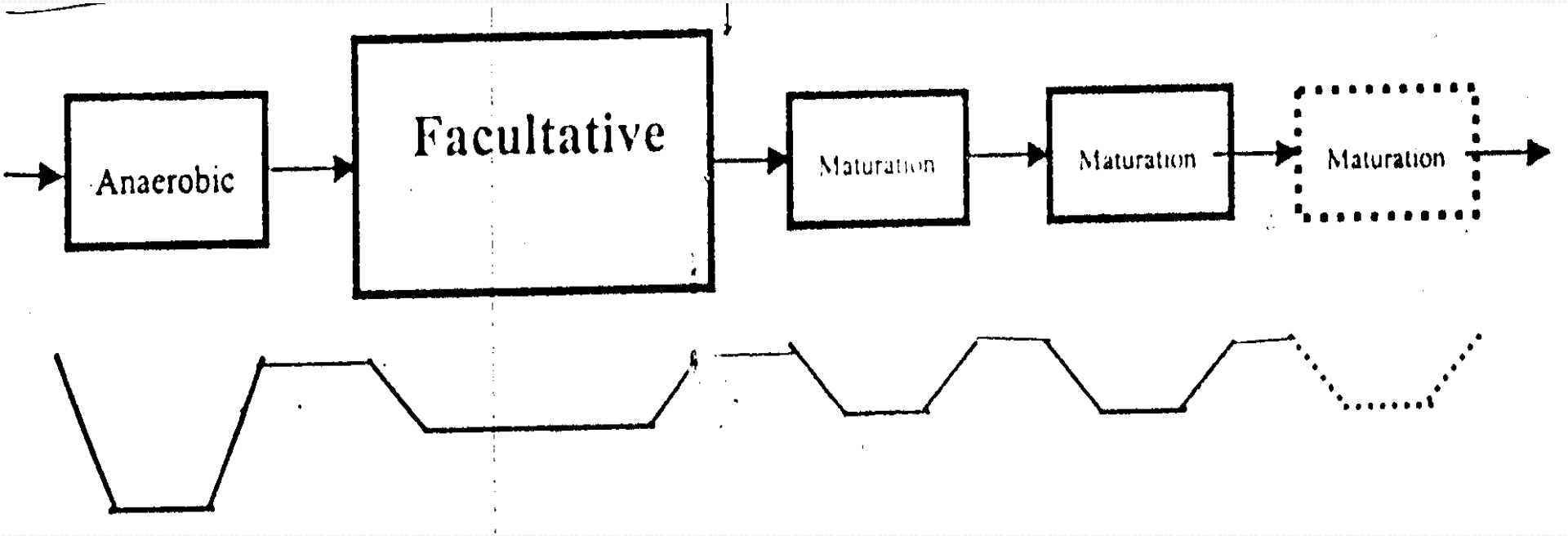
- Upper aerobic zone is maintained by algae
- Lower anaerobic zone
- Aerobic, facultative and anaerobic organisms act in these ponds

Types of Waste Stabilization Ponds

(c) Aerobic / Maturation Ponds

- Aerobic bacteria break down the wastes

- Algae provide oxygen through photosynthesis to maintain aerobic condition



Anaerobic Pretreatment Ponds

- Receive a high organic loading and become completely devoid of dissolved oxygen.
- Used to pre-treat strong wastes having a high solids content.
- The solids settle to the bottom and digested anaerobically.

Anaerobic Pretreatment Ponds

- Partially clarified supernatant liquor is discharged into a facultative pond for further treatment.
- The successful operation of anaerobic ponds depends on the delicate balance between the acid-forming bacteria and the methanogenic bacteria.

Anaerobic Pretreatment Ponds

Favorable Conditions in Anaerobic Ponds:

- Temperature > 15 °C
- pH > 6

Under the above conditions -

- Sludge accumulation is minimum
- Desludging is required only at every 3-5 years

Facultative Ponds

- Receive raw sewage or that which has received only preliminary treatment
- Treat the settled effluent from septic tanks and anaerobic pretreatment ponds.
- Aerobic condition is maintained in upper layers while anaerobic conditions exist towards the bottom.

Facultative Ponds

- Oxygen in the upper aerobic layer comes from re-aeration from surface, but major portion of O_2 is supplied by photosynthesis of algae.
- Bacteria use the algal O_2 to oxidize organic waste, whereas algae use CO_2, which is the end product of bacterial metabolism. This association is called symbiosis between bacteria and algae.
- The pH of the pond contents also follows a daily cycle increasing with photosynthesis to a maximum which may be as high as 10.

Facultative Ponds

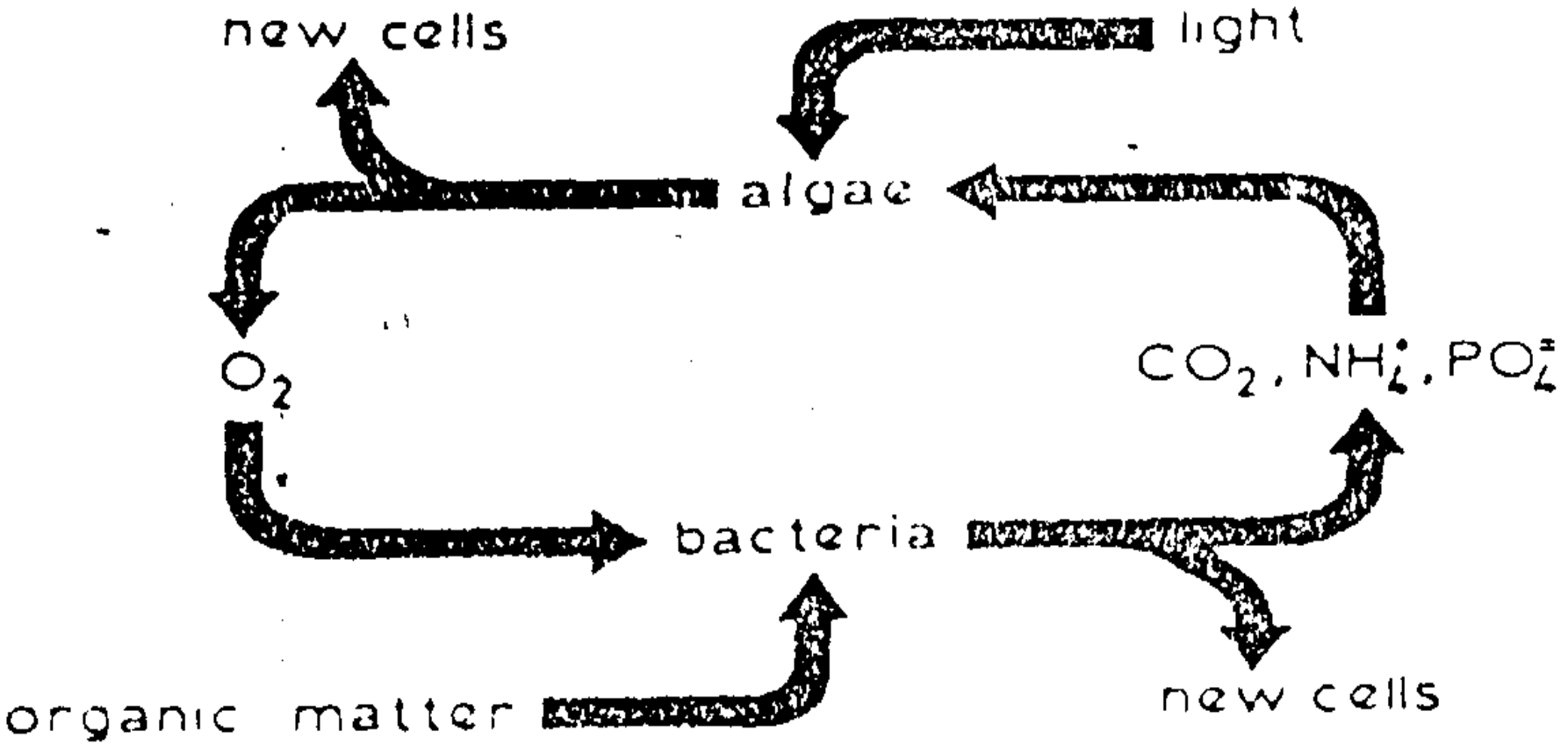


Figure: Symbiosis of algae and bacteria

Facultative Ponds

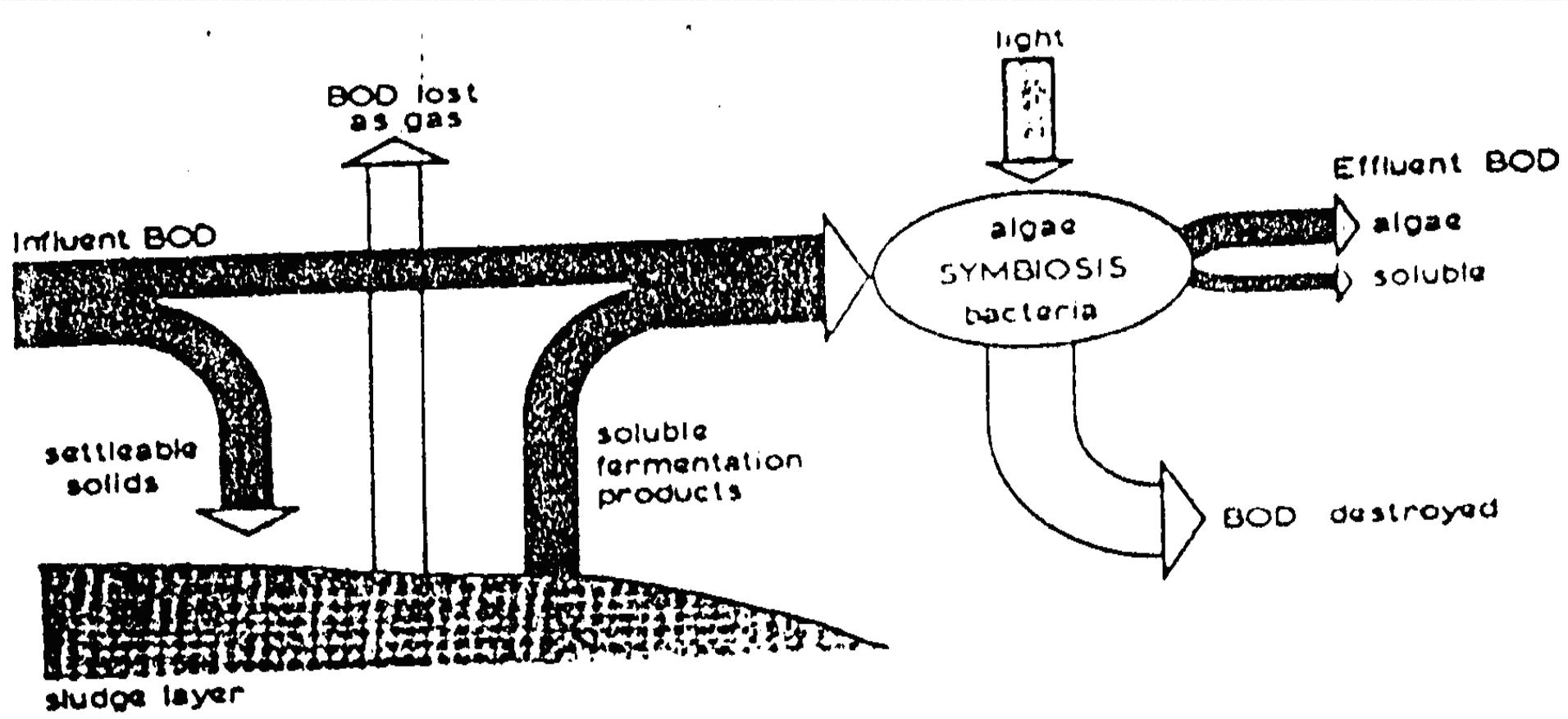


Figure: Principal pathways of BOD removal in facultative ponds

Maturation Ponds

- Used as a second stage to facultative ponds.
- Main function is the destruction of pathogen.
- Completely aerobic and able to maintain aerobic conditions at depths of up to 3 m.
- Usually, the depth of a maturation lagoon is 1-1.5 m.

Maturation Ponds

- BOD removal is small.
- Two maturation ponds in a series, each with a retention period of 7 days, are required to reduce BOD from about 50-70 mg/L to 25 mg/L (about 50%).
- Effectiveness in removing pathogens is assessed by the removal of faecal coliforms.
- More than 99% removal of pathogens is possible by proper design.
- Effluent standard of < 5000 FC / 100 ml can be maintained with proper design of maturation ponds.

Design Preliminaries of Stabilization Ponds

Depth

Most commonly used depth:

Anaerobic ponds	: 2 - 4 m
Facultative ponds	: 1-1.5 m
Maturation ponds	: 1-1.5 m

Design Preliminaries of Stabilization Ponds

Area

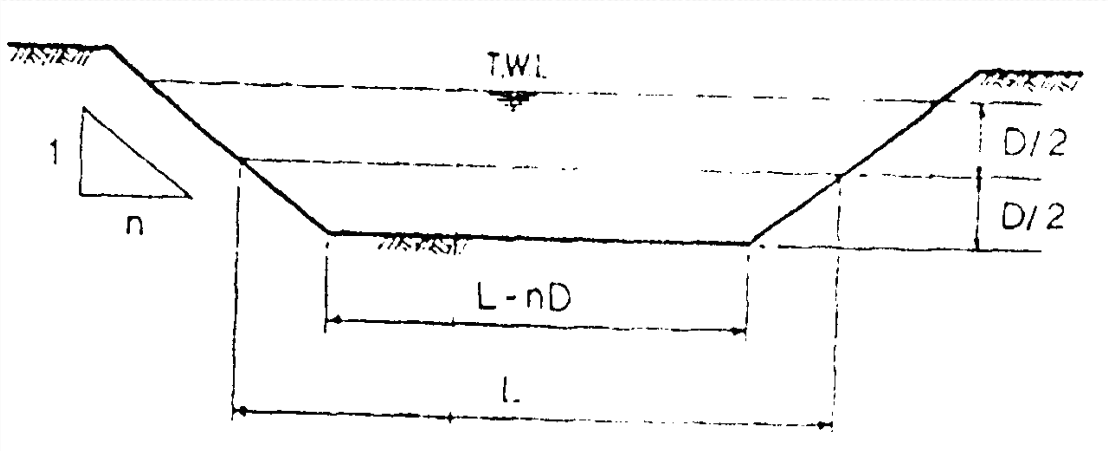
- Length / Width ratio is generally 2-3 to 1. The length and breadth are obtained from the mid-depth area, shown in the following figure.
- The mid-depth area (which is what the surface and base areas would be if the pond had vertical sides) is given by:

$$\mathbf{A = Q*t / D}$$

where, Q = Volumetric flow rate (m^3/day)

t = Retention time (day)

D = Pond depth (m)



Design Preliminaries of Stabilization Ponds

Surface BOD_5 Loading

- The areal or surface BOD_5 loading (λ_s) is the weight of BOD_5 applied per unit area per day.
- The weight (g) of BOD_5 applied to the pond (A, m^2) each day is L_iQ.
- Therefore, expressing λ_s in its usual units of kg/ha-d:

$$\lambda_s = (10^{-3} L_i Q) / (10^{-4} A)$$
$$= 10 L_i Q / A$$

Design Preliminaries of Stabilization Ponds

Volumetric Loading

- Used particularly with anaerobic ponds.
- Volumetric loading λ_v is the weight of BOD_5 applied per unit volume per day.
- Expressing λ_v in g/m^3 d:

$$\boldsymbol{\lambda_v = L_i\, Q\, /\, AD}$$

Since, AD / Q = retention period, t

Therefore, $\boldsymbol{\lambda_v = L_i\, /\, t}$

- In anaerobic ponds, $\lambda_v > 100$ g/m^3 d, which is a criterion for odour development.
- In facultative ponds, λ_v ranges from 15 to 30 g/m^3 d.

Design of Anaerobic Ponds

- **Volumetric Loading Rate**:

The volumetric loading rate, λ_v can be expressed as

$$\boldsymbol{\lambda_v = L_i\, Q\, /\, V_a}$$

where, L_i = BOD of the raw wastewater (mg/L)

Q = Wastewater flow rate (m^3 /d)

V_a = Anaerobic pond volume (m^3)

Design of Anaerobic Ponds

- **Temperature:**

  At pH > 6, BOD reduction in anaerobic pond = f (temperature)

  BOD reduction increases with increasing temperatures > 15°C

Design of Anaerobic Ponds

Table: Design values of λ_v and BOD removal rate at various temperatures

Temperature (° C)	Volumetric Loading Rate, λ_v (g/m^3 d)	BOD removal (%)
<10	100	40
11	120	42
12	140	44
13	160	46
14	180	48
15	200	50
16	220	52
17	240	54
18	260	56
19	280	58
20	300	60
21	300	62
22	300	64
23	300	66
24	300	68

Design of Anaerobic Ponds

- **Retention Period**:

Table: Design values of BOD reduction for varying retention period

Retention Period (d)	BOD reduction (%)
1	50
2 - < 5	60
5	70

- Optimum retention period is 5 days.
  ✓Ponds operated with retention period > 5 days, act as facultative rather than anaerobic.
  ✓Retention periods < 5 d are not recommended, because
  – The risk of odor release is greater.
  – The interval between successive desludging operations is shorter.
  – The bacterial quality of the final effluent is poorer.
  – The BOD removal is smaller.

Design of Anaerobic Ponds

Desludging Frequency:

- Rate of sludge accumulation is approx. 0.03-0.04 m^3/hd year. For design, 0.04 m^3/hd year can be considered.

- Desludging is required when the pond is half-full of sludge.

- Desludging frequency is given by, **N = V/CP**

Where, V = Pond volume (m^3)

C = Sludge accumulation rate (m^3/hd year)

P = No of population

Design of Anaerobic Ponds

Odor Release and Control:

- Sources of odor release –
  - ✓ Volumetric Loading Rate, $\lambda_v > 400$ g/m^3 d
  - ✓ Presence of industrial or organic wastes, particularly those with high concentration of sulphate.
- Control of odor –

✓ Raising of pH to about 8, to convert odorous sulphide (formed by bacterial reduction bacteria) to odorless bisulphide ion.

✓ Recirculating the effluent from the facultative or maturation ponds to the anaerobic pond in the ratio of 1:6 (Effluent : Raw sewage)

Design of Facultative Ponds

- ***Surface Loading rate:***

Surface Loading Rate, λ_s (kg/ha-d) can be expressed as:

$$\lambda_s = (10^{-3} L_i Q) / (10^{-4} A)$$
$$= 10 L_i Q / A$$

Design of Facultative Ponds

Table: Design values for surface BOD loading rates for facultative ponds at various temperatures

Temperature (ºC)	Surface loading rate, λ_s (kg/ha d)	Temperature (ºC)	Surface loading rate, λ_s (kg/ha d)
10	100	20	**253**
11	112	21	**272**
12	124	22	**292**
13	137	23	**311**
14	152	24	**331**
15	167	25	**350**
16	183	26	**369**
17	199	27	**389**
18	217	28	**406**
19	**235**	**29**	**424**

Design of Facultative Ponds

BOD removal kinetics:

If L_0 = Ultimate CBOD

L_t = amount of oxygen demand after time t

Then, assuming first order reaction, $\frac{dL_t}{dt} = -kL_t$

here, k = BOD rate constant

= f(nature of waste, ability of bacteria, temperature)

$$\int_{L_0}^{L_t} \frac{dL_t}{L_t} = -k\int_0^t dt \qquad \therefore L_t = L_0 e^{-kt}$$

Now, $L_0 = BOD_t + L_t$

$$\therefore\ BOD_t = L_0\left(1 - e^{-kt}\right)$$ ……. BOD rate equation

Design of Anaerobic Ponds

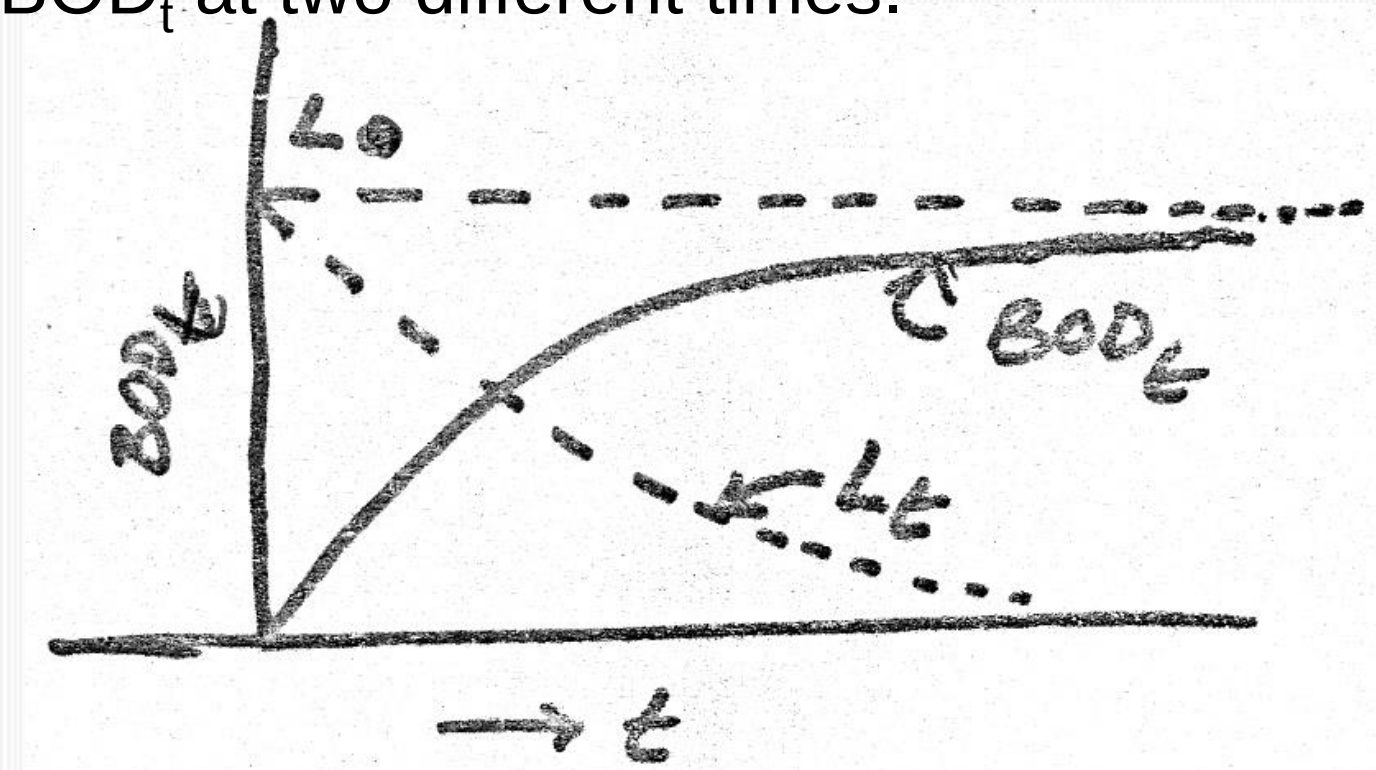
Typical k values:

Raw sewage: 0.35 – 0.70 /day

Treated sewage: 0.10 – 0.25/day

Higher k for sugar, lower for cellulose

k can be determined in laboratory along with L_0 by measuring BOD_t at two different times.



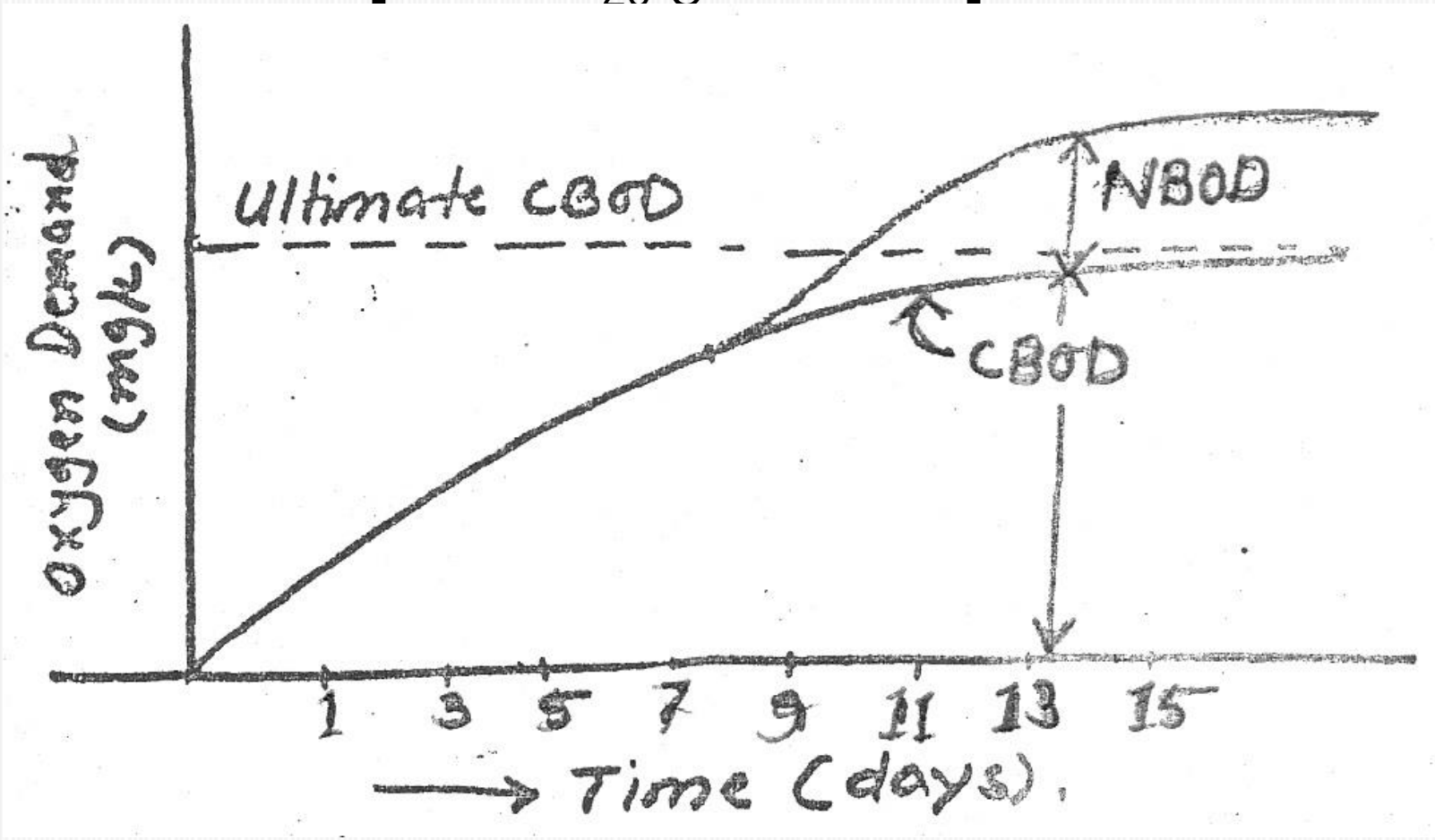
Design of Anaerobic Ponds

Effect of temperature on k values

Commonly used expression:

$$k_{T°C} = k_{20°C}\ \theta^{(T-20)},\ \ \theta = 1.047$$

[here, $K_{20°C} = 0.3\ d^{-1}$]



Mathematical Problems on BOD Kinetics

Problem:

For a BOD test: initial DO = 8.5 mg/L. After 5 days, DO = 4.5 mg/L. If dilution factor P = 50 and k = 0.20/d, calculate: (i) BOD_5 (ii) ultimate CBOD, (iii) BOD remaining after 5-days.

Solution:

(i) $BOD_5 = (DO_0 – DO_5) \times$ dilution factor = (8.5 – 4.5) × 50 = 200 mg/L

(ii) $BOD_t = L_0 (1- e^{-kt})$

Therefore, ultimate CBOD,

$L_0 = BOD_5 / (1- e^{-0.20\times5}) = 200/ (1- e^{-0.20\times5}) = 316.4$ mg/L

Mathematical Problems on BOD Kinetics

(iii) BOD remaining after 5 days

$L_5 = L_0 – BOD_5$

$= 316.4 – 200$

$= 116.4$ mg/L

Mathematical Problems on BOD Kinetics

Problem on effect of temperature on BOD:

For a wastewater ultimate BOD= 350 mg/L. BOD_5 = 200 mg/L (determined at 20°C) and k = 0.22/day (also at 20°C). What would be BOD_5 at 25°C?

Solution:

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

$k_{25} = 0.22\ (1.047)^5 = 0.277/day$

Now, BOD_5 (25°C) $= L_0\ (1- e^{-kt})$

$= 350\ (1- e^{-0.277\times5})$

$= 262$ mg/L

BOD Kinetics in Facultative Ponds

- In completely mixed reactors, BOD removal follows the first order kinetics, as follows:

$$\frac{L_e}{L_i} = \frac{1}{1 + k_1 t}$$

$$t = \left(\frac{L_i}{L_e} - 1 \right) \frac{1}{k_1}$$

$$A = \frac{Q}{D k_1} \left(\frac{L_i}{L_e} - 1 \right)$$

- To maintain the pond contents predominately aerobic, L_e should be in the range of 50-70 mg/L for pond depths of 1-1.5 m.

BOD Kinetics in Facultative Ponds

- The value of k_1 is about 0.3 d^{-1} at 20 ºC. The variation of k_1 is given by –

$$k_{1(T)} = 0.3(1.05)^{T-20}$$

- Substitution of this equation into above equation and selection of L_e as 60 mg/L gives the following design equation for A:

$$A = \frac{Q(L_i - 60)}{18D(1.05)^{T-20}}$$

BOD Kinetics in Facultative Ponds

- Maximum BOD_5 surface loading that can be applied to a facultative pond before it failed (i.e. become completely anaerobic) is related to the monthly ambient air temperature, T (ºC)

$$\lambda_s = 20T - 120$$

- The Design equation for A is then simply obtained from equation:

$$A = \frac{L_i Q}{2T - 12}$$

Design of Maturation Ponds

- ***Retention Period:***

To produce an effluent with BOD_5 < 25 mg/l –
7 days (each) for two ponds in series
5 days (each) for three ponds in series

- ***Bacterial Reduction:***

The primary objective of maturation pond design is to remove faecal coliform bacteria.

Design of Maturation Ponds

- Reduction of faecal bacteria in a pond (anaerobic, facultative or maturation) follows first order kinetics.

$$N_e = \frac{N_i}{1 + k_b t}$$

where, N_e = Number of FC/100 ml of effluent
N_i = Number of FC/100 ml of influent
K_b = First order rate constant for FC removal (d^{-1})

- For n ponds in series, the equation becomes:

$$N_e = \frac{N_i}{(1 + k_b t_1)(1 + k_b t_2)\ldots.(1 + k_b t_n)}$$

where, t_n = retention time in the n^{th} pond

Design of Maturation Ponds

- The value of k_b is extremely temperature sensitive, which is given by the following equation:

$$k_{b(T)} = 2.6(1.19)^{T-20}$$

where, $k_{b(T)}$ = the value of k_b at T °C

- A reasonable value of N_i is 4×10^7 FC/100 ml, which is slightly higher than average values found in practice.

Design of Stabilization Ponds

Problem:

Design a waste stabilization pond system to treat 2000 m^3/d of domestic sewage with a BOD contribution of 400 mg/l. The mean temperature of the coolest month is 20°C and during irrigation season, 25°C. It is desired that the final effluent be used for crop irrigation. Assume fecal coliform concentration in raw waste water to be 1×10^8 per 100 ml. The required effluent standards are FC < 1000 per 100 ml. Assume k and k_b as 0.3 d^{-1} and 2.6 d^{-1} respectively at 20 °C.

$$k_{b(T°C)} = k_{b(20°C)} \, X \, (1.19)^{T-20}$$

$$k_{(T°C)} = k_{(20°C)} \, X \, (1.05)^{T-20}$$

Design of Stabilization Ponds

Solution:

$Q = 2000\ m^3/d$

$L_i = 400\ mg/l$

$N_i = 1 \times 10^8\ FC/100\ ml$

$k_{(25°C)} = 0.3\ X\ (1.05)^{25-20} = 0.38\ d^{-1}$

<u>Anaerobic pond design:</u>

The volumetric loading rate at 20°C, $\lambda_v = 300\ g/m^3\ d$ (from table)

Now, $V_a = L_i\ Q/\ \lambda_v = 400 \times 2000\ /300 = 2667\ m^3$

Assuming a depth of 3 m, $A_a = 2667/\ 3 = 889\ m^2$

Design of Stabilization Ponds

The BOD removal in the anaerobic pond is 60% (from table)

So, the BOD of the anaerobic pond effluent =400×0.40=160 mg/L

Now, the retention time, $t_a = V_a / Q = 2667 / 2000$ =1.33 days

Facaltative pond design:

The BOD surface loading rate at 20°C, $\lambda_s = 253$ kg/ha d (from table)

The pond area is given by,

$A_f = 10 L_i Q / \lambda_s$

$= 10 \times 160 \times 2000 / 253 = 12648\ m^2$

Design of Stabilization Ponds

Retention time, $t_f = A_f D_f / Q$

Assuming a depth of 1.5 m,

$$t_f = 12648 \times 1.5 / 2000$$

$$= 9.5 \text{ days}$$

Maturation pond design:

The FC removal rate at 25°C,

$$k_{(25°C)} = 2.6 \text{ X } (1.19)^{25-20} = 6.2 \text{ d}^{-1}$$

Assuming a maturation pond depth of 1.0 m, 50% BOD removal in facultative pond and 75% loading in the first maturation pond, the retention time in the first maturation pond is

$$t_{m1} = 10 L_i D_m / 0.75 \lambda_s$$

$$= (10 \times 0.5 \times 160 \times 1.0) / (0.75 \times 350) = 3.05 \text{ days}$$

Design of Stabilization Ponds

Now, using

$t_m = \{[N_i / N_e (1+k_b t_a) (1+k_b t_f)]^{1/n} - 1\} / k_b$

$= \{[1\times10^8 / 1000 (1+ 6.2\times 1.33) (1 + 6.2 \times 9.5)]^{1/n} - 1\} / 6.2$

when, n = 1,

t_m = 28.96 days (ignore as > t_f)

when, n = 2,

t_m = 2.00 days (ignore as < 3 days)

So, two maturation ponds with retention times t_{m1} = 3.05 days and t_{m2} = 3.0 days may be selected.

Design of Stabilization Ponds

Check for coliform concentration:

$N_e = N_i / (1+ k_b t_a) (1+ k_b t_f) (1+ k_b t_{m1}) (1+ k_b t_{m2})$

$= 10^8 / (1+ 6.2\times1.33) (1+ 6.2\times9.5) (1+ 6.2\times3.05)$ $(1+ 6.2\times3.0)$

$= 465$ per 100 ml, which is satisfactory

Now the corresponding areas for maturation pond 1 and 2 are

$A_{m1} = 2000 \times 3.05 / 1.0 = 6100\ m^2$

$A_{m2} = 2000 \times 3.00 / 1.0 = 6000\ m^2$

Design of Stabilization Ponds

A complete stabilization pond system would be:

Anaerobic pond: $A_a = 889\ m^2$, $t_a = 1.33$ days

Facultative pond: $A_f = 12648\ m^2$, $t_f = 9.50$ days

1st maturation pond: $A_{m1} = 6100\ m^2$, $t_{m1} = 3.05$ days

2nd maturation pond: $A_{m2} = 6000\ m^2$, $t_{m2} = 3.00$ days