Lecture 16 - Stabilization Ponds

"Simple" technology for wastewater treatment

Uses large shallow basins to treat raw wastewater by natural processes

Rate of waste oxidation is slower than engineered systems

Three general categories of waste stabilizations ponds:

anaerobic ponds - removes BOD by sedimentation, sludge is then digested in bottom layer

facultative lagoons - bacteria degrade waste, use O_2 and generate CO_2 algae use CO_2 and generate O_2

maturation pond - disinfection

Usual arrangement:

waste water → Anaerobic Pond → Facultative Lagoon → Maturation Ponds in series → ...

Anaerobic pond - primarily a sedimentation pond

high wastewater loading - depletes all O_2

solids settle to pond

anaerobic digestion of sludge occurs in pond bottom

Anaerobic digestion process:

1. Hydrolysis - complex organics (proteins, polysaccarides (i.e. multi-ring sugars), and fats) broken down to simpler compounds by various bacteria

2. Acidogenesis (Fermentation) - fatty acids and alcohols oxidized
amino acids and carbohydrates fermented
form volatile fatty acids and hydrogen

example

Sugar (glucose) to acetic acid:

$$C_6H_{12}O_6 + 2H_2O \rightarrow 2CH_3COOH + 4H_2 + 2CO_2$$

or propionic acid and butyric acid when H_2 conc is high:

$$C_6H_{12}O_6 + 2H_2O \quad \underset{\text{propionic acid}}{CH_3CH_2COOH} + 3CO_2 + 10H_2$$

$$C_6H_{12}O_6 \rightarrow \underset{\text{butyric acid}}{CH_3(CH_2)_2COOH} + 2CO_2 + 2H_2$$

(last reaction also can occur in beer production and causes off-flavor)

3. Acetogenesis - conversion of complex fatty acids to acetic acid

$$\underset{\text{propionic acid}}{CH_3CH_2COOH} + 2H_2O \rightarrow \underset{\text{acetic acid}}{CH_3COOH} + CO_2 + 3H_2$$

4. Methanogenesis - conversion of acetic acid to methane and CO_2, and CO_2 and H_2 to methane

$$CH_3COOH \longrightarrow CH_4 + CO_2$$

$$CO_2 + 4H_2 \longrightarrow CH_4 + 2H_2O$$

See summary figure - pg 4

With temperatures > 15°C digestion will generate enough biogas to cause pond surface to bubble

Biogas ~ 70% CH_4 30% CO_2

Digested solids accumulate in pond and require cleanout every 1 to 3 years

Hydraulic detention time is short ~ 1 day
Depth is 2-5 m (usually 3 m)

Design is highly empirical : based on volumetric load (gm BOD/m³·day) and <u>minimum</u> winter air temperature, Ta

$T_a \leq 10°C$ Europe - Loading = 100 g BOD/m³·day
$T_a \approx 20°C$ 300
$T_a \geq 25°C$ Tropics 350

100 g BOD/m³·day to 3-m deep pond = 3000 Kg/ha·day

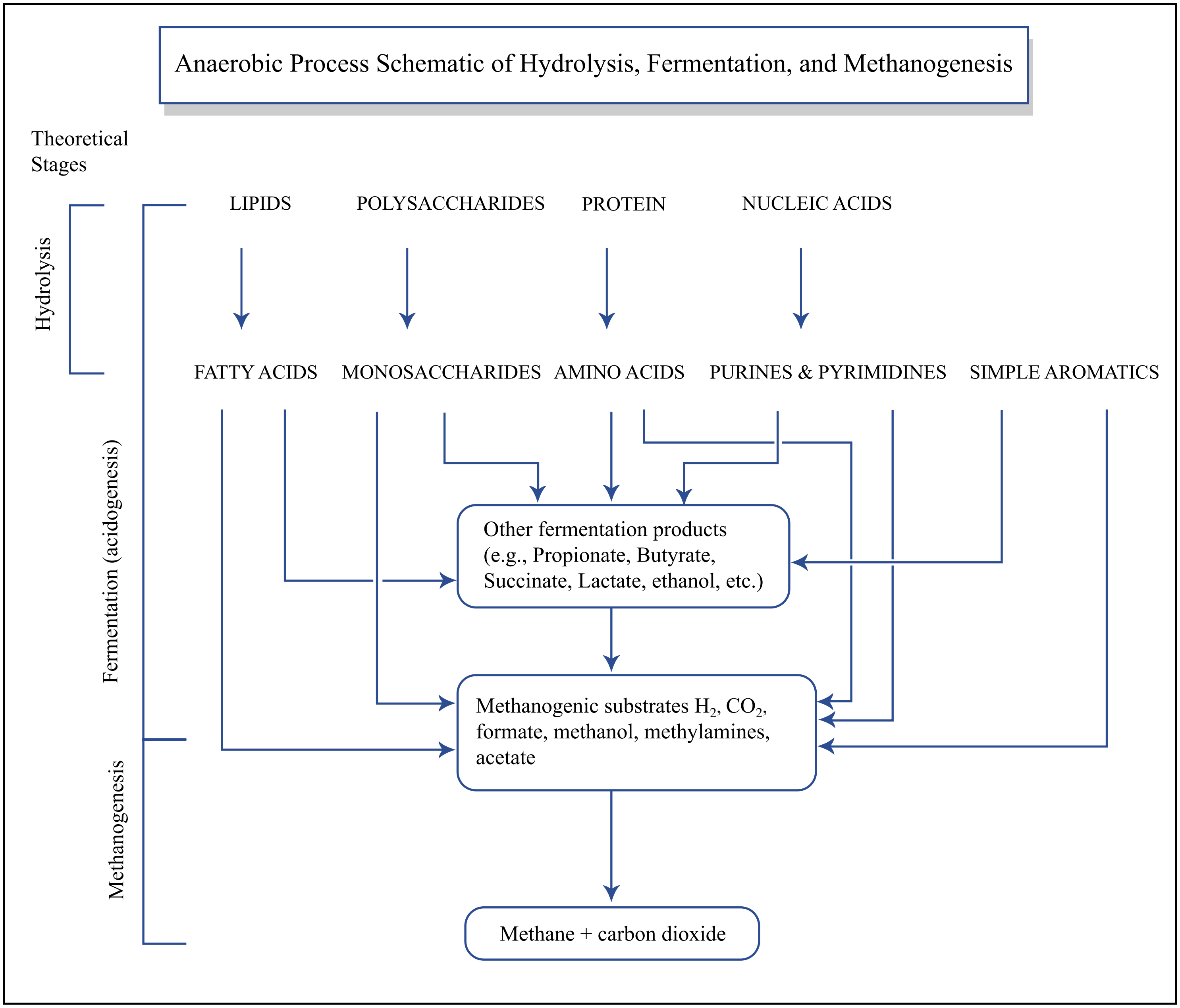


Figure by MIT OCW.

Adapted from: G. Tchobanoglous, F. L. Burton, and H. D. Stensel. *Wastewater Engineering: Treatment and Reuse*. 4th ed. Metcalf & Eddy Inc., New York, NY: McGraw-Hill, 2003, 631.

pH is critical for anaerobic ponds (Figure pg 6)

In well operating pond pH ≈ 7.5
S → bisulfide ion (HS^-) which has no odor

At low pH, below ~7, H_2S forms and causes odor

Below pH ~6.2, conditions are toxic to anaerobic bacteria

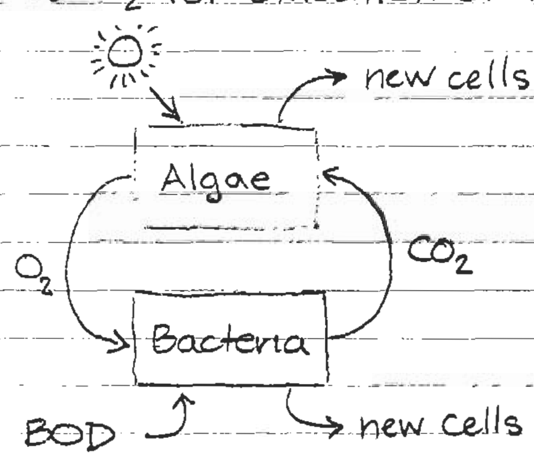
Facultative ponds

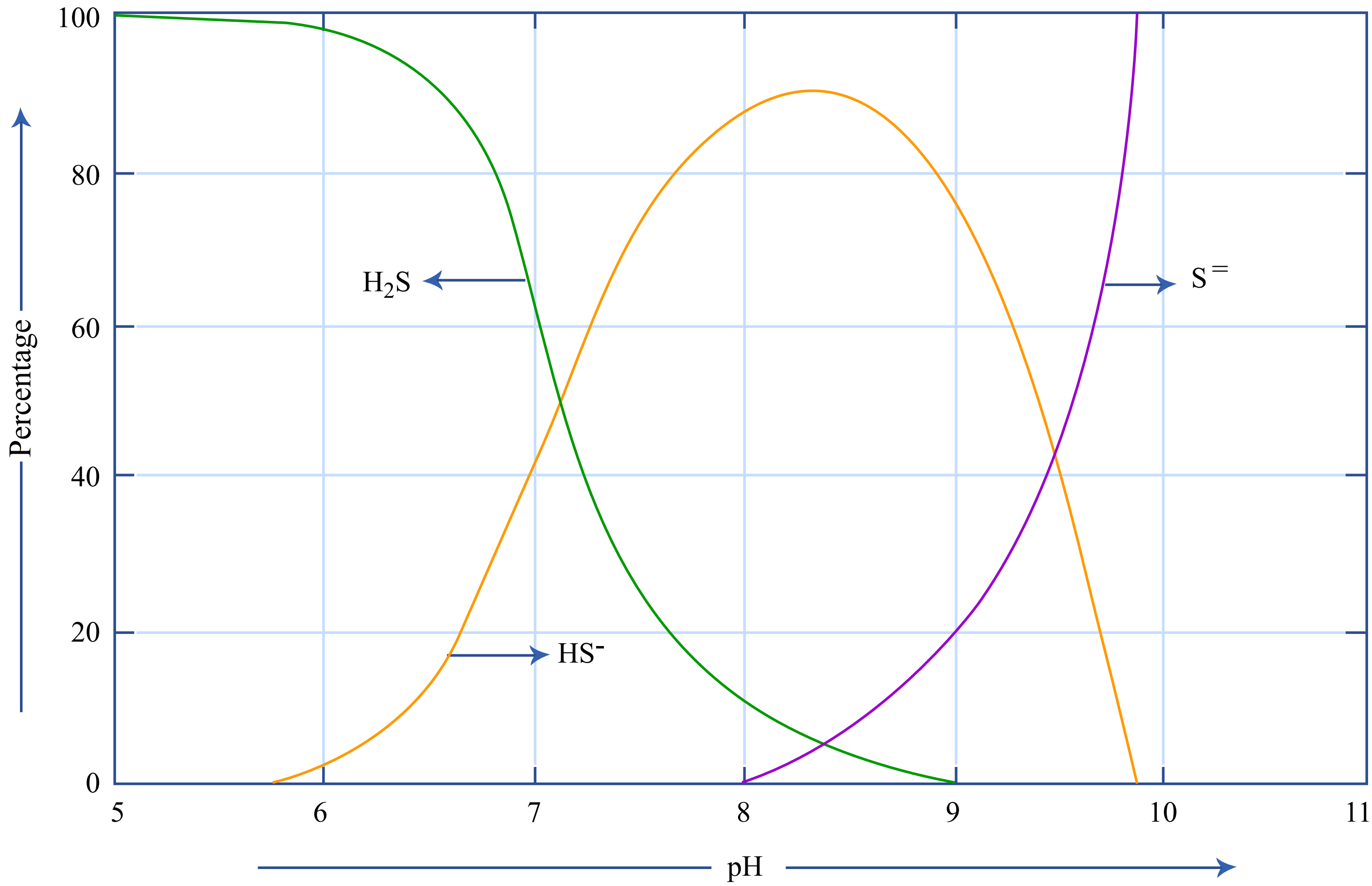
Much lower areal loading rates: 100–400 Kg/ha-day (vs. 3000+ for anaerobic ponds) of BOD

Pond water is aerobic and supports very high density algal population

Algae generate O_2 by photosynthesis during the day

This provides O_2 for oxidation of wastes by bacteria





Variation of the proportions of hydrogen sulphide, bisulphide and sulphide with pH in aqueous solutions.

Figure by MIT OCW.

Adapted from: Mara, D. *Domestic Wastewater Treatment in Developing Countries*. London, UK: Earthscan, 2003, p. 107.

Beneath water is an anaerobic bottom layer (sludge) in which sludge is digested

Facultative ponds may operate as primary ponds (with no anaerobic pond for pretreatment)
or secondary ponds (after anaerobic ponds)

Pond performance varies in two dimensions: time (diurnally) and vertical space

Vertical variations:

Algae require light but depth of photic zone (light penetration) may be limited in pond with heavy algae growth and turbid water
Light penetrates only about 30 cm (1 foot)

Pond algae tend to be motile species that can swim to optimum level in the pond

Non-motile species require wind mixing to regularly circulate through photic zone

Wind also mixes O_2 from photic zone to pond depths (see Figure pg 8)

Wind mixing is critical! Mara cites example of pond in Zambia:

2-m fence erected → pond went anaerobic in a few days
Fence removed → pond returned to aerobic

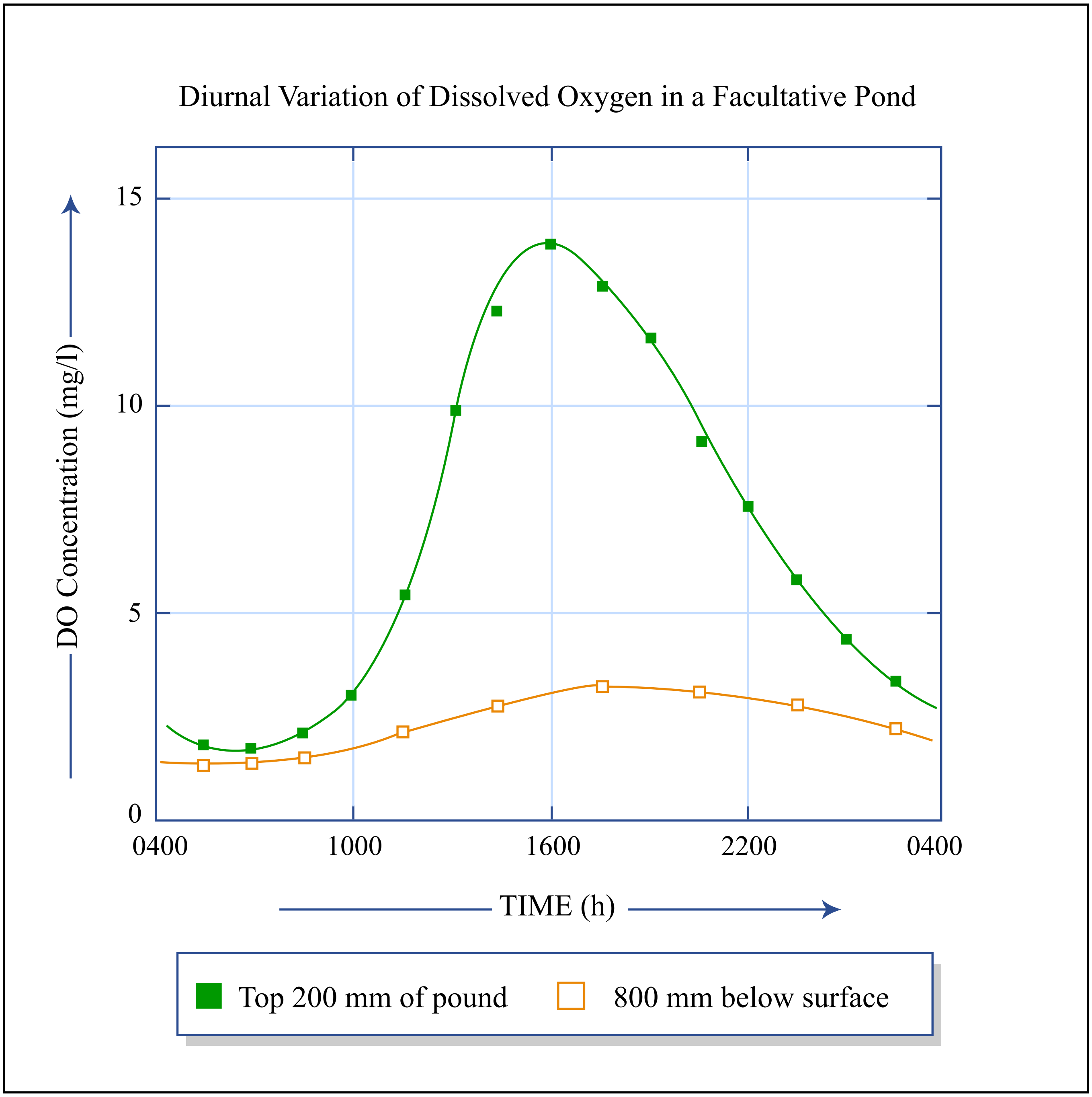


Figure by MIT OCW.

Adapted from: Mara, D. *Domestic Wastewater Treatment in Developing Countries*. London, UK: Earthscan, 2003, p. 115.

In tropics, ponds go through diurnal stratification pattern - observations of 1.5-m deep pond in Zambia:

Morning - wind mixing, uniform temp thru' depth

Mid-day - warming of surface water, sudden onset of stratification during lull in wind
thermocline forms - hot water above, cooler water below, almost no mixing across thermocline

Late afternoon, evening - top layer cools, mixing occurs after cooler than bottom layer or during wind mixing

Motile algae optimum depth - not very upper water (too hot) not too deep (too dark) - band around 30-50 cm below surface

Ponds generally have an "oxypause" - depth at which DO goes to zero. Moves up and down during the day

Besides generating O_2, bacteria consume CO_2 to the point that depleted CO_2 alters carbonate equilibrium and

$$2HCO_3^- \rightarrow CO_3^{2-} + H_2O + CO_2$$

$$CO_3^{2-} + H_2O \rightarrow CO_2 + 2OH^-$$

This raises pH, which kills fecal bacteria

Diurnal pattern of temperature and light leads to diurnal treatment performance

Pg 8 shows diurnal variation in DO
Pg 11 shows diurnal variation of pond effluent

Note: rise in DO, pH during day

decrease in coliform (due to pH, DO)

rise in BOD, TSS along with rise in chlorophyll-a

BOD is still high in effluent, but it is algae and not organic waste
Chlor-a = 500-1000 $\mu g/L$ (compared to 100-150 for hypereutrophic lake)

Vertical and diurnal patterns fix pond depth, H

If $H < 1$ m → emergent plants grow, foster mosquito growth

If $H > 1.8$ m → oxypause is too shallow relative to overall pond depth – pond is more anaerobic than aerobic

Optimal $H \sim 1.5$ m ($1 < H < 1.8$)

Deep ponds are better where evaporation is high (to reduce surface area) or weather is cold (to retain heat)

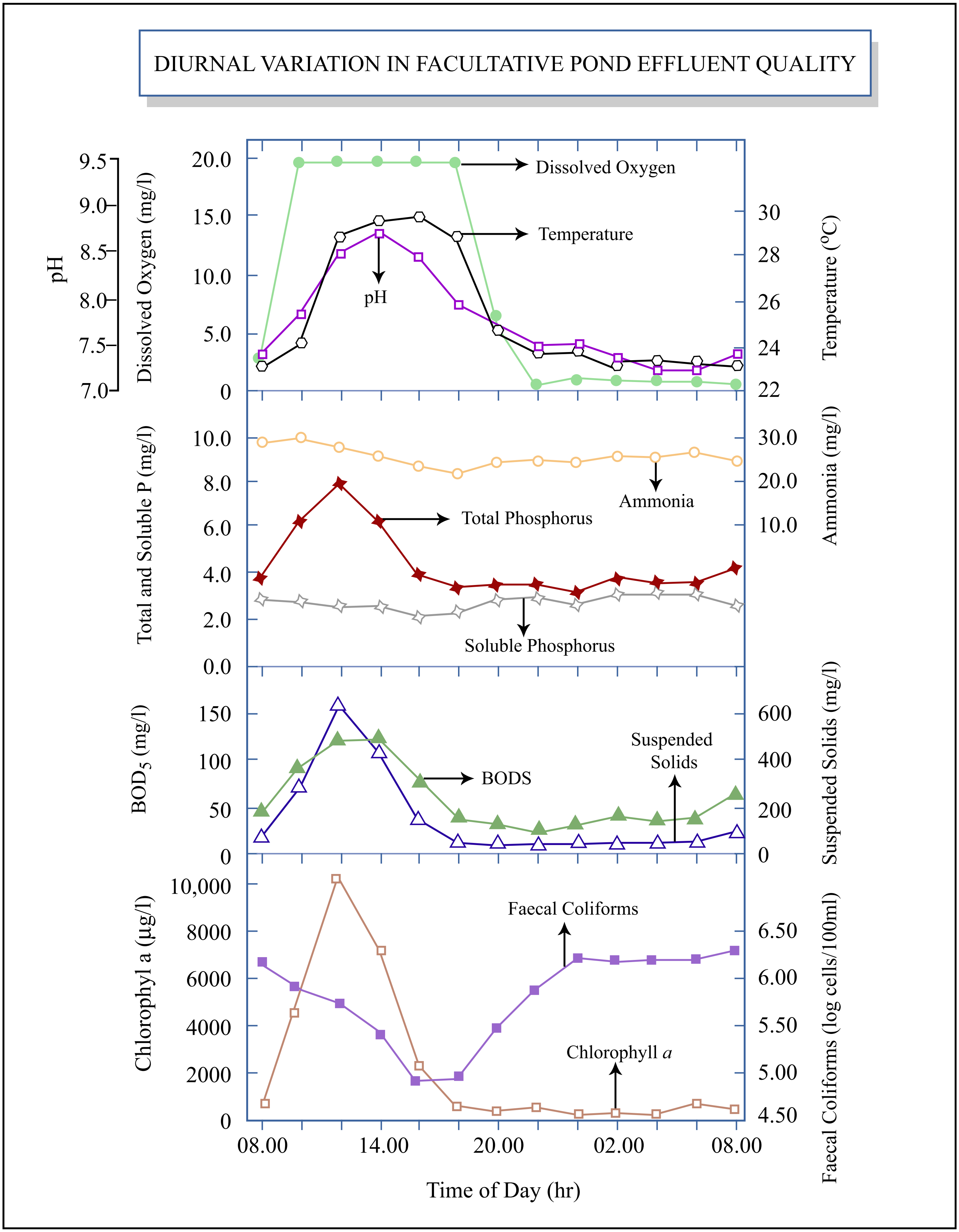


Figure by MIT OCW.

Adapted from: Mara, D. *Domestic Wastewater Treatment in Developing Countries*. London, UK: Earthscan, 2003, p. 122.

Pond design

Empirical design is based on areal loading rate (Kg BOD / ha · day) as function of temperature

Range of loadings: 80 Kg/ha-day at 8°C temperate
350 25°C
500 35°C tropical

Required hydraulic retention time $t_R = \frac{\forall}{Q}$:

$t_R \geq 5$ days for $T < 20°C$
$t_R \geq 4$ days for $T \geq 20°C$

Maturation Ponds

Used to reduce pathogenic bacteria and viruses

e coli removals of 6 log units (6 nines, ie. 99.9999% removal) achieved in 3 maturation ponds-in-series in Brazil

viruses - 99.9997%

Removal mechanisms:

Solar disinfection - UV light inactivation and OH-radical formation

High pH

Design

~ 1 m deep

Total detention time on order of 10 days

Modeling for Facultative Lagoons

For design, simpler FMT and PFR are usually used.

Thirumurthi (1969, 1974 - see also Mara, 2003) has presented design procedure and charts based on dispersed-flow reactor concept.

Thirumurthi chart gives BOD remaining vs. Kt_{res} and dispersion number d (see chart)

Thirumurthi (1974) gives method to adjust standard value for given pond to changes in temperature, organic load, and toxic industrial chemicals

Procedure: Known Q and K, estimate pond dimensions to find $t_{res} = \forall/Q$ and $d \approx W/L$, find if % treatment is adequate

Thirumurthi, D., 1969. Design principles of waste stabilization ponds. Journal of the Sanitary Engineering Division, ASCE. Vol. 95, No. SA2, Pp. 311 - 330. April 1969.

Thirumurthi, D., 1974. Design criteria for waste stabilization ponds. Journal Water Pollution Control Federation. Vol. 46, No. 9, Pp. 2094 - 2106. September 1974.

Mara, D., 2003. Domestic Wastewater Treatment in Developing Countries. Earthscan, London.

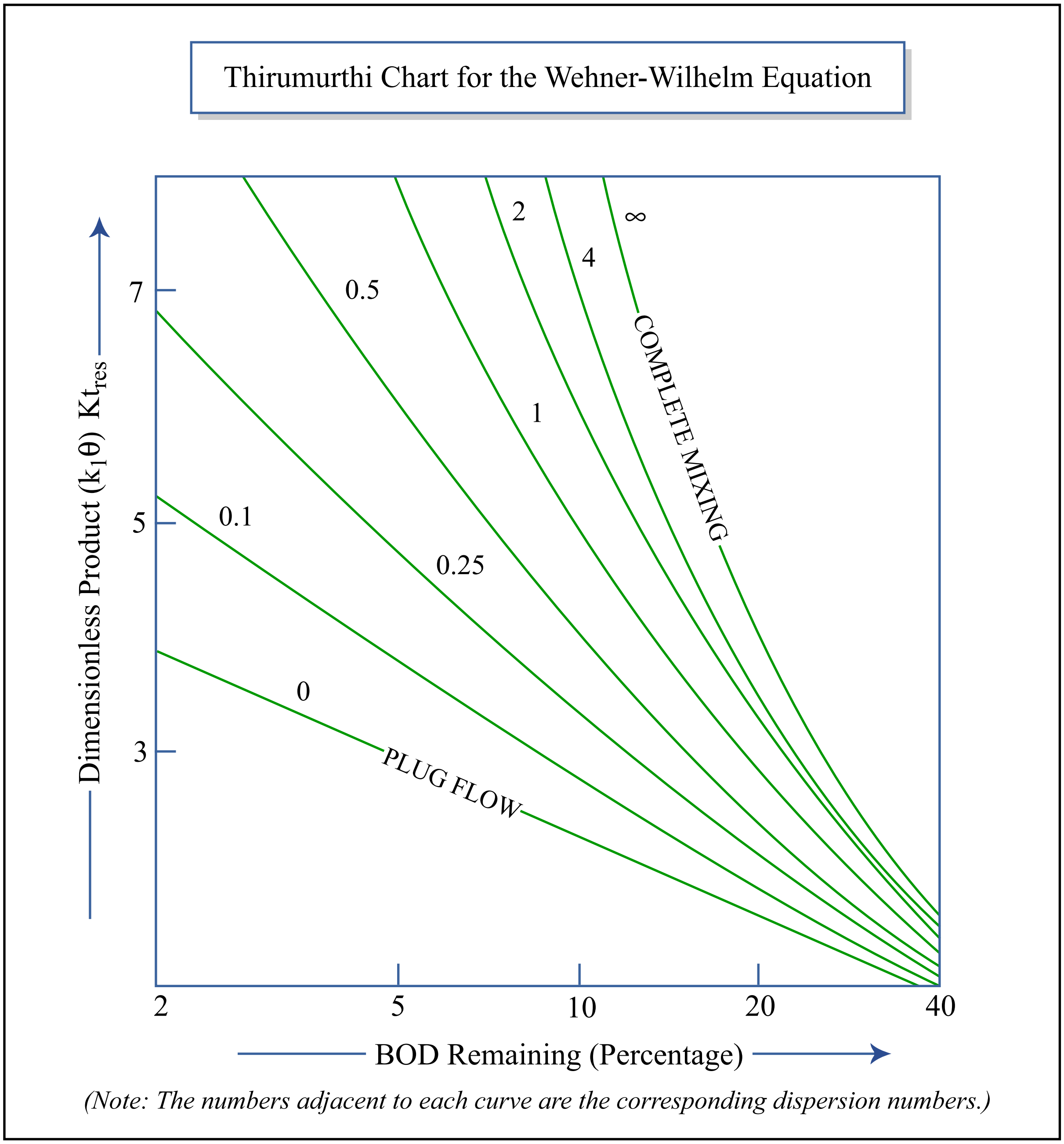


Figure by MIT OCW.

Adapted from: Mara, D. *Domestic Wastewater Treatment in Developing Countries*. London, UK: Earthscan, 2003, p. 62.

More complicated models are also possible but seldom used

Example: R.A. Ferrara and D.R.F. Harleman, 1978. A dynamic nutrient cycle model for waste stabilization ponds. Technical Report 237. Ralph M. Parsons Laboratory, MIT, Cambridge, Massachusetts, USA.

Model accounts for aerobic surface zone (see page 16) and anaerobic sludge zone (see page 17)

Surface zone has reaeration, algae, bacteria, N and P (shown as inorganic elements) and C (shown as organic material)

Anaerobic zone has some elements but without algal growth or reaeration and different coefficients

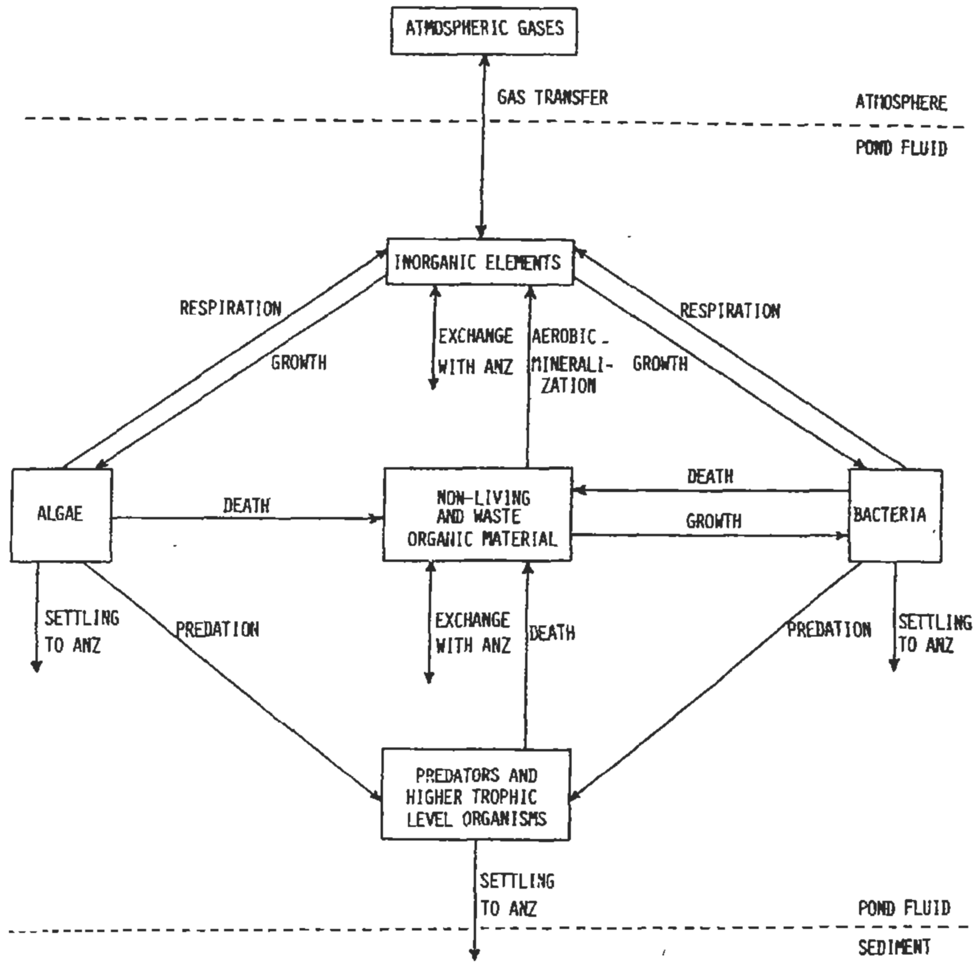


Figure 5.1 Conceptual Model of Aerobic Fluid Zone in a Facultative Waste Stabilization Pond (ANZ = Anaerobic Zone of Figure 5.2)

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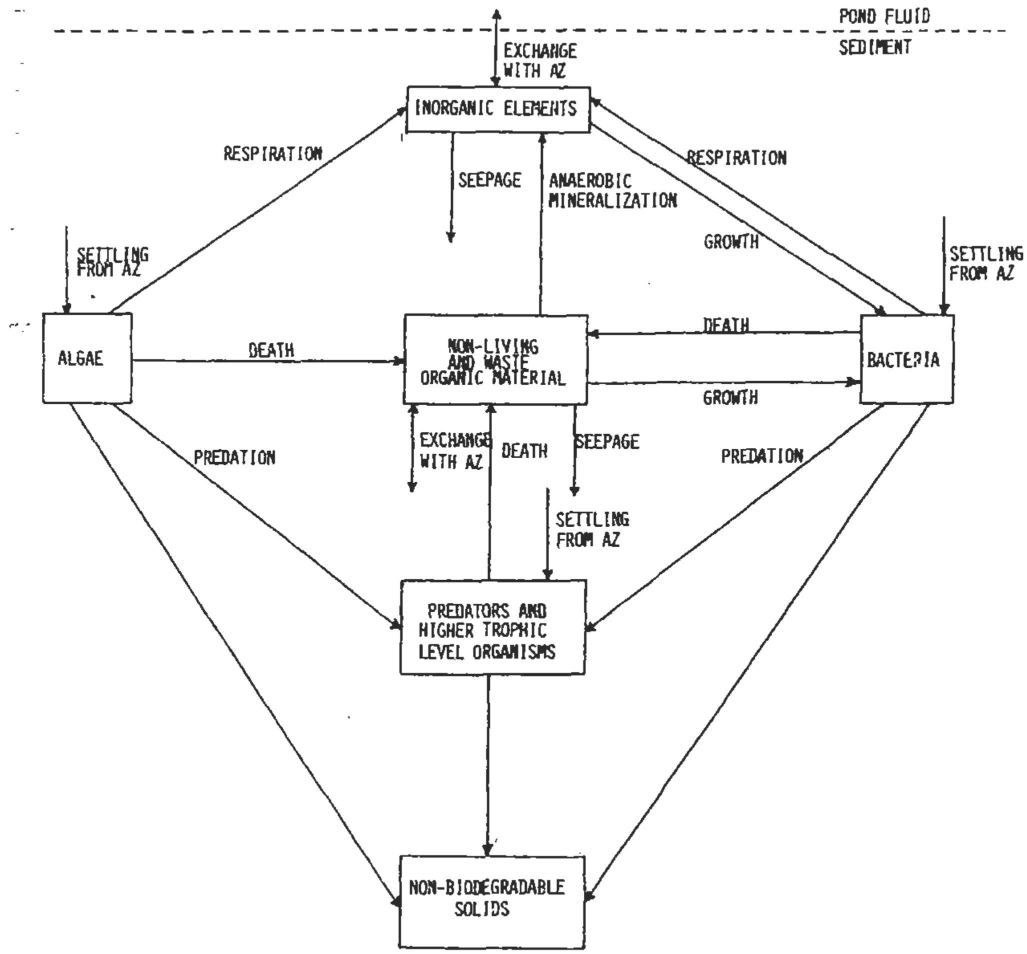

Figure 5.2 Conceptual Model of Anaerobic Zone in a Facultative Waste Stabilization Pond (AZ = Aerobic Zone of Figure 5.1)