Water Pollution-3

-Biochemical Oxygen Demand (BOD)

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Biochemical Oxygen Demand

- **Biochemical Oxygen Demand (BOD) :**
  Amount of molecular oxygen needed for microorganisms to stabilize waste i.e., oxidize waste by aerobic action.
  - BOD is a surrogate for organic waste concentration.
  - O_2 is used as electron acceptor.
  - The largest problem with surface waters is oxygen demand.

- Aerobic biodegradation:

  Organic matter + O_2 → CO_2 + H_2O + new cells + stable products

  Stable products are: SO_4^{2-}, PO_4^{3-}, NO_3^-

- Anaerobic biodegradation:

  Organic matter → CO_2 + CH_4 + new cells + unstable products

  Unstable products are H_2S, NH_3, fatty acids

BOD_5 Test

- **BOD_5 : oxygen consumed during 5 days of degradation**
  - Test run at 20°C
  - Run in the dark to eliminate photosynthesis (O_2 source)
  - For BOD larger than initially available DO (9.2 mg/L at 20˚C), samples are diluted in 300-mL bottles

- General procedure
  - Dilute sample
  - Measure initial DO (DO_i)
  - Wait 5 days, measure final DO (DO_f)

BOD_5 Test

$$BOD_5 = \frac{DO_i - DO_f}{P}$$

P = dilution fraction

$$P = \frac{V_{waste}}{V_{total}}$$

Example

- 15 mL of industrial effluent is mixed with water in a 300 mL BOD bottle.

  The initial DO of the mixture is 8 mg/L. After 5 days the remaining DO is 3 mg/L.

  What is the BOD_5?

Example

- A 10.0-mL sample of sewage mixed with enough water to fill a 300-mL bottle has an initial DO of 9.0 mg/L.

To help assure an accurate test, it is desirable to have at least a 2.0-mg/L drop in DO during the 5-day run, and the final DO should be at least 2.0 mg/L.

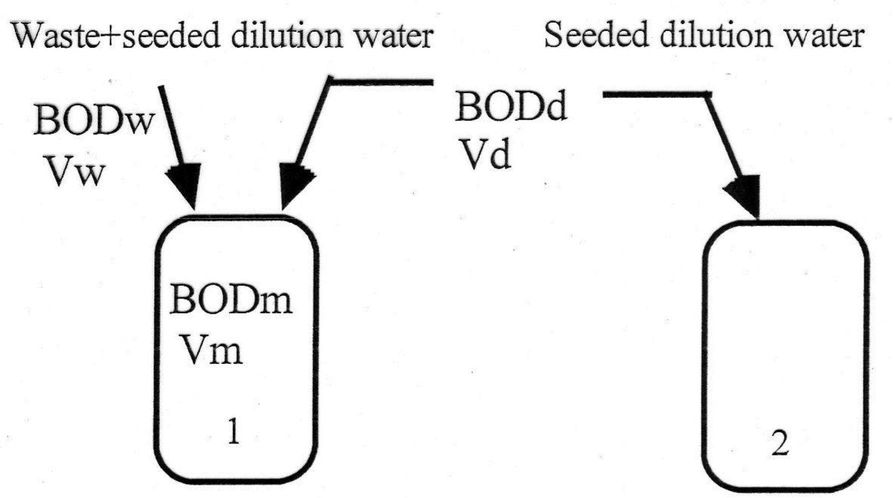
For what range of BOD_5 would this dilution produce the desired results?

The dilution fraction is P = 10/300.

Seeded BOD Test

- Another test is frequently used: seeded BOD test
  - When there are not enough microorganisms in the waste to stabilize it, they need to be added.

- Need to differentiate between effects of O_2 demand of seed from waste demand.
  - One bottle with only seeded dilution water as control
  - Another bottle with seeded dilution water + waste.



DO_i, DO_f:
Initial and final DO
in the diluted sample bottle

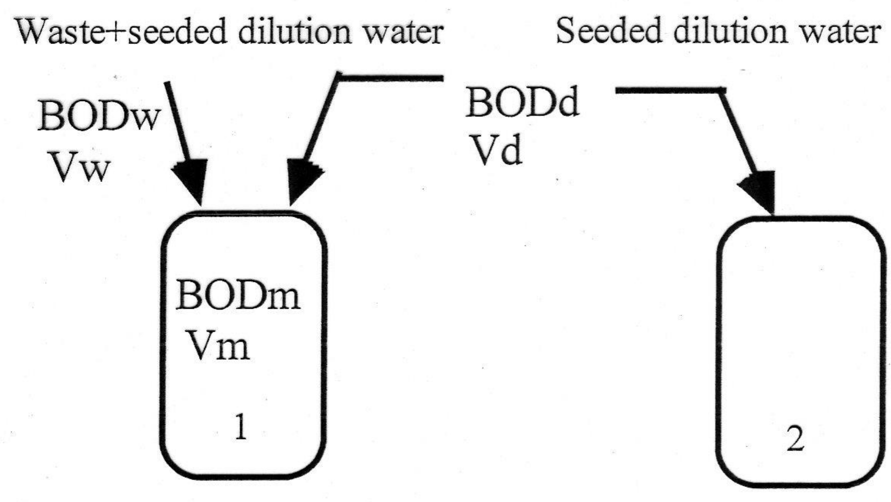
B_i, B_f:
Initial and final DO
in the control bottle

$V_m = V_w + V_d$

$P : V_w/V_m$

$1\text{–}P : V_d/V_m$

Seeded BOD Test



$$\mathrm{BOD_m}V_\mathrm{m} = \mathrm{BOD_w}V_\mathrm{w} + \mathrm{BOD_d}V_\mathrm{d}$$

$$\mathrm{BOD_w} = \mathrm{BOD_m}\left(\frac{V_\mathrm{m}}{V_\mathrm{w}}\right) - \mathrm{BOD_d}\left(\frac{V_\mathrm{d}}{V_\mathrm{w}} \times \frac{V_\mathrm{m}}{V_\mathrm{m}}\right)$$

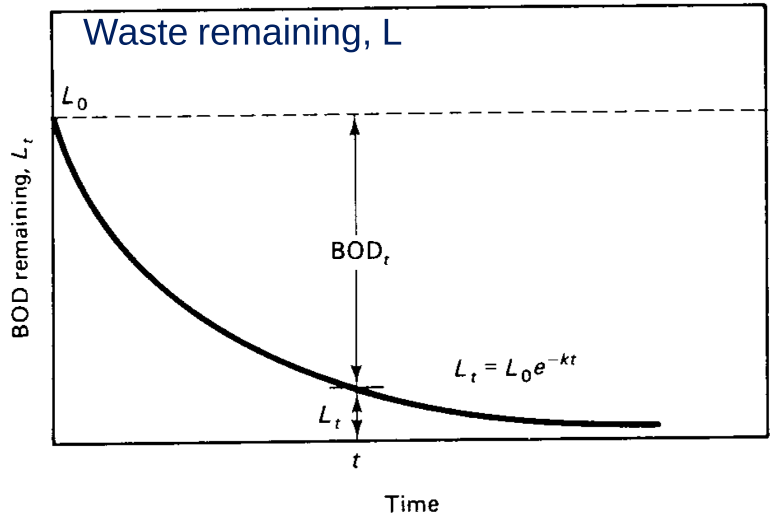
$$\mathrm{BOD_w} = \frac{(\mathrm{DO_i} - \mathrm{DO_f}) - (B_\mathrm{i} - B_\mathrm{f})(1 - P)}{P}$$

Example

- 300 mL test bottle has 15 mL of waste plus seeded solution.
  The DO drop is 7.2 mg/L in 5 days. The control DO drop is 1 mg/L in 5 days.
  What is the BOD of the waste?

$$BOD_w = \frac{(DO_i - DO_f) - (B_i - B_f)(1-P)}{P}$$

Modeling BOD Removal



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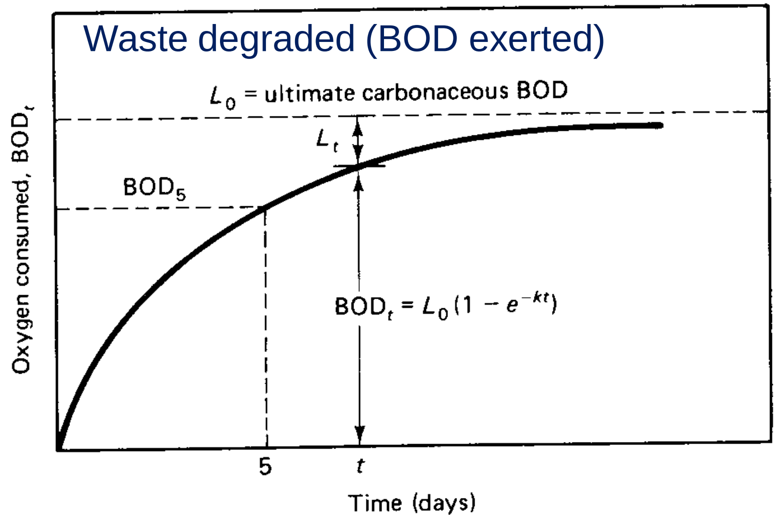


- **Modeling BOD removal as a function of time :First order kinetics**

$$\frac{dL_t}{dt} = kL_t$$

$$L_t = L_o e^{-kt}$$

$$BOD_t = L_o - L_t$$
$$= L_o (1 - e^{-kt})$$

Example

- BOD_5 = 125 mg/L
  If k is 0.25/day (typical),
  what is the ultimate carbonaceous biochemical oxygen demand, L_o?

Modeling BOD Removal

$$L_t = L_O e^{-kt}$$

- **What does k depend on?**
  - *Waste* – some wastes degrade faster than others
  - *Microorganisms* – type and concentration
  - *Temperature* – faster at higher temperatures
- Typical values
  - Raw sewage – 0.35 to 0.70/day
  - Treated sewage – 0.10 to 0.25 /day
- To account for temperature changes
  - $k = k_{20}\ \theta^{(T-20)}$
  - θ : temperature coefficient $\cong$ 1.047

Nitrification

- Nitrogen containing compounds = additional oxygen demand
- Many wastes contain ammonia which is toxic to fish and exerts an oxygen demand.
- Important reactions (aerobic environment):

$$2NH_3 + 3O_2 \rightarrow 2NO_2^- + 2H^+ + 2H_2O$$ (*Nitrosomonas)*

$$2NO_2^- + O_2 \rightarrow 2NO_3^-$$ (*Nitrobacter*)

OVERALL: $NH_3 + 2O_2 \rightarrow NO_3^- + H^+ + H_2O$

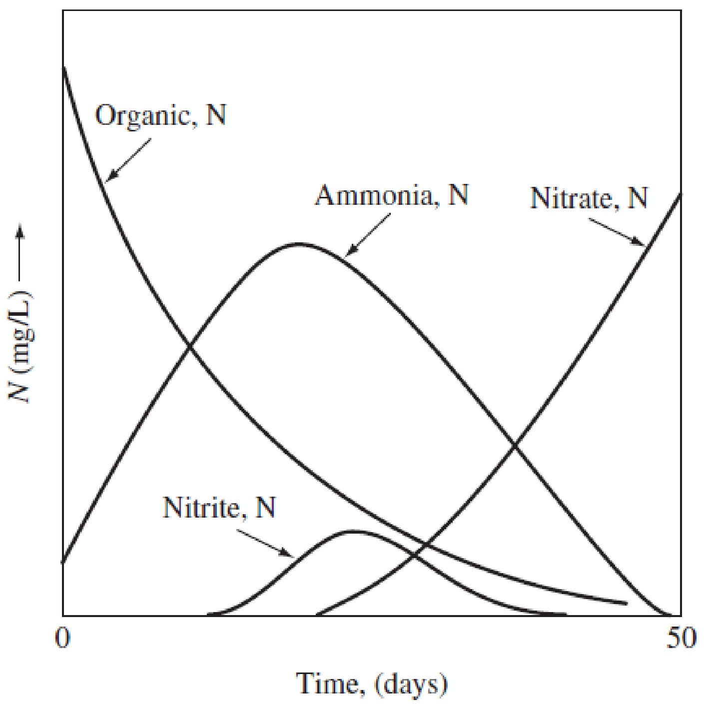
NH_3 = ammonia; NO_2^- = nitrite; NO_3^- = nitrate

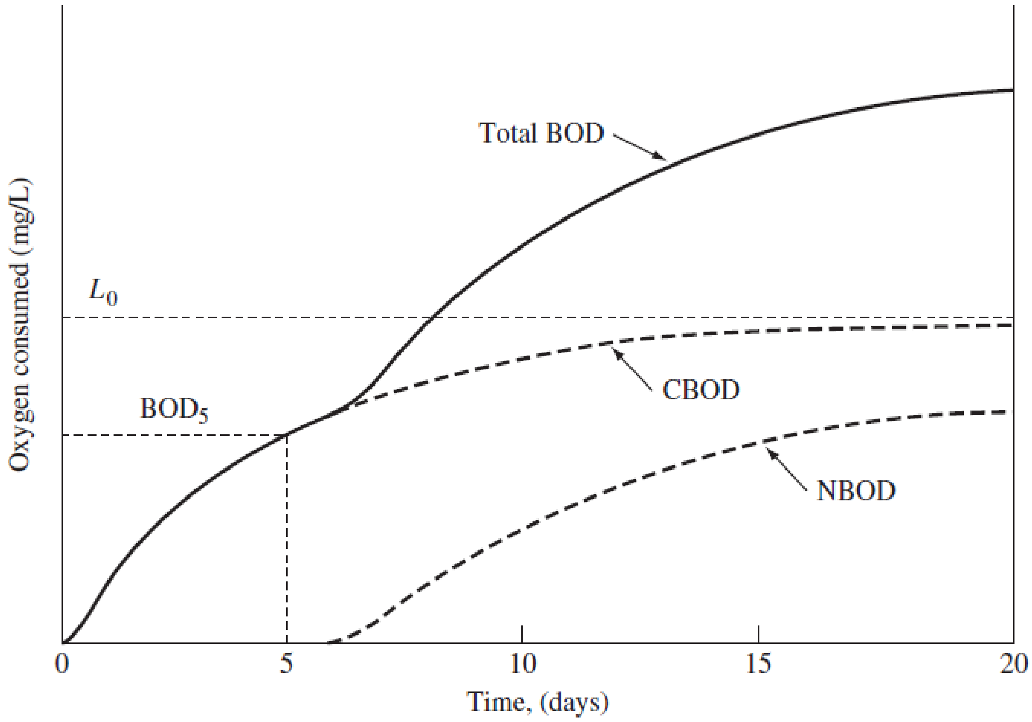
- "Comammox" (COMplete AMMonia OXidiser) is a *Nitrospira* that oxidizes NH_3 to NO_3^-

- Nitrogenous Oxygen Demand of ammonia is 2 moles O_2 per mole N (4.57 g-O_2 per g-N)

NBOD

√ **NBOD: Nitrogenous Biochemical Oxygen Demand**





Nitrifiers are autotrophs, grow slower than heterotrophs.

NBOD

- Wastes contain mainly organic-N, and NH_3.
- Organic-N hydrolyzes, becomes NH_3.
- 1 mole of Org-N → 1 mole NH_3
- NBOD is exerted after 5 to 14 days.
- Nitrification occurs after a lag, and nitrate becomes dominant species in final stages of aerobic stabilization.
- TKN: Total Kjeldahl Nitrogen = organic-N + NH_3

  NBOD = 4.57 * TKN

Oxygen Demands

- CBOD : carbonaceous biochemical O_2 demand
- NBOD : nitrogenous biochemical O_2 demand
- ThOD : theoretical O_2 demand - from stoichiometric considerations, including theoretical NBOD
- ThOD > BOD
  - Organic matter is not fully oxidized all the way to CO_2, some is used for cell synthesis.
- COD : chemical oxygen demand – use a strong chemical oxidizer
  - A faster test than BOD
  - Sometimes used to estimate ultimate BOD