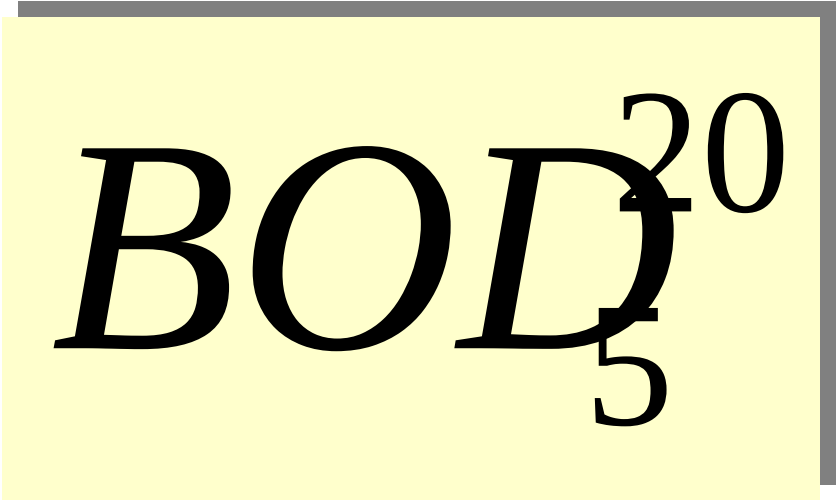


Biochemical Oxygen Demand

A Conventional Perspective



BOD_{20}^{5}

ZAINI UJANG

Institute of Environmental & Water Resource Management

Universiti Teknologi Malaysia

Zaini Ujang, Notes on Biochemical Oxygen Demand

Presentation Menu

- Introduction
- Nature of BOD reaction
- Methodology
- Rate of biochemical oxidations
- Examples on calculations

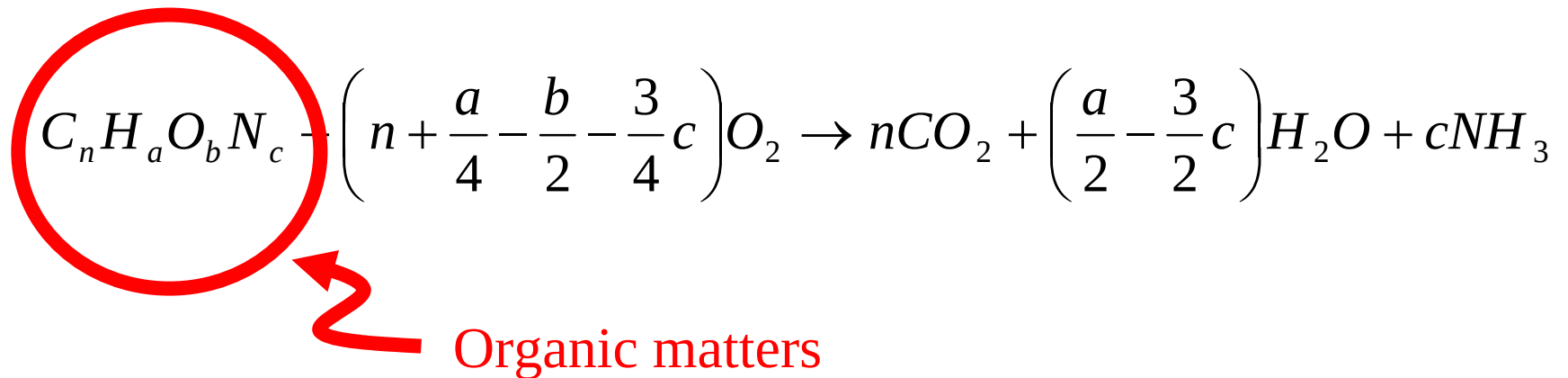


- BOD → amount of oxygen required by bacteria while stabilizing decomposable organic matter under aerobic conditions.
- Decomposable → organic matter that can serve as food for bacteria, and energy is derived from its oxidation
- BOD → measure pollution strength of wastewater or polluted water

- BOD → the most important analysis for in stream-pollution-control activities
- BOD → important in regulatory work
- BOD test → bioassay procedure involving the measurement of oxygen consumed by living organisms (mainly bacteria) while utilizing organic matter present in a waste, under conditions as similar as possible to nature.

Concept for BOD test

- Wet oxidation procedure in which living organisms serve as the medium for oxidation of the organic matter to CO_2 and water.
- Generalized equation:

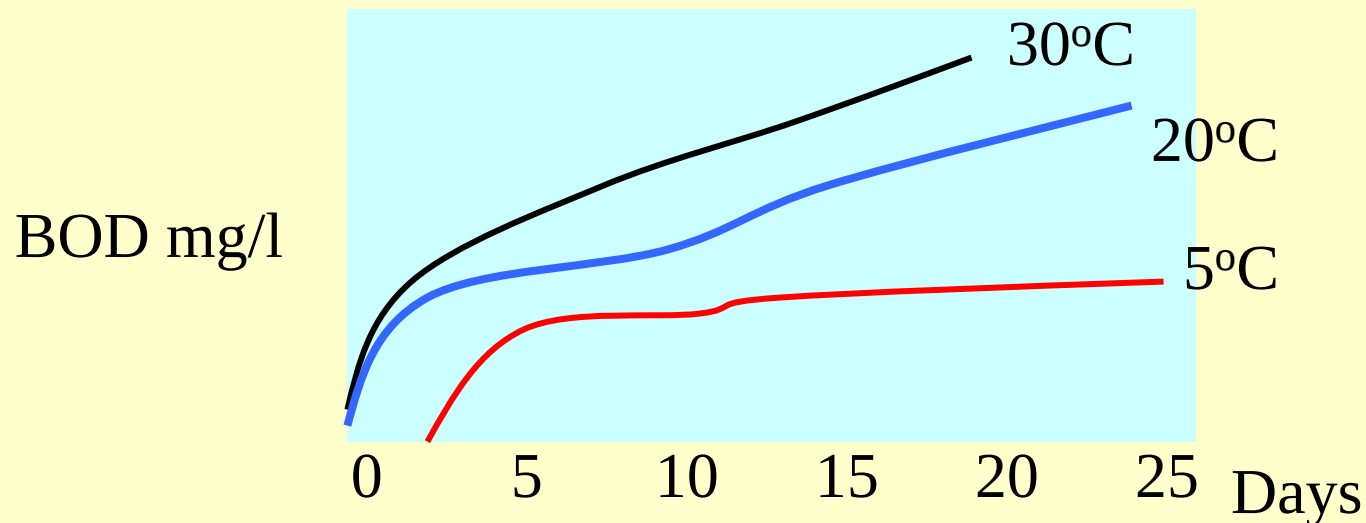


Time for BOD test

- Theoretically an **infinite time** is required for complete biological oxidation of organic matter, but for practical purposes, the reaction may be considered complete in 20 days.
- But for practical reasons, **5 days** was used since large percentage of the total BOD is exerted in 5 days.
- **5 days BOD values only represent a portion of the total BOD values.**
- For most industrial and municipal wastewater, the 5-day BOD value is about **70 to 80 percent of the total BOD.**

Temperature for BOD test

- Temperature effects for microbial dynamics are constant at 20°C.
- Predominant organisms responsible for the stabilization of organic matter in natural waters are forms native to the soil.



Nature of the BOD Reaction ...

- ❑ First order kinetics
- ❑ The rate of the reaction is proportional to the amount of oxidizable organic matter remaining at any time, as modified by the population of active organisms
- ❑ Once the population of organisms has reached a level at which only minor variations occur, the reaction rate is controlled by the amount of food available to the organisms:

$$\begin{aligned}\frac{-dC}{dt} &\propto C \\ \frac{-dC}{dt} &= k' C\end{aligned}$$

C = concentration of oxidizable organics (pollutants) at the start of the time interval, t
k' = rate constant for the reaction

...Nature of the BOD Reaction

- ❑ L is normally to replace C in BOD terms
- ❑ L represents the ultimate demand:

$$-\frac{dL}{dt} = kL_t$$

- ❑ $-dL/dt$ = the rate at which organic polluting matter is destroyed
- ❑ Oxygen is used in stabilizing organic matter in direct ratio to the amount of organics oxidized, it is possible to interpret L in terms of organic matter , or in terms of oxygen used.

...Nature of the BOD Reaction

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

$$\frac{dL_t}{L_t} = -kdt$$

$$\int_{L_o}^L \frac{dL_t}{L_t} = -k \int_0^t dt$$

$$\ln \frac{L_t}{L_o} = -kt$$

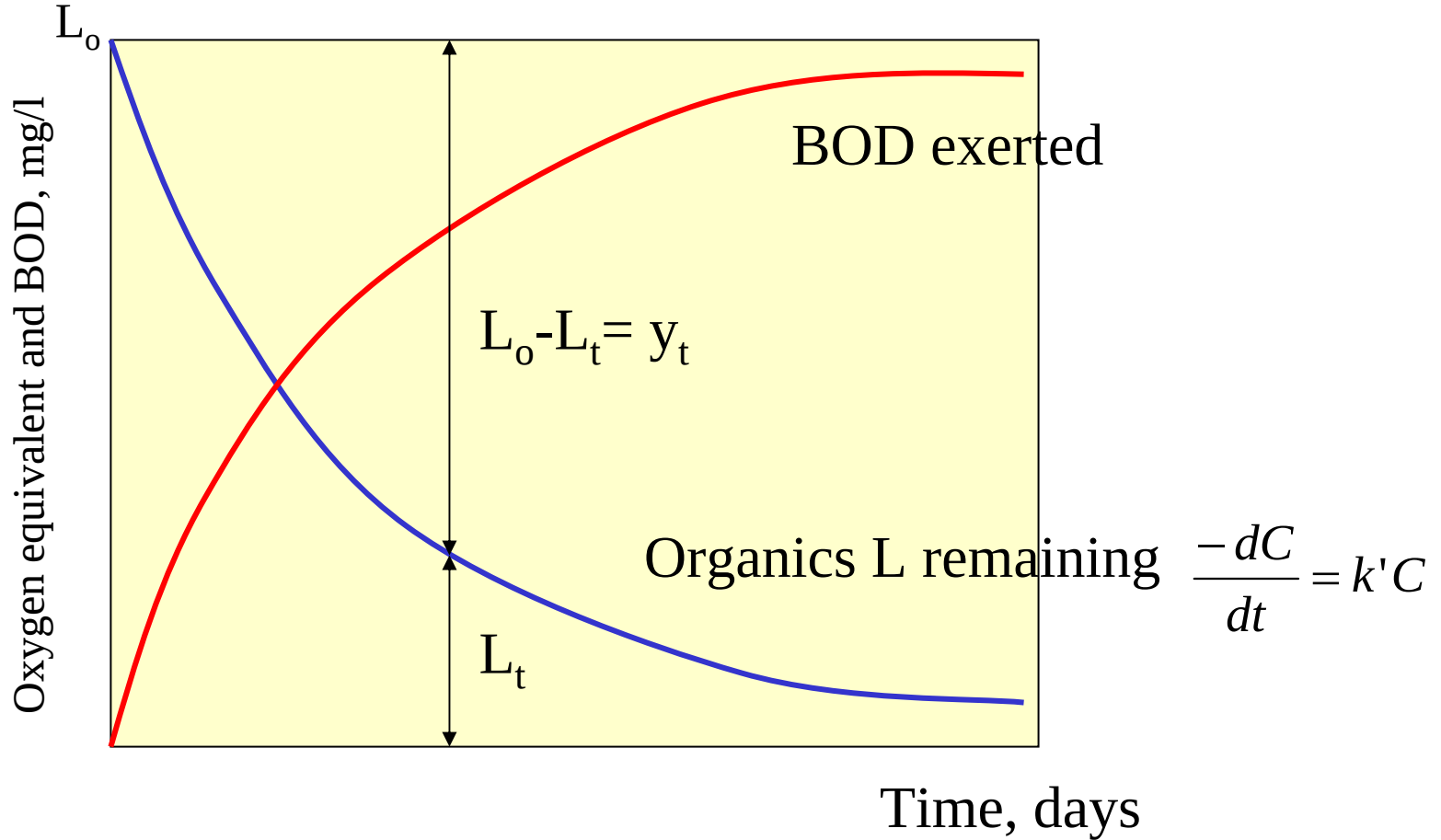
$$L_t = L_o e^{-kt}$$

L_t = oxygen equivalent of the organics
at time t

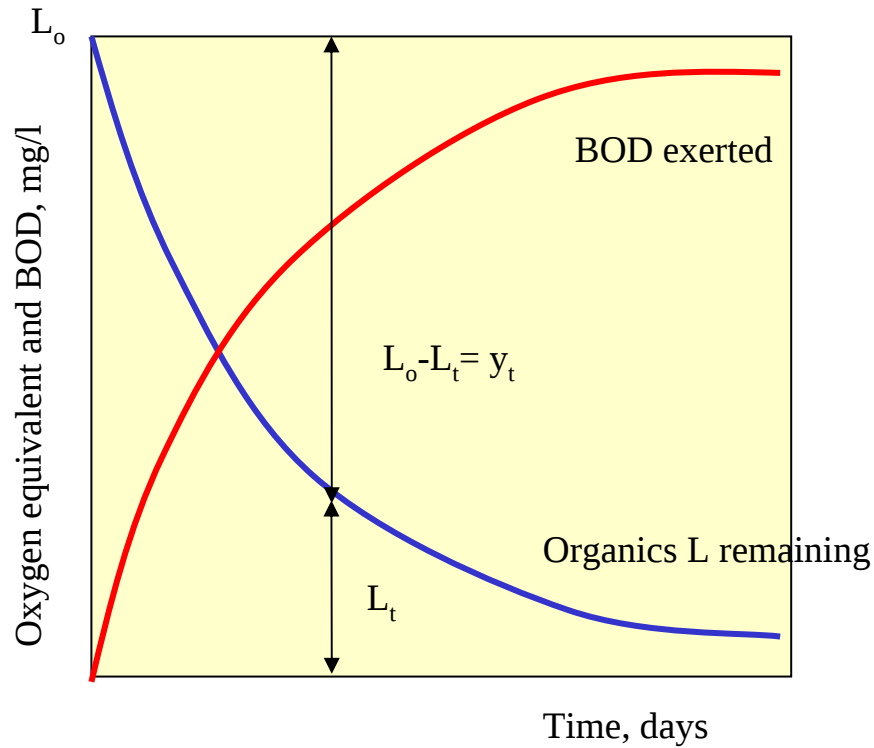
k = reaction constant, d^{-1}

L_o = total oxygen equivalent of
organics at time 0

BOD and oxygen-equivalent relationships



BOD and oxygen-equivalent relationships



$$y_t = L_o - L_t$$

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

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

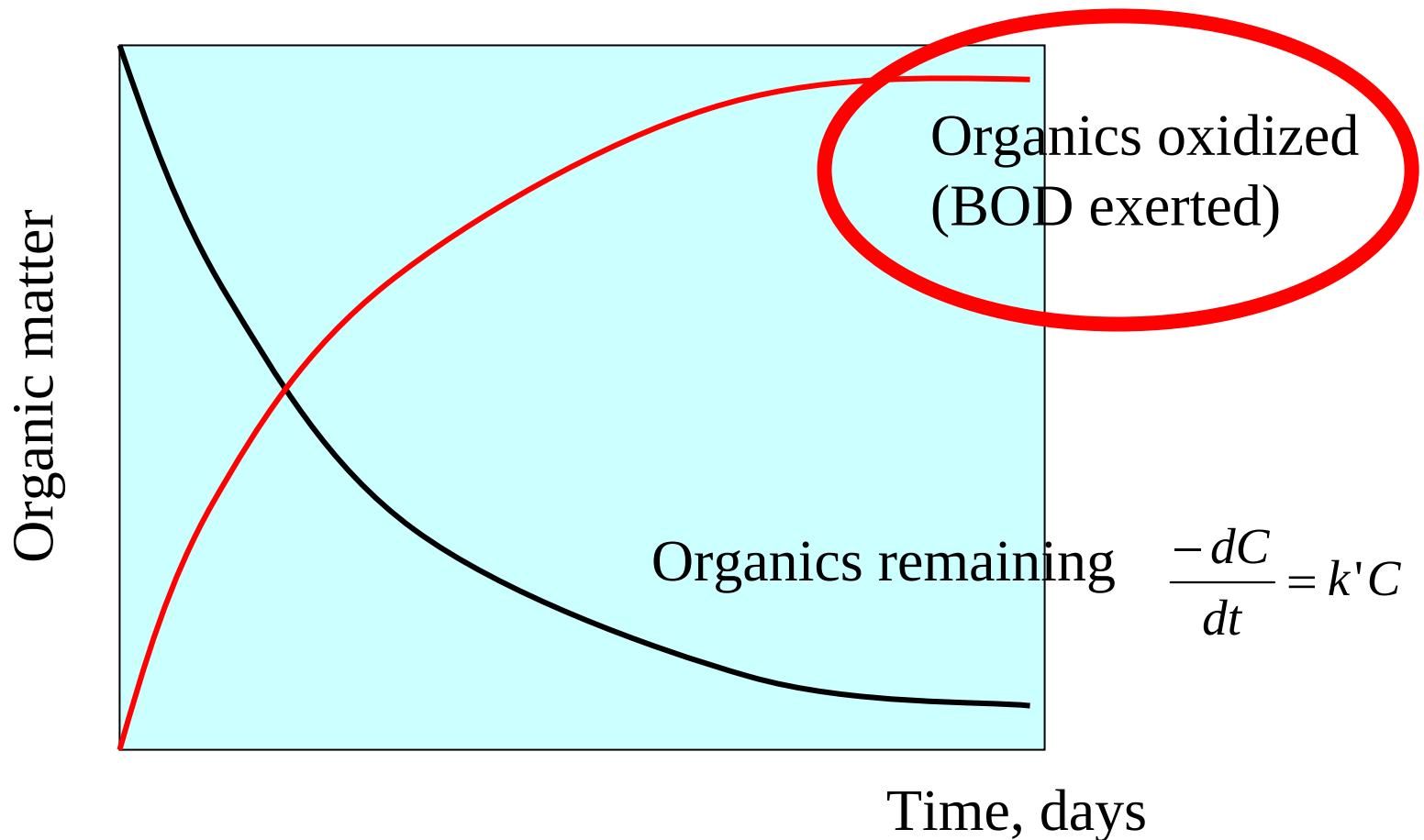
$Y_t = \text{BOD}_t$ of the water samples

- ❑ Environmental engineers are more interested on BOD exerted.
- ❑ Test – using dissolved-oxygen measurements
- ❑ Use 5-day result to total or ultimate BOD (y_u) or BOD at some other time:

$$y_t = L_o \left(1 - e^{-kt} \right)$$

- ❑ y = BOD at any time t
- ❑ L = total or ultimate BOD
- ❑ k = determine by experiment

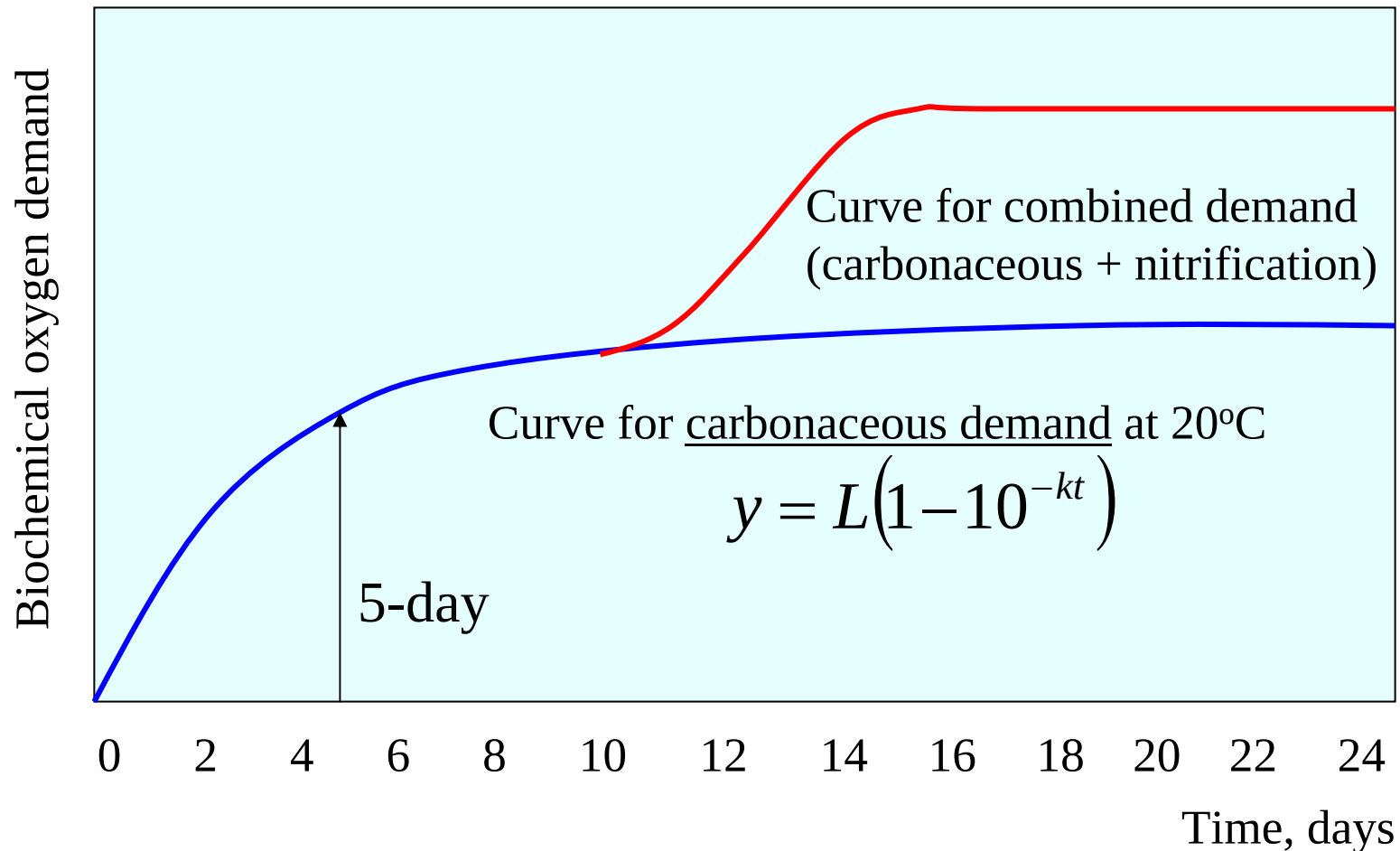
Changes in organics during biological oxidization of polluted waters under aerobic conditions



The BOD curve:

(a) Normal curve for oxidization of organics

(b) The influence of nitrification



Reaction constant

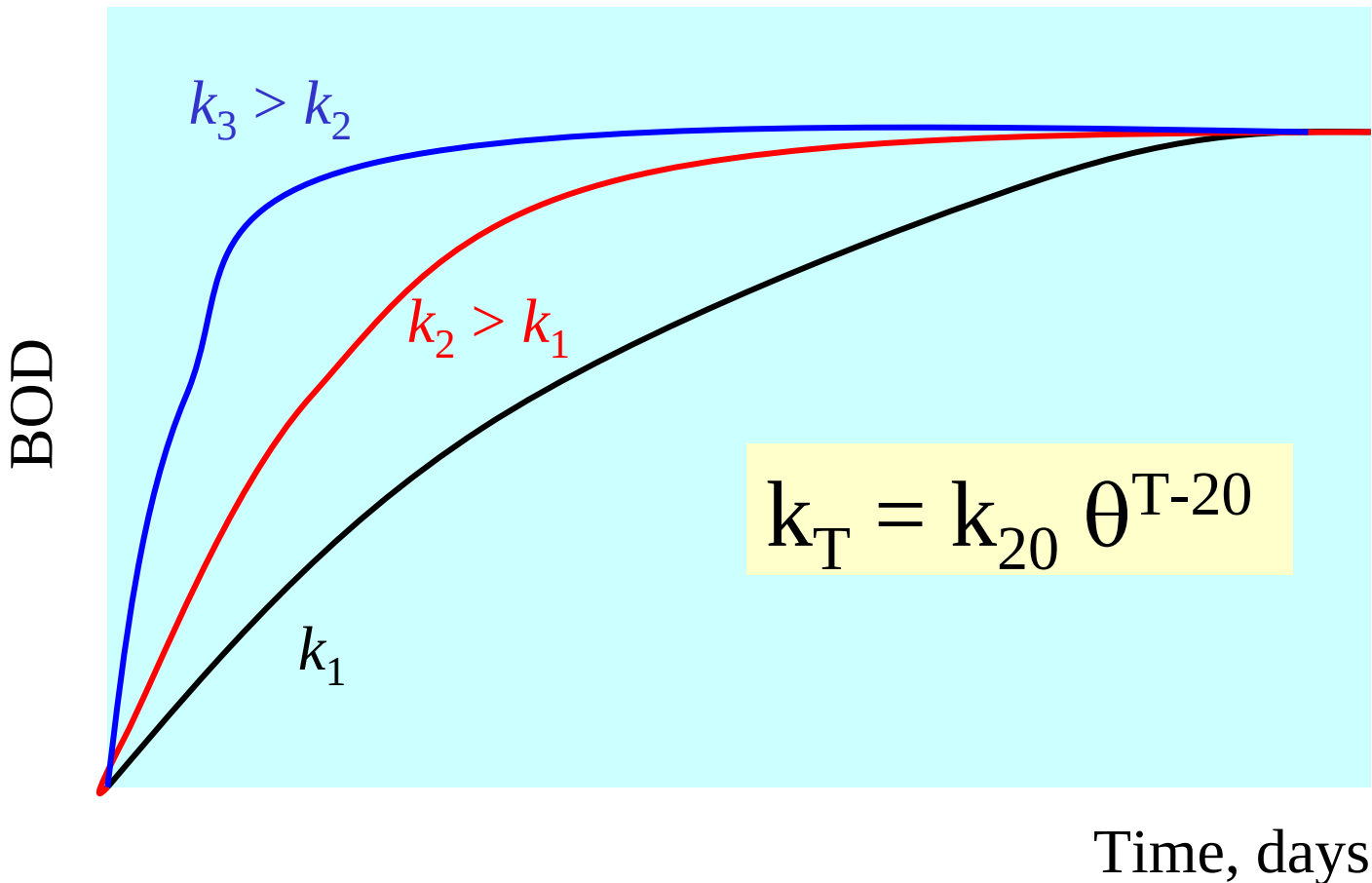
- Value of k (in some books, μ) determines the speed of the BOD reaction without influencing the magnitude of the ultimate BOD.
- $k = 0.1$ to 0.5 per day depending on the nature of the organic molecules.
- Simple sugars have high values of k rate, vice versa.

Reaction constant

Water type	k , per day (base e)	y_u , mg/l
Tap water	<0.1	0-1
Surface water	0.1-0.23	1-30
Weak municipal wastewater	0.35	150
Strong municipal wastewater	0.40	250
Treated effluent	0.12-0.23	10-30

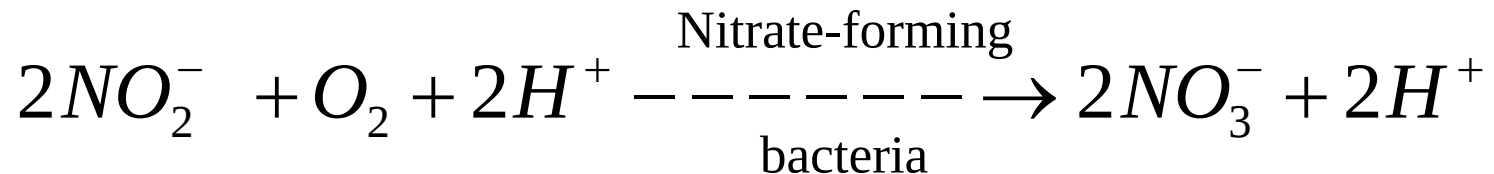
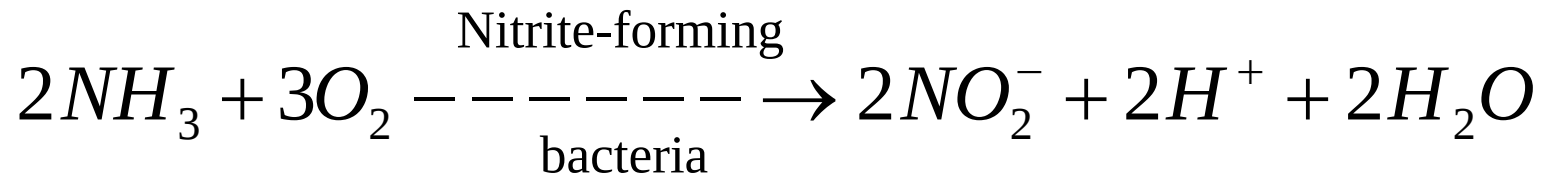
Reaction constant

- k is temperature-dependent, because microorganisms are more active at high temperature, where k values are higher.



Nitrification-Denitrification

Nitrogenous BOD by nitrifying bacteria



Nitrification-Denitrification

Nitrogenous BOD

- The interference caused by nitrifying bacteria makes the actual measurement of total carbonaceous BOD impossible unless provision is made to eliminate them.
- Nitrifying bacteria was the major reason for selecting 5-day for BOD test.
- For samples with high concentration of nitrifying bacteria use the following inhibiting agent:

2-chloro-6-(trichloro methyl)pyridine (TCMP)

Method for Measuring BOD

- Basis: determinations of dissolved oxygen
- Methods:
 - a) **Direct method** for 5-day BOD < 7 mg/l
 - b) **Dilution method** for samples >> 7 mg/l

BOD test again!

Dilution method

- Polluted water is mixed with clean aerated water
- The mixture is poured into a bottle which is sealed so that there is no air above the liquid.
- The microorganisms in the polluted water consume oxygen, and it is necessary to ensure that oxygen is present for the process within the 5-day.
- If the oxygen is depleted, or if its concentration becomes low, the measuring result cannot be used.
- Therefore requires more dilution!!

BOD test again!

Calculated values

- Based on 5-day oxygen demand and the volume of polluted water in the laboratory flask, the BOD can be calculated:

$$BOD = \frac{DO_I - DO_F}{P}$$

DO_I , DO_F = initial and final dissolved oxygen, mg/l

P = decimal fraction of sample in the 300-ml bottle

Example: Calculation of BOD values

- The BOD of a wastewater is suspected to range from 50 to 200 mg/l. Three dilutions are prepared to cover this range. The procedure is the same in each case. First the sample is placed in the standard BOD bottle and is then diluted to 300 ml with organic-free, oxygen-saturated water. The initial DO is determined and the bottles tightly stoppered and placed in the incubator at 20°C for 5 days, after which the DO is again determined. If the third value is disregarded (the final DO being less than 2 mg/l), calculate the average BOD.

BOD Calculation

Wastewater, ml	DO _I , mg/l	DO _F , mg/l	O ₂ used, mg/l	P	BOD ₅ , mg/l
5	9.2	6.9	2.3	0.0167	138
10	9.1	4.4	4.7	0.033	142
20	8.9	1.5	7.4	0.067	110

If the third value is disregarded (final DO is less than 2 mg/l) then the average BOD value is $(138 + 142)/2 = 140$ mg/l

Question: The BOD_5 of a wastewater is determined to be 150 mg/l at 20°C. The k value is known to be 0.23 per day. What would be the BOD_8 be if the test were run at 15°C?

a) Determine the ultimate BOD:

$$y_u = \frac{y_5}{1 - e^{-kt}}$$

$$y_u = \frac{150}{1 - e^{-0.23 \times 5}} = 220 \text{ mg / l}$$

b) Correct the k value for 15°C:

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

$$k_{15} = 0.23(1.047^{-20}) = 0.18$$

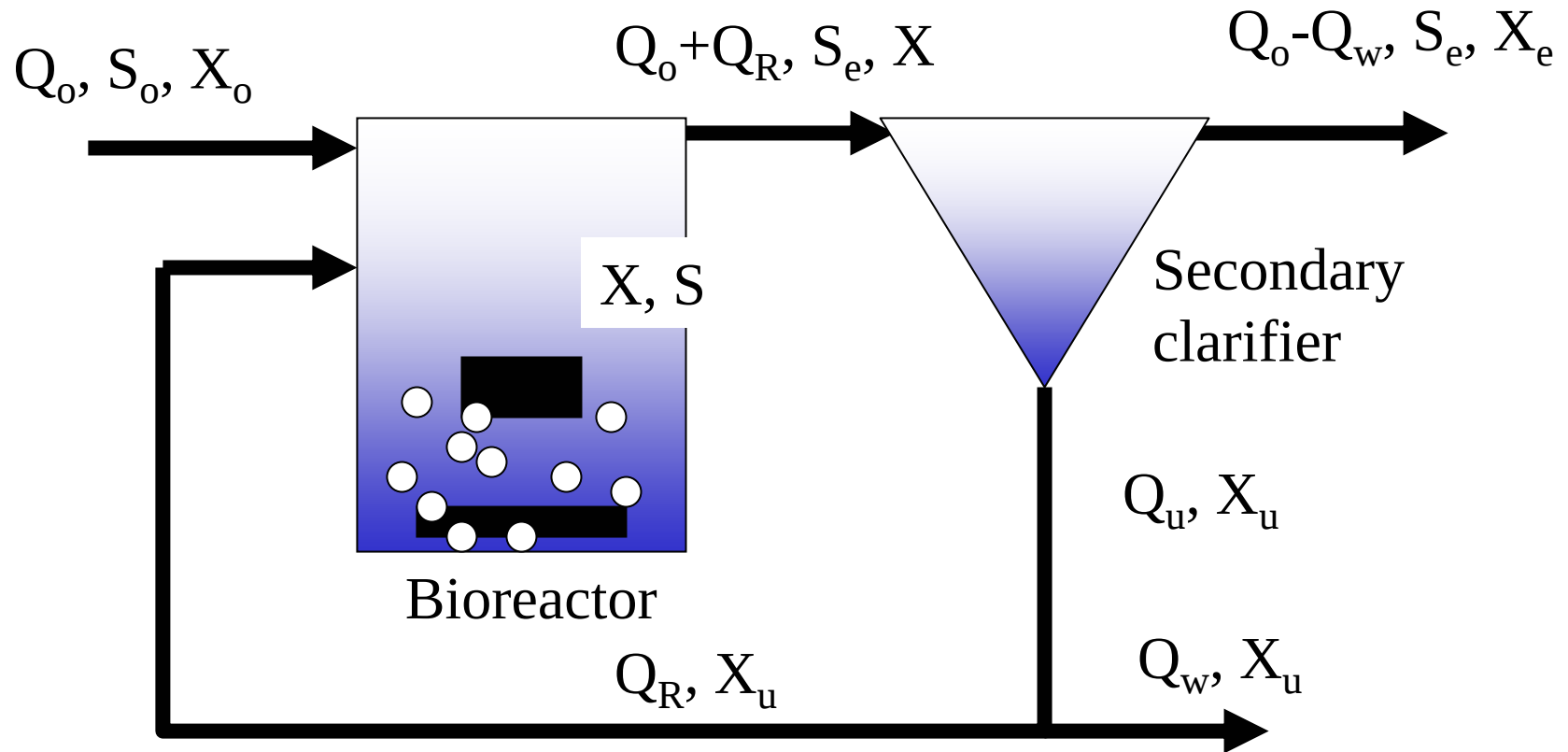
c) Calculate y_8 :

$$y_t = y_u (1 - e^{-kt})$$

$$y_8 = 220(1 - e^{0.18 \times 8}) = 168 \text{ mg / l}$$

Process Theory

(ii) Plug-flow reactor



Disadvantages of BOD

- Long bioassay period, minimum of 5 days
- Depending on microorganisms
- Labourous exercise
- Will not suitable for complex organics, e.g. lignin
- Not able to use for process control in wastewater treatment plants
- Procedures are diverse and results are not consistent