Water and Wastewater Technology

Raw water supply
Coagulant
Auxiliary chemicals
Rapid mix
Flocculation
Settling tank
Filter
Rapid mix
Chlorination basin
Potable water
Chlorine

Water Treatment

Water Distribution

Surfacewater Discharge

Secondary Treatment

Preliminary and Primary Treatment

Final settling
Biological treatment
Primary settling
Grit chamber
Pumping station
Return activated sludge or recycle flow

Sewage Collection

Wastewater Treatment

Primary Effluent
Anaerobic Zone
Organic P → P
N_2 gas
Anoxic Zone
$NO_3^- \rightarrow N_2$
Aerobic Zone
$NH_3 \rightarrow NO_3^-$
$P \rightarrow$ Cell Mass
Final Settling
Effluent
Lake
Mechanically mixed anaerobic chambers
Mechanically mixed anoxic chambers
Air mixed aerobic chambers
NO_3^-
Recirculation of NO_3, $Q_s = Q$
Sludge
Return Activated Sludge, $Q_R = 0.3Q$

Advanced Wastewater Treatment

Secondary effluent
Coagulant
Auxiliary chemicals
Rapid mix
Flocculation
Settling tank
Filter
Chlorine
Rapid mix
Chlorination basin
Tertiary effluent
Irrigation

Recycled Water

Secondary effluent
Cartridge filters
MicroFilters
Break tank
Cartridge filters
High-pressure pumps
Reverse Osmosis Units
Ultraviolet Disinfection
Packed-tower decarbonator
Injection well
Compressed air
Chlorine
Sulfuric acid
Threshold inhibitor

Water Reclamation

2-1 CHEMISTRY

2-1

(a) $Al_2(SO_4)_3 \cdot 14.3\ H_2O = 2A1 + 3S + 12O + 14.3\ (2H + O)$
$MW = 2 \cdot 27.0 + 3 \cdot 32.1 + 12 \cdot 16.0 + 14.3\ (2 \cdot 1.0 + 16.0) = 600$
$EW = 600/6 = 100$

(b) lime = CaO
$MW = 40.1 + 16.0 = 56.1$
$EW = 56.1/2 = 28.0$

(c) $FeSO_4 \cdot 7H_2O = Fe + S + 11O + 14H$
$MW = 55.8 + 32.1 + 11 \cdot 16.0 + 14 \cdot 1.0 = 278$
$EW = 278/2 = 139$

(d) flousilicic acid = $H_2SiF_6 = 2H + Si + 6F$
$MW = 2 \cdot 1.0 + 28.1 + 6 \cdot 19.0 = 144$
EW is not applicable since F^- is released in solution.

(e) soda ash = $Na_2CO_3 = 2Na + C + 3O$
$MW = 2 \cdot 23.0 + 12.0 + 3 \cdot 16.0 = 106$
$EW = 106/2 = 53$

2-2. (a) $NaNO_3 = Na^+ + NO_3^-$
(b) $H_2SO_4 = 2H^+ + SO_4^=$
(c) $Ca(OC1)_2 = Ca^{++} + 2OC1^-$
(d) $Na_2CO_3 = 2Na^+ + CO_3^=$ (below pH 8.3, HCO_3^-, Equation 2-7)

2-3. F concentration $= 1.0\dfrac{(6 \cdot 19.0)}{144} = 0.79$ mg/l

2-4. $\text{Hardness} = 29.0\dfrac{50}{20} + 16.4\dfrac{50}{12.2} = 140$ mg/l

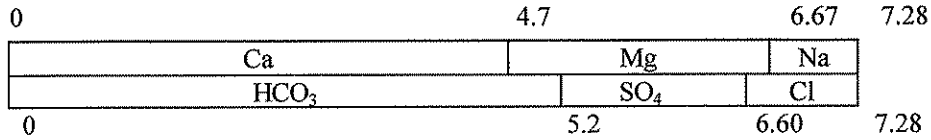
2-5. $Ca^{++} = 20\dfrac{175}{50} = 70$ mg/l

$Mg^{++} = 12.2\dfrac{40}{50} = 9.8$ mg/l

2-6. $\text{Alkalinity} = 12\dfrac{50}{30.0} + 100\dfrac{50}{61.0} = 102$ mg/l

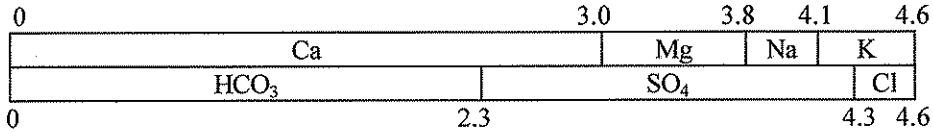
2-7. $\text{Alkalinity} = 20\dfrac{50}{30} + 34\dfrac{50}{61} = 61.2$ mg/l

2-8.
Calcium = 94/20.0 = 4.70 meq/l
Magnesium = 24/12.2 = 1.97
Sodium = 14/23.0 = 0.61
Bicarbonate = 317/61.0 = 5.20
Sulfate = 67/48.0 = 1.40
Chloride = 24/35.5 = 0.68



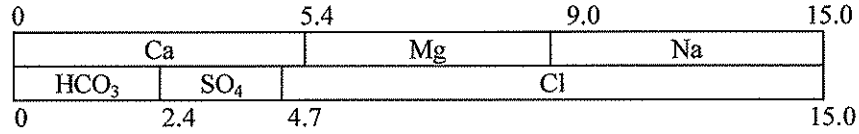
2-9.

Component	mg/l	EW	meq/l
Ca	60	20.0	3.0
Mg	10	12.2	0.8
Na	7	23.0	0.3
K	20	39.1	0.5
HCO_3(Alk)	115	50.0	2.3
SO_4	96	48.0	2.0
Cl	11	35.5	0.3



2-10. Calcium = 108/20.0 = 5.40 meq/l

Magnesium = 44/12.2 = 3.61
Sodium = 138/23.0 = 6.00
Bicarbonate = 146/61.0 = 2.39
Sulfate = 110/48.0 = 2.29
Chloride = 366/35.5 = 10.31



Carbonate hardness = 2.4 • 50 = 120 mg/l
Noncarbonate hardness = (5.4 - 2.4)50 = 150 mg/l
Total hardness = 9.0 • 50 = 450 mg/l
Alkalinity = 2.4 • 50 = 120 mg/l

2-11.

Component	Mg/l	EW	meq/l
Ca hardness	150	50.0	3.0
Mg hardness	65	50.0	1.3
Na	8	23.0	0.3
K	4	39.1	0.1
Alkalinity	190	50.0	3.8
SO_4	29	48.0	0.6
Cl	10	35.5	0.3

Hypothetical combinations: 3.0 $Ca(HCO_3)_2$; 0.8 $Mg(HCO_3)_2$; 0.5 $MgSO_4$; 0.1 Na_2SO_4; 0.2 NaCl; 0.1 KCl

2-12. $H_2SO_4 + 2CaCO_3 = Ca(HCO_3)_2 + CaSO_4$

$$\frac{X}{98.1} = \frac{20\ mg/l}{2 \times 100} \qquad X = 9.8\ mg/l\ of\ H_2SO_4$$

2-13. 2-13. $$\frac{\text{Wt. of acid / l}}{\text{MW} \cdot 1000} = \frac{10\,mg/l}{98{,}100\,mg/mole} = 0.000{,}101{,}9\ mole/l\ H^+$$

$$pH = \log\left[\frac{1}{0.000{,}101{,}9}\right] = 4.0$$

2-14. (a) $$\frac{\text{Wt. of acid/l}}{\text{MW} \cdot 1000} = \frac{3.0mg/l}{98{,}100mg/mole} = 0.000{,}030{,}6 mole/l\ H^+$$

$$pH = \log\left[\frac{1}{0.000{,}030{,}6}\right] = 4.5$$

(b) $\frac{1.0}{98{,}100} = 0.000{,}010{,}2$ mole/l H^+, pH = 5.0

2-15. $CO_2 + Ca(OH)_2 = CaCO_3 + H_2O$ [Eq. 7-19]

$$\frac{X}{44.0} = \frac{35}{74.1} = \frac{Y}{100} \qquad X = 20.8\ mg/l,\ Y = 47.2\ mg/l$$

2-16. $CaCO_3 + CO_2 + H_2O = Ca(HCO_3)_2$ [Eq. 7-23]

$$\frac{47.2}{100} = \frac{X}{44.0}$$

X = 20.8 mg/l

2-17. $Ca(OH)_2 + Ca(HCO_3)_2 = 2CaCO_3 \downarrow + 2H_2O$

Since one equivalent of lime (CaO) reacts with one equivalent of calcium hardness, the calculation for this problem is easily performed using equivalent weights.

$$\frac{CaO}{CaCO_3} = \frac{28.0}{50} = \frac{X}{100} \qquad X = 56 \text{ mg/l}$$

2-18. $3Mn_2^{+} + 2Mn_7 + O_4^{-} = 5Mn_4 + O_2 \downarrow$

$2MnO_4^{-}$ is in solution from dissolution of $KMnO_4$

$3Mn^{2+}$ gains $3 \cdot 2e = 6e$

$2Mn^{7+}$ loses $2 \cdot 3e = 6e$

$$\frac{3Mn}{2KMnO_2} = \frac{3 \cdot 54.9}{2 \cdot 15.8} = \frac{X}{1.0} \qquad X = 0.52 \text{ mg/l as Mn}$$

2-19. $CaO + 2CO_2 + H_2O = Ca(HCO_3)_2$

$$\frac{A}{56.1} = \frac{B}{88.0} = \frac{45 \text{ mg/l}}{40.1} \qquad A = 63 \text{ mg/l CaO} \qquad B = 99 \text{ mg/CO}_2$$

2-20. (a) The rate of a zero-order reaction depends only on time since it is independent of the concentration of any reactant or product.
(b) The rate of a first-order reaction proceeds at a rate directly proportional to the remaining concentration of one reactant.

2-21. The value of θ in Equation 2-26 is 1.072 if the rate of a reaction doubles for a 10°C temperature increase, therefore, the increase from a 5°C increase is:

$$k_2/k_1 = (1.072)^5 = 1.42$$

2-22 Using Table 2-5,
DO saturation at 15°C at sea level = 10.1 mg/l
At an elevation of 2000 ft, DO saturation = 9.5, more accurately 9.3 mg/l

2-23 DO saturation at 22°C at sea level = 8.7 mg/l
At an elevation of 4000 ft, 7.5

2-24. A portion of the OH^- added to the water containing carbonic acid converts H_2CO_3 going to HCO_3^- and HCO_3^- converting to $CO_3^=$ without shifting pH. All the OH^- added to pure water combines with H^+ to form H_2O and thus increasing the pH.

2-25. Using Equation 2-29,

$$\text{Alkalinity} = \frac{16 \cdot 0.02 \cdot 50{,}000}{100} = 165 \text{mg/l}$$

Bicarbonate alkalinity exists at a pH less than 8.3

2-26.

A 1.00N solution contains one gram of available hydrogen ions, or its equivalent, per liter of solution. The acid titrant for alkalinity is 0.02N and therefore contains 0.02 grams of available hydrogen ions. The equivalent weight of $CaCO_3$, used to express alkalinity, is 50 g. The titration test uses a sample volume of 100 ml and 1.00 ml of titrant equivalent to 10 mg/l of alkalinity.

Substituting into Eq. 2-29 determines the constant to met these conditions.

$$\frac{1 \text{ml of titrant} \bullet 0.02 \bullet K}{100 \text{ml}} = 10 \text{mg/l} \qquad K = \frac{100 \bullet 10}{0.02} = 50{,}000$$

2-27. Colloids are particles held in suspension by their extremely small size (1-200nm), state of hydration (chemical combination with water), and surface electric charge. Colloidal particles are resistant to sedimentation by gravity because of their high ratio of surface area to mass. The intensity of a colloidal suspension is measured by a turbidimeter (nephelometer) and expressed as Nephelometric Turbidity Units (NTU).

2-28. The reactions of alum and polymer in coagulation of suspended and colloidal solids are described in Section 2-8 and illustrated in Figure 2-7.

2-29. In organic compounds, carbon exhibits four connecting bonds and carbon atoms connect to each other in chain or ring structures (Section 2-9). An example of an organic chemical with a straight chain is propane (a saturated hydrocarbon). An example of a branched structure is isopropyl alcohol or glycerol. An example of a ring is benzene.

2-30.

CH_3CH_2COOH = propionic acid (propanoic acid)
CH_3--NH_2 = methyamine (aminomethane)
CH_3CH_2 --O--CH_2CH_3 = ethyl ether (ethoxyethane)

propane = $CH_3CH_2CH_3$
acetic acid = CH_3COOH
sodium acetate = $CH_3C(=O)O^- Na^+$

2-31. Carbohydrates consist of sugar units containing carbon, hydrogen, and oxygen--short chains are soluble, while polysaccharides like starch and cellulose are insoluble. Proteins are long strings of amino acids containing all the essential nutrients (C, H, O, N, P) for biological growth. Fats are soluble in organic solvents like hexane but only sparingly soluble in water; the structure of a simple fat is a triglyceride.

2-32. A portion of the carbon in the organic matter is synthesized into biological cells rather than conversion to carbon dioxide. Also, a fraction of the organic matter is difficult to decompose under the time and environmental limitations of biological treatment. (Refer to Section 2-10)

2-33. (a) One mg/l, being 1 part by weight per 1,000,000 parts by volume (weight of water), is equivalent to 8.34 lb/mil gal, since the weight of 1 gal of water is 8.34 lb.
(b) 50 mg/l = 50 • 8.34 = 417 lb/ mil gal
50 mg/l = 50 • 62.4 = 3120 lb/ mil cu ft.
(c) 100 lb/ mil gal = 100/ 8.34 = 12.0 mg/l
(d) 5.0 gpg = 5.0 • 17.1 = 86 mg/l

2-34. $40\ \text{mg/l} \cdot 5.0\text{mgd} \cdot 8.34 = 1670\ \text{lb/day}$

2-35. $\text{Chlorine usage} = \left(\frac{400 \cdot 60}{1{,}000{,}000}\right) = 0.5 \cdot 8.34 = 0.10\ \text{lb/hr}$

2-36. $\text{Fluoride concentration} = \frac{41.1 \cdot 0.61}{3.5 \cdot 8.34} = 0.86\ \text{mg/l}$

2-37. The definition of hardness and the laboratory test is given under the heading "Hardness" in Section 2-11.

2-38. Laboratory apparatus used in colorimetric techniques are the colorimeter (Figure 2-10) and spectrophotometer (Figure 2-11). The common tests performed by colorimetric procedures are: iron and manganese, color, fluoride, chlorine (in clear water), nitrite, nitrate, and phosphorus.

2-39. Jar tests are used to simulate a full-scale coagulation-flocculation process to estimate required chemical dosages. The first trial dosage in full-scale plant operation is the lowest dosage that provides good turbidity removal. Ordinarily a full-scale treatment plant gives better results than a jar test at the same dosage.

2-40. The colorimetric method for measuring chlorine residual in wastewater is not used because of interference from organic matter. The iodometric method is used.

2-41. (a) The laboratory test for ammonia nitrogen is a distillation process (Figure 2-16). A strong basic chemical is added to the sample in the flask to convert all ammonium ion to ammonia so gaseous ammonia is released along with steam. The vapor distillate is condensed and collected in a beaker containing a measured concentration of boric acid. The amount of ammonia in the sample is determined by the consumption of boric acid in the beaker.

(b) Kjeldahl nitrogen is both ammonia nitrogen and organic nitrogen. It is determined by first digesting the sample to release the organic nitrogen as ammonia and then distilling both this ammonia and the ammonia originally in the sample to measure Kjeldahl nitrogen.

2-42. The reagents used in the azide modification of the iodometric method to determine dissolved oxygen are given under the heading "Dissolved Oxygen" (Section 2-11) and shown in Figure 2-17.

2-43. Suspended solids are those solids retained by a standard glass-fiber filter after drawing a sample through the filter by suction (Figure 2-19).

2-44. Trace organic chemicals are detected in a drinking water by gas chromatography (Figure 2-12).

2-45. The concentration of organic acids is expressed in mg/l of acetic acid.

3 BIOLOGY

3-1. Bacteria are one-celled plants capable of self-reproduction (Section 3-1). Heterotrophic bacteria use organic matter for sources of both energy and carbon for synthesis. The sequence of oxygen usage is DO, nitrate, sulfate. Obvious odors occur when DO and nitrate are depleted. Bacteria stabilize organic wastes by metabolism producing new growth while taking in DO and releasing CO2.

3-2. Nitrification (Equations 3-7 and 3-8) is performed by autotrophic bacteria to gain energy for growth by synthesis of carbon dioxide in an aerobic environment. Facultative heterotrophic bacteria can decompose organic matter to gain energy under anaerobic conditions by removing the oxygen from nitrate releasing nitrogen gas.

3-3. Autotrophic bacteria oxidize inorganic compounds for energy and use carbon dioxide as a carbon source. Nitrification reactions are Eqs. 3-7 and 3-8 (Section 3-1). In sewer corrosion, the biological reaction is oxidation of H_2S to H_2SO_4 (Eq. 3-9) and the chemical reaction is H_2SO_4 with concrete pipe (Figure 10-12).

3-4. The three primary waterborne pathogenic bacteria are *Salmonella* spp., *Vibrio cholerae,* and *Shigella* spp. Shigellosis outbreaks are most likely to occur in private and noncommunity water supplies. Outbreaks have also been associated with recreational exposure to fecal contaminated swimming pools and natural surface waters.

3-5. Protozoa are single-celled aquatic animals (Section 3-2). Protozoa grazing on bacteria (1) stimulates further bacterial growth accelerating metabolism of organic matter and (2) improves settleability of bacterial floc by reducing the number of free bacteria in solution.

3-6. The symptom of these protozoa infections is diarrhea described as gastrointestinal distress ranging from no symptoms to hospitalization for giardiasis and profuse and watery diarrhea for crytosporidiosis. The common mode of transmission is the fecal-oral route by close person-to-person contact among family members, day-care children, and nursing home residents. Drinking water is the largest potential common source of transmission.

3-7. Viruses are obligate, intracellular parasites that replicate inside living hosts' cells (Figure 3-4). Heterotrophic bacteria are one-celled plants that decompose dead organic matter for nutrients and energy for reproduction.

3-8. Algae are photosynthetic microscopic plants gaining energy from light and releasing oxygen during metabolism. Algae synthesize inorganic nutrients for the primary purpose of producing new plant life. The process of photosynthesis is illustrated by Eq. 3-11.

3-9. Although impounded waters are oxygenated by diffusion from the atmosphere and algal photosynthesis, the major periods of oxygenation are during spring and autumn circulations (turn-over).

3-10. Oligotrophic lakes are nutrient poor and biologically unproductive. Mesotrophic lakes have an increased nutrient level to support some aquatic plants, greenish water from algae in the summer, and moderate populations of sport fish. Eutrophic lakes are nutrient rich with heavy weed growth along shores, blooms of algae, and tolerant fish.

3-11. Thermal stratification of an eutrophic results in reduced quality of the impounded water in the hypolimnion. Since the water below the themocline is not oxygenated, decomposition of organic matter can delete the dissolved oxygen concentration.

3-12. The best way to prevent or retard the rate of eutrophication of a lake is to reduce the nitrogen and phosphorus inputs. For an oligotrophic lake, either nutrient can promote plant growth, whereas for an eutrophic lake, phosphorus is the primary nutrient to control.

3-13. Pathogens are disease-producing organisms including viruses, bacteria, protozoa, and helminthes (parasitic worms).

3-14. The fecal-oral route is the transmission of pathogens in the feces of an infected person into the mouth of another person by person-to-person contact with contaminated fingers or through water and food contaminated by feces.

3-15. Latency is the period of time between excretion of a pathogen in feces and its becoming infective to a new host. Persistence is measured by the length of time that a pathogen remains viable in the environment outside a human host. Infective does is the number of organisms that must be ingested to result in disease.

Ascaris (roundworm) is III: latent, persistent, one egg produces one intestinal worm.
Salmonella (bacteria) are II: non-latent, moderately persistent, medium to high infective dose.

3-16. Typhoid, cholera, and dysentery were virtually eliminated in the U. S. A. by pasteurization of milk and chlorination of water supplies. Waterborne giardiasis and crytosporidiosis can be prevented by removal and disinfection of protozoa cysts during treatment of surface waters including chemical coagulation, filtration, and chlorination (Section 7-16).

3-17. Human carriers exist for all enteric diseases and are significant sources in the spread of infectious diseases since carriers may not exhibit any symptoms of illness. Human carriers without symptoms of disease are primarily responsible for continued transmission of the intestinal protozoa *Giardia lamblia* and *Cryptosporidium* species. Beavers can transmit *Giardia* and cattle and sheep feces can transmit *Cryptosporidium*.

3-18. The following are the three phases in testing for enteric viruses. (1) Extraction from water is by pumping a large volume, 100s of liters up to 1000 liters, through a cartridge or a large disc filter. (2) Concentration of the eluate from the filter can be by adsorption , adsorption-precipitation, or hydroextraction-dialysis. (3) Identification is by using two or more cell culture systems, such as monolayers of African green monkey cells, and perhaps suckling mice. To determine the precision of separation, the procedure must be conducted on water samples to which known suspensions of one or more test virus types have been added to a water sample to establish recovery efficiency. Testing for enteric viruses is recommended for water quality investigations in special circumstances such as research studies, wastewater reclamation, or disease outbreaks.

3-19. Problems in isolation of viruses result from their small size, low concentrations in water, variability in amounts and types, their instability, and presence of solids interfering with concentration of samples. Problems in identification relate to use of host-cell systems and specificity of the host for different viruses. The concentrate from a water sample is spread on the monolayer of a cell culture. After incubation, the clear areas in the monolayer are where viruses have destroyed host-cells. Each clear area is a PFU (plaque-forming unit).

3-20. The general process in testing for *Giardia* cysts and *Cryptosporidium* oocysts is filtration from a water sample through a very fine filter, extraction of cysts or oocysts from the filter and separation from particulate debris, extract concentration, and staining with indirect fluorescent antibody for identification by microscopic examination. The accuracy of Method 1622 for detection and enumeration of *Cryptosporidium* oocysts was low because of the interference from turbidity in natural surface waters.

3-21. *Cryptosporidium* are difficult to identify from other organisms of similar size and shape. Two case histories in major cities mentioned (without names) are examples of laboratory failures in proper identification of *Cryptosporidium* oocysts resulting in false public health concerns.

3-22. Coliform bacteria are natural residents of the human intestinal tract and are excreted in large numbers in feces. Pathogens of enteric diseases originate from the same source, although their numbers in water are considerably less since they are contributed only by diseased persons. Consequently, water containing a significant number of coliforms is likely to contain pathogens. These arguments are valid for surface waters adequately processed by chemical coagulation and filtration followed by chlorination and well waters where the groundwater is filtered through subsurface soils and then chlorinated if necessary. The absence of coliforms in drinking water without physical removal of protozoal cysts, even if chlorinated, is not a reliable indication of microbiological quality.

3-23. Fecal coliforms from humans and warm-blooded animals are the same bacterial species. Coliforms originating from the soil can be separated from fecal species by a confirmatory procedure using EC medium broth incubated at the elevated temperature of 44.5°C.

3-24. Fecal coliforms indicate fecal contamination from humans or warm-blooded animals and the possible presence of pathogens. Total coliforms, which include fecal coliforms, may originate from non-fecal sources such as soil that do not indicate the presence of pathogens. A positive total coliform test must be tested by the second-phase fecal coliform test, which must be positive to indicate the possible presence of human pathogens.

3-25. *Escherichia coli* is a nonpathogenic coliform that resides in the intestinal tracts of humans and warm-blooded animals. *E. coli* O157:H7 is an antibiotic-resistant mutant strain pathogenic to humans found in the feces of infected cattle and diseased humans. Transmission is by contaminated ground beef, unpastuerized fruit juices, and fecal-oral route from diseased persons.

3-26. Lactose is fermented by coliform bacteria to form lactic acid, thus, lowering the pH and releasing gas.

3-27. Select positive tube numbers 5, 2, and 1 for serial dilutions 0.1, 0.01, and 0.001. The multiplier is therefore 10, and from Table 3-2 the MPN = 2200 with confidence limits of 900 and 7,000.

3-28. For the lactose tubes, select the positive numbers 5, 2, and 0 for serial dilutions 0.1, 0.01, and 0.001. The multiplier is therefore 100, and from table 3-2 the MPN = 4900 with confidence limits of 1700 to 13,000. The positive EC tubes are 5, 2, and 2 with a multiplier of 10 for 940, 280 - 2200.

3-29. From Table 3-3, for 3 tubes showing growth with gas, MPN Index/100 ml = 3.6 and confidence limits 0.69 and 10.6.

3-30. From Table 3-3,
To meet <2.2 MPN Index, 1 of 10 tubes can be positive.
To meet <23 MPN Index, 8 of 10 tubes can be positive.

3-31. In the presence-absence test for coliform bacteria, a positive test for total coliforms is a yellow color. A positive test for fecal coliforms is florescence of a positive test with a bluish color.

3-32. The procedure for collecting a drinking water sample for coliform testing is given under the heading "Sampling and Testing for Different Waters" in Section 3-9.

3-33. Using Equation 3-13, $\text{BOD} = \dfrac{8.1 - 4.2}{6.0/300} = 195\,\text{mg/l}$

From Equation 3-14, $\text{Ultimate BOD} = \dfrac{195}{1-10^{-0.1\cdot 5.0}} = 290\,\text{mg/l}$

3-24. (a) Based on data in Table 3-2: volume of seed for BOD test on seed = 7.0 ml, and volume of wastewater for BOD test = 2.0 ml plus 0.7 ml of seed.

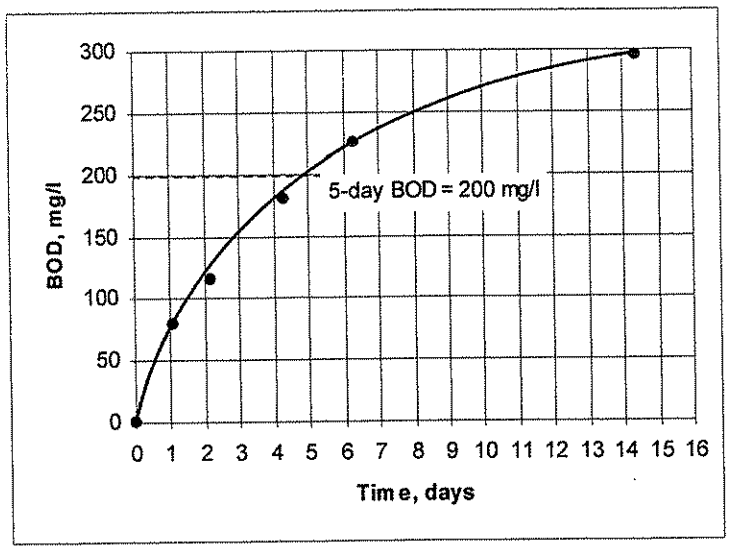
(b) Using Equation 3-16, $\text{BOD} = \dfrac{(8.2 - 4.0) - (8.2 - 3.5)(0.7/7.0)}{2.0/300} = 560\,\text{mg/l}$

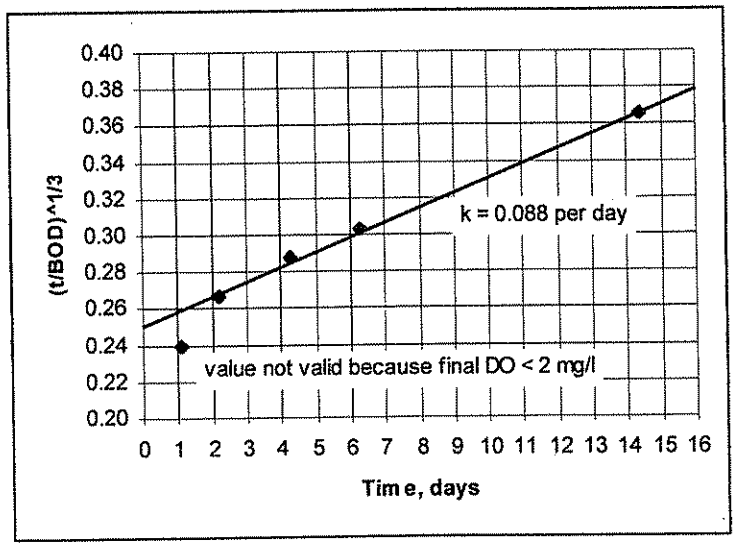
3-35.

Time (days)	D_2	D_1	$D_1 - D_2$	BOD (mg/l)	$\left(\frac{t}{BOD}\right)^{1/3}$
0	8.3	8.3	0		
1.1	6.7	8.3	1.6*	80	0.240
2.2	6.0	8.3	2.3	115	0.268
4.3	4.7	8.3	3.6	180	0.288
6.3	3.8	8.3	4.5	225	0.304
14.4	2.4	8.3	5.9	295	0.366

* Less than 2.0 mg/l DO used is not a valid test.

P = 0.020

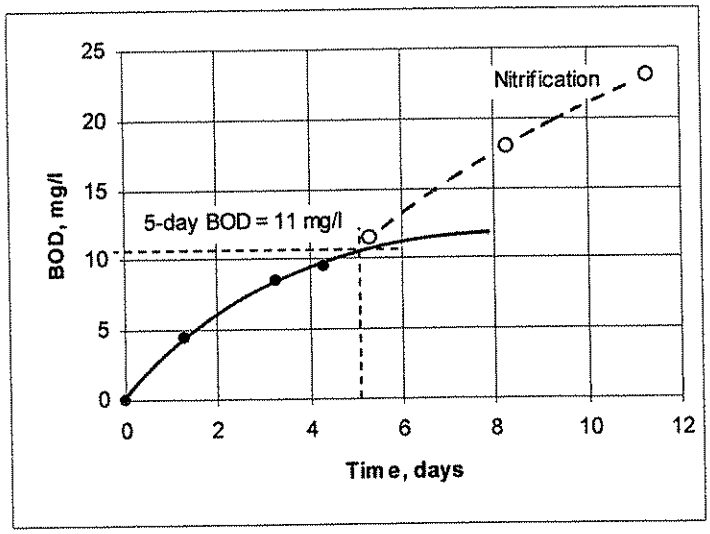


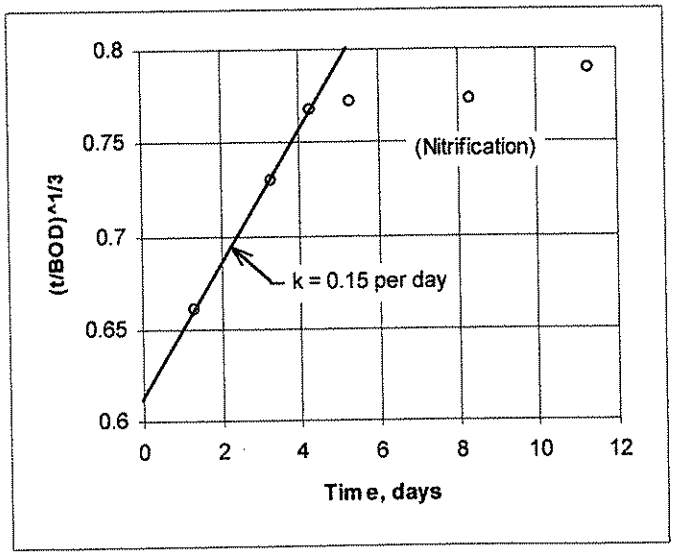


3-36.

Time (days)	D_2	D_1	$D_1 - D_2$	BOD (mg/l)	$\left(\frac{t}{BOD}\right)^{1/3}$
0	8.1	8.1	0		
1.3	7.2	8.1	0.9*	4.5	0.661
3.3	6.4	8.1	1.7*	8.5	0.730
4.3	6.2	8.1	1.9*	9.5	0.768
5.3	5.8	8.1	2.3	11.5	0.773
8.3	4.5	8.1	3.6	18	0.773
11.3	3.5	8.1	4.6	23	0.789

* Less than 2.0 mg/l DO used is not a valid test

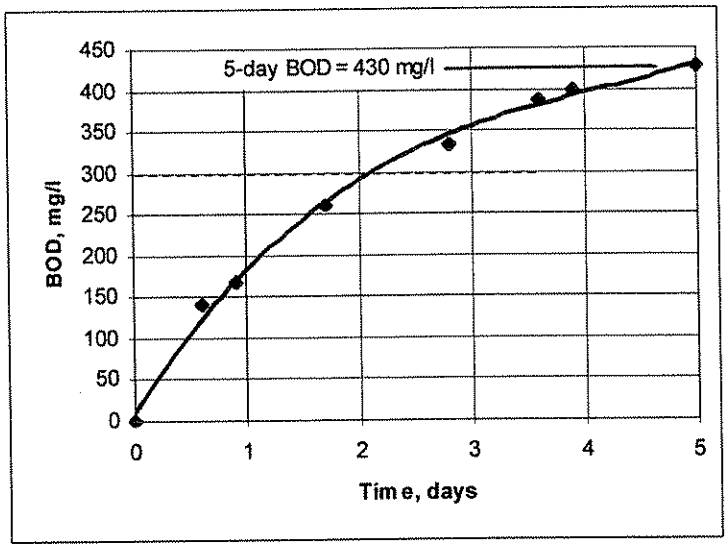


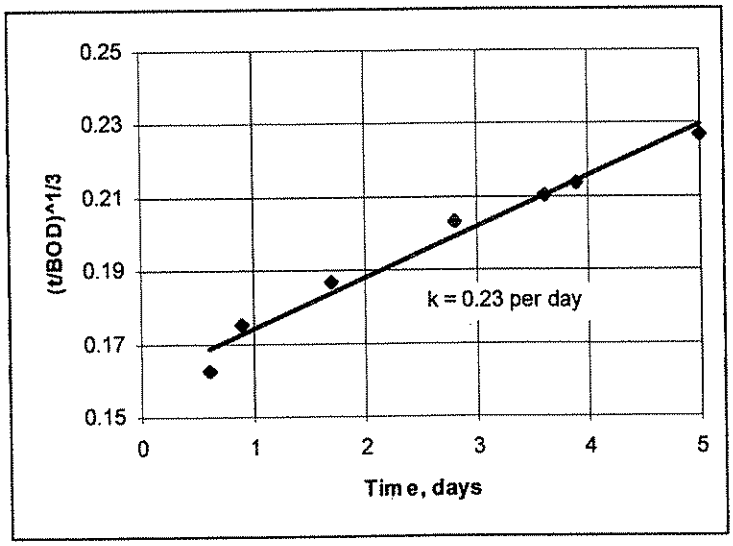


3-37.

Time (days)	D_2	D_1	$D_1 - D_2$	BOD (mg/l)	$\left(\frac{t}{BOD}\right)^{1/3}$
0	8.1	8.1	0		
0.6	6.0	8.1	2.1	140	0.163
0.9	5.6	8.1	2.5	167	0.176
1.7	4.2	8.1	3.9	260	0.187
2.8	3.1	8.1	5.0	333	0.204
3.6	2.3	8.1	5.8	387	0.211
3.9	2.1	8.1	6.0	400	0.214
5.0	1.7	8.1	6.4	427	0.227

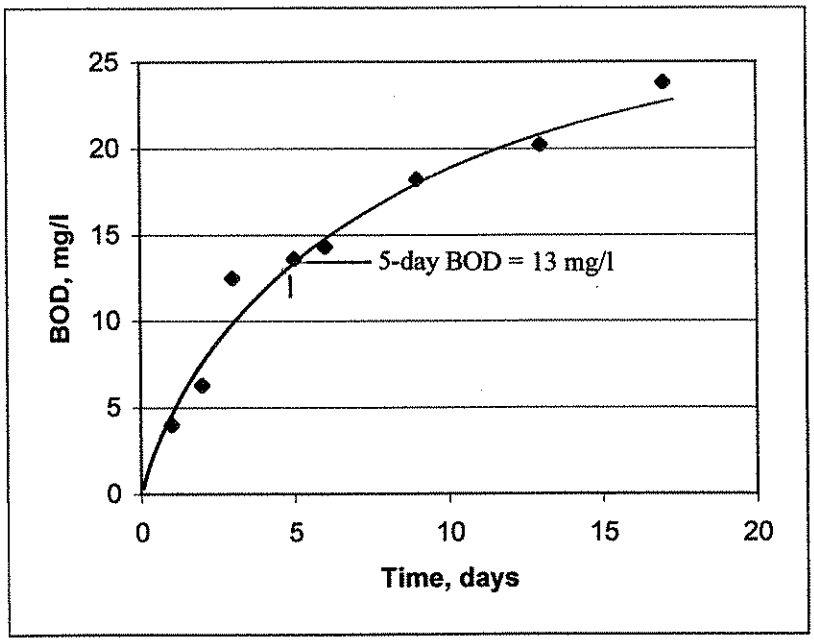
P = 0.015

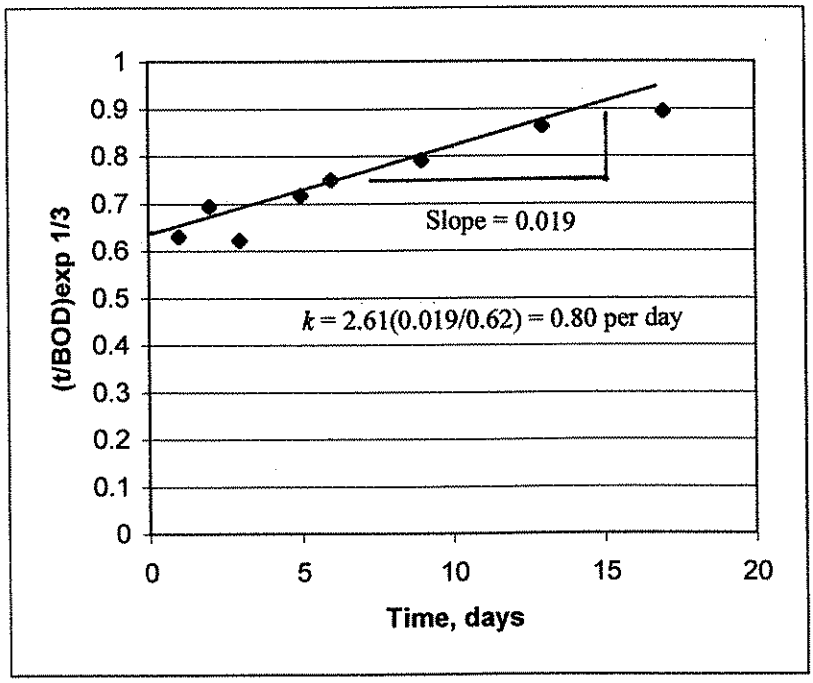




3-38.

Time, d	BOD,mg/l	$(t/BOD)^{1/3}$
1	4	0.63
2	6.3	0.694
3	12.5	0.622
5	13.6	0.717
6	14.3	0.749
9	18.2	0.791
13	20.2	0.863
17	23.8	0.894

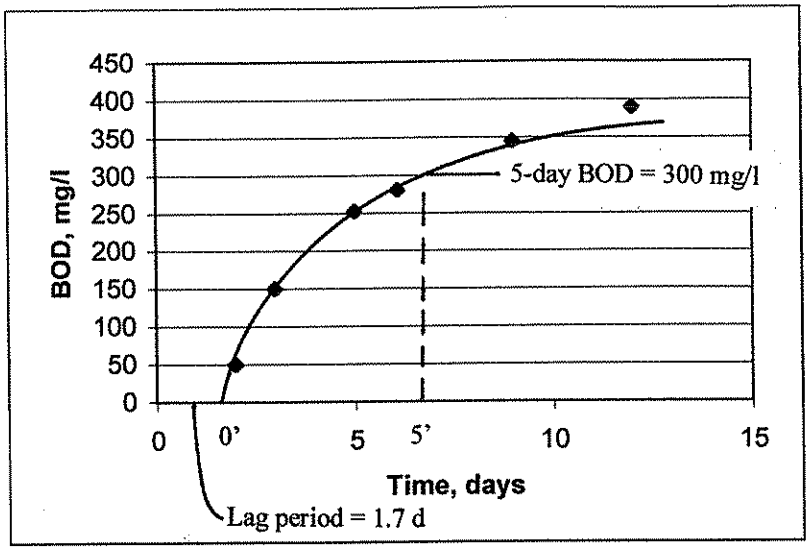


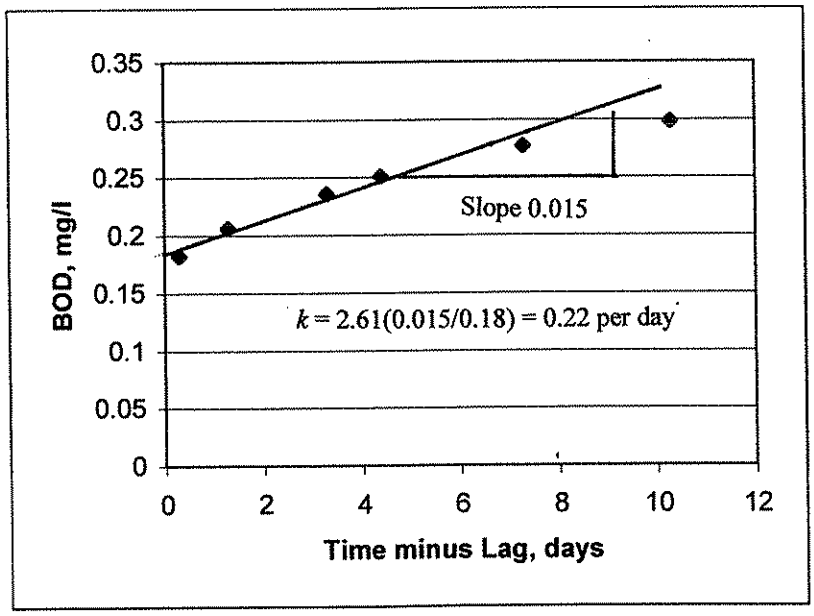


3-39.

TIME AND BOD	
Time, d	BOD,mg/l
2	50
3	150
5	252
6.1	280
9	345
12	390

TIME -- LAG AND (T/BOD)$^{1/3}$		
TIME	BOD,mg/l	(T/BOD)1/3
0.3	50	0.182
1.3	150	0.206
3.3	252	0.236
4.4	280	0.251
7.3	345	0.277
10.3	390	0.298





3-40.

Average initial DO of settled wastewater bottles = 8.8 mg/l.
Average initial DO of seed bottles = 5.5 mg/l.
The bottles with 8.0 ml of wastewater are invalid tests since the DO was less then 1.0 mg/l.
Average final DO of bottles with 6.0 ml = 3.0 mg/l.
Average final DO of bottles with 4.0 ml = 4.6 mg/l.

$$\text{BOD at 6 ml} = \frac{(8.8 - 3.0) - (8.8 - 5.5)1.5/15}{6/300} = 275 \text{ mg/l}$$

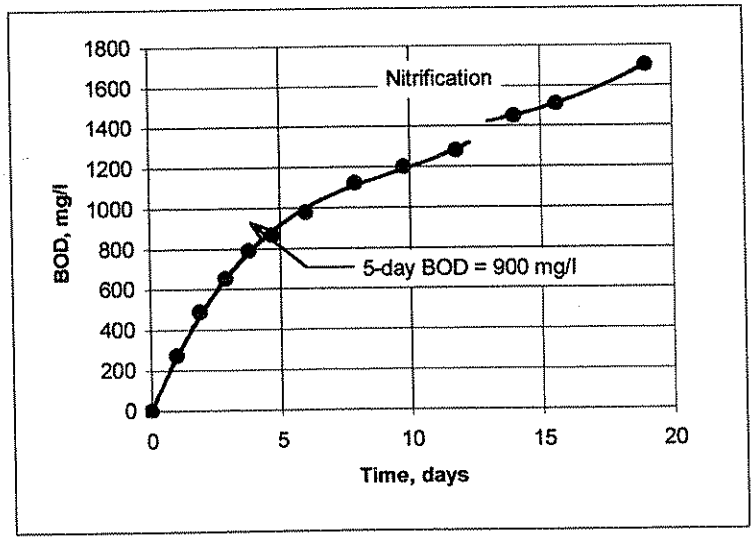
$$\text{BOD at 4 ml} = \frac{(8.8 - 4.6) - (8.8 - 5.5)1.5/15}{4/300} = 292 \text{ mg/l}$$

BOD of wastewater = 280 mg/l

3-41. Equation 3-16, $\text{BOD} = \frac{(8.2 - D_2) - (8.2 - B_2)0.10}{1.0/300}$

For k-rate plot, ordinate values = $\left[\frac{\text{days}}{\text{BOD}}\right]^{1/3}$

Time (days)	BOD (mg/l)	Ordinate Value	Time (days)	BOD (mg/l)	Ordinate Value
0	0		7.9	1120	0.192
1.0	273	0.154	9.8	1200	0.201
1.9	489	0.157	11.8	1280	0.210
2.9	651	0.165	14.0	1450	0.213
3.8	789	0.169	15.6	1510	0.218
4.7	867	0.176	19.0	1700	0.224
6.0	978	0.183			

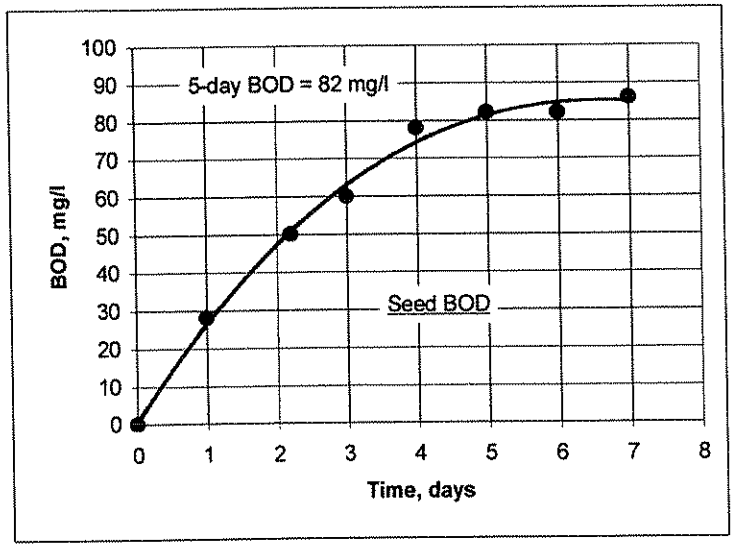


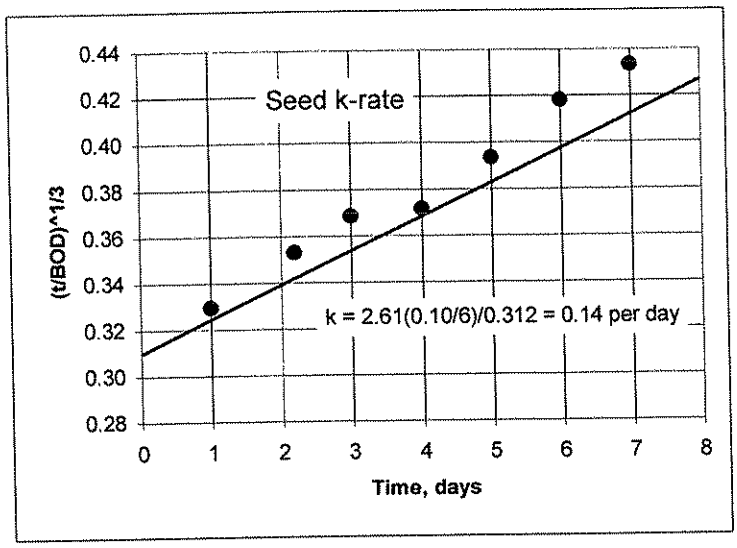
3-42. Data for BOD test on the seed. P = 15 ml/300 ml = 0.05

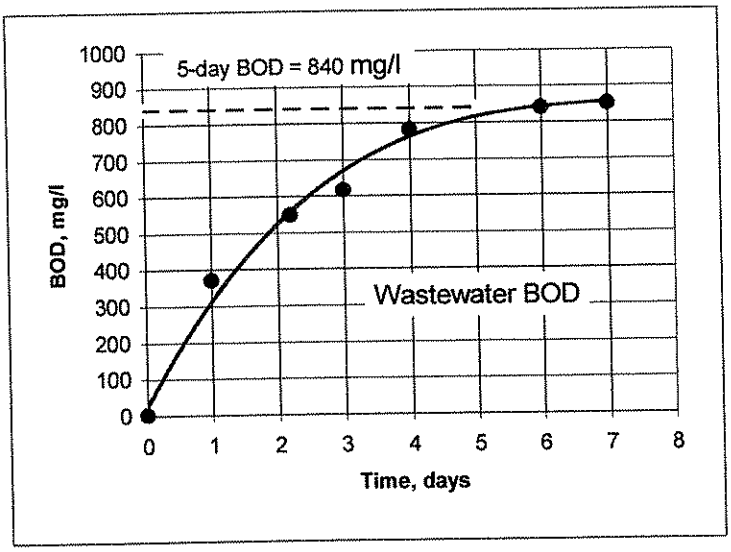
Time (days)	B_2	B_1	$B_1 - B_2$	BOD (mg/l)	$\left(\frac{t}{BOD}\right)^{1/3}$
0	7.9	7.9	0	0	
1.0	6.5	7.9	1.4	28	0.329
2.2	5.4	7.9	2.5	50	0.353
3.0	4.9	7.9	3.0	60	0.368
4.0	4.0	7.9	3.9	78	0.372
5.0	3.8	7.9	4.1	82	0.394
6.0	3.8	7.9	4.1	82	0.418
7.0	3.6	7.9	4.3	86	0.431

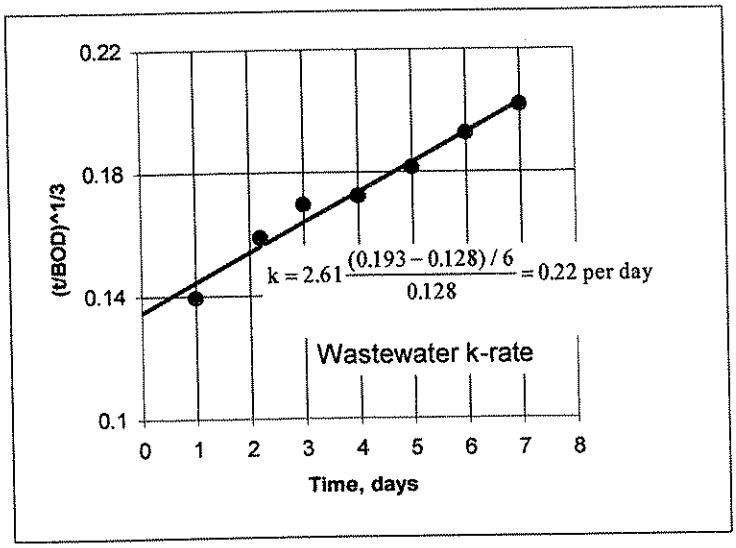
Data for seeded BOD test on wastewater. P = 2.0/300 and f = 1.5/15 = 0.10

Time (days)	D_2	D_1	$D_2 - D_1$	$(B_2 - B_1)\,f$	BOD (mg/l)	$\left(\frac{t}{BOD}\right)^{1/3}$
0	8.1	8.1	0	0	0	
1.0	5.5	8.1	2.6	0.14	369	0.139
2.2	4.2	8.1	3.9	0.25	548	0.159
3.0	3.7	8.1	4.4	0.30	615	0.170
4.0	2.5	8.1	5.6	0.39	782	0.172
5.0	2.1	8.1	6.0	0.41	837	0.181
6.0	2.1	8.1	6.0	0.41	839	0.193
7.0	2.0	8.1	6.1	0.43	851	0.201




Seed k-rate
k = 2.61(0.10/6)/0.312 = 0.14 per day
(t/BOD)^1/3
Time, days
0.44
0.42
0.40
0.38
0.36
0.34
0.32
0.30
0.28
0 1 2 3 4 5 6 7 8


5-day BOD = 840 mg/l
Wastewater BOD
BOD, mg/l
Time, days
1000
900
800
700
600
500
400
300
200
100
0
0 1 2 3 4 5 6 7 8


$k = 2.61\frac{(0.193 - 0.128)/6}{0.128} = 0.22$ per day
Wastewater k-rate
(t/BOD)^1/3
Time, days
0.22
0.18
0.14
0.1
0 1 2 3 4 5 6 7 8